Title: Impact Assessment for the level of the fifth carbon budget **IA No:** DECC0231 **RPC Reference No:** N/A **Lead department or agency:** Department of Energy and Climate Change (DECC) **Other departments or agencies:** N/A **URN:** 16D/221	**Impact Assessment (IA)** **Date: 29th June 2016** **Stage:** Final Proposal **Source of intervention:** Domestic **Type of measure:** Secondary Legislation **Contact for enquiries:** Adam Harmon (adam.harmon@decc.gsi.gov.uk)

Summary: Intervention and Options

RPC Opinion: Not applicable

Cost of more likely option (Option 4)				
Total Net Present Value	**Business Net Present Value**	**Net cost to business per year** (EANDCB in 2014 prices)	**One-In, Three-Out**	**Business Impact Target Status**
£5.5bn (2028-32)	£0m	£0m	Not in scope	Not a regulatory provision

What is the problem under consideration? Why is government intervention necessary?

There is overwhelming scientific consensus that significant climate change is happening, driven predominantly by man-made greenhouse gas (GHG) emissions. This is leading to rising temperatures and sea levels, causing extreme weather, damaging ecosystems, and reducing the productivity of crops. Coordinated global action is needed to substantially reduce GHGs, which would not happen at sufficient scale without Government intervention, as climate change costs are not fully factored into private decisions. Global climate action will help secure the UK's long-term economic security and prosperity. The Climate Change Act 2008 and the accompanying Impact Assessment provide the rationale for action to reduce UK emissions on 1990 levels by at least 80% by 2050. The UK has committed to the 2015 Paris Agreement binding every country to the ambition to limit the global average temperature rise to well below 2°C.

What are the policy objectives and the intended effects?

The Act requires the Government to set the fifth carbon budget, a five-year cumulative limit on the level of the net UK carbon account over 2028-32. The Act requires this level must be set with a view to reducing emissions in order to meet the UK's 2050 target. The objective now is to set the level of the budget, while proposals on how the budget is met are to be published as soon as reasonably practical thereafter.

What policy options have been considered, including any alternatives to regulation? Please justify preferred option (further details in Evidence Base)

There is no alternative to the Act requirement to set the fifth carbon budget level. The following options for the level of the fifth carbon budget have been considered:

- **Option 1 (Do minimum): e.g. 2,100 million tonnes of carbon dioxide equivalent ($MtCO_2e$)** (e.g. 47.5% below 1990 levels); assumed European Emissions Trading System (EU ETS) share of 590 $MtCO_2e$ and non-traded share of e.g.1,510 $MtCO_2e$
- **Option 2**: **1,830 $MtCO_2e$** (54.3% below 1990 levels); assumed EU ETS share of 590 $MtCO_2e$ and non-traded share of 1,240 $MtCO_2e$
- **Option 3**: **1,725 $MtCO_2e$** (56.9% below 1990 levels); assumed EU ETS share of 590 $MtCO_2e$ and non-traded share of 1,135 $MtCO_2e$ - the Committee on Climate Change's (CCC) recommended level (excluding international shipping emissions)
- **Option 4**: **1,670 $MtCO_2e$** (58.3% below 1990 levels); EU ETS share of 590 $MtCO_2e$ and non-traded share of 1,080 $MtCO_2e$.

Will the policy be reviewed? Evidence & assumptions will be refreshed when setting the sixth carbon budget

Does implementation go beyond minimum EU requirements?	N/A			
Are any of these organisations in scope?	**Micro** Yes	**Small** Yes	**Medium** Yes	**Large** Yes
What is the CO_2 equivalent change in greenhouse gas emissions? (Million tonnes CO_2 equivalent)	**Traded:** 0		**Non-traded:** 311 (2028-32)	

I have read the Impact Assessment and I am satisfied that, given the available evidence, it represents a reasonable view of the likely costs, benefits and impact of the leading options.

Signed by the responsible Minister Amber Rudd Date: 29.06.2016

Summary: Analysis & Evidence Policy Option 1

Description: A "do minimum" budget (2,100 $MtCO_2e$), likely to require no new emissions reductions

FULL ECONOMIC ASSESSMENT

Price Base Year 2015	PV Base Year 2016	Time Period Years 5	Net Benefit (Present Value (PV)) (£m)		
			Low: £0	**High: £0**	**Best Estimate: £0**

COSTS (£m)	**Total Transition** (Constant Price)	Years	**Average Annual** (excl. Transition) (Constant Price)	**Total Cost** (Present Value)
Low	£0		£0	**£0**
High	£0		£0	**£0**
Best Estimate	£0		£0	**£0**

Description and scale of key monetised costs by 'main affected groups'

There are no technical abatement costs associated with this option as it is estimated under most reasonable emissions scenarios, the UK net carbon account will remain within this budget level.

Other key non-monetised costs by 'main affected groups'

There may be wider impacts on the total cost of achieving the UK's 2050 emissions reduction target, resulting from subsequent increases in the rate of required emissions reductions. These are outside the five-year appraisal period considered here.

BENEFITS (£m)	**Total Transition** (Constant Price)	Years	**Average Annual** (excl. Transition) (Constant Price)	**Total Benefit** (Present Value)
Low	£0		£0	**£0**
High	£0		£0	**£0**
Best Estimate	£0		£0	**£0**

Description and scale of key monetised benefits by 'main affected groups'

There are no benefits associated with this option as it is estimated under most reasonable emissions scenarios, the UK net carbon account will remain within this budget level.

Other key non-monetised benefits by 'main affected groups'

N/A

Key assumptions/sensitivities/risks | **Discount rate (%)** | 3.5%

Risk of undermining the credibility of UK action on climate change and sending negative signals to investors in low carbon technologies. The budget levels considered will have varying degrees of residual risk around missing the UK's 2050 emissions reduction target.

BUSINESS ASSESSMENT (Option 1)

Direct impact on business (Equivalent Annual) £m:			**Score for Business Impact Target (qualifying provisions only) £m:**
Costs: £0	**Benefits: £0**	**Net: £0**	£0

Summary: Analysis & Evidence Policy Option 2

Description: A "straight line" budget (1,830 $MtCO_2e$), meeting the 2050 target with equal reductions from 2020

FULL ECONOMIC ASSESSMENT

Price Base Year 2015	PV Base Year 2016	Time Period Years 5	Net Benefit (Present Value (PV)) (£m)		
			Low: £6,900	High: £20,900	Best Estimate: £12,600

COSTS (£m)	Total Transition (Constant Price)	Years	Average Annual (excl. Transition) (Constant Price)	Total Cost (Present Value)
Low	£0		£2,200	**£6,900**
High	£0		£4,500	**£13,900**
Best Estimate	£0		£3,400	**£10,400**

Description and scale of key monetised costs by 'main affected groups'

Costs captured are the illustrative static amortised capital, finance, and hidden costs; together with in-year increases in operating and maintenance costs over 2028-2032 of delivering the required non-traded sector emissions reductions (£10.4bn).

Other key non-monetised costs by 'main affected groups'

Policy costs, including administrative costs and additional costs of overcoming barriers to delivery of measures, are not captured as the portfolio of policies to deliver this budget level is unknown at this stage. Impacts on the overall cost of meeting the UK's 2050 target are also not captured. Costs attributable outside the fifth carbon budget period are not included.

BENEFITS (£m)	Total Transition (Constant Price)	Years	Average Annual (excl. Transition) (Constant Price)	Total Benefit (Present Value)
Low	£0		£6,500	**£20,800**
High	£0		£8,800	**£27,800**
Best Estimate	£0		£7,500	**£23,100**

Description and scale of key monetised benefits by 'main affected groups'

There are benefits from a reduction in the cost of energy consumption, additional space heating in the domestic buildings sector (£11.3bn), and GHG emissions impacts (£10.4bn). Smaller benefits include impacts on air quality, and improvements in natural capital primarily from the amenity value of afforestation (£1.4bn).

Other key non-monetised benefits by 'main affected groups'

Impacts on natural capital are only included where evidence is available. Benefits outside the fifth carbon budget period are not included.

Key assumptions/sensitivities/risks **Discount rate (%)** 3.5%

The portfolio of policies to deliver the budget level is unknown at this stage. The monetisation of emissions reductions measures is provided as an illustration only, and is based on knowledge of theoretically achievable options, which are assumed to be deliverable from a technical perspective. There is a high degree of uncertainty around resulting electricity demand changes, the costs and availability of emissions reductions technologies, the role of international credits, and energy prices. The UK's share of EU ETS (traded sector) allowances is unknown, so an estimate of 590 $MtCO_2e$ is assumed based on the CCC's estimate included in its advice. The budget levels considered will have varying degrees of residual risk around missing the UK's 2050 emissions reduction target. The range in costs and benefits above reflect ranges in assumed energy prices and technology costs.

BUSINESS ASSESSMENT (Option 3)

Direct impact on business (Equivalent Annual) £m:			Score for Business Impact Target (qualifying provisions only) £m:
Costs: £0	Benefits: £0	Net: £0	£0

Summary: Analysis & Evidence Policy Option 3

Description: A "CCC recommended" budget (1,725 $MtCO_2e$), reflecting 2015 advice, current accounting basis

FULL ECONOMIC ASSESSMENT

Price Base Year 2015	PV Base Year 2016	Time Period Years 5	Net Benefit (Present Value (PV)) (£m)		
			Low: -£14,500	**High: £28,800**	**Best Estimate: £5,500**

COSTS (£m)	**Total Transition** (Constant Price)	Years	**Average Annual** (excl. Transition) (Constant Price)	**Total Cost** (Present Value)
Low	£0		£7,400	**£22,600**
High	£0		£16,300	**£50,000**
Best Estimate	£0		£11,700	**£35,900**

Description and scale of key monetised costs by 'main affected groups'

Costs captured are the illustrative static amortised capital, finance, and hidden costs; together with in-year increases in operating and maintenance costs over 2028-2032 of delivering the required non-traded sector emissions reductions (£31.2bn). There are additional costs associated with rebound effects in transport, increased congestion (£4.7bn).

Other key non-monetised costs by 'main affected groups'

Policy costs, including administrative costs and additional costs of overcoming barriers to delivery of measures, are not captured as the portfolio of policies to deliver this budget level is unknown at this stage. Impacts on the overall cost of meeting the UK's 2050 target are also not captured. Costs attributable outside the fifth carbon budget period are not included.

BENEFITS (£m)	**Total Transition** (Constant Price)	Years	**Average Annual** (excl. Transition) (Constant Price)	**Total Benefit** (Present Value)
Low	£0		£11,200	**£35,500**
High	£0		£16,400	**£51,400**
Best Estimate	£0		£13,300	**£41,400**

Description and scale of key monetised benefits by 'main affected groups'

There are benefits from a reduction in the cost of energy consumption, additional space heating in the domestic buildings sector (£23.6bn), and GHG impacts (£15.5bn). Smaller benefits include impacts on air and noise quality, as well as improvements in natural capital primarily from the amenity value of afforestation (£2.3bn).

Other key non-monetised benefits by 'main affected groups'

Impacts on natural capital are only included where evidence is available. Benefits outside the fifth carbon budget period are not included.

Key assumptions/sensitivities/risks — **Discount rate (%)** 3.5%

The portfolio of policies to deliver the budget level is unknown at this stage. The monetisation of emissions reduction measures is provided as an illustration only, and is based on knowledge of theoretically achievable options, which are assumed to be deliverable from a technical perspective. There is a high degree of uncertainty around resulting electricity demand changes, the costs and availability of emissions reductions technologies, the role of international credits, and energy prices. The UK's share of EU ETS (traded sector) allowances is unknown, so an estimate of 590 $MtCO_2e$ is assumed based on the CCC's estimate included in its advice. The budget levels considered will have varying degrees of residual risk around missing the UK's 2050 emissions reduction target. The range in costs and benefits above reflect ranges in assumed energy prices and technology costs.

BUSINESS ASSESSMENT (Option 4)

Direct impact on business (Equivalent Annual) £m:			**Score for Business Impact Target (qualifying provisions only) £m:**
Costs: £0	**Benefits: £0**	**Net: £0**	£0

Summary: Analysis & Evidence Policy Option 4

Description: An "equal percentage reduction" budget (1,670 $MtCO_2e$), with equal annual % reductions in emissions from the average level of the fourth carbon budget in 2025 to the UK's 2050 target

FULL ECONOMIC ASSESSMENT

Price Base Year 2015	PV Base Year 2016	Time Period Years 5	Net Benefit (Present Value (PV)) (£m)		
			Low: -£28,600	High: £30,000	Best Estimate: -£100

COSTS (£m)	Total Transition (Constant Price)	Years	Average Annual (excl. Transition) (Constant Price)	Total Cost (Present Value)
Low	£0		£10,100	**£30,900**
High	£0		£22,800	**£69,800**
Best Estimate	£0		£15,900	**£48,900**

Description and scale of key monetised costs by 'main affected groups'

Costs captured are the illustrative static amortised capital, finance, and hidden costs; together with in-year increases in operating and maintenance costs over 2028-2032 of delivering the required non-traded sector emissions reductions (£43.6bn). There are additional costs associated with rebound effects in transport, increased congestion (£5.3bn).

Other key non-monetised costs by 'main affected groups'

Policy costs, including administrative costs and additional costs of overcoming barriers to delivery of measures, are not captured as the portfolio of policies to deliver this budget level is unknown at this stage. Impacts on the overall cost of meeting the UK's 2050 target are also not captured. Costs attributable outside the fifth carbon budget period are not included.

BENEFITS (£m)	Total Transition (Constant Price)	Years	Average Annual (excl. Transition) (Constant Price)	Total Benefit (Present Value)
Low	£0		£13,100	**£41,200**
High	£0		£19,500	**£60,800**
Best Estimate	£0		£15,900	**£48,800**

Description and scale of key monetised benefits by 'main affected groups'

There are benefits from: a reduction in the cost of energy consumption, additional space heating in the domestic buildings sector (£28.4bn), and GHG impacts (£18.0bn). Smaller benefits include impacts on air and noise quality, as well as improvements in natural capital primarily from the amenity value of afforestation (£2.3bn).

Other key non-monetised benefits by 'main affected groups'

Impacts on natural capital are only included where evidence is available. Benefits outside the fifth carbon budget period are not included.

Key assumptions/sensitivities/risks — **Discount rate (%)** 3.5%

The portfolio of policies to deliver the budget level is unknown at this stage. The monetisation of emissions reductions measures is provided as an illustration only, and is based on knowledge of theoretically achievable options, which are assumed to be deliverable from a technical perspective. There is a high degree of uncertainty around resulting electricity demand changes, the costs and availability of emissions reductions technologies, the role of international credits, and energy prices. The UK's share of EU ETS (traded sector) allowances is unknown, so an estimate of 590 $MtCO_2e$ is assumed based on the CCC's estimate included in its advice. The budget levels considered will have varying degrees of residual risk around missing the UK's 2050 emissions reduction target. The range in costs and benefits above reflect ranges in assumed energy prices and technology costs.

BUSINESS ASSESSMENT (Option 5)

Direct impact on business (Equivalent Annual) £m:			Score for Business Impact Target (qualifying provisions only) £m:
Costs: £0	**Benefits: £0**	**Net: £0**	£0

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Executive Summary

Introduction

1. There is overwhelming scientific consensus that significant climate change is happening, driven predominantly by man-made greenhouse gas (GHG) emissions. This is leading to rising temperatures and sea levels, causing extreme weather, damaging ecosystems, and reducing the productivity of crops. Coordinated global action is needed to substantially reduce GHGs, which would not happen at sufficient scale without Government intervention, as climate change costs are not fully factored into private decisions. Global climate action will help secure the UK's long-term economic security and prosperity. The Climate Change Act 2008 ("the Act") and the accompanying Impact Assessment provide the rationale for action to reduce UK emissions on 1990 levels by at least 80% by 2050 ("the 2050 target"). The UK is also committed to the 2015 Paris Agreement binding every country to the ambition to limit the global average temperature rise to well below 2^{o}C.
2. The Act requires Parliament to set the level of the fifth carbon budget, a limit on the UK's net carbon account over the five years between 2028 and 2032. This covers emissions of UK GHGs offset by any purchases of international emissions credits. The first four carbon budget levels covering 2008-2012, 2013-2017, 2018-2022 and 2023-2027 have already been set.
3. The Act specifies that the level of the budget must be set with a view of meeting the target of reducing net UK emissions by at least 80% by 2050 relative to 1990 carbon budgets base emissions. The fifth carbon budget must also be set with a view to complying with the UK's wider (e.g international) obligations. This Impact Assessment informs the decision on the level of the UK's fifth carbon budget.
4. Whilst the fifth carbon budget is a single level set to cover all sectors of the economy (currently excluding international aviation and international shipping) for the purposes of analysis this level is split into the traded and non-traded sectors. The traded sector consists of sectors covered by the EU Emissions Trading System (EU ETS), such as electricity generation and heavy industry. The non-traded sector consists of those emissions not covered by the EU ETS, for example from domestic buildings and road transport.
5. Once the level of the budget is set in legislation, the Act requires the Government to publish a report on the policies and proposals to deliver the fifth carbon budget (and those carbon budgets up to this point) 'as soon as is reasonably practicable' thereafter. This will provide more in-depth analysis on specific sectors. In the absence of the exact details of policies and proposals to meet the fifth carbon budget, this Impact Assessment considers, at a high level, the illustrative impacts of meeting different budget levels.
6. In setting the level of the fifth carbon budget the Government has to take into account the advice of the independent Committee on Climate Change (CCC) and the representations of the Devolved Administrations. In November 2015, the CCC recommended a budget level of 1,765 million tonnes of carbon dioxide equivalent ($MtCO_2e$) with emissions from international shipping included (or 1,725 $MtCO_2e$ if these emissions are excluded); equivalent to a 56.9% reduction on 1990 levels. The Devolved Administrations have confirmed their view that a budget level of 1,765 $MtCO_2e$ should be adopted and that emissions from international shipping should be included. Following the outcome of the United Nations Framework Convention on Climate Change (UNFCCC) climate change negotiations in Paris in December 2015, the CCC also reaffirmed its original advice on the level of the budget.
7. International aviation and shipping emissions are not included within the 2050 target as defined by the Act, or within the first four carbon budgets. The CCC recommended that international shipping emissions be included in the fifth carbon budget, and the Devolved Administrations agreed with this advice. The Government has considered these views and has come to the conclusion that it is not appropriate to include international shipping emissions given negotiations through the International Maritime Organization (IMO) have not yet been completed (see section 2.1 for more detail).

Options under consideration

8. Four options for the level of the fifth carbon budget are presented in this Impact Assessment. Three analytical lenses have been applied to appraise these options, and an assessment has also been made against specific factors set out in the Act.

9. A representative range of options has been selected, from a budget of 1,670 $MtCO_2e$ at one end, to an illustrative budget level of 2,100 $MtCO_2e$, to represent a level not expected to require further policy action to reduce emissions.[1] These represent average reductions in 2030 of 58.3% and 47.5% on the carbon budgets base year (1990) emissions of 800 $MtCO_2e$ respectively.[2] Central projections, in the absence of any new policy commitments, suggest net emissions will fall by around 49% by 2030 (to 2,036 $MtCO_2e$ over the fifth carbon budget period). These perspectives establish the range of plausible carbon budget levels by assessing which levels could be consistent with international action to tackle climate change; which levels could be consistent with meeting the UK's 2050 target in a cost-effective way; and which levels are feasible and affordable given expectations of baseline emissions.

10. The options for appraisal are presented in Table 1 below. The options considered include a level consistent with the CCC's advice (Option 3), and basic trajectories representing alternative views on steady emissions reductions rates to 2050 (Options 2 and 4), giving levels above and below the CCC's recommended level. Also included in the range of options is a "do nothing / do minimum" option (Option 1).

Table 1: Fifth Carbon Budget level options

Option	**Description of non-traded emissions cap**	**Fifth Carbon Budget level ($MtCO_2e$)**	**Average emissions reductions relative to 1990 base**	**Assumed traded share ($MtCO_2e$)**	**Intended non-traded share ($MtCO_2e$)**
Option 1	"**Do minimum**" – any non-constraining budget	E.g. 2,100	e.g. 47.5%	590	e.g. 1,510
Option 2	**Constant absolute annual reductions** (48 $MtCO_2e$ per year) in non-traded emissions, from intended allowance in third carbon budget, to the CCC's central estimate of 2050 non-traded emissions.	1,830	54.3%	590	1,240
Option 3	**CCC recommended level** of non-traded emissions, excluding international shipping (and international aviation).	1,725	56.9%	590	1,135
Option 4	**Constant proportionate reductions** (9% per year) in emissions from the average intended allowance in fourth carbon budget, to the CCC's central estimate of 2050 non-traded emissions.	1,670	58.3%	590	1,080

[1] However, this budget level could become binding and require further policy action if actual emissions during the fifth carbon budget period are higher than currently projected.
[2] Carbon budgets base year emissions are published in table 9 of the supporting data tables for the UK's Final UK Greenhouse Gas Emissions National Statistics. https://www.gov.uk/government/collections/final-uk-greenhouse-gas-emissions-national-statistics

Analytical approach: three perspectives

11. The approach undertaken takes into account the substantial complexity in identifying and analysing appropriate fifth carbon budget level options.

12. Three analytical perspectives are explored in order to identify a wide range of potentially plausible levels of the fifth carbon budget. These provide a bound on the range of budget levels that could potentially fulfil the requirements of the Act. These analytical perspectives are informed by the range of different approaches that could reasonably be taken in assessing appropriate levels of the fifth carbon budget, reflecting the requirements of the Act.

Perspective 1) International context

13. This considers three elements. The first is an appropriate level of UK territorial emissions that could be, as part of a global effort to reduce emissions, consistent with meeting the objective of limiting temperature rises to well below 2°C above pre-industrial levels by 2100. The second is a comparison against emissions reductions commitments made by other countries. The third is the UK's current wider (e.g. international) commitments. The conclusions of this analysis are:

- The Paris Agreement committed countries to a collective global temperature target of 'well below 2°C' and obliges them to 'pursue efforts' to limit temperature rise to 1.5°C. The analysis of different equity-based global effort sharing approaches suggests that the appropriate contribution from the UK to the global 2 degree objective could be equivalent to a 58% to 62% reduction in emissions from 1990 levels, reflecting alternative views on how effort could be shared.

- In total, 188 countries, including all of the G20, have now announced mitigation targets for the post-2020 period. It is not possible to compare directly the relative ambition of all these targets, but collectively they present a significant reduction in emissions relative to the current emissions pathway. However targets announced by countries in advance of the Paris agreement collectively fall short of what's needed to meet the below 2°C objective. The Paris Agreement created a mechanism of five-yearly cycles to look at and increase the level of global ambition. This could result in countries increasing the ambition of their targets.

- Ahead of Paris, the EU and its Member States submitted an Intended Nationally Determined Contribution with an overall target for 2030 of an at least 40% reduction in domestic emissions compared to 1990 levels[3]. This will be delivered through legislation covering the EU Emissions Trading System (EU ETS), and an Effort Share Decision which assigns a single target to each Member State for those sectors not covered by the EU ETS. Overall, therefore, this perspective points to a budget level that constrains future UK emissions below current projections (i.e. a budget level tighter than option 1) but with a relatively wide range for how tight the budget level should be set.

Perspective 2) UK emissions pathways to 2050

14. This perspective draws on modelling by the Department of Energy and Climate Change (DECC) using UK TIMES[4] (a model of the UK energy system) to identify least cost technology options for given emissions pathways, for the period to 2050 and the extent to which different fifth carbon budget level options are consistent with a low-cost smooth transition to meet the UK's 2050 emissions target. The model only takes account of direct technology and energy related costs. Wider costs and benefits (e.g. to economic growth), distributional effects and behavioural or other practical barriers to rolling out technologies are not considered. The key conclusions from the analysis are:

- The technology mix and cost in 2050 is highly sensitive to the availability of key resources (for example biomass) and technologies.

- The least-cost technology mix in 2050 is not sensitive to the level of the fifth carbon budget. Tighter budget levels do not "lock-in" large amounts of low carbon technologies that are not

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[4] UK TIMES Model Overview – November 2014, http://www.wholesem.ac.uk/documents/uktm-documentation

part of the least-cost mix, and looser budget levels do not restrict the development and deployment of the technologies needed to meet the 2050 target.

- However, the latter finding is based on specific assumptions used in the modelling, in particular around technology deployment rates and the availability of future technologies and resources. In practice there can be very substantial uncertainty around these assumptions. Tighter fifth carbon budget levels can reduce the risk of missing the 2050 target due to technology failure or resource unavailability (e.g. because future technologies cannot be deployed at sufficient rates and/or are not available).

Perspective 3) Affordability and deliverability (static costs and benefits)

15. This considers by how much the UK can feasibly and cost-effectively reduce emissions by the end of the fifth carbon budget period, recognising the challenge in overcoming deliverability constraints around identified opportunities for emissions reductions ("abatement measures"). This is based on an assessment of maximum technically feasible emissions reduction potential. The analysis shows that:

    - Option 2 (straight line) could potentially be delivered through mostly cost-effective measures and would be broadly feasible to deliver despite some strong non-cost barriers.
    - Option 3 (the CCC's recommended level) would potentially require a stretching level of abatement action, given current knowledge of technology. Although a budget at this level is estimated to be feasible to deliver, future innovation could help reduce the scale of the challenge.
    - Option 4 (equal percentage reduction) would require even more stretching and high cost abatement measures and would be highly challenging to deliver.

Options appraisal

16. The above conclusions are considered alongside a full illustrative cost-benefit analysis of the potential impacts of each budget level option. While these impacts will depend very significantly on the specific policies and actions to meet the budgets, which are unknown at the time the budget is set, the analysis gives an assessment of the likely scale and direction of the impacts.

17. The <u>direct</u> costs and benefits of setting legislation on the level of the fifth carbon budget alone are negligible, as no specific emissions reductions actions occur solely as a direct result. Nevertheless, the budget level imposes a requirement on Government to ensure the UK net carbon account does not exceed the level of the budget for the years 2028-2032. After the budget is set, the Government has the freedom to choose appropriate policies to ensure the budget is met, and therefore the costs and benefits of these future actions will be unknown at the time the budget is set. This means the analysis presented in this Impact Assessment is an illustration only of the potential scale of impacts of these future policies. While there is significant uncertainty around the aggregate costs and benefits to the UK, there is even greater uncertainty over their composition and distribution across the economy.

18. The illustrative costs and benefits presented in Table 2 (below) are based on an identification of technical opportunities to reduce emissions to the required level, relative to a counterfactual emissions scenario based on the latest published 'Reference' Government projections.[5] This 'Reference' scenario gives an estimate of what emissions are projected to be if recent[6] implemented, adopted, and planned climate policies are implemented as intended.[7] Costs and benefits are calculated using the Government's Green Book appraisal methodologies, and with

[5] DECC (2015), UK Energy and Emissions Projections https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2015
[6] "Recent" relates to policies announced within or since the publication of the UK's 2009 Low Carbon Transition Plan (DECC, 2009, https://www.gov.uk/government/publications/the-uk-low-carbon-transition-plan-national-strategy-for-climate-and-energy)
[7] This scenario does not reflect changes resulting from the 2015 Spending Review, and other changes which will be reflected in the 2016 DECC Energy and Emissions Projections

energy prices, emissions factors, and other core assumptions taken from Green Book supplementary guidance.[8]

Table 2: Summary of cost-benefit analysis of fifth carbon budget level options

Budget level option		**Option 1** Non-binding	**Option 2** Straight line from CB3	**Option 3** CCC's advised level	**Option 4** Equal reduction from CB4
Budget level	$MtCO_2e$	**e.g. 2,100**	**1,830**	**1,725**	**1,670**
Estimated non-traded abatement required	2028-2032 $MtCO_2e$	0	206	311	366
Static Net Present Value	(£m 2016, 2028-2032)	0	12,600	5,500	-100

19. In net present value (NPV) terms (i.e. the present value of social benefits less social costs), the tables shows that budget level Option 2 has the potential to be met at a net benefit to society of around £12.6bn[9], including a valuation of avoided GHG emissions. The CCC's advised budget level (Option 3) could in theory be met at a net social benefit of around £5.5bn over the fifth carbon budget period if met through UK domestic abatement. The tightest budget level considered (Option 4) would result in broadly offsetting social costs and benefits over the fifth carbon budget period.

20. There is considerable uncertainty around these NPV estimates, especially while the policies to meet the budget are unknown. However, the NPVs are also highly dependent on energy prices, changes in costs of technologies over time, the value placed on GHG savings, and on the success in overcoming non-cost barriers to delivery. In many cases, the impact on the NPV of different budget levels is smaller than the impact of varying the core assumptions of energy prices, capital costs, the availability and use of international credits, and the ability of policy to overcome stronger non-cost barriers to delivery

21. In meeting the budget there are a number of flexibilities that can be used, for example, banking or borrowing of emissions from other budget periods, or purchasing international emissions credits to offset domestic emissions reductions. Utilising available international credits would mean there would be potential for the CCC's recommended budget level to be achieved at a greater net benefit to the UK, depending on the future price of international credits.

22. It should be noted that the tighter budget levels could potentially bring substantial longer-term cost-reductions in meeting the 2050 target that are not captured in this static cost-benefit analysis. For example, tighter budget levels can reduce the rate of low carbon technology deployment required to meet the 2050 target after the period of the fifth carbon budget, have the potential to increase the rate of technology cost-reductions, and also increase the value of additional exports of UK low carbon technologies.

23. The most significant contributions to the overall costs and benefits are the technology and finance costs of the abatement measures[10], as well as the impacts on energy consumption. For the looser budget options, energy savings tend to outweigh the costs of the measures, while with tighter budgets the reverse holds. This is because tighter budgets generally require less cost-effective measures with greater up-front costs to realise the same energy savings.

24. The Act also requires a consideration of a number of specific matters, which are assessed in turn in the Impact Assessment:

    a) Scientific knowledge about climate change;
    b) Technology relevant to climate change;

[8] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[9] All NPVs are expressed in 2015 prices, discounted to 2016, and represent costs attributable to the costs and benefits realised in the five years covering the fifth carbon budget period only.

[10] Including capital, maintenance, and non-fuel operating costs

c) Economic circumstances, and in particular the likely impact of the decision on the economy and the competitiveness of particular sectors of the economy;
d) Fiscal circumstances, and in particular the likely impact of the decision on taxation, public spending and public borrowing;
e) Social circumstances, and in particular the likely impact of the decision on fuel poverty;
f) Energy policy, and in particular the likely impact of the decision on energy supplies and the carbon and energy intensity of the economy;
g) Differences in circumstances between England, Wales, Scotland and Northern Ireland;
h) Circumstances at European and international level; and
i) The estimated amount of reportable emissions from international aviation and international shipping for the budgetary period or periods in question.

25. The detail in the following sections presents the full evidence base supporting these conclusions.

1 Introduction

26. This Impact Assessment supports the decision on the level of the UK's fifth carbon budget, a limit on the amount of greenhouse gas emissions (GHGs) the UK can produce for the five years covering 2028-2032. This introductory section provides background including details on the 2008 Climate Change Act ("the Act")[11] and the UK's role in tackling the global challenge of man-made climate change.

27. Section 2 sets out the four options under consideration for the fifth carbon budget level, along with the options appraisal framework and counterfactual scenario. Section 3 provides the rationale for adopting the shortlisted options. It takes three analytical perspectives which reveal the range of budgets that could be: feasibly delivered; appropriate in an international context; and in line with the objective of reducing the UK's GHG emissions in 2050 by at least 80% below the 1990 baseline[12] ("the 2050 target"). Section 4 conducts a full appraisal of the costs and benefits of the options before section 5 summarises the advice provided to the Government and Parliament by the Committee on Climate Change (CCC).

1.1 Policy objective

Rationale for Government intervention

28. There is overwhelming scientific consensus that significant climate change is happening, driven predominantly by man-made GHG emissions, and this is leading to rising temperatures and sea levels, causing extreme weather, damage to ecosystems and a reduction in productivity of crops. It is important and economically beneficial for there to be global reductions in man-made GHG emissions to limit global warming and avoid the risk of significant global costs to the environment and the economy. Setting long-term targets to reduce carbon emissions will help securing the UK's long-term economic security and prosperity.

29. As set out in the Stern Review[13] , and the Impact Assessment for the Act, the primary rationale for Government intervention is that those who produce GHG emissions do not directly face the consequences of their actions, or take into account these consequences when taking decisions. This is because climate change is global in both its causes and consequences; its impacts are long-term and persistent; and there are substantial uncertainties and risks in the economic impacts. As a result, without Government intervention individual efforts to mitigate climate change are unlikely to reduce emissions on sufficient scale.

1.2 Context

Scientific context

30. Recent publications, in particular the latest assessment of the Intergovernmental Panel on Climate Change (IPCC AR5)[14], serve to reinforce the overwhelming scientific consensus that climate change is happening; and that human activity is extremely likely to be the predominant cause, through emissions of GHGs. Climate change driven by GHG emissions is leading to rising temperatures and sea levels, retreating ice and other changes to the natural environment. Many impacts are already being detected globally, from changes to extreme weather and ecosystems to a reduction in productivity gains for some key crops.

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[11] Climate Change Act 2008, http://www.legislation.gov.uk/ukpga/2008/27/contents

[12] Under the Kyoto Protocol, the UK uses 1990 as the base year for carbon dioxide, methane and nitrous oxide emissions, and 1995 as the base year for the fluorinated gases (or F-gases: hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride). To ensure consistency with our international obligations, the same base year for each greenhouse gas is used under the Climate Change Act.

[13] Stern Review on the Economics of Climate Change (2006, archived) http://webarchive.nationalarchives.gov.uk/+/http:/www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm

[14] Fifth Assessment Report, Intergovernmental Panel on Climate Change (2014), https://www.ipcc.ch/report/ar5/

31. Much of the evidence linking GHG emissions to climate risk has been covered in previous Impact Assessments, including the Impact Assessment for the Act, and for the level of the fourth carbon budget[15]. The Act based the UK's 2050 target on advice from the CCC. The CCC's past advice has been based on an objective of keeping central estimates of warming by 2100 as close as possible to 2°C above pre-industrial levels, as well as keeping the chance of a 4°C rise to very low levels. This approach has been followed in its recent advice to Government on the level of the fifth carbon budget.[16]

International context

32. The UK's carbon budgets are domestic commitments, but are intended to be set in the context of efforts worldwide to reduce GHG emissions. Successful action to tackle climate change and reduce emissions can only be achieved if it is coordinated across countries, and all countries are working towards achieving the same global ambition. Without this, it will be very difficult to ensure the transition is globally cost-effective and that countries are not unnecessarily disadvantaged by taking action.

33. International negotiations on climate change are governed through the United Nations Framework Convention on Climate Change (UNFCCC) to which 195 countries plus the EU are party. The most recent negotiations concluded the Paris Agreement (the Agreement) in December 2015[17]. This historic Agreement reaffirmed global ambition to limit temperature rises to below 2°C and so sends a strong signal to investors that governments are committed to a low carbon future.

34. The Agreement binds every country to the collective ambition which should guide national plans to reduce emissions. The Agreement also contained a further collective aspirational goal to reduce emissions in line with keeping the temperature increase to 1.5°C. As a result of the UNFCCC negotiating process, 188 countries have come forward with mitigation commitments to reduce GHG emissions (their "Intended Nationally Determined Contributions" or "INDCs"). The UK's own INDC is currently represented within the EU's collective pledge of a 40% reduction in emissions on 1990 levels by 2030.

35. The total impact of the current national INDCs is not enough to bring global emissions into line with a trajectory consistent with the below 2°C goal. However, the Agreement has also set up a cycle of stocktakes which will review progress towards meeting the 2°C goal. These stocktakes will start in 2018 and then take place every five years thereafter, providing regular opportunities for countries to review their current INDCs. The Agreement also sets a long term goal for net zero emissions in the second half of the century.

36. The UK's role in contributing to this global effort is reviewed in section 3.1 using a range of different approaches. Several of these approaches point to the potential role for developed countries, including the UK, to take a lead in delivering emissions reductions. As wider context, the UK has also committed to spending £3.87bn from 2011/12 to 2015/16 on climate finance and, at least, a further £5.8 billion in the period to 2020/21.

37. Under the existing framework, the EU's member states agreed a 2030 target for the EU as a whole of an at least 40% reduction in domestic GHG emissions below 1990 levels[18] ("the 2030 target"). This will be delivered through legislation covering the EU Emissions Trading System (EU ETS), and an Effort Share Decision which assigns a single target to each Member State for those sectors not covered by the EU ETS. The European Commission has not yet published the Effort Share Decision, but government analysis suggests a target for the UK within this framework would likely be equivalent in carbon budget terms to between a 52% to 54% reduction on 1990 levels.

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[15] Impact Assessment for the level of the fourth carbon budget, DECC (2011), https://www.gov.uk/government/publications/fourth-carbon-budget-level

[16] The Fifth Carbon Budget - The next steps towards a low-carbon economy, Committee on Climate Change, (2015), https://www.theccc.org.uk/publication/the-fifth-carbon-budget-the-next-step-towards-a-low-carbon-economy/

[17] UNFCCC Paris Conference of Parties 21, http://www.cop21.gouv.fr/en

[18] European Council Conclusions October 2014 (EUCO 169/14)

The Climate Change Act and the 2050 target

38. To ensure the UK makes an appropriate contribution to global emissions reductions, the UK government introduced the Act in 2008, establishing the 2050 target and the supporting framework of carbon budgets.

39. The UK's performance against its 2050 target and carbon budgets is assessed relative to the UK's net carbon account,[19] and is measured in terms of tonnes of carbon dioxide equivalent (tCO_2e), recognising the different global warming potentials of different GHGs. The net UK carbon account comprises:

- GHG emissions from the UK (not including Crown Dependencies and UK Overseas Territories) as reported under the UNFCCC. Carbon budgets therefore cover emissions of: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O); and three F-gases: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6);
- Net emissions/removals from Land-Use, Land-Use Change and Forestry (LULUCF); and
- Net purchases of international carbon units. Carbon units include allowances issued under cap and trade systems, such as EU ETS, and international carbon units representing developing country emissions reductions issued under the Clean Development Mechanism.[20]

40. The scope of the UK's 2050 target and carbon budgets currently excludes emissions from international aviation and international shipping. However, the Act states that in setting carbon budgets, Government must take these emissions into account. The CCC considers that, in practice, the requirement to take international aviation and shipping emissions into account when setting carbon budgets "means carbon budgets need to allow for emissions from international aviation and shipping by ensuring that emissions from other sectors are at a level consistent with meeting the overall 2050 target when international aviation and shipping emissions are included".

41. In reaching in its recommendation on the level of the fifth carbon budget, the CCC has consequently made an allowance for the level of international aviation and shipping emissions in 2050 and has analysed the level of emissions reductions that are required from other sectors of the UK economy in order to achieve the 2050 target when international aviation and shipping emissions are included. This approach has been referred to elsewhere as leaving "headroom" for international aviation and shipping emissions.

Climate Change Act provisions for complying with carbon budgets

42. The structure of the UK's net carbon account has particular implications for setting and meeting carbon budgets, which is explained in more detail in section 2.3. In practice, the Government has a number of options to comply with carbon budget levels, besides delivering domestic emissions reductions action. These include the banking and borrowing of emissions from previous and subsequent budget periods, and purchasing international credits to cover shortfalls. Within the Act, there are limits on the extent to which these flexibilities are permitted:

- No limit is placed on banking of overachievement.
- Borrowing of emissions is constrained to at most 1% of the level of the subsequent budget level.
- Before deciding to borrow emissions from the subsequent period or banking overachievement, the Secretary of State must consult other national authorities and obtain/take into account the advice of the CCC. The decision must also be made no later than 31st May in the second year after the end of the earlier of the two budgetary periods affected. So, if overachievement on the fourth carbon budget were to contribute to the fifth carbon budget, a decision would need to be made in by 31st May 2029.

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[19] See section 27 of Climate Change Act 2008

[20] UNFCCC, http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php

- The Government must set through secondary legislation the limit of international credits it may purchase in the following budget period. This limit must be set 18 months before the beginning of the budget period in question.

43. The Act allows for legislated carbon budget levels to be amended if the Government believes that, since the budget level was originally set, there have been significant changes affecting the basis on which the previous decision was made (Section 21 of the Act). The UK is currently in the second budget period, and has previously announced it overachieved against the first carbon budget (2008-2012) with headroom of 36 $MtCO_2e$.

Existing legislation on Carbon Budgets

44. The level of each carbon budget is shown in Table 3 below. The fourth carbon budget was set at in 2011 and was reviewed in 2014. The CCC advised there was no significant change in circumstances to warrant adjusting the level of the fourth carbon budget at that time.[21] The Government accepted this advice and agreed to maintain the level at 1,950 $MtCO_2e$.[22]

Table 3: UK legislated carbon budgets

	First Carbon Budget (2008-2012)	Second Carbon Budget (2013-2017)	Third Carbon Budget (2018-2022)	Fourth Carbon Budget (2023-2027)
Legislated Carbon Budgets ($MtCO_2e$)	3,018	2,782	2,544	1,950
Equivalent percentage reduction from carbon budgets base year[23]	25%	30%	36%	51%

Role of the Committee on Climate Change

45. The Act also established the CCC which is an independent statutory body to advise the UK and devolved administration governments on setting and meeting carbon budgets, and preparing for climate change.

    The Act lays a duty on the CCC to advise on: the level of each carbon budget (Section 4 of the Act); the extent to which the carbon budget could be met through the purchase of carbon units from overseas using carbon units; the respective contributions that different sectors should make (Section 34 of the Act); and the matters it needs to consider when developing that advice (Section 10). These matters are listed in the executive summary of this Impact Assessment.

46. The CCC gave its advice on the level of the fifth carbon budget on the 26th November 2015.[24] The Act states that Government has to take into account this advice before proposing a carbon budget level for agreement by Parliament. A summary of the CCC's advice is provided in Section 5, with specific components discussed within the relevant sections of this Impact Assessment.

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[21] CCC (2013) – *Fourth Carbon Budget Review* - https://www.theccc.org.uk/publication/fourth-carbon-budget-review/

[22] Statement by Edward Davey on the Fourth Carbon Budget (July 2014) - https://www.gov.uk/government/speeches/review-of-the-fourth-carbon-budget

[23] These percentages are implicit only as carbon budgets are set in terms of total greenhouse gas emissions, in millions of tonnes of carbon dioxide equivalent. Since the budgets were originally set, estimates of the carbon budgets base year emissions have changed, due to revisions in the underlying inventory of emissions. The resulting percentage reductions have also changed accordingly, while the budget levels themselves have remained fixed.

[24] CCC (2015) – *The fifth carbon budget: The next steps towards a Low Carbon Economy*: https://www.theccc.org.uk/publication/the-fifth-carbon-budget-the-next-step-towards-a-low-carbon-economy/

2 Analytical framework

2.1 Options under consideration

47. Within this Impact Assessment four options for the level of the fifth carbon budget are considered, shown in Table 4, with the costs and benefits of these options appraised in section 4.

48. These options have been shortlisted from a longer list of options, and have been selected to cover the full range of potentially plausible budget levels derived through the “three perspectives” analysis in section 3 below. These perspectives establish the range of plausible carbon budget levels by assessing: which levels could be consistent with international action to tackle climate change; which levels could be consistent with meeting the UK’s target to reduce UK emissions on 1990 levels by at least 80% by 2050 (“the 2050 target”) in a cost-effective way; and which levels are feasible and affordable given expectations of baseline emissions.

49. A representative range of options has been selected, ranging from 1,670 $MtCO_2e$ at the lowest level to an illustrative budget of 2,100 $MtCO_2e$ at the highest end. These represent average reductions of 58.3% and 47.5% on the carbon budgets base year emissions of 800 $MtCO_2e$[25] respectively. Further carbon budget levels within this range have not been appraised, primarily due to the lack of granularity of the evidence base, meaning it is not possible to definitively appraise small differences between carbon budget levels. The options appraised in this Impact Assessment have been judged to strike the right balance between covering the range of plausible options, and allowing different impacts to be distinguished between levels.

50. The options considered include a level consistent with the CCC’s advice (Option 3), and basic trajectories representing alternative views on steady emissions reductions (Options 2 and 4) giving levels above and below the CCC’s recommended level. Also included in the range of options is a “do minimum” option (Option 1).

51. International aviation and shipping emissions are not included within the 2050 target as defined by the 2008 Climate Change Act (“the Act”), or within the first four carbon budgets. The CCC recommended that international shipping emissions should be included within scope of the fifth carbon budget, and the Devolved Administrations agreed with this advice. The recommended level including international shipping emissions is 1,765 $MtCO_2e$. However the CCC provided an alternative level excluding this allowance, at 1,725 $MtCO_2e$. Under the Act, the Government must take into account the views of the CCC and the Devolved Administrations. The Government has considered these views and has come to the conclusion that it is not the appropriate time for the inclusion of international shipping emissions for the following reasons:

    - International shipping emissions are by their nature an international issue, with an international solution. A global solution is currently being sought and is best achieved at the International Maritime Organization (IMO), where progress in limiting and reducing emissions from international shipping has been, and continues to be made.
    - A decision to include international shipping emissions in carbon budgets at this stage could be seen as the UK taking unilateral policy action on this issue, which could undermine our ability to achieve a global solution.
    - A unilateral decision on treatment of international shipping emissions could filter through to the International Civil Aviation Organization (ICAO), where negotiations on a global solution to international aviation emissions are due to reach a critical point later this year.

52. Therefore, Option 3 is taken at the CCC’s recommended level, excluding an allowance for international shipping emissions.

53. International aviation emissions are also excluded from the range of budget level options, consistent with the CCC’s advice that their inclusion remains impractical at this time, given the scope of the EU Emissions Trading System (EU ETS) for aviation and on-going uncertainty about how this will be treated in future. In particular, this depends on the next ICAO “Assembly” in 2016, which aims to develop a global market-based measure to tackle emissions from

[25] Carbon Budgets base year emissions are published in table 9 of the supporting data tables for the UK’s Final UK Greenhouse Gas Emissions National Statistics. https://www.gov.uk/government/collections/final-uk-greenhouse-gas-emissions-national-statistics

international aviation as well as a work programme to finalise its design, for implementation from 2020. Until the outcome of this ICAO Assembly and subsequent EU discussions on the EU ETS, there remains significant uncertainty around the treatment of aviation emissions within the scope of the EU ETS.

54. However, while international aviation and shipping emissions are excluded from the scope of the carbon budget options considered here, the Act requires Government to take these emissions into account when setting carbon budgets. As discussed in section 1.2, the CCC considers that, in practice, this "means carbon budgets need to allow for emissions from international aviation and shipping by ensuring that emissions from other sectors are at a level consistent with meeting the overall 2050 target when international aviation and shipping emissions are included". The CCC's recommended level of non-traded emissions in the fifth carbon budget and the CCC's central estimate of 2050 non-traded emissions, which additionally inform Options 2, and 4 in Table 4, have been determined on this basis. They are therefore at a level which the CCC considers would be consistent with meeting the 2050 target when international aviation and shipping emissions are included.

55. The Act requires a single carbon budget level to be set, with no option for setting sub-targets. In particular, targets are not set for specific economic sectors and no distinction is made between emissions covered by the EU ETS, and those outside the EU ETS. When setting a carbon budget level it is necessary to follow the framework of the UK Net Carbon Account and to construct the total carbon budget as a sum of individual components. In practical terms, this means taking the sum of the intended level of non-traded emissions, which the carbon budget directly constrains, and a separate estimate of the UK's allocation of EU ETS Allowances (EUAs) for the period ("traded emissions"), which the carbon budget does not directly influence. Section 2.3 explains this and the UK's Net Carbon Account in more detail, including how performance against carbon budget levels is measured.

56. The options for appraisal are presented in Table 4 below. For each of these options, an allowance of 590MtCO_2e is made for traded (EU ETS) emissions based on the CCC's estimate included in its advice. This is broadly consistent with the Government's own estimate of the UK's share of EUAs over the period, although there is considerable uncertainty while the details of the post-2020 EU ETS are established. The estimate of the UK's share of EUAs is discussed in more detail in the International perspective in section 3.1. If the UK's share turns out to be significantly different from the 590 MtCO_2e assumed in the above carbon budget levels, this will affect the headroom available for emissions in the non-traded sector and may require a revision to the level of the chosen budget.

Table 4: Fifth Carbon Budget level options for appraisal

Option	Description of non-traded emissions cap	Fifth Carbon Budget level (MtCO_2e)	Average emissions reductions relative to 1990 base	Assumed traded share (MtCO_2e)	Intended non-traded share (MtCO_2e)
Option 1	"**Do minimum**" – any non-constraining budget	e.g. 2,100	e.g. 47.5%	590	e.g. 1,510
Option 2	**Constant absolute annual reductions** (48 MtCO_2e per year), from intended allowance in third carbon budget, to the CCC's central estimate of 2050 non-traded emissions[26]	1,830	54.3%	590	1,240
Option 3	**CCC recommended level** of non-traded emissions, excluding international shipping (and international	1,725	56.9%	590	1,135

[26] These budget levels explicitly take into account an allowance for International Aviation and Shipping emissions in 2050.

	aviation)[26]				
Option 4	**Constant proportionate reductions** (9% per year) in emissions from the average intended allowance in fourth carbon budget,[27] to the CCC's central estimate of 2050 non-traded emissions[26]	1,670	58.3%	590	1,080

2.2 Options appraisal framework

57. There is substantial complexity in identifying appropriate fifth carbon budget level options for appraisal, and in undertaking the cost-benefit analysis and wider assessment of these options. The approach taken in this Impact Assessment broadly follows the framework adopted when appraising options for setting the fourth carbon budget.[28]

58. First, a counterfactual emissions scenario is established, providing the emissions baseline from which further emissions reductions are required to meet the different options of the fifth carbon budget. The choice of counterfactual is explained in the following section.

59. Three analytical perspectives are then explored, in order to identify a wide range of potentially plausible levels of the fifth carbon budget. These analytical perspectives are informed by the range of different approaches that could reasonably be taken in assessing appropriate levels of the fifth carbon budget, reflecting the requirements of the Act. These perspectives are explained in further detail in section 3. The three perspectives provide a bound on the range of carbon budget levels that could potentially fulfil the requirements of the Act.

60. Having established the short list of carbon budget level options, a full static cost-benefit analysis is undertaken of their potential impacts during the fifth carbon budget period. While these impacts will depend very significantly on the specific policies and actions to meet the carbon budgets, the analysis gives an assessment of the likely scale and direction of the impacts. There will also be important impacts outside this period which are considered throughout this Impact Assessment, in particular in section 3.2.

61. The Act also requires a consideration of a number of specific matters, listed in the executive summary. These are taken in turn in section 4.3 and considered against each of the carbon budget levels, using a range of analytical approaches. The Act also requires the CCC's advice to be taken into account. This is considered within the relevant sections of this Impact Assessment, with the main elements of the advice presented in section 5. Representations from the Devolved Administrations have also been received and the views provided are detailed in Annex 7.1.

62. The evidence is then brought together to allow a comparison of the range of options for the level of the fifth carbon budget against each of these factors. The Government has discretion to attach more or less weight to each of the factors the Act requires to be considered. Different factors point towards different carbon budget options, and as such there is no overall recommended option within this Impact Assessment. The cover sheet of this Impact Assessment presents the costs and benefits of the option laid before parliament (the CCC's recommended level, Option 4).

2.3 Counterfactual emissions scenario

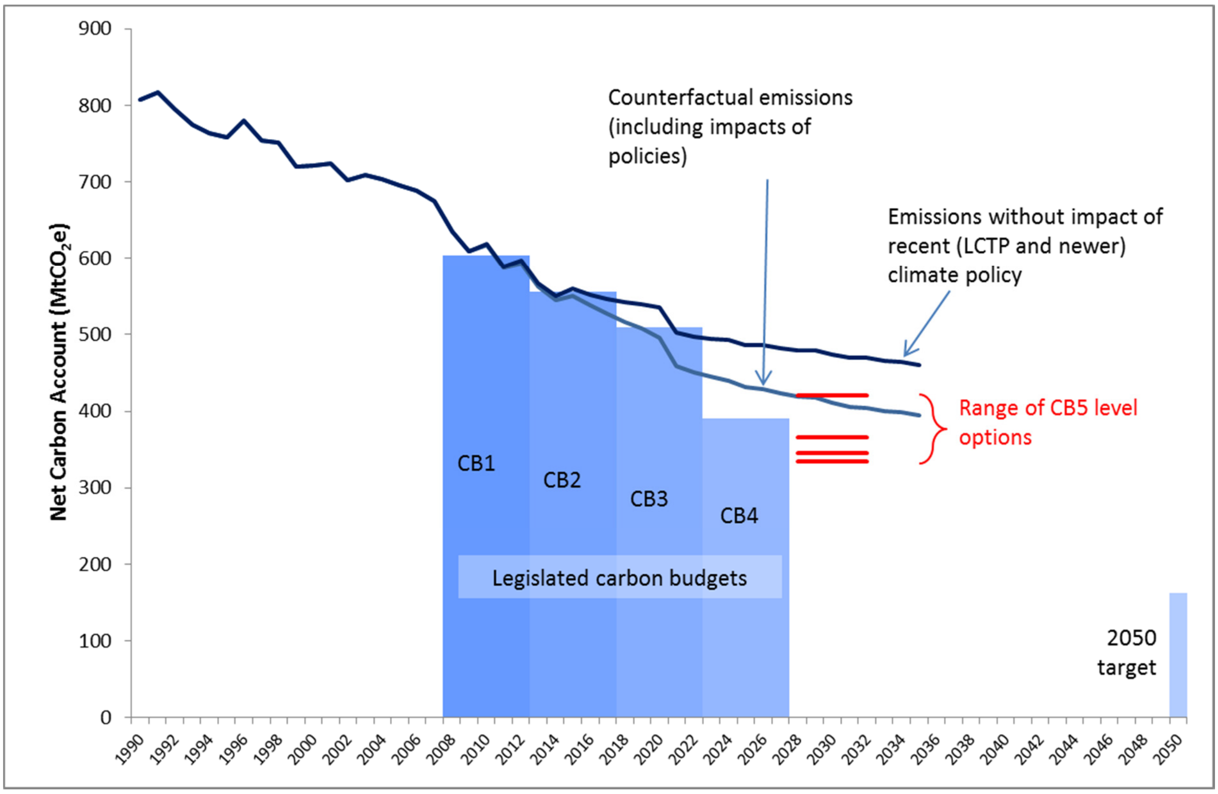
63. To frame the appraisal of the options for the level of the fifth carbon budget, it is necessary to consider how UK emissions are likely to evolve from now in the absence of any new (and as yet unannounced) policy action to reduce emissions. This provides a frame of reference for considering the range of feasible and desirable budget levels, in addition to providing a counterfactual for the options appraisal in section 4.

[27] The fourth carbon budget level, covering 2023-2027 was intended to include an allowance of 1,260 $MtCO_2e$ for emissions in the non-traded sector.
[28] Fourth Carbon Budget level: Impact Assessment, DECC (2011), https://www.gov.uk/government/publications/fourth-carbon-budget-level

64. DECC publishes projections of emissions and energy demand for the UK to 2035.[29] Two core scenarios are produced for this publication: Firstly, a "baseline" emissions projection assuming recent (within or since the publication of the UK's 2009 Low Carbon Transition Plan, LCTP)[30] implemented, adopted, and planned climate policies had not been, or will not be, implemented; Secondly, a "Reference" scenario of emissions assuming these and any previous policies are implemented as planned. **This Impact Assessment takes the Reference scenario from the latest set of emissions projections from 2015, including the effects of existing and planned policies, as the counterfactual for appraising the impacts of setting a fifth carbon budget.**[31]

65. These emissions projections are shown in Figure 1. The first four carbon budgets, applying to the period 2008-2027, have already been set in legislation. The UK announced it had met the first carbon budget in 2014[32], and under central projections the UK is on track to meet the second and third carbon budgets, to 2022. For the fourth budget, there is an estimated shortfall of around 187 $MtCO_2e$, reflecting that the full range of policies to meet the budget have yet to be announced.

Figure 1: Projected UK net carbon account and legislated carbon budgets



66. When full details are known of how the Government intends to meet the fourth carbon budget, it is likely these plans would also result in emissions savings in the fifth carbon budget period. These will be realised independently of the level at which the fifth carbon budget is set. Therefore, the extent of additional emissions reductions required to meet any level of fifth carbon budget is likely to be smaller than projected in the counterfactual emissions scenario. Therefore this Impact Assessment may overstate the extent of emissions reductions specifically required by the fifth carbon budget.

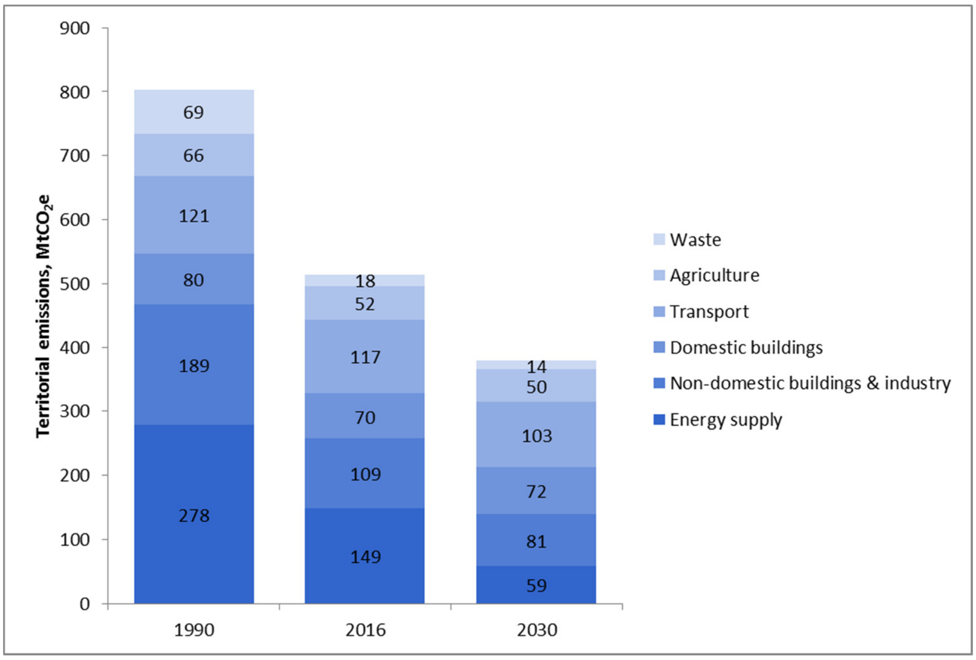
[29] DECC (2015), UK Energy and Emissions Projections https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2015
[30] DECC, 2009, https://www.gov.uk/government/publications/the-uk-low-carbon-transition-plan-national-strategy-for-climate-and-energy)
[31] This scenario does not reflect changes resulting from the 2015 Spending Review, and other changes which will be reflected in the 2016 DECC Energy and Emissions Projections
[32] Final Statement for the first Carbon Budget period, DECC, 2014 https://www.gov.uk/government/statistics/final-statement-for-the-first-carbon-budget-period

67. In contrast, the CCC in its advice adopts an emissions baseline before any impacts of recent existing or planned climate policies. The approach the CCC adopts is to then estimate a cost-effective pathway of emissions based on actions relative to this pre-policy baseline. This means that existing and planned policies are not directly taken into account when making an assessment of the pathway. Existing policies are however taken into account when the CCC considers the challenges in achieving the advised pathway. In assessing the macroeconomic costs and benefits of the recommended carbon budget level, the CCC assumes the fourth carbon budget is met through the actions underpinning its estimated cost-effective pathway, and reported costs of the recommended fifth carbon budget level are additional to these actions. This is explained in more detail in section 4.3.3.

68. The latest emissions projections presented above are of the UK's Net Carbon Account, which takes account of international trading of emissions credits, for example through the EU ETS. Also published are projections of territorial emissions broken down by sector. Relative to the 1990 carbon budgets base year, it is estimated that territorial emissions in 2016 will be around 34% lower, with the largest reductions in the waste, non-domestic buildings, and energy supply sectors. Emissions for agriculture, transport, and domestic buildings are also estimated to have fallen recently but remain around base year levels. The projections suggest these trends are expected to broadly continue under existing and planned policies.

69. Since 1990, reduced use of coal in power generation and significantly less waste sent to improved landfill sites have played important roles in reducing the UK's territorial emissions. From now until 2030, the 2010 Building Regulations; improved energy using product standards; improved road vehicle efficiencies and shift to low emission vehicles; and impacts of the Renewable Heat Incentive are expected to result in substantial emissions reductions.

Figure 2: Historical and projected emissions by sector[33]



70. As with all projections, particularly over the longer term, the amount of uncertainty can be sizeable. The extent of uncertainty underlying these emissions projections has been assessed in the published projections. This is shown in Table 5, and is based on Monte Carlo analysis of in four key areas: macroeconomic factors (such as projected gross domestic product); demographic factors (households, population); the impacts of Government policies; and future temperatures. There are in practice several other uncertainties not quantified in this range, for example uncertainties on model parameters and uncertainties associated with the GHG inventory. These factors can have a substantial impact on the costs of meeting a fixed carbon budget level, and

[33] DECC (2015): Annex A, Energy and Emissions Projections (https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2015)

can increase the risk of emissions exceeding the intended level. The potential impacts of this uncertainty are assessed in section 4.1.

71. Other elements of the assumed counterfactual scenario, including fossil fuel prices, energy demands, carbon prices, and power generation are explained in the relevant sections of this Impact Assessment and in Annex 7.2.

Table 5: 95% confidence interval; DECC Energy and Emissions Projections (2015), Reference Scenario

Net Carbon Account, Reference Scenario ($MtCO_2e$)	**First carbon budget**	**Second carbon budget**	**Third carbon budget**	**Fourth carbon budget**
	2008-12	**2013-17**	**2018-22**	**2023-27**
95% confidence - high emissions		+16	+47	+69
Central projection	2,982 (actual)	2,722	2,493	2,137
95% confidence - low emissions		-15	-49	-65

Net Carbon Account and Carbon Accounting Regulations

72. For the purpose of tracking performance against carbon budgets, UK emissions are measured according to the Net Carbon Account, with the precise calculation set out through the Carbon Accounting Regulations (CARs).[34] CARs covering the period of the fifth carbon budget have not yet been set in legislation, and are unlikely to be in place before the limit for international credit purchases is set for the fifth budget period in 2026. Therefore, for pragmatic reasons it is assumed throughout this Impact Assessment that the CARs applicable in the fifth carbon budget period will be broadly consistent with those established for the first and second budget periods.

Box 1: The UK's Net Carbon Account

The UK's Net Carbon Account and implications for setting the fifth carbon budget

The UK's net carbon account tracks the amount of emissions the UK has produced in a given year, with an adjustment for any trading of international permits. The scope of the net carbon account is explained in section 1.2 of this Impact Assessment. The net carbon account equals the total amount of emissions produced within the UK's territory less any purchase of international credits from other countries, plus any sales of such credits. Graphically it is illustrated in figure 3 below.

In effect the net carbon account is calculated from three components:

1) Territorial emissions from sources not covered by the EU ETS
2) The UK's initial allocation of allowances under the EU ETS for the period (the "UK share")
3) The net amount of any credits purchased outside the EU ETS

This is based on the assumption that UK holders of any unused EU ETS Allowances (EUAs) will sell these to installation owners elsewhere. Therefore any reduction in UK territorial emissions covered by the EU ETS does not result in a reduction in the net carbon account, as the increase in net sales of EUAs will offset these emissions reductions. As a result, **only action to reduce emissions in the non-traded sector will have a direct effect on reducing the net carbon account, and therefore only abatement of non-traded emissions will count towards meeting carbon budgets.**

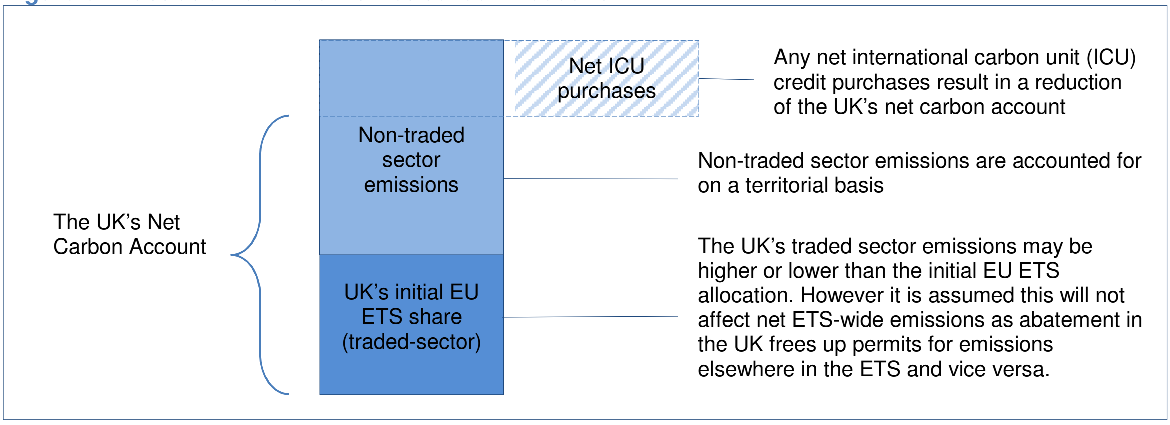
Carbon budgets therefore provide a direct constraint on non-traded emissions only. Conversely, emissions from heavy industry and from the power sector are primarily influenced through the EU ETS and domestic policy targeting the supply and demand of electricity.

Setting the level of the fifth carbon budget therefore requires identifying a desired level of non-traded sector emissions, and forming a total budget level by combining this non-traded level with an estimate

[34] For CARs relating to the second carbon budget period, see The Carbon Accounting (2013-2017 Budgetary Period) Regulations 2015. http://www.legislation.gov.uk/uksi/2015/775/contents/made

of the UK's initial share of allowances under the EU ETS. The estimate of this share is explained in section 3.1.4.

Figure 3: Illustration of the UK's Net Carbon Account



73. Table 6 presents the legislated carbon budget levels, and the projected UK net carbon account.

Table 6: UK emissions and carbon budget levels

	First carbon budget	Second carbon budget	Third carbon budget	Fourth carbon budget
Established carbon budget levels				
Carbon budget level, *of which intended:*	3,018	2,782	2,544	1,950
Traded sector emissions	*1,227*	*1,078*	*985*	*690*[35]
Non-traded sector emissions	*1,791*	*1,704*	*1,559*	*1,260*
DECC Energy and Emissions Projections, 2015:				
Projected total territorial emissions, of which:	2,945	2,646	2,208	1,979
Territorial non-traded emissions	*1,827*	*1,644*	*1,508*	*1,447*
Territorial traded emissions	*1,180*	*1,003*	*700*	*533*
EUAs available for sale		*76*	*285*	*157*
Projected/recorded UK Net Carbon Account	**2,982**[36]	**2,722**	**2,493**	**2,137**
Emissions headroom	*36*	*60*	*51*	*-187*

3 Plausible budget levels: The three perspectives

74. In order to identify the appropriate range of options of fifth carbon budget levels for appraisal, described in section 2 above, three differentiated analytical perspectives have been applied. These perspectives provide alternative viewpoints to assessing an appropriate fifth carbon budget level, recognising the 2008 Climate Change Act ("the Act") requires many factors are to be taken into account, and that it is not possible to develop one single analytical tool to make a

[35] Assumed when the fourth carbon budget was set. There remains considerable uncertainty over this estimate, which depends on the forthcoming negotiations of Phase IV (2012-2030) of the EU Emissions Trading System (EU ETS). These negotiations could potentially conclude in summer 2017. This will, to a lesser degree, also affect the UK share of EU ETS allowances in the third carbon budget period.

[36] As reported when the UK net carbon account for the first carbon budget was closed.

comprehensive assessment. In addition, these perspectives are also each used to provide a partial appraisal of the four carbon budget level options shortlisted.

75. In addition to helping define a plausible range of carbon budget level options, these perspectives also inform a cost-benefit analysis of these options and an appraisal against each of the factors that must be taken into account according to section 10 of the Act. This is undertaken in section 4. These perspectives include: 1) The international context; 2) The UK emissions pathway to 2050; and 3) an assessment of near-term affordable and deliverable emissions reductions.

76. No single perspective can give a full appraisal of different carbon budget levels. The analysis within each of these perspectives should therefore be considered together with the wider evidence on the other perspectives and any additional factors being taken into account. As each perspective is partial, the conclusions from the different perspectives are not necessarily fully consistent. As an example of this, the analysis underpinning the assessment of potential shares of global action to meet a 2°C target in Perspective 1 does not fully consider the same issues underpinning pathway analysis, including the interaction between different decisions over time.

3.1 Perspective 1: International context

3.1.1 Overview

77. The international perspective places the UK's action in a wider context. In doing so, it makes three considerations:

    I. what UK action could be considered to be efficient, fair, and equitable for 2 degrees if there were to be further progress in securing commitments from other countries this goal;

    II. the emissions reduction commitments made by other countries;

    III. the UK's existing international commitments.

78. Overall this perspective points to a carbon budget level that constrains future UK emissions below current projections (i.e. a budget level tighter than Option 1) but with a relatively wide range for how tight the budget level should be set. This depends on the relative weight placed on each of these three considerations.

3.1.2 The UK's role in Global action on climate change

3.1.2.1 Global action on climate change

79. Global mean temperature rises do not depend on emissions in any given year but on atmospheric concentrations of greenhouse gases (GHGs), driven by cumulative net GHG emissions. There is therefore no specific level of emissions for a given year which can be considered consistent with the "well below 2°C" goal of the UNFCCC. This depends on: when global emissions peak, the rate of decline after the peak, and the scope for negative emissions technologies later in the century. The later the date at which global GHG emissions peak, the faster emissions need to fall in later years to meet a given temperature target.

80. Delaying global emissions reductions (and so imposing faster reductions later) is likely to increase the overall costs of tackling climate change, as more carbon intensive assets would need to be retired before the end of their economic life. A review of the literature[37] on rapid emissions reductions suggested a number of reasons why earlier action could reduce overall costs. Early action:

    - induces innovation sooner as learning, experience, economies of scale and networks are given time to evolve;

[37] Bowen, Alex, and Nicola Ranger. (2009); 'Mitigating climate change through reductions in greenhouse gas emissions: the science and economics of future paths for global annual emissions'; Policy Brief. London: The Grantham Institute and Centre for Climate Change Economics and Policy: http://www.cccep.ac.uk/Publications/Policy/Policy-docs/bowen-Ranger_MitigatingClimateChange_Dec09.pdf

- avoids globally piecemeal application of policies and the displacement of GHG emissions to late adopters of policies;
- allows policy-makers to establish the long-run credibility of the policy framework sooner, encouraging firms to pursue innovation and market opportunities in low-emissions technologies and products; and
- allows more gradual and hence less expensive capital replacement and retrofitting.

81. According to the United Nations Environment Programme (UNEP) Gap Report 2015[38] the GHG emissions targets submitted by countries in the run up to the Paris climate conference would lead to global emissions in 2030 of between 54 gigatonne of carbon dioxide equivalent ($GtCO_2e$) and 56 $GtCO_2e$, if fully implemented. This would represent a significant reduction on both 'no-policy' business-as-usual and current policy scenarios, but still represents a shortfall of required action.

82. The Intergovernmental Panel on Climate Change (IPCC) produces a number of plausible scenarios for global emissions and the global mean temperature rise. UNEP analysis of the IPCC scenarios which result in a likely chance[39] of staying below 2°C in 2100, but with action to 2020 consistent with current near-term projections, have emissions in 2030 in the range 29-44 $GtCO_2e$, with a median estimate of 42 $GtCO_2e$. The analysis in this Impact Assessment is based on this median estimate, which compares to global GHG emission of 52.7 $GtCO_2e$ in 2014. For those scenarios resulting in a "medium" [40] chance of staying below 2°C in 2100, global emissions in 2030 are estimated to need to be between 46 $GtCO_2e$ and 48 $GtCO_2e$, with a central estimate of 47 $GtCO_2e$.

Table 7: UNEP 2030 global emission scenarios

$GtCO_2e$	Median	Range
Business as usual projection	65	60-70
Current policy projection	60	58-62
Intended Nationally Determined Contribution (INDC) targets	54-56	52-59
Medium chance of below 2C (50-66%)	47	46-48
Likely chance of below 2C (>66%)	42	29-44
Medium chance of below 1.5C (50-66%)	39	37-40

Source: The Emissions Gap Report 2015. United Nations Environment Programme (UNEP)

3.1.2.2 The UK role in meeting the 2°C objective

83. Climate change is a global problem which requires action from all countries. The UK was responsible for around 1% of emissions globally in 2014.[41] While this is a small share, it is reasonable to consider what an appropriate contribution should be for the UK to make towards overall global emissions reductions. This consideration underpinned the UK's domestic target to reduce emissions on 1990 levels by at least 80% by 2050 ("the 2050 target"), which drew on the Committee on Climate Change's (CCC's) advice to arrive at equal per capita global emissions in 2050. This is assuming a 50% chance of achieving the below 2°C objective. [42]

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[38] The Emissions Gap Report 2015. United Nations Environment Programme (UNEP), Nairobi http://uneplive.unep.org/media/docs/theme/13/EGR_2015_Technical_Report_final_version.pdf page xviii
[39] The IPCC definition of likely chance is greater than 66%.
[40] The IPCC definition of medium chance is a 50% to 66%.
[41] 2014 UK Greenhouse Gas Emissions Statistics and *The Emission Gap Report 2015*, UNEP
[42] The CCC based its recommendation on the UK reducing its emissions per capita to the global average consistent with meeting the below 2°C goal. Parliament adopted the 2050 target on the basis of this recommendation/principle. The CCC recommendation can be found here: https://documents.theccc.org.uk/wp-content/uploads/2013/03/Interim-report-letter-to-DECC-SofS-071008.pdf

84. There are two dimensions to consider when assessing what the UK's medium term contribution should be.

    1. The **economically efficient UK share of global emissions reductions**, which is the level of action within the UK that would be consistent with reducing global emissions to required levels in a way that minimises costs globally at a given point in time; and
    2. An additional **equity-based UK contribution to global emissions reductions**, which recognises the UK's relatively high level of development and historical emissions compared to other countries.

85. If it were feasible to coordinate the economically efficient action in the first approach, the extra abatement in the second dimension provides a sense of the scale of effort the UK could reasonably support in other countries if equity considerations were factored into global climate change actions. Beyond the economically efficient approach, there is no single agreed methodology or formula that can be used to define what a country's appropriate contribution to mitigating climate change should be, given it depends on value judgments about the relevant importance of different principles of an "appropriate" contribution.

86. While action can be coordinated through carbon markets or provision of international climate finance, there are no particular constraints on how UK contributions to global effort should be undertaken. As well as taking action to reduce its own emissions, the UK is also currently supporting low carbon growth in developing countries. The UK is committed to spending £3.87bn from 2011/12 to 2015/16 on climate finance and, at least, a further £5.8 billion in the period to 2020/21. This is compatible with the UK's fair share of developed countries' collective commitment to mobilise $100bn climate finance a year by 2020.

Economically efficient UK share of global emissions reductions

87. To assess the economically efficient UK action in the first approach, the Department of Energy and Climate Change (DECC) Global Carbon Finance (GLOCAF) model has been used. Further details on GLOCAF may be found in Annex 7.4.

88. The 'minimum global cost' scenario is the combination of targets that would lead to equal marginal cost of mitigation across all countries leading to the 'efficient' level of mitigation in all countries. This approach focuses only on economic efficiency and places no emphasis on equity of the targets. It also only seeks to minimise global costs in 2030, and so does not take into account dynamic effects which could affect the total cost of decarbonisation in the long run. This minimum global cost approach suggests a carbon budget level equivalent to around a 52% reduction on 1990 emissions levels. However, the result is highly sensitive to the assumptions used in the GLOCAF model, which are detailed in annex 7.4.

Equity-based UK contribution to global emissions reductions

89. For making an assessment of equity-based emissions reductions contributions, a wide range of different possible approaches to allocating emissions targets to countries have been proposed by academics. The IPCC Working Group III 5th Assessment Report included a summary of what the academic literature on 'effort share' approaches suggests regional targets should be, based on a review of 50 studies.[43] Most of these methodologies base emission reduction targets on historical emissions, per capita emissions, minimising or sharing abatement costs, or ability to pay (usually measured through national income per capita).

90. Six of these effort sharing approaches have been assessed within this Impact Assessment, to illustrate implied emissions reductions contributions of the UK, in the context of coordinated and adequate effort from other countries. Importantly however, some of these approaches are not consistent with the level of the UK's 2050 target. Given the focus of carbon budgets is to meet the UK's 2050 target, effort share methods that are not consistent with this target have been excluded from the assessment here of the range of plausible levels of the fifth carbon budget (although they are included in the table below).

[43] Niklas Höhne, Michel Den Elzen & Donovan Escalante , Climate Policy (2013): Regional GHG reduction targets based on effort sharing: a comparison of studies, Climate Policy, DOI:10.1080/14693062.2014.849452

91. It is also important to note that these approaches do not capture all the elements relevant to assessing how equitable a country's target is. For example, potential economic benefits of mitigation exist, such as helping to develop new exportable technologies. A more complete assessment of different targets should consider the opportunities from climate action, rather than just focus on allocating a mitigation burden. Equally, these approaches do not take into account the potential costs of climate change impacts, which are unlikely to be evenly distributed across countries. The results therefore provide an illustration only rather than a definitive answer.

92. Applying the different approaches gives a wide range of emissions reductions for the UK that could be considered consistent with the below 2°C objective:

- The '**Contraction and Convergence**' and '**Common but Differentiated (CBD) Convergence**' approaches share effort to ensure that nations meet a target for equal emissions per capita by 2050 (the approach adopted by the CCC in its recommendation on the 2050 target). Approaches differ in the point at which developing countries are required to take action; with the latter providing some scope for countries with very low emission per capita to increase emissions in the medium term.
- The '**Global Carbon Budgets**' and the '**Historical emissions index**' approaches take no account of relative costs, only historical emissions. As they would require significant negative emissions from the UK before 2050, they suggest action considerably beyond that required within UK Climate Change Act's 2050 emissions reduction target, and are therefore excluded from consideration
- The '**Equal cost**' and '**Income group**' approaches are based on costs as a share of GDP, and are equivalent to a flat tax rate on income (or progressive tax based on a countries income group for the later).

93. The results of the effort share analysis are shown in Table 8.

Table 8: Illustrative UK contributions to global emissions reductions

	Approach 1: Economically efficient global action	**Approach 2:** Equity-based UK contribution to global emissions reductions					
2030 UK emissions consistent with 2°C objective	Minimum global cost	Contraction & Convergence	CBD convergence	Equal cost	Income group	*Global carbon budget*	*Historic emissions index*
$MtCO_2e$	1,905	1,665	1,560	1,645	1,505	*795*	*810*
% fall, 1990	52%	**58%**	**61%**	**59%**	**62%**	*80%*	*80%*

94. Excluding the approaches inconsistent with the Act (Global Carbon Budget and Historical Emissions Index), the effort share approaches suggest UK emissions reductions during the fifth carbon budget period on 1990 levels of around 58% to 62%. Meeting the 2°C goal would still require the rest of the world to adopt consistent targets. These equity approaches provide a guide for what an appropriate contribution from the UK would be to the global emission reduction, not all of which should necessarily be delivered through domestic emissions cuts.

95. Table 7 shows that current post-2020 mitigation targets take global emissions about half way between the business as usual scenario and a level consistent with the below 2°C goal. Meeting the global goal is likely to therefore require an increase in ambition before 2030. If countries do not bring forward more ambitious targets the global costs of meeting the temperature goal in the long run will be higher (as will the risk of missing the temperate goal altogether).

96. The CCC recommended the UK's 2050 target be set at an at least 80% reduction on 1990 on the basis that is an appropriate contribution to meeting the global temperature objective. In its advice to Government on the outcome of the Paris climate conference, the CCC confirmed that the 2050 target remained an appropriate contribution from the UK.

97. The CCC presented the same effort share analysis in its advice on the level of the fifth carbon budget. The CCC concluded an indicative range for UK emissions reductions on 1990 levels by 2030 of 53-80%. This is similar to the analysis presented above, but that analysis considered it appropriate to exclude approaches that require significantly more action than required under the UK's 2050 target.

3.1.3 Commitments of other countries

98. In the run up to and following Paris, 188 countries, including all of the G20, announced commitments for the post-2020 period. It is difficult to directly compare targets between different countries. However, the level of information available has improved when compared to previous target announcements, in many cases it is not clear which sectors and gases the targets cover. Issues such as the accounting rules used to measure emissions from LULUCF or the extent to which targets can be met through the use of international credits also make direct comparisons challenging. Countries also often use different metrics or base-years to measure their targets and are additionally likely to have different national circumstances affecting the scope for domestic emissions reductions, which together makes it difficult to directly compare the 'effort' required to meet national targets.

99. Below is a summary of the key emission targets adopted by the G20 countries, which between them produce over 66% of global GHG emissions.[44] The important context is the agreement at the 2015 Conference of Parties (COP 21) in Paris to a five-yearly cycle to look at global ambition in light of the well below 2°C objective. As part of this Parties will review their individual action on GHG emissions on the same cycle. The first cycle takes place in 2018-2020.

Table 9: Summary of 2030 GHG emission target of G20 countries[45]

Country	2030 GHG target
Argentina	15-30% reduction on business as usual
Australia	26-28% reduction on 2005
Brazil	37% reduction on 2005 by 2025, with indicative 2030 target of 43% reduction
Canada	30% reduction on 2005 by 2030
China	60-65% reduction in emission intensity of GDP compared to 2005
European Union	At least 40% reduction on 1990
France	40% reduction from 1990 levels
Germany	55% reduction from 1990 levels
India	33-35% reduction in emission intensity of GDP compared to 2005
Indonesia	29% reduction below business as usual
Japan	26% reduction below 2013
Mexico	22-36% reduction on business as usual
Russia	25-30% reduction below 1990
Saudi Arabia	130Mt reduction on business as usual
South Africa	Emission target of 398-614Mt
South Korea	37% reduction on business as usual
Turkey	21% reduction below business as usual
United States	26-28% reduction on 2005 by 2025

3.1.4 The UK's emissions reductions commitments at an international level

3.1.4.1 Kyoto Protocol

100. The UK currently has targets under the Kyoto Protocol. These do not apply directly to the period of the fifth carbon budget.

[44] CAIT Climate Data Explorer. 2015. Washington, DC: World Resources Institute.
[45] Source(s): UNFCCC website, http://unfccc.int/focus/indc_portal/items/8766.php; German Federal Ministry of Economics and Technology http://www.bmwi.de/English/Redaktion/Pdf/energy-concept,property=pdf,bereich=bmwi,sprache=en,rwb=true.pdf; French Ministry of Ecology, Sustainable Development, and Energy http://www.developpement-durable.gouv.fr/-France-launches-its-energy-

3.1.4.2 EU climate policy framework

101. In October 2014 the European Council agreed an EU-level target of at least a 40% reduction in EU domestic emissions from 1990 levels by 2030.[46] This target will be split into an EU-wide target for the traded sector (governed by the Emissions Trading System (EU ETS)) and member-state-level targets for the non-traded sector (set via the Effort Sharing Decision (ESD)). As part of this agreement, the overall 40% reduction comprises a reduction in emissions subject to the EU ETS of 43% compared to 2005 levels, while emissions not covered by the EU ETS (non-ETS emissions) must fall by 30% on 2005 levels.

3.1.4.3 UK emissions covered by the EU ETS (The "Traded sector")

102. The EU ETS sets a total cap on the amount of certain GHGs that can be emitted by factories, power plants and other installations in the system. Within the cap companies receive or buy emissions allowances, which they can trade, in theory allowing the carbon market to determine the cost of the allowances (carbon price) and therefore where emissions can be reduced most cheaply.

103. The cap is ETS-wide (it covers all EU member states, plus Norway, Iceland and Liechtenstein) and so there is not a UK-specific cap. There are currently around 900 UK-based installations participating in the EU ETS. Participating installations can obtain allowances through:

i. free allocation (if they are deemed at risk of "carbon leakage", where production moves to countries outside the ETS as a result of carbon costs);

ii. buying them in Member State auctions; or

iii. buying on the secondary market (from other operators or traders). Historic emissions, along with other factors, are used to calculate how many allowances each Member State can auction and freely allocate to installations.

104. As described in section 2.3, to set the level of the fifth carbon budget an allowance for traded sector emissions must be made, based on estimates of the UK's share of the ETS cap during the period. In 2021 Phase IV of the EU ETS will begin and will run to 2030. In 2015, the European Commission published a proposal for the design of this Phase, with a number of changes intended to strengthen the effectiveness of the EU ETS in reducing traded sector emissions. The introduction of a Market Stability Reserve (MSR)[47] will help to address market imbalance, reducing the current surplus of allowances and improving the system's resilience to major shocks by adjusting the supply of allowances to be auctioned. The final rules of the EU ETS in Phase IV will not be agreed before the fifth carbon budget level is set; although negotiations have already begun. As a result, there are a number of uncertainties to consider when estimating the UK share of the overall ETS cap during Phase IV and the fifth carbon budget. As no agreement has been reached over any EU Emissions Framework for the period after 2030, there is a high degree of uncertainty over any such trading system for the final two years of the fifth carbon budget period. For pragmatic purposes, it has been assumed in this Impact Assessment the overall trajectory and rules would continue as in previous periods.

105. Annex 7.7.1 describes all of the factors that may affect the UK share of the EU ETS cap during the fifth carbon budget period. The CCC presented estimates of the UK's share of the EU ETS cap during the period in its advice to the Government on the scientific and international context for the fifth carbon budget (October 2015) and updated its estimate in its final advice on the setting of the fifth carbon budget (November 2015). The CCC's latest best estimate for the UK's share is 590 $MtCO_2e$, which falls well within the Government's estimated range of uncertainty for this share. This Impact Assessment therefore assumes the UK's share to be 590 $MtCO_2e$, while recognising there is considerable uncertainty. Were the actual share to be different to this estimate, this would affect the headroom available for emissions outside the EU

[46] http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf

[47] The MSR will address the significant surplus of carbon allowances in the EU ETS to help provide a more stable price signal for decarbonisation. It is a mechanism for adjusting the volume of auctioned allowances via a reserve, with the aim of making supply respond to changing circumstances, as in natural markets, and promoting market balance.

ETS. These potential impacts are assessed in the sensitivity analysis in the cost-benefit analysis in section 4.1.

3.1.4.4 UK emissions not covered by the EU ETS (The "Non-Traded sector")

106. The overall EU-level 40% target will include member state targets for the non-traded sector. These "effort share decision" (ESD) targets concern emissions from most sectors not included in the EU ETS such as transport (except aviation and international shipping), buildings, agriculture and waste.

107. In order to make sure the EU as a whole achieves its 2030 target, the European Commission will publish an Effort Share Decision which assigns a single target to each Member State for sectors not covered by the EU ETS. The Commission has not yet published the Effort Share Decision for 2030, but government analysis suggests a target for the UK within this framework would likely be equivalent in carbon budget terms to between a 52% to 54% reduction on 1990 levels. This is estimated to be equivalent to cap on non-traded emissions during the fifth carbon budget period of 1,350 to 1,240 $MtCO_2e$, accounting for differences in scope of carbon budgets and ESD targets. Annex 7.7 describes the methodology used to estimate this range in detail.

Overall implications for the UK

108. Combining a UK share of the EU ETS cap of 590 $MtCO_2e$ with an estimated range of UK ESD 2030 target on current commitments under the EU 2030 climate and energy framework gives an estimated range for the equivalent UK net carbon account of around 1,940-1,830 $MtCO_2e$ (equivalent to a 52-54% reduction on the carbon budgets base year). Options 2, 3, and 4 for the level of the fifth carbon budget considered in this impact assessment are therefore expected to be at least as ambitious as the equivalent UK share of current EU targets.

109. As described in the previous section this range is based on current emissions data and reflects assumptions regarding the starting point for AEAs. In addition to the uncertainty from the final shape of the ESD methodology, there are a number of differences between UK carbon budgets and the EU 2030 Framework limiting the confidence with which a comparison may be made:

- Timing: The EU 2030 framework defines EU action to 2030 but not beyond it. The analysis presented here is based on the assumption that EU abatement effort continues on the same overall trajectory beyond 2030 as that from 2021 to 2030.
- Treatment of LULUCF: Emissions from soils and forestry are counted towards the UK's carbon budgets but are not currently counted towards current EU targets for 2020. Whether and how LULUCF might be included in the ESD for 2030 is yet to be determined.
- Use of international carbon credits ("credits"): The Act allows for the purchase of international emissions credits to be used as a flexibility for meeting carbon budgets. While Member States may purchase a limited number of credits towards their EU non-traded sector targets for 2020, the EU post-2020 framework targets are set in terms of EU domestic emissions.

3.2 Perspective 2: Emissions pathways to 2050

3.2.1 Overview

110. This perspective uses modelling from the UK TIMES model (UKTM)[48] of emissions pathways for achieving the 2050 target.[49] Since the model depends on a large number of uncertain input assumptions, and in particular does not take into account risks associated with different pathways (for example of missing climate targets), UKTM cannot determine which precise fifth carbon

[48] UK TIMES Model Overview – November 2014, http://www.wholesem.ac.uk/documents/uktm-documentation

[49] The modelling makes an allowance for international aviation and shipping emissions within the 2050 target. International aviation and shipping are not modelled directly in UK TIMES; the allowance made for international aviation and shipping emissions in 2050 in the CCC's analysis has been used as a modelling assumption when determining the level of emissions reductions that are required from other sectors of the UK economy in order to achieve the 2050 target when international aviation and shipping emissions are included.

budget level is best. Neither can it determine with any certainty which precise pathway to 2050 will be cheapest. UKTM can however identify technology options that could help meet the 2050 target at least cost. The model can also provide an indication of the extent to which different fifth carbon budget level options are consistent with a least-cost smooth transition to 2050, and an indication of which pathways through 2030 may help manage risks of technology failure or missing future targets. To explore these questions a wide range of different scenarios are used, reflecting variations in assumptions on the costs, performance, and availability of different technologies and resources, plus a wide range of social and economic factors. The results are highly sensitive to many of these assumptions.

111. The key conclusions from the modelling are:

- The technology mix and cost in 2050 is highly sensitive to the availability of key resources (for example biomass) and technologies.
- The least-cost technology mix in 2050 is not sensitive to the level of the fifth carbon budget. Tighter budget levels do not "lock-in" large amounts of low carbon technologies that are not part of the least-cost mix, and looser budget levels do not restrict the development and deployment of the technologies needed to meet the 2050 target.
- However, the latter finding is based on specific assumptions used in the modelling, in particular around technology deployment rates and the availability of future technologies and resources. In practice there can be very substantial uncertainty around these assumptions. Tighter fifth carbon budget levels can reduce the risk of missing the 2050 target due to technology failure or resource unavailability (e.g. because future technologies cannot be deployed at sufficient rates and/or are not available).

112. A number of factors are taken into account when assessing the advantages and disadvantages of different fifth carbon budget levels. These include:

- costs and emissions over the period 2010-2060[50] under different fifth carbon budget options;
- the extent to which tighter or looser fifth carbon budget levels imply different levels of reliance on uncertain technologies or on achieving maximum feasible build rates;
- the extent to which least-cost technology mixes around 2030 under different fifth carbon budget levels are consistent with estimates of least-cost mixes in 2050; and
- the extent to which tighter or looser budgets affect the share of the total transition costs faced in fifth carbon budget or in later periods.

113. This section begins by describing how UKTM has been used. The analysis first considers what a least-cost energy and emissions system might look like in 2050 having met an 80% reduction target on 1990 levels. Pathways to 2050 based on given emissions trajectories are modelled[51] and are then considered in the context of uncertainty about future technologies. Finally the implications of these pathways for fifth carbon budget levels are considered.

3.2.2 Methodology: The UK TIMES model (UKTM)

114. The pathways analysis uses UKTM, an optimisation model for the whole UK energy system covering the period 2010 to 2060. The model's inputs include assumptions about technology costs, availability, performance, build rates, fossil fuel prices and end-use energy demand (for example heat, light, industrial output, distance travelled). Assumptions are pre-determined for each model run, for example demand for energy services does not vary with the costs. Based on these assumptions, the model identifies the least-cost way of meeting a given GHG reduction trajectory while also meeting assumed end-use demand for energy services.

115. The model takes account of the direct costs of purchasing, installing, running and maintaining the technologies and, in scenarios where EU ETS trading is allowed, the assumed price placed on emissions in the traded (EU ETS) sector. Running costs include the costs of energy supply

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[50] Model runs extent to beyond the UK's 2050 target to 2060 to avoid modelling artefacts occurring in 2050, given the importance of this period in assessing the UK's 2050 target

[51] Modelling of the energy system to 2050 is also undertaken without imposing a given emissions trajectory.

covering both domestic supplies and any imports. The cost of borrowing to pay for capital investment is also taken into account as are revenues from energy exports. However, no account is taken of non-monetary or indirect economic costs and benefits such as cumulative emissions, air quality, innovation, economic growth, or health. Costs are discounted into present value terms at the social discount rate. While not factored into the modelling, there are likely to be additional barriers beside cost and technical build rates that could potentially constrain the take-up of options that UKTM analysis suggests may be important in 2050. These barriers are considered separately in section 3.3.5, and include factors such as necessary changes in consumer and business behaviour, lack of access to finance, and a lack of access to information.

116. A particular advantage of UKTM is that it identifies least-cost technology pathways for a given set of assumptions, taking account of interactions across energy carriers and economic sectors over time. The model is therefore useful for identifying which technologies could be important in the long run for achieving a low cost, low carbon system, and the appropriate sequencing for technology deployment. However the model cannot be used directly to determine what the level of the fifth carbon budget should be.

117. There are a number of limitations to the modelling. In particular:

- Not all costs and benefits are accounted for in the model, in particular many behavioural and practical (e.g. geospatial) considerations are not accounted for;
- The model takes no account of risks to costs and meeting future targets resulting from uncertainty around technological, economic, and social factors;
- The model varies in detail across different sectors, and in some areas only high level representations are provided.

These limitations, and additional detail on specific modelling assumptions and technology options are explained in more detail in annex 7.3.

3.2.3 Evidence base

118. The UKTM input assumption database was initially developed by University College London (UCL). DECC and UCL set up a collaboration agreement to update the model to meet joint DECC and UCL requirements and to align with HM Government assumptions. An extensive quality assurance and consultation process was carried out as part of this process.

119. The UKTM reference case macro-economic assumptions (economic growth, population, fossil fuel prices) are aligned with standard HM Government guidance[52] and the DECC Energy and Emissions Projections Reference scenario. These assumptions are the same as those used in the bottom-up analysis on static costs and benefits presented in section 3.3. Wherever possible technical assumptions on costs, performance and availability have also been aligned with the models used to produce the evidence underpinning the static costs and benefits analysis. However, this was not possible for all model parameters due to differences in modelling approaches. More details on assumptions are included in section 7.3.

3.2.4 Scenario definitions

120. This section describes how the counterfactual emissions pathway and the 2050 emissions reductions pathway scenarios are defined.

121. The core analysis is based on the assumption that technologies, markets, and supply chains are fully developed for all existing and nascent technologies specified in the model. There are however very substantial uncertainties surrounding these "maximum development" assumptions, and also around other social and economic factors. A range of sensitivity scenarios described below is therefore also analysed.

122. The model reports results at five year intervals. For the purpose of this analysis results for 2030 are therefore used to draw conclusions about the fifth carbon budget level.

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[52] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

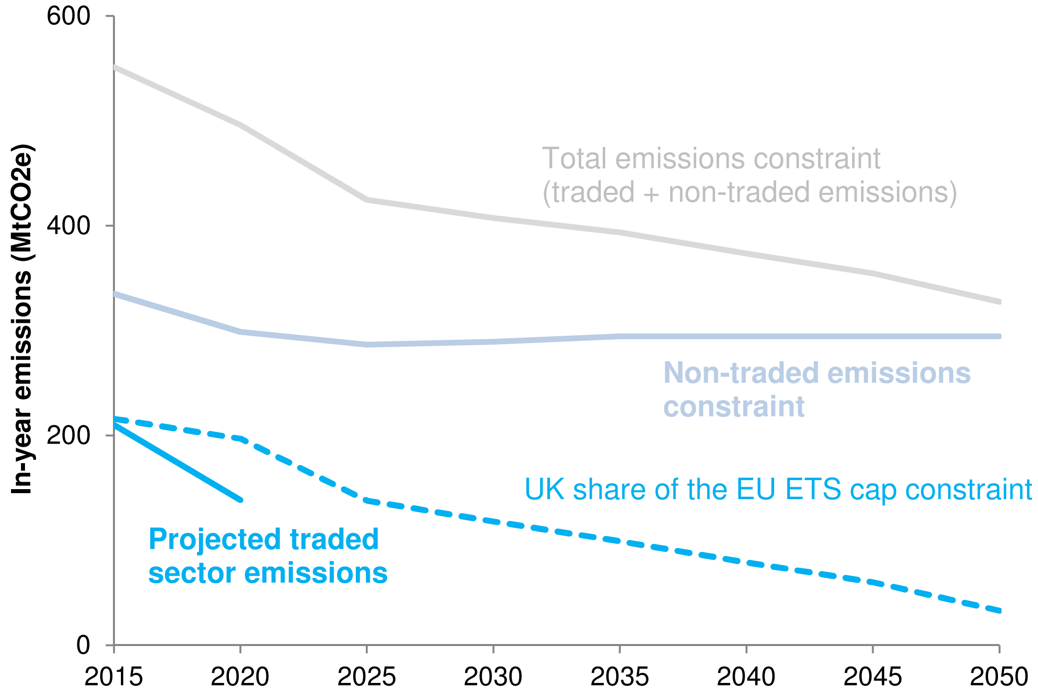
Counterfactual GHG emissions scenario

123. The counterfactual emissions scenario against which costs are compared is based on latest published projections of emissions under existing climate policy only, for core assumptions around a number of social and economic factors. Specifically, the counterfactual scenario is characterised as follows:

- A non-traded emissions trajectory based on latest government projections (see section 2.3 for a description of published Energy and Emissions Projections, "EEP", Reference case)
- A traded emissions trajectory based on latest projections up to and including 2025. 2030 emissions are set equal to the CCC's estimate of the UK's share of EU ETS allowances, and afterwards decline in line with an estimate of the overall EU ETS trajectory
- Trading of emissions permits within the EU ETS from 2025 is allowed at a level of up to +/- 30% of the total traded emissions cap

Figure 3 shows the counterfactual scenario GHG constraints.

Figure 3: UK TIMES Counterfactual emissions constraints



NOTE: From 2025-2050, it is assumed that up to +/-30% of the UK's share of EU ETS allowances can be traded

2050 emissions reductions pathways

124. Emissions reductions scenarios to 2050 are then modelled and compared to the counterfactual scenario described above. These scenarios broadly track latest projected emissions up to and including 2025, before meeting a given level of emissions in the fifth carbon budget period. Cumulative emissions after 2030 are based on pathways with a steady decline in emissions between 2030 and 2050.

125. For these, up to 2025 upper bound constraints on both traded and non-traded emissions are set equal to latest government projections, consistent with the counterfactual scenario. From 2030 onwards the results are taken from runs under the following two scenarios:

a) For 2050 results: a GHG emissions constraint set for overall emissions produced in UK territory. Under this scenario no distinction is made between emissions in the traded and non-traded sectors and the model is free to find the least-cost balance of effort across the economy as a whole. Runs with this constraint are referred to as "Territorial target" runs.

b) For 2030 results: separate GHG constraints for emissions in the traded and non-traded sectors, reflecting current carbon accounting rules. (See Annex paragraph 7.3 for details). Runs with this constraint are referred to as “net emissions” runs.

126. The GHG constraint for 2030 to 2050 is set at a fixed level of cumulative emissions over the period regardless of the level of the fifth carbon budget. This constraint is set at the amount of total cumulative emissions under a straight line trajectory from the CCC’s recommended fifth carbon budget level to the 2050 target. This fixed post-2030 cumulative constraint is used in order to isolate the impact of decisions taken on the fifth carbon budget from decisions taken on future carbon budget levels[53].

127. The use of the territorial target for 2050 is based on the assumption that, whatever carbon trading system is in place in 2050, the UK would seek to balance effort between traded and non-traded sectors in a manner that is cost-effective for the economy as a whole. However, carbon accounting regulations for 2050 are not yet set. The territorial target runs are therefore used to assess which technologies are potentially important in 2050 and beyond for the long-run transition to a low cost and low carbon technology mix. In both scenario types, it is assumed that there is no use of international credit purchases (outside the EU ETS) or other flexibilities (see section 1.2) to comply with the 2050 target or budget levels.

128. By 2050 there is negligible impact resulting from any actions the model adopts to meet different fifth carbon budget levels. Therefore unless otherwise stated, results in 2050 are reported for emissions scenarios based on the CCC’s recommended level (option 3).

129. The “net emissions” scenarios are used for drawing conclusions in 2030 as these align most closely to current accounting rules and observed levels of trading. Comparing modelling results for 2030 and 2050 shows the extent to which it is possible to achieve a given fifth carbon budget level with a technology mix that is both low cost in the fifth carbon budget period under current accounting rules and consistent with progress towards a cost-effective mix in 2050.

Sensitivity analysis

130. For each of the scenarios described above, a wide range of sensitivities are assessed, covering the trajectory for the decline in GHGs over time (GHG constraints), economic growth, fossil fuel prices, and the availability of key technologies.

Sensitivity 1) GHG trajectory after the fifth carbon budget

131. The core analysis specifies a full emissions pathway to 2050, including beyond the fifth carbon budget period, however the UK has not yet set emission targets between the fifth carbon budget and 2050. To assess the impact of this assumed emissions pathway, an alternative “freesolve” specification has been analysed with no emissions constraint beyond 2030 until 2050 (when emissions must be at least 80% below 1990 levels).

132. In the freesolve runs, where “full development” technology and resource assumptions are realised in practice, delaying action reduces the total system cost (over 2010-60[50]) of meeting the 2050 target but at the expense of higher cumulative emissions. In these runs, emissions rise after 2030 for the CCC’s recommended level (Option 3) and equal percentage reduction level for the fifth carbon budget (Option 4) and for all options the emissions trajectory declines sharply by 60% between 2045 and 2050 at a rate of around 40 $MtCO_2e$ per annum (an annual average reduction in emissions of around 17%), which is unlikely to be viable in practice.

133. Analysis is therefore based on the assumption that cumulative emissions between 2030 and 2050 are equivalent to a straight line pathway to the 2050 target, since this results in more plausible emissions pathways than the alternative “freesolve” runs.

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[53] Because the decision on the fifth carbon budget level does not constrain decisions on future carbon budgets a fixed cumulative post 2030 constraint is used for the results reported here. This means that the rate of decarbonisation after 2030 is effectively fixed. Under this constraint, there is little difference in pathway costs outside of the fifth carbon budget period under different fifth carbon budget options and the direct costs of the choice of fifth carbon budget level is isolated from the choices made for future carbon budget levels.

Sensitivity 2) Economic Growth

134. The model has also been run with three economic growth scenarios aligned with the 2015 EEP's low, reference and high growth scenarios.[54] Generally higher growth scenarios lead to higher decarbonisation costs, due to the additional infrastructure needed to meet higher demands for energy. Higher growth scenarios may also lead to earlier roll-out of technologies because build rate constraints mean action has to be taken earlier to achieve the higher capacities needed in the long run. Some more expensive technologies are also occasionally required in the long-run. However the impact of economic growth on the technology mix is generally small and therefore these effects are not considered in any further detail here.

Sensitivity 3) Fossil Fuel Prices

135. The model has been run with three fossil fuel price trajectories (low, central and high) aligned with DECC's 2015 published fossil fuel price projections (see Annex 7.2). Lower fossil fuel prices lead to slightly higher relative decarbonisation costs because there are lower fuel cost savings from improvements in energy efficiency. However the impact on the technology mix in 2030 or 2050 is small. Therefore the effects of this sensitivity are not considered in any further detail here.

Sensitivity 4) Technology availability

136. Many alternative sets of assumptions for technologies and resources have been run as sensitivities to the core "full development" assumptions set. These included the following technology scenarios, to which the results were sensitive:

- Low sustainable biomass availability
- No carbon capture and storage (CCS)
- No hydrogen
- No district heating

137. While scenarios around the availability of these technologies were modelled, the sensitivity of the UKTM technology mix to costs, performance and maximum practical potential for CCS, hydrogen and district heating were not tested and nor were sensitivities to the cost of or emissions from biomass. However the results from the technology availability scenarios above suggest that the technology mix is likely to be sensitive to these factors. Further detail on UKTM technology assumptions is given in Annex 7.3. There are likely to be additional assumptions that strongly influence the UKTM technology mix that have not been assessed here, for example the emergence of currently unknown technologies.

3.2.5 The 2050 energy and emissions system

138. This section considers possible technology mixes in 2050 which could be least-cost under different scenarios. It identifies technologies which could be an important part of the least-cost mix, if they are available as the model assumes, and those that could be required in their absence. However, these technology mixes and their associated costs are highly sensitive to assumptions on the availability, deployment, performance, and cost of technologies and resources, which are uncertain. This is particularly the case for CCS, sustainable biomass and hydrogen. If the modelling assumptions used for these technologies and resources are too optimistic, they would be less important and less reliable components for the cost-effective path to 2050, and alternatives would need to be implemented. UKTM analysis suggests that these alternatives would likely need to be greater electrification of transport and heating.

139. As more information becomes available and a clearer understanding of possible technologies develops over time, uncertainty over the cost-effective path and technology mix for the UK's 2050 target will reduce. Meanwhile, there is likely to value in continuing to appraise a range of options to reduce as far as practical the risk of increased costs of meeting the UK's 2050 target.

[54] Annex M, Updated Energy and Emissions Projections (DECC, 2015); https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2015

3.2.5.1 2050 sector emissions

140. Within this section looking at the cost-effective 2050 mix, analysis is based on "territorial target" scenarios, where a single emissions constraint is applied to all UK territorial emissions. As described above, this is to reflect that carbon accounting regulations for 2050 are not yet known, and that there are likely to be cost advantages to undertaking similar efforts to decarbonise across the two sectors.

141. Table 10 shows the illustrative range of emissions remaining in 2050 by sector under a range of UKTM scenarios. These scenarios include at one end an optimistic outcome where the "full development" assumptions are realised. The ranges result from scenarios where one or more of these assumptions is not realised in practice.

Table 10: Total territorial GHG emissions ($MtCO_2e$) in 2050 under different technology scenarios[55]

Sector	2010 emissions ($MtCO_2e$)	2050 illustrative emissions range ($MtCO_2e$)
Electricity	155	-121 – 3[56]
Transport (excluding IAS emissions)	122	13 – 74
Domestic buildings	81	4 – 47
Non-domestic buildings	30	6 – 25
Agriculture & LULUCF	53	35 – 39
Industry	84	33 – 38
Processing (refining / waste)	92	24 – 33
Total GHG (excluding IAS emissions)	**618**	**127**[57]

142. The size of the ranges in Table 10 illustrates the sensitivity of the least-cost technology mix in 2050 to the cost, performance, and availability of key technologies and resources. This is particularly pertinent in the electricity, transport and domestic buildings sectors. In all scenarios, energy efficiency and decarbonisation of the power sector are important. Assumptions on the costs and availability of negative emission technologies in the traded sector (for example biomass with CCS) are also important.

3.2.5.2 2050 technology deployment and resource use

143. The table below summarises those main technology options identified as likely to be important in the modelled 2050 least-cost technology mixes identified by UKTM. As noted earlier, UKTM only takes account of direct costs and technology constraints, and also does not contain the full range of options likely to be available. There may therefore be other options that are as or more cost-effective than those identified in this modelling.

144. Table 11 illustrates the importance suggested within the modelling of having a range of options to reduce emissions in the non-traded and traded sectors in order to manage risks to achieving the 2050 target. When the costs, performance, and availability of technologies are more certain, it may be appropriate to adopt a narrower range of technologies towards 2050.

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[55] For these runs, emissions during the fifth carbon budget period are set at the CCC's recommended level. The results in 2050 are not sensitive to this level however. The table excludes international aviation and shipping emissions, although an allowance is made for their inclusion in the 2050 target.

[56] Scenarios include modelled biomass feedstocks from both imports and domestic production. Emissions from the use of biomass are assumed to be zero rated. Impacts on the LULUCF sector vary depending on the details of production and are not addressed. There exist other modelling sources that suggest there could theoretically be potential for this extent of negative emissions within electricity generation.

[57] The latest GHG Inventory available at the time of modelling was February 2015. The 2050 target level was therefore set using the February 2015 GHG Inventory. The Inventory was updated in March 2015.

Table 11: Potential key technologies in 2050 based on UKTM cost-effective pathways analysis (territorial target)

Sector energy service demand	Abatement Technologies that are important across most scenarios	Technologies that are important in some scenarios
Domestic buildings	District heating Electric heating (e.g. heat pumps) Insulation	Liquid natural gas and compressed natural gas heavy goods vehicles
Non-domestic buildings	District heating Electric heating (e.g. heat pumps) Insulation	
Industry	Biomass (where available) CCS (where available) Electrification *Note that the sector continues to be a user of gas in most scenarios*	
Transport (exc. international aviation and shipping)	Hydrogen and hybrid heavy goods vehicles Electric cars and vans	
Agriculture & Land-use	Afforestation	

3.2.6 Emissions and technology pathways between now and 2050

145. This section explains a range of plausible, but non-exhaustive, technology deployment pathways to meet the UK's 2050 target.

3.2.6.1 Technology and energy pathways

Energy efficiency

146. The results of the modelling indicate that energy-saving technological progress is essential across all modelled scenarios to reduce the costs of decarbonisation. In the modelled scenarios the majority of the improvement occurs between 2010 and 2030 and is particularly important for reducing the costs of decarbonisation. Across the range of scenarios, overall energy intensity of the economy approximately halves from 2010 to 2030 when looking at the primary energy consumption per unit of GDP.

147. Within the domestic buildings sector 85-100% of available thermal insulation measures are rolled out by 2030 across the range of modelled scenarios. Efficiency improvements in lighting and refrigeration are also important. Lighting consumption per unit output declines to 30% of the 2010 level by 2030 in the domestic buildings sector and to around 40% in the non-domestic sector across all scenarios. This alone reduces overall electricity consumption by around 15% in the fifth carbon budget period compared to the EEP counterfactual scenario.

148. In the scenarios modelled, transport emissions reductions during the fifth carbon budget period result from the model undertaking improvements in conventional vehicle efficiency as much of the fleet remains conventionally fuelled across the range of scenarios. The assumed energy efficiency improvement of conventional cars means that a new car in 2030 consumes less than half the fuel of a car from the 2010 stock. This improvement brings about a reduction in emissions in the UKTM scenarios in 2030 despite the continued increase in kilometres travelled.

149. Energy efficiency options in the industrial sector are modelled in less detail, being mostly generic options rather than specific technologies. However energy efficiency improvements are important with industrial energy demand per unit of output falling across a range of subsectors to 2030.

Role of electricity

150. Electrification of heating, transport and certain industrial processes is important in most modelled scenarios by 2050. However, the extent of electrification and therefore electricity demand in 2050 varies substantially depending on the modelling assumptions. In all scenarios, electricity consumption falls to 2025 due to efficiency improvements and rises after 2035 but the precise turning point varies. Electricity demand in 2030 is higher for the scenarios with tighter levels of the fifth carbon budget.

151. The UKTM modelling suggests the cost-effective level of electricity supply in 2050 is very uncertain. Under current maximum build rate assumptions it is possible to delay substantial electrification of heating and transport beyond 2030. However, earlier electrification would reduce the risk of being unable to achieve the rapid growth in electricity generation and electric heating and vehicles required under these scenarios. This is consistent with a tighter modelled fifth carbon budget level, though greater electrification could also be achieved independently of the budget.

Role of sustainable biomass

152. A further main area of considerable uncertainty is how any available sustainable biomass should be used. Across scenarios, it is generally more cost-effective to deploy biomass in industry and electricity generation than to use it for heating buildings and in transport.

153. Under tighter fifth carbon budget levels the UKTM modelled least-cost technology mix includes more biofuel in transport in 2030 than would be part of the least-cost 2050 energy system. However, by 2030 it is expected that delivering significant emissions savings whilst avoiding sustainability issues would likely require the use of advanced biofuels in transport. There are considerable uncertainties about the development and costs of advanced biofuels which the model does not fully capture and hence it may be over-reliant on biofuels to meet the emissions constraint over this time period. Future sensitivity analysis on biofuel costs should be carried out, however current modelling shows that it is likely to be possible to achieve a similar level of decarbonisation in the fifth carbon budget by bringing forward electrification of cars and Light Goods Vehicles.

154. A tighter fifth carbon budget level may affect which industrial sectors deploy biomass early because it will tend to require greater early decarbonisation in sectors which have higher non-traded emissions. However the budget level has little impact on aggregate industrial deployment in the long run. The modelling suggests that even under tighter fifth carbon budgets there is little deployment of biomass in domestic or non-domestic buildings as part of the least-cost mix during the period.

Role of hydrogen

155. The role of hydrogen in the fifth carbon budget period is small in the modelled UKTM scenarios. The main role for hydrogen in the model during the period is to provide some heating in industry and non-domestic buildings. Deployment around 2030 is part of the modelled pathway to greater deliverability in 2050. If roll-out rates of hydrogen infrastructure become more challenging than current UKTM assumptions then it may be prudent to have greater hydrogen levels in the fifth carbon budget period as a risk mitigation option.

156. Based on least-cost pathways, in 2050 the majority of hydrogen in the model is expected be used by HGVs, with some providing heating to the non-domestic sector. The extent to which hydrogen is used across the economy however depends on the availability of technologies used in its production. UKTM hydrogen cost assumptions are based on the assumption that a new hydrogen network would need to be built in order for widespread use of hydrogen in heating. If it is feasible to repurpose the gas grid this would substantially reduce the costs of rolling out hydrogen for heating and transport. If this becomes the case, findings from the UKTM modelling presented here could understate the role for hydrogen in meeting 2050 targets, and it is possible the mix action chosen by the model in the wider economy would be different.

Role of fossil fuels

157. The model indicates there is a potential residual role for fossil fuels in 2050 in the transport and industry sectors where abatement is more expensive. The modelling suggests an important role for road transport options which can utilise both biofuels and oil-based products, although this

is likely to rely on the significant use of advanced biofuels in order to avoid sustainability issues, the availability of which is highly uncertain. In industry, gas could still satisfy up to half of fuel consumption across the sector.

3.2.6.2 Costs

Table 12: Total abatement and discounted system costs 2010 to 2060[58]

Fifth carbon budget level ($MtCO_2e$)	Total discounted system costs (2010-60) beyond cost of EEP counterfactual	Additional discounted cost over Option 1	Average undiscounted cost per tonne CO_2e abated beyond the EEP counterfactual 2010-2060
	£2015 bn	£2015 bn	£2015/tCO_2e
1): Non-binding (2,100[59])	256	-	56
2): Straight line (1,830)	259	3	56
3): CCC (1,725)	270	14	56
4) Equal annual % reduction (1,670)	281	25	58

158. Table 14 shows that the impact of varying the budget is mainly to shift the distribution of costs between the fifth carbon budget and subsequent budgets. The additional modelled cost of meeting the 2050 target beyond a baseline with only current policies in place is £256bn (discounted, 2015 prices) or around £17bn per year (undiscounted, 2015 prices, over 50 years). Meeting the 2050 target and a fifth carbon budget level of 1,725 $MtCO_2e$ (Option 3: recommended CCC level) would add an extra £0.3bn (approximately 2%) per year (undiscounted, 2015 prices) to this additional cost.

159. As noted earlier, UKTM only includes direct technology and energy-related costs. The benefits of different levels of abatement are not taken into account, including for example health, air quality, cumulative GHG emissions, or innovation benefits. The costs therefore do not show whether higher or lower cost options are most beneficial to society nor can the model say anything about the distribution of how those costs fall. This is assessed in detail in section 4.

3.2.7 2030 and the fifth carbon budget period

160. This section explores what can be deduced about 2030, including both the level of decarbonisation, and the way in which this decarbonisation is undertaken. The aim is to look at the budget levels that could be consistent with a range of actions in each sector to balance costs with risks of failing to decarbonise sufficiently for 2050.

161. Section 3.2.6 highlighted the range of technologies that UKTM modelling suggests could be important for 2050, and illustrated how the 2050 target could be met. If the UK were to keep options open to accommodate the different potential outcomes for the different roles of the energy pathways in 2050, then by 2030 the UKTM modelling suggests that there should be:

- substantially improved energy efficiency
- further decarbonisation of heating and road transport
- an increase in the deployment of district heating
- a start to decarbonisation in the industrial sector
- implementation of some of the available decarbonisation options in agriculture and LULUCF.

162. Figure 4 shows the emissions by sector estimated by UKTM across the range of fifth carbon budget options in this Impact Assessment. This shows that effort is required across the economy.

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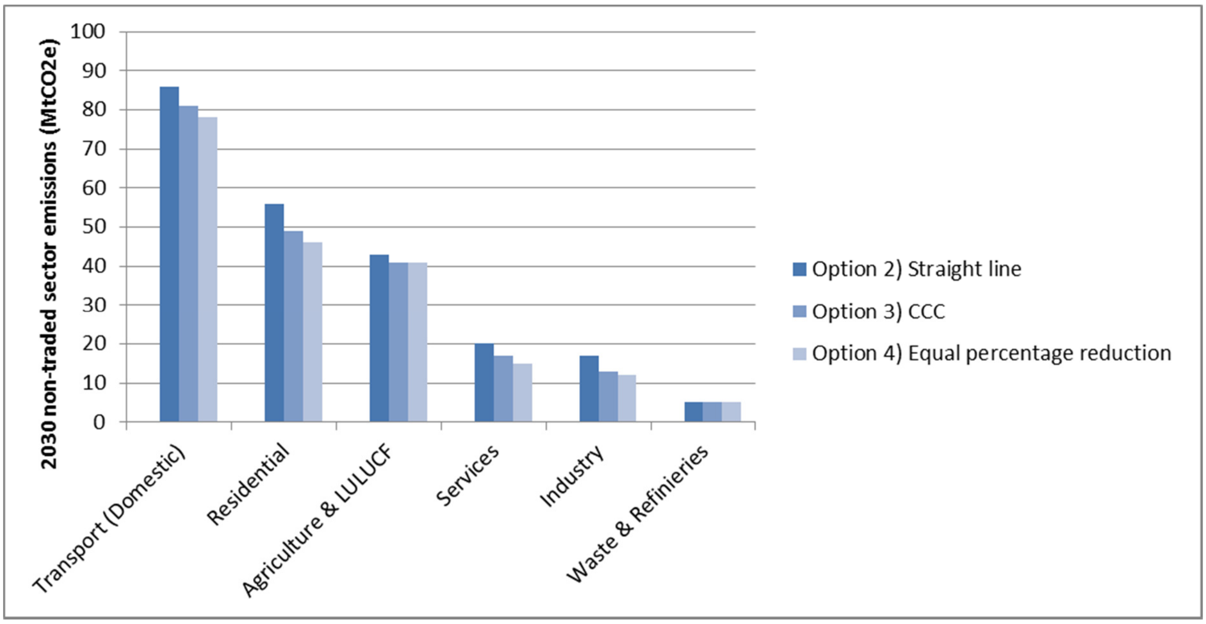
[58] These costs are based on the “net emissions” scenarios.

[59] model chooses 1,938 $MtCO_2e$

Figure 4: Non-traded emissions in 2030 (MtCO2e) under different carbon budget levels[60]



163. Taken together the UKTM pathways evidence suggests that all of the fifth carbon budget options are consistent with a range of low cost pathways to 2050. Based on the modelling assumptions, all are achievable using a mix of technologies that are important as part of a long-term low carbon technology mix in 2050 under a wide range of scenarios. For the tightest fifth carbon budget level (Option 4), the modelling suggests it is achievable using a technology mix compatible with a transition to a low-cost 2050 technology mix. However, there is some evidence that it could require greater electrification and/or use of biomass outside of the power sector than the model suggests is optimal. The CCC's recommended level (Option 3) is modelled to be slightly more costly over the whole period than the looser budget options but is consistent with bringing forward the electrification that the model suggests may be needed. The delays to electrification of heat and transport that UKTM chooses for budget Option 2 is consistent with a smooth low cost transition in the full technology scenario. However this model run requires a rapid increase in electrification from 2035 onwards unless the full range of low carbon technologies across the economy is available. This is achievable under current maximum build rate assumptions but could result in greater risks of missing the target if these cannot be met.

3.3 Perspective 3: Affordability and deliverability (Static costs and benefits)

3.3.1 Overview

164. This third perspective looks at the technical feasibility and costs of reducing domestic emissions in the fifth carbon budget period, relative to projections of emissions under the UK's existing policy framework (see an explanation of the counterfactual emissions scenario in section 2.3). It builds a detailed bottom-up measure-by-measure assessment of emissions reductions opportunities. It also analyses the challenges around delivering such emissions reductions.

165. The analysis shows:

- Option 2 (straight line) would broadly be feasible to deliver and could potentially be mostly met through abatement measures (e.g. technologies, changes in behaviour) estimated to be statically cost-effective over the fifth carbon budget period.[61]

[60] Scenario with target set on net carbon account basis and trading allowed in the traded sector up to +/- 30%.
[61] "Statically cost-effective" means that the social benefits outweigh the social costs accruing specifically in the fifth carbon budget period (2028-2032). Any impacts outside this period are not

- Option 3 (the CCC's recommended level) would potentially require a stretching level of abatement action, given current knowledge of technology, although a budget at this level is estimated to be feasible to deliver. Future innovation could help reduce the scale of the challenge.
- Option 4 (Equal percentage reduction) would require even more stretching and high cost abatement measures and is likely to be highly challenging to deliver.

166. In contrast to the second perspective which looks at pathways of technology deployment and emissions reductions (see section 3.2), no consideration is given here to the wider implications beyond the fifth carbon budget period, in particular meeting the 2050 target. Instead, this perspective is applied to understand in detail the maximum plausible emissions reductions that could be achieved for the fifth carbon budget period on the basis of current knowledge of technologies, and the proportion of these which could be statically cost-effective and relatively straightforward to deliver. In doing so, it provides a bound on the feasible levels of the fifth carbon budget that could be met through domestic emissions reductions, given the current domestic climate policy context and expectations of future drivers of emissions. This bound does not mean tighter budgets should automatically be excluded from consideration; rather, any tighter such budgets would likely need to be met using credit purchases, or by using banked or borrowed allowances from other budgets (see section 1.1 for an explanation of the flexibilities available).

167. The evidence underpinning this perspective also provides the foundation for the cost-benefit analysis of the budget level options in section 4.

3.3.2 Methodology

3.3.2.1 Marginal Abatement Cost Curves (MACCs)

168. The analytical approach for this perspective is based on a cross-sectoral bottom-up analysis of domestic opportunities to reduce emissions in the fifth carbon budget period beyond levels suggested by latest Government projections (as outlined in section 2.3). The analysis has been conducted based on knowledge of existing technologies and also includes an assessment of the potential for savings from behaviour change. Sector analysis has been carried out using latest available evidence where possible, and using a number of bespoke Government models. The evidence base and sources are explained in annex 7.5.1. The analysis examines opportunities to reduce emissions across the full range of domestic GHG emissions across all sources to ensure that abatement opportunities identified are as comprehensive as possible.

169. The identified domestic opportunities are ranked according to a metric of social cost-effectiveness, in terms of net cost per tonne of carbon dioxide equivalent abated (£/tCO_2e), where lower or negative values indicate a measure can deliver emissions reductions more cost-effectively. Further detail is given on cost-effectiveness in Box 2. This ranking of measures by cost-effectiveness then allows the construction of MACCs which show the level of abatement opportunity available and the costs associated with this opportunity.

Box 2: Carbon cost-effectiveness

Carbon cost-effectiveness is a metric measuring the average net social cost of reducing GHG emissions through the adoption of a given abatement opportunity, expressed as a net cost per tonne of carbon dioxide equivalent abated (£/tCO_2e). Lower or negative cost-effectiveness estimates are associated with more cost-effective actions to reduce greenhouse gas (GHG) emissions.

Within this Impact Assessment, estimates of cost-effectiveness are made for actions that result in emissions reductions occurring specifically in the fifth carbon budget period, following the methodology set out in the Department of Energy and Climate Change (DECC)/HM Treasury (HMT) Green Book supplementary appraisal guidance[62].

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accounted for. In particular, benefits from reduced risk of missing the UK's 2050 target; innovation spillover benefits; technology cost reductions; and wider effects on the UK economy are not valued.
[62]Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

The cost-effectiveness metric is derived from the (negative of the) net present value (NPV) associated with a given abatement measure excluding the value of the emissions saved in either the traded or non-traded sector (depending on which sector is being assessed), divided by the amount of abatement in this sector as shown in the following formula:

$$CE_s = -\frac{NPV - PVC_s}{C_s}$$

CE_s = Cost-effectiveness in sector s (T or NT)

NPV = Net present value of option (£)

PVC_s = PV of change in GHG emissions (T or NT) (£)

C_s = GHG emissions change in sector s (T or NT) (tCO_2e)

For example: If an abatement measure which has a lifetime of one year, costs £10 and delivers £20 of fuel savings and 1 tCO_2e of emissions saving in the non-traded sector at a value of £70/tCO_2e, the cost-effectiveness of the emissions savings delivered through this measure would be:

$$-\frac{(20+70-10)-70}{1} = -£10/tCO2e$$

This assumes that there are no other costs and benefits, and that the costs and benefits are discounted to the same year with a consistent price base.

In order to determine whether the abatement options should be considered statically cost-effective, the metric is then compared to a measure-specific weighted average cost comparator (WACC, traded or non-traded). This WACC represents the net cost per unit of emissions which society should be willing to incur when undertaking emissions reductions.[63] If the cost-effectiveness of the measure is below its respective WACC, the measure is considered to reduce emissions in a statically cost-effective way.

For a measure delivering savings in a single year, the WACC is the weighted average discounted price of traded or non-traded carbon in the relevant year, as set out in the Government's carbon values for policy appraisal.[64] The Government is currently undertaking a review of its approach to carbon valuation, which it plans to publish in conjunction with the Government's emissions reduction plan.

The Government's carbon values do not reflect a market price of carbon but instead aim to value carbon in a way consistent with meeting global climate change targets (a 'target-consistent' approach, outlined in "Carbon valuation in UK policy appraisal").[65] Table 13 presents the carbon values for selected years.[66] For emissions impacts appraised over the fifth carbon budget period, the WACC for a measure will be broadly equivalent to the 2030 value of £78/tCO_2e in 2015 prices.

In this analysis, cost-effectiveness estimates have been calculated on a year-by-year basis, using amortised one-off costs (e.g. capital), together with specific in-year recurring costs and benefits (e.g. operating and maintenance costs, and fuel savings). As an alternative, carbon cost-effectiveness can

[63] It can often be appropriate for society to undertake additional abatement actions, where the quantified cost-effectiveness of these actions does not compare favourably to the WACC, but where important benefits are not quantified. In particular, the value of reducing risk through keeping technology options open, and the value an action may have to an overall emissions pathway to the 2050 target. Further details may be found on page 26 of the Green Book supplementary appraisal guidance on the valuation of energy use and greenhouse gas emissions. https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[64] Carbon Valuation in UK Policy Appraisal', DECC, July 2009, https://www.gov.uk/government/publications/carbon-valuation-in-uk-policy-appraisal-a-revised-approach

[65] Ibid

[66] Ibid

be calculated on a lifetime basis.

This Impact Assessment uses in-year, rather than lifetime, cost-effectiveness estimates for three main reasons: first, opportunities for realising emissions reductions have generally been assessed independent of specific delivery profiles, since these profiles would depend on the range of policy levers adopted. Different deployment profiles would result in different lifetime cost-effectiveness estimates. Second, in-year cost-effectiveness estimates allow measures to be compared on a like-for-like basis, as the in-year WACC will be the same for each measure, equal to the relevant in-year benchmark value of carbon. Finally, considering lifetime cost-effectiveness disguises changes in cost-effectiveness over time.

Where specific deployment profiles for emission reductions measures are being considered (for example when designing policies to meet the UK's carbon budgets), lifetime cost-effectiveness of the range of measures would be a more appropriate metric.

Table 13: Traded and non-traded carbon values (£/tCO_2e)

Year	Traded (Real, undiscounted, £2015)			Traded (Real £2015, discounted to 2016)		
	Low	Central	High	Low	Central	High
2015	0	6	21	0	6	22
2020	0	7	39	0	6	34
2025	20	43	78	14	31	57
2030	39	78	118	24	48	73
2035	57	115	172	30	60	90

Year	Non-traded (Real undiscounted £2015)			Non-traded (Real £2015 discounted to 2016)		
	Low	Central	High	Low	Central	High
2015	31	62	94	32	65	97
2020	34	67	101	29	59	88
2025	36	73	109	27	53	80
2030	39	78	118	24	48	73
2035	57	115	172	30	60	90

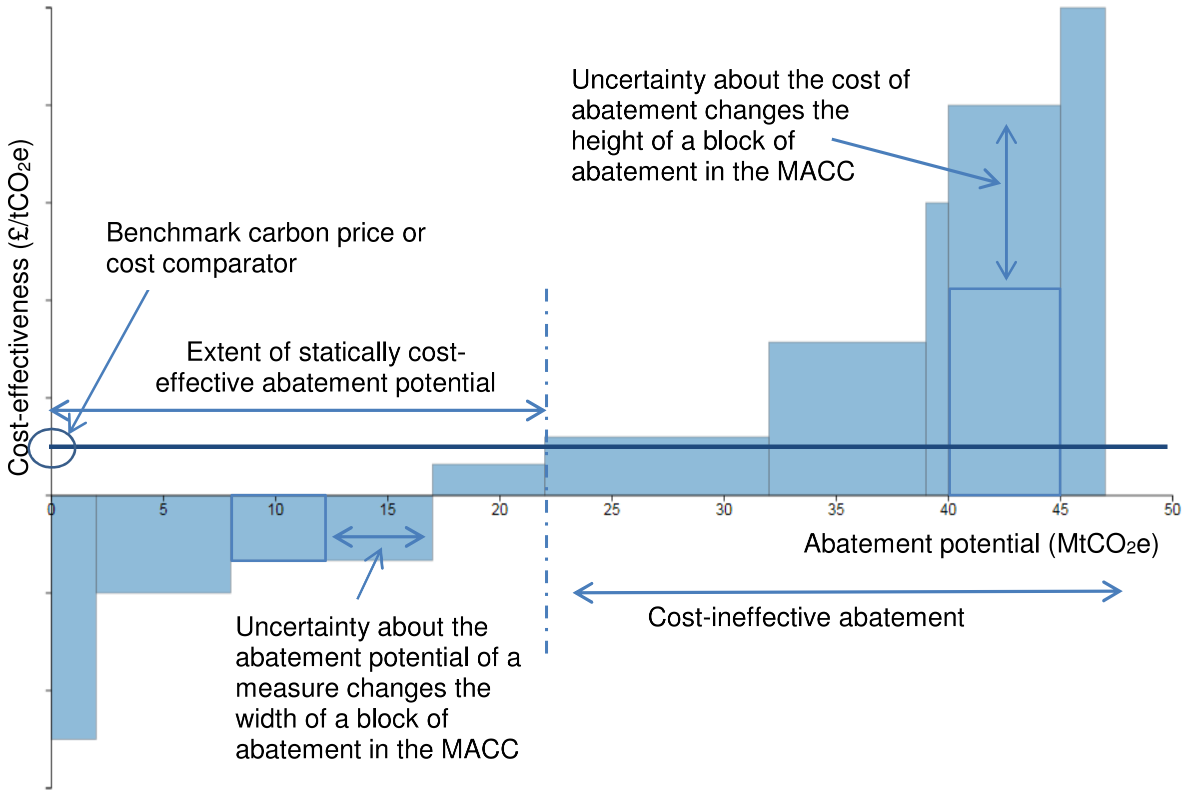
170. For any time period of interest a MACC ranks the emission reduction potential of identified abatement measures according to their cost-effectiveness (as explained in Box 2). The MACC analysis in this Impact Assessment presents abatement potential for the five years of the fifth carbon budget period (2028-2032), unless stated otherwise.

171. Graphically each abatement opportunity is presented as a block. The width of the block represents the total amount of abatement the measure can deliver and the height represents the cost-effectiveness (in £/tCO_2e). Because the measures are ranked by cost-effectiveness, the most statically cost-effective measure (delivering abatement at the least-cost per tonne) will be found on the left hand side of the diagram. Moving to the right, measures become subsequently more costly. Figure 5 below shows an illustrative MACC curve.

172. The cost-effectiveness metric of each measure can be compared to the relevant weighted average cost comparator (WACC - see Box 2), or benchmark carbon price for the fifth carbon budget period to determine whether or not a measure is considered statically cost-effective at reducing GHG emissions. If the abatement cost is less than the WACC, the benefits of the measure from a social perspective overall outweigh the costs and the measure is based on this criterion socially desirable in the short-term.

173. Graphically this can illustratively be shown in the figure through the blue horizontal cost comparator line, with measures represented by boxes falling below the line being cost-effective and those above cost-ineffective. This is equivalent to making an assessment of whether or not the NPV of the measure over a given period is positive, when valuing the GHG emissions impacts at the benchmark carbon price.

Figure 5: Illustrative Marginal Abatement Cost Curve



174. MACC analysis provides a static snapshot of the time period being analysed, and gives a broad indication of the least-cost way to meet a given level of emissions reductions, and the amount of abatement that could potentially be delivered cost-effectively. However, there are limits to the extent to which this can be done, due to the absence of the international and dynamic considerations discussed in sections 3.1 and 3.2.

175. The MACC evidence can then be used to assess the potential costs of delivering a given amount of emissions abatement, or alternatively the amount of abatement that could potentially be considered cost-effective for any given value placed on the resulting carbon savings.

176. The cost and benefit data for the emissions abatement opportunities presented within this impact assessment includes:

- Estimates of fixed and variable costs, including, where possible, any to monetised hidden and hassle costs
- Changes in fuel costs and net purchases of emissions allowances under the EU ETS.
- Wider social impacts of carbon abatement (such as changes in noise pollution, air quality and wider environmental impacts) are included insofar as these could be monetised.

177. The evidence base includes a wide range of different measures, including technological efficiency improvements, switching to low carbon fuels, non-energy-based emissions reductions (e.g. through different livestock feed and afforestation), and savings from behaviour change such as avoiding unnecessary space heating.

178. Given the large range of uncertainty associated with the MACC evidence, sensitivity analysis reveals how the above estimates change depending on different underlying assumptions. Key areas of uncertainty investigated in this Impact Assessment include: fossil fuel prices, technology costs, carbon values, and uncertainty in the baseline. The full sensitivity analysis of the appraisal of costs and benefits of meeting the fifth carbon budget options can be found in section 4.1.

179. The MACC approach has a number of limitations:

- Dynamic impacts are generally not captured, including any impacts on future emissions pathways, technology costs, or market development
- Macroeconomic second-order effects are not reflected in the total resource costs, for example from indirect impacts on wider economic activity from investing in abatement opportunities or impacts from policy instruments. However, an assessment of the potential scale of these impacts has been undertaken using computable general equilibrium modelling, and is explained in section 4.3.3.
- Interactions exist between abatement actions. Direct interactions between measures have been addressed through an assumed ordering of implementation. An example of this is in assessing the impact of improvements in building fabric which reduce the need for heating, and the impacts of switching heat source from gas to a low carbon alternative: improving building fabric will reduce subsequent emissions savings from fuel switching and this interaction has been accounted for in the analysis.
- The optimal allocation of constrained energy vectors across (e.g. biomass, hydrogen) is not directly accounted for.
- Individual abatement measures are often aggregated. For example, the cost of installing insulation in non-domestic buildings can vary widely according to the unique characteristics of individual buildings. This implies that the cost-effectiveness of this insulation measure will have a large range. For practical reasons the analysis will be based on an average cost-effectiveness estimate, which may conceal a substantial variation between different instances of the measure.
- There are very significant uncertainties surrounding a range of assumptions, for example around energy prices, the emissions baseline, and technology costs. In addition the Government is currently undertaking a review of the approach to carbon valuation, which it plans to publish in conjunction with the Government's forthcoming emissions reduction plan.
- For some measures it has not been possible to quantify all the costs, and while the best available evidence has been used, assumptions have been made based on varying strengths of evidence.

180. One further important limitation of this type of analysis is the lack of consideration of the non-cost barriers to deployment, for example a lack of consumer awareness of the fuel savings that could arise; businesses lacking access to finance to make efficiency improvements; and a lack of public acceptability. To help overcome this limitation, evidence has been collected on the level and type of barriers that would have to be overcome to reach the maximum abatement potential for each measure. This evidence is explained in section 3.3.4 together with an assessment of the potential impact of known barriers to delivery, including:

- how estimates of the amount of feasible abatement potential could be affected;
- the challenge policymakers are likely to face in order to deliver required abatement potential;
- the potential value of overcoming barriers to delivery; and
- the impact barriers could have on delivering measures needed for reaching the UK's 2050 target.

3.3.2.2 Approach to assessing emissions abatement in the traded (EU ETS) sector

181. As set out in Box 1, only non-traded sector emissions abatement has a direct impact on the UK's net carbon account and subsequently on compliance with legislated carbon budgets. However, there are three reasons why the traded sector is also considered in this Impact Assessment:

- Firstly abatement action to reduce emissions in in the non-traded sector can have direct implications for traded sector emissions, and vice versa.
- Analysis of abatement opportunities in the traded sector reveals the opportunities to reduce the net purchases of EUAs required to meet the UK's EU emission reduction commitments
- Finally, the analysis of the traded sector implications give an understanding of the wider costs and benefits to society, distributional implications (which are assessed in section 4.3.5) and the UK's contribution to global emission reduction efforts.

182. MACC analysis of the traded sector has been undertaken in all sectors apart from the power sector, where bespoke illustrative modelling of the impact of changes in electricity demand has been undertaken. Depending on the approach taken to meet the fifth carbon budget, the impacts on electricity demand could be substantial. Undertaking all identified emissions abatement options in the non-traded sector could create additional demand for electricity averaging up to 24 TWh (7%) per year over the fifth carbon budget period. Deploying only statically cost-effective measures in the non-traded sector has a negligible net impact on demand and there is significant scope to offset increases in demand with measures that improve the efficiency of electricity use. Section 4.1 estimates whether changes in electricity demand from meeting carbon budgets could have an impact on the long-run variable cost of electricity supply, as a result of changes in the capacity and generation mix, and whether this could lead to changes in the retail electricity price.

183. Different levels of decarbonisation in the power sector have not been assessed within this Impact Assessment. As explained above, the focus of the assessment is on the feasibility and costs of reducing emissions in the non-traded sector: Due to the carbon accounting treatment of emissions within the traded sector, changes in power sector emissions have essentially no direct effect on compliance with carbon budgets.[67]

3.3.3 Evidence base

184. The MACC analysis assesses the maximum technical potential (MTP) for emissions abatement across the UK economy for all emissions within scope of the carbon budgets framework. These sector-by-sector assessments use detailed studies, simulation modelling and in situations where no alternative could be found, expert judgement. The Devolved Administrations contributed to the evidence base for the individual UK nations. Annex 7.5.1 describes the evidence base for each sector.

185. Evidence is at the level of technical or behavioural emissions reductions opportunities (e.g. installing heat pumps, or switching mode of transport from cars to walking). This is in contrast to a policy lever-based approach (e.g. a subsidy to incentivise heat pump deployment; or a regulation on minimum thermal efficiency standards for new buildings). Developing the evidence in this way recognises that a decision on budget level does not determine which policies and actions will deliver emissions reductions, and there are often several policy options for each emission reduction opportunity. To deliver the technologies and actions identified could require additional costs, for example through administration of a policy. These additional delivery costs are not included in this analysis.

186. MACC data has been collected across key economic sectors and sources of emissions. This includes opportunities identified in agriculture; waste; LULUCF; industry; transport; domestic and non-domestic buildings (new build and retrofit). The data includes one-off and recurring costs of each measure (including where possible hidden and hassle costs); changes to fuel consumption, the scale of any rebound effects[68]; traded and non-traded sector emission impacts; as well as impacts on air quality, noise, road congestion, and the wider environment. All impacts are valued using HM Treasury Green Book-consistent methodologies.

[67] A proportion of grid electricity is produced by non-EU ETS participants. However, almost all of this generation is from zero-emissions rated plant, for example resulting from Feed-In Tariffs (FiTs). Therefore, it is a reasonable approximation to allocate all grid electricity emissions to the traded sector.

[68] Rebound effects in the domestic buildings and transport sectors result from increased efficiency in the provision of energy services, such as heating. These can be as a result of improved boiler or vehicle efficiency, or reductions in heat loss through building fabric improvements. To maintain the same level of energy services following efficiency improvements requires less energy to be consumed, resulting in energy bills savings. Consumers may choose to use some of these bills savings to increase consumption of energy services, for example heating homes for longer or to a higher temperature, or making more journeys by car if fuel costs are lower. These effects are valued according to Government guidance.

187. Assumptions on fossil fuel prices, emissions factors, and carbon prices are taken from the Green Book Supplementary Guidance on the Valuation of Emissions and Energy Use.[69] More information on the assumed counterfactual and common input assumptions across the analysis can be found in section 2.3 and Annex 7.2 of this Impact Assessment respectively.

188. Illustrative scenarios to assess potential impacts in the power sector from changes in electricity demand have been estimated using DECC's Dynamic Dispatch Model (DDM).

Box 3: The DECC Dynamic Dispatch Model (DDM)

The DDM is a comprehensive fully-integrated power market model covering the market in Great Britain over the medium to long-term. The model enables analysis of electricity dispatch from GB power generators and investment decisions in generating capacity from 2010 through to 2050. It considers electricity demand and supply on a half-hourly basis for sample days. Investment decisions are based on projected revenue and cash flows taking into account policy impacts and changes in the generation mix. The full lifecycle of power generated plant is modelled, from planning through to decommissioning. The modelling accounts for risk and uncertainty involved in investment decisions. Outputs include social cost-benefit analysis, wholesale electricity prices and changes in the costs of operating the electricity network.

Further information on the DDM may be found in Annex 7.9 and online: https://ww.gov.uk/government/publications/dyanamic-dispatch-model-ddm

3.3.4 Feasible abatement opportunities

189. The MACC analysis shows the amount of abatement that could be considered statically cost-effective against the Government's benchmark carbon values, and also the potential costs and benefits or realising this abatement, under a range of assumptions**.** The presence of specific measures in the table and MACC below does not necessarily mean that these measures will be taken forward by Government as part of its strategy to reduce emissions. Furthermore, some of the measures included in this assessment face significant practical barriers to delivery, which could potentially incur additional costs to overcome. Section 3.3.5 below considers the impacts of these barriers.

3.3.4.1 Sector emissions reduction opportunities

Box 4: Maximum technical potential for emissions reductions during the fifth carbon budget period

As a best estimate of maximum technical potential, around 527$MtCO_2e$ of non-traded emissions abatement has been identified. Of this, around 172 $MtCO_2e$ (33%) could be considered statically cost-effective against central Government benchmark carbon values.[70]

In the traded sector, excluding options to decarbonise the mix of power generating technologies, around 111 $MtCO_2e$ of emissions could be saved through predominantly efficiency improvements in industrial processes and energy using products (domestic & non-domestic). Of this abatement, around 86 $MtCO_2e$ is statically cost-effective (77%). Further traded sector emissions reductions could be achieved through greater power sector decarbonisation, not considered in this Impact Assessment.

190. The table below disaggregates the identified maximum technical potential across the sectors of the UK economy and highlights key abatement measures. Across the economy as a whole, the majority of emissions reductions can be characterised by efficiency improvements (particularly in buildings and vehicles), fuel switching (for example to electricity in providing heat), and electrification (particularly of heat supply in buildings, and road transport).

[69] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal
[70]https://www.gov.uk/government/collections/carbon-valuation--2

Table 14: Emission reduction potential over the fifth carbon budget period

Sector	Maximum technical abatement potential ($MtCO_2e$, 2028-2032)		Primary emissions reduction opportunities
	Traded	**Non-traded**	
Agriculture	0	84	Wide variety of measures, with significant abatement potential from improving livestock health and Countryside Stewardship schemes.
Waste (incl F-Gases)	0	80	Reduction of waste sent to landfill and various interventions to reduce emissions from waste already in landfill.
LULUCF	0	29	Afforestation[71]; peatland restoration.
Transport	-1[72]	107[73]	Electrification and increased efficiency of vehicles (cars, vans and HGVs); and moving some journeys to lower-emission modes of transport.
Domestic buildings[74]	57	145	Energy efficiency measures (particularly solid wall insulation), behavioural changes in how households choose to use energy, plus decarbonisation of heat sources through heat pumps, district heat networks, or use of hydrogen in gas networks.
Non-domestic buildings	16	70	Energy efficiency measures (particularly solid wall insulation); behavioural changes in how businesses, charities, and public sector organisations choose to use energy; plus decarbonisation of heat sources through heat pumps, or district heat networks; as well as improved ventilation in non-domestic buildings.
Industry	39	12	The measures causing abatement will vary for the traded/non-traded sectors. Initial analysis suggests a substantial proportion of the non-traded abatement opportunity is through improvements in energy efficiency.
Total	**111**	**527**	

191. The spread of opportunities across sectors indicates that abatement action across multiple sectors within the UK economy is likely to be needed in order to realise substantial emissions reductions.

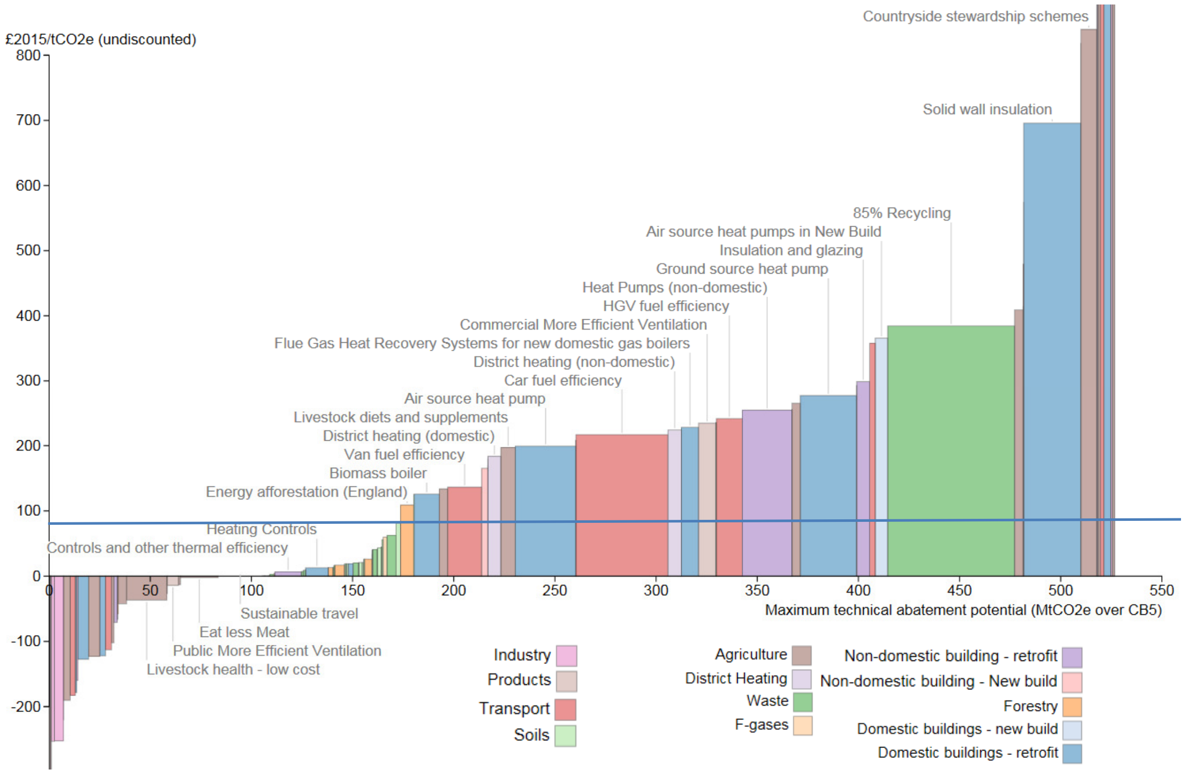
3.3.4.2 Non-traded sector emissions reductions

192. Figure 6 shows a UK-wide MACC for abatement opportunities in the non-traded sector. The MACC depicts the central estimate for maximum technical abatement potential across the whole economy[75] and does not take into account implementation barriers to delivery. The horizontal line

[71] Afforestation would comprise a mix of native and exotic species, meet the requirements of the UK Forestry Standard, and include a significant proportion of productive woodland.
[72] In transport there is a net increase in traded sector emissions as a result of electrification of vehicles and rail transport.
[73] Due to modelling constraints around the overlaps between mode-shifting options, overall abatement potential in the transport sector may be slightly lower than presented here.
[74] The analysis of space heating in the domestic buildings sector in this impact assessment is based on an electrification scenario. Alternative solutions to decarbonise domestic space heating via greening the gas grid can exist.
[75] This is based on central appraisal values (carbon values, fossil fuel prices) and central cost estimates for each of the underlying sectors

shows the central benchmark government value of carbon at around £78/tCO_2e in 2030. The amount of abatement which is estimated to be statically cost-effective against this benchmark varies with assumptions on energy prices and capital costs. Table 15 reports these sensitivities.

Figure 6: Non-traded sector MACC showing maximum technical potential (central case, 2028-2032)



193. The above chart and table below show the portion of maximum technical potential estimated to be statically cost-effective when compared with benchmark carbon values in the central energy price and capital cost scenarios, and under sensitivities around these variables.

194. The **private perspective** considers only costs and benefits of an abatement measure accruing to the individual or business carrying out the measure, such as investment and operating cost of a measure and any associated energy bill savings valued at retail prices. If private cost-effectiveness is less than £0/tCO_2e and consumers and businesses have perfect knowledge of the costs and benefits of the measure, the abatement would likely be considered worthwhile by the consumer or business. The existence of significant amounts of privately cost-effective abatement indicates that there are non-cost barriers to deploying these measures which are preventing these otherwise net beneficial actions. This is discussed in greater detail in section 3.3.5.

195. The **social perspective** considers the welfare of the UK population as a whole, accounting additionally for the range of public costs and benefits that arise as a result of abatement activity (such as impacts on air quality and noise or the costs of increased congestion). Changes in energy consumption are valued at its long-run variable cost of supply (LRVC) which reflects the value to society as a whole.[76] Some measures, such as countryside stewardship schemes, may include benefits for which it is not yet possible to accurately monetise (e.g. biodiversity value, cultural/historic value, and landscape amenity value). Including this valuation would improve the cost-effectiveness of the measures.

[76] The long-run variable cost of energy supply (LRVC) excludes those fixed cost components (such as office overheads) that will not change in the long run despite a sustained marginal change in energy use. The variable costs exclude carbon costs, since these are valued separately, and also exclude taxes, margins and other components that should be viewed only as transfers between groups in society.

Table 15: Cost-effectiveness of maximum technical abatement potential (non-traded, 2028-32)

Maximum identified technical abatement potential: non-traded sector ($MtCO_2e$)		**Cost-effectiveness threshold in 2030 (£/tCO_2e)**					
		Private perspective	**Social perspective**				
Scenario/ sensitivity		<£0 /tCO_2e	<£0 /tCO_2e	< £39 /tCO_2e (low carbon values)	<£78 /tCO_2e (central carbon value)	<£118 /tCO_2e (high carbon value)	**Total abatement potential**
Core estimate		**175**	**108**	**159**	**172**	**198**	**527**
Sensitivity: *Energy prices*[77]	*Low*	*-8*	*-12*	*-26*	*-3*	*-20*	**527**
	High	*+3*	*+35*	*+29*	*+38*	*+64*	**527**
Sensitivity: *Capital costs*	*Low*	*+27*	*+52*	*+81*	*+113*	*+134*	**527**
	High	*-22*	*-11*	*-35*	*-11*	*-27*	**527**

196. The analysis suggests there is more privately cost-effective abatement than socially cost-effective abatement. This is largely because private energy savings are valued at the retail price of energy, whereas energy savings from a social perspective are valued at the LRVC, which is lower than the retail price. This generally more than offsets the exclusion of social benefits (such as air quality, carbon benefits and noise quality) from the calculation. Furthermore, for some measures the social elements can be net costs, such as increased congestion as a result of the rebound effect from more efficient vehicles.

197. The sensitivities shown in the table above have no impact on total maximum technical potential identified, but they change the estimated costs of delivering this potential and therefore the proportion of this potential that can be considered cost-effective at reducing emissions. For example, higher energy prices mean that efficiency improvements become more cost-effective because the value of the energy saved is greater.

198. 97 $MtCO_2e$ of abatement can be identified as both privately and socially cost-effective (where social cost-effectiveness is assessed against central carbon values). Low capital costs have the largest impact on estimated cost-effective potential both from a private and public perspective and under the full range of carbon prices considered.

3.3.4.3 Traded sector emissions reductions

199. Abatement opportunities in the traded sector (excluding decarbonisation of power generation) lie predominantly in the industrial sector (39$MtCO_2e$), as well as from greater deployment and more efficient use of energy-using products across domestic and non-domestic users (78$MtCO_2e$). Based on the monetised costs and benefits, many of these opportunities are estimated to be socially cost-effective. While there would be no direct impact in helping meet carbon budgets under the current accounting framework, realising these opportunities could improve the efficiency and competitiveness of industrial firms, and increase the UK's net sales of EU ETS allowances (EUAs).

[77] This sensitivity does not include variations in the price of biomass for domestic use.

Table 16: Abatement potential in the traded sector, 2028-32 (excl. options to decarbonise power supply)

Maximum identified abatement potential: Traded sector ($MtCO_2e$)		**Cost-effectiveness threshold in 2030 (£/tCO_2e)**					
		Private perspective	**Social perspective**				
Scenario/ sensitivity		<£0 /tCO_2e	<£0 /tCO_2e	<£39 /tCO_2e (low carbon values)	<£78 /tCO_2e (central carbon value)	<£118 /tCO_2e (high carbon value)	**Total abatement potential**
Core estimate		**95**	**78**	**86**	**86**	**86**	**111**
Sensitivity: *Energy prices*	Low	0	+1	0	0	0	**111**
	High	-1	-4	-1	8	0	**111**
Sensitivity: *Capital costs*	Low	+1	+5	+3	+1	+1	**111**
	High	-1	-6	-5	-5	-5	**111**

3.3.5 Accounting for barriers to delivery

Analytical framework

200. Analysis using MACCs typically focusses only on two dimensions: the scale of emissions savings opportunities and the static cost-effectiveness of realising these savings. Although this shows how much abatement could theoretically be achieved, it does not capture the extent to which wider non-cost barriers may inhibit the realisation of their full potential.

201. In compiling the MACC evidence base used within this Impact Assessment, the impact of different barriers to delivery may have on the overall feasibility of realising this abatement is also analysed. Where possible this is based on published evidence and external expert assessments, although in several cases this information is not available and a best estimate is made. A summary of the evidence quality underpinning the assessment is given in Annex 7.8. Evidence is collected at the measure level (e.g. 'installing additional insulation in buildings to improve the heat retention properties'), and in some cases further broken down by how barriers vary between different segments (e.g. splitting into owner-occupied and rented properties).

202. Barriers to take up of new technologies or behaviour change are assessed along the following dimensions:

Financial: sufficient finance cannot be accessed[78].
Regulatory: regulation needs to be created or changed.
Infrastructure & markets: supply chain currently unable to fully deliver the measure and/or the UK lacks the required supporting infrastructure.
Misaligned incentives: costs and benefits not accruing to the same party.
Public acceptance: opposition to a measure.
Informational: lack of knowledge about the existence and/or application of a measure.
Uncertainty: the expected costs and benefits of a measure are not known, or are not guaranteed.
Behavioural: measure requires people to change their behaviour significantly.

203. A rating for each of the barriers above across each measure is estimated, using a 0 to 5 scoring system outlined below. In addition, an overall feasibility rating for each measure is provided. This reflects the overarching strength of non-cost barriers (taking all the above barrier

[78] High cost in itself is not considered a barrier in this context, as this is captured through the cost-effectiveness metric described in Box 2.

ratings into consideration) in realising delivery of a particular measure among that population or segment of the population. The framework uses a five point scale to rate each type of barrier according to the level of effort required to overcome them:

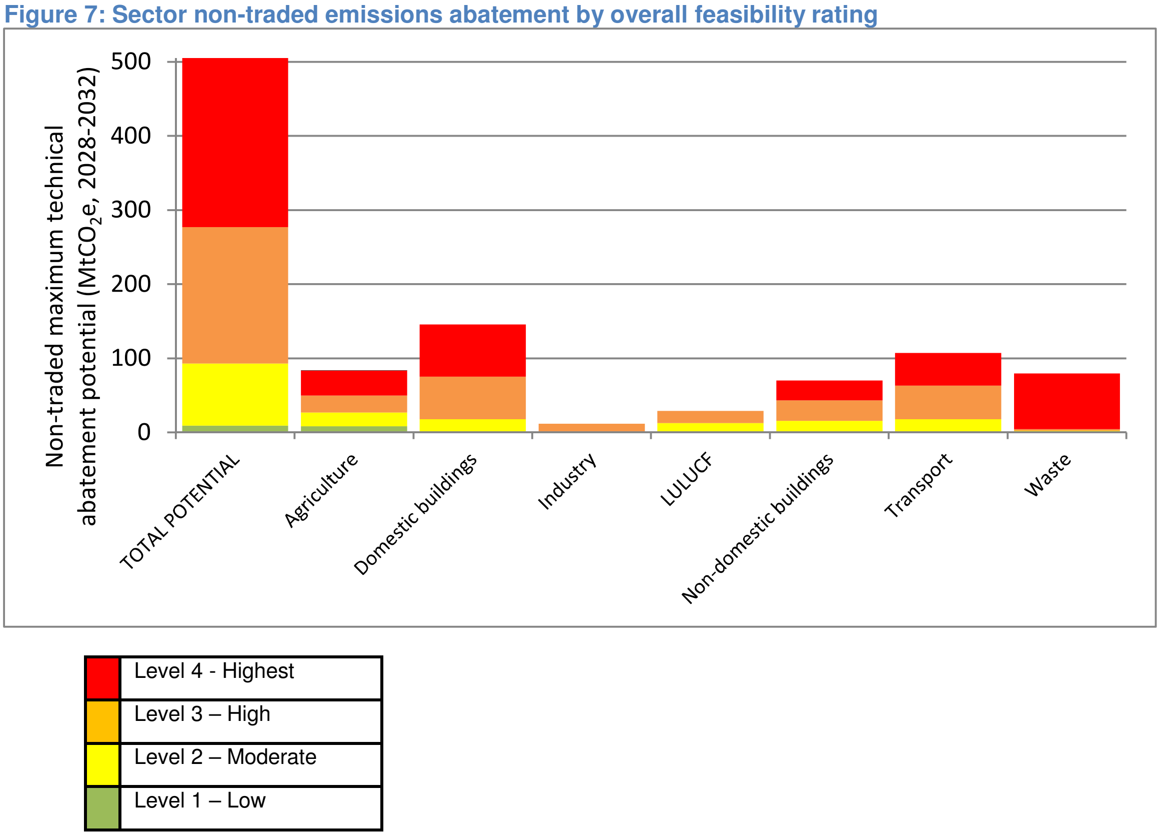
Level 0 - Barrier not preventing uptake (although high costs or other barriers may prevent uptake).
Level 1 - Low: comparable to barriers successfully overcome to date.
Level 2 - Moderate: achievable, but generally stronger than those overcome to date.
Level 3 - High: achievable to overcome, but requiring significant effort with few comparable examples to date.
Level 4 - Highest: potentially feasible to overcome, but requiring very significant additional effort and with almost no comparable examples successfully achieved to date.
Level 5 - Not feasible to overcome: measures which scored a 5 are excluded from the analysis of maximum technical potential.

204. Steps have been taken in the evidence gathering process to ensure a reasonable degree of consistency between barrier scores. However, the method of scoring barriers for each measure involves a degree of subjective judgement, and care must be taken when interpreting levels between measures and sectors. The barriers results should therefore be treated as an illustration of where the stronger barriers might be. More detail on the assessment and classification of barriers can be found in Annex 7.8.

Evidence on barriers to delivery

205. Using the scale described above, the amount of effort required to overcome barriers to deployment can be assessed. Reflecting the comprehensive nature of the evidence collection exercise, where very stretching options are considered, almost half of all potential abatement is estimated to face the highest barriers to deployment (47%), with an additional third still facing high barriers to deployment (35%). Only 18% of the potential identified is considered to face moderate or low barriers, although a higher than average proportion of this is statically cost-effective against benchmark carbon values.

Figure 7: Sector non-traded emissions abatement by overall feasibility rating



206. The **domestic buildings sector** has the highest technical potential, but in many areas faces substantial barriers. These include access to finance for households; planning rules governing building modifications; insufficiently developed markets for new low carbon technologies; the requirement for disruption and changes in behaviour; and examples of misaligned incentives, in particular where the tenant benefits from lower energy bills but the owner pays for the improved efficiency. Similar barriers are faced in the non-domestic buildings sector, in particular where the landlord does not directly benefit from reduced energy bills or there is uncertainty over the impacts on fuel costs from alternative heating technologies.

207. There are sizeable emissions reductions opportunities in the **transport sector**, but these are similarly subject to delivery constraints. In particular, delivery of increased vehicle efficiency will require regulatory standards agreed internationally. There are also strong behavioural constraints in the transport sector, as much of the opportunity to reduce emissions requires a degree of behaviour change relating to the adoption of electric cars, reducing car trips or increasing the proportion of journeys made by rail. Furthermore, substantial uptake of electric vehicles will require significant deployment of charging infrastructure as well as investment in grid capacity and reinforcement.

208. Within the **agricultural sector**, many farms require access to finance to take-up cost-saving options. Some options, such as the use of alternative feeds or the use of genetic modification to reduce the emissions intensity of food production, face regulatory and public acceptability constraints.

209. Within the **waste sector**, measures with the largest abatement potential are aimed at limiting the amount of waste sent to landfill. Achieving the maximum potential would entail very high rates of recycling and food waste prevention and there is significant uncertainty over the feasibility of changing public behaviours to meet these levels. Furthermore, financing of extensive improvements to waste collection and treatment infrastructure at the Local Authority level would be required, along with a significant change in public acceptance towards the siting of additional infrastructure, such as new incinerators or recycling plants, to manage and treat diverted waste.

210. Within the **Land Use, Land Use Change and Forestry sector (LULUCF)**, afforestation measures offer the highest abatement potential, through acting as a carbon sink by absorbing greenhouse gases and by providing bioenergy feedstock. Although upfront grants are available for landowners, there is uncertainty over the long-term profitability due to uncertainty over future demand for biomass energy and for its use in providing heat. The reductions in land value following afforestation also represent a barrier. The current regulatory framework for afforestation coupled with the need to balance food production, biodiversity, landscape and cultural objectives also limit take-up at the current time.

211. Within **manufacturing and processing industries**, the majority of emissions are covered by the EU Emissions Trading System and are not directly influenced by carbon budgets. There is, however, around 12 $MtCO_2e$ of abatement potential in non-traded industrial emissions through improvements to heating and cooling processes and other energy efficiency measures in major manufacturing and processing industries (chemicals, food & drink, iron & steel, non-ferrous metals, non-metallic minerals, paper and cement). The main barriers include potential disruption to production from large scale changes to machinery, and possible competition from high-emissions firms in countries with looser environmental standards.

212. While the presence of non-cost barriers can increase the challenge to delivering emissions reductions, there is also the possibility of beneficial **disruptive innovation.** Unanticipated technological developments including new emissions reductions technologies, significant reductions in the costs of existing low carbon technologies, and design improvements reducing the strength of barriers (e.g. public acceptability) can serve to substantially increase the feasibility of achieving emissions reductions.

Implications for the fifth carbon budget

213. This section assesses what abatement could potentially be achieved under different assumptions about the extent to which measures with high barriers or high costs can be delivered. See Section 3.3.3.1 for an explanation of methods used for estimating carbon values and cost-effectiveness.

Table 17: Impacts of costs and delivery barriers on achievable emissions reductions

		All measures		**Cost-effective measures only**	
		Non-traded abatement potential ($MtCO_2e$, 2028-2032)	Implied average achievable % reduction on 1990	Non-traded abatement potential ($MtCO_2e$, 2028-2032)	Implied average achievable % reduction on 1990
Overall feasibility rating	0-4	527	62%	172	53%
	0-3	277	56%	122	52%
	0-2	93	51%	55	50%
	0-1	9	49%	2	49%

214. The estimated maximum technical non-traded abatement potential across the wider economy for the fifth carbon budget period is around 527 $MtCO_2e$. If all of this were delivered, emissions abatement equivalent to around a 62% reduction on 1990 levels could theoretically be achieved.

215. There are significant challenges to delivering certain measures. A large proportion of potential originates from measures which face barriers considered to be the hardest to overcome while still being feasible to deliver (Level 4), notably the wide-scale retrofitting of buildings with heat pumps, high levels of electric car and van uptake, improvements in vehicle efficiency and sustainable travel. Further innovation could play an important role in overcoming some of these barriers. For example, greater up-front cost reductions and range improvements in electric vehicles could increase public acceptability and consumer take-up.

216. If the highest barriers to uptake were not successfully overcome then the remaining Level 0 to 3 measures offer 277 $MtCO_2e$ of non-traded abatement potential in the fifth carbon budget period; which could potentially deliver a 56% reduction in emissions from base year levels.

217. From this 277 $MtCO_2e$ of potential, some measures have been estimated to be statically cost-ineffective. These cost-ineffective lower-barrier measures include a lesser degree of improved vehicle efficiency, district heating, solid wall insulation in domestic homes, and more efficient ventilation in non-domestic buildings. If take up of these measures were also not achieved then the remaining (cost-effective) measures offer a total abatement opportunity of 122 $MtCO_2e$ over the period, with the potential to deliver a 52% reduction in emissions from 1990 levels.

218. Lastly, a proportion of the 122 $MtCO_2e$ cost-effective measures are still deemed to have 'high' barriers to uptake (Level 3). These include: abatement from afforestation, improved heating controls, more efficient ventilation in public buildings and hard to treat cavity wall insulation. If abatement of these measures were not achieved either, leaving only the cost-effective least-difficult measures (Level 0 to 2), this would equate to a total of 55 $MtCO_2e$ of potential, allowing a theoretical reduction of around 50% from 1990 levels.

Delivery constraints in emissions pathways to 2050

219. The evidence on barriers to delivery can also be considered alongside the findings from the pathways analysis in section 3.2 to provide a sense of the challenges to delivering measures for meeting the UK's 2050 target. Table 18 below lists the technologies that UKTM has identified as potentially important for meeting 2050 targets with a description of the main types of barriers to delivering these measures during the fifth carbon budget period. The presence of barriers should not in itself reduce the need to deploy these measures, but rather demonstrates instead the likely scale of challenge involved. Importantly, UKTM does not include a full specification of all technologies or abatement opportunities, meaning there are likely to be additional important technologies not listed below. Furthermore, there may be additional unknown future technology options that will be low cost and may reduce the need to deploy technologies currently known about.

Table 18: Key technologies in 2050 based on UKTM cost-effective pathways analysis and relevant barriers to delivery in CB5 period.

Sector	Examples of technologies that are important across a broad range of UKTM 2050 scenarios	Barriers for relevant measures in fifth carbon budget period (where comparable)
Domestic buildings	Electric heating District heating Insulation	Retrofitting low carbon heat sources can have long payback periods, meaning some support for credit constrained households could be required. Actions to bring these technologies into the mainstream may require overcoming perceived differences in operating characteristics. Uptake of district heating can require coordination in high density housing.
Non-Domestic buildings	District heating Electric heating Insulation	Retrofitting low carbon heat sources and energy efficiency measures can face similar challenges to those in domestic buildings. Actions could be required to manage different incentives faced by owners and tenants.
Industry	Biomass CCS Electrification Gas remains important	There are benefits from coordinating with standard investment cycles, which can lead to longer lead-in times. Policy may be required to manage any production cost impacts of businesses to maintain competitiveness.
Transport (exc. international aviation and shipping)	Electric cars Electric LGVs HGVs: Hydrogen and hybrid	Requires roll-out of recharging infrastructure and mainstreaming of the technology among consumers, including any changes to usage. Improving vehicle standards can require coordination internationally.
Agriculture & Land-use change	Afforestation	Requires long-term commitments needing sufficient incentives for landowners. A degree of uncertainty exists over future demand for biofuels.

220. Some types of barriers can vary over time, whereas others will always face challenges in achieving full potential due to intrinsic technical or behaviour change challenges. An example of this is reducing average vehicle emissions in the transport sector. Although a sizeable amount of abatement could be achieved by overcoming only lower level barriers, realising full potential would encounter some higher barriers. The vehicle market would need to move away from the internal combustion engine, which is likely to require 2030 regulation agreed at an international level to ensure manufacturers supply low emission vehicles. Government intervention is likely to be needed to address the additional upfront cost of low emission vehicles and to influence consumer decisions. Furthermore, to maximise their usability and limit the impact on consumer behaviour (most likely from reduced vehicle performance and increased cost), infrastructure challenges related to sufficient recharging facilities for electric vehicles would need to be addressed.

221. While fully overcoming these barriers may be difficult to achieve by the fifth carbon budget period, it is likely to be more feasible by 2050 because of extended time to implement new infrastructure and improve technology. The potential for disruptive innovation to reduce emissions will increase over time in the transport, buildings and industrial process sectors. However, measures which face high barriers in terms of changing behaviours of public acceptance are likely to remain difficult to overcome through the 2030 to 2050 period unless significant changes in social attitudes are observed.

Conclusions for the fifth carbon budget

222. As the above analysis indicates, if all 527 $MtCO_2e$ of abatement potential identified in the analysis were successfully delivered, then non-traded sector emissions could technically be reduced to around 919 $MtCO_2e$ in the fifth carbon budget period, based on latest emissions projections. Assuming a UK share of allocated EU ETS allowances of 590 $MtCO_2e$, **this would make a fifth carbon budget of as low as around 1,509 $MtCO_2e$ (equivalent to around a 62% reduction on 1990) technically achievable**. This suggests that all four budget levels considered in this Impact Assessment are feasible from a purely technical, otherwise unconstrained and static perspective.

223. If only the abatement which has been identified as socially cost-effective during the fifth carbon budget period were successfully delivered, then according to this analytical approach, non-traded sector emissions could technically be reduced to around 1,274 $MtCO_2e$ in the fifth carbon budget period, based on latest emissions projections. **This would make a fifth carbon budget as low as around 1,864 $MtCO_2e$ (equivalent to a 53% reduction on 1990) technically and cost-effectively achievable based on this analytical approach.** However, many of the statically cost-ineffective measures may additionally be an important part of the portfolio of measures which could be deployed to meet the UK's 2050 target in a cost-effective way. Considering impacts on the full pathway may reveal wider benefits not fully captured in the static MACC analysis (such as indirect economic impacts, risk of technology failure and/or missing future targets, technology cost reductions, barriers, cumulative emissions, lower particulate emissions or improved air quality and health). In addition, undertaking action beyond the level achievable through statically cost-effective measures alone could be appropriate in the context of contributing further to global emissions reductions (see section 3.1). This may involve undertaking action through the purchase of international credits, which could reduce the need to undertake higher cost abatement.

224. It is important to note though that there is considerable uncertainty around these estimates, due in part to: uncertainties around baseline emissions; the costs, performance, and availability of technologies; plus economic and demographic factors.

4 Options appraisal

225. The three perspectives above have provided an assessment of the range of different options that could be considered consistent with the requirements of the Climate Change Act, and have informed the choice of budget level options explained in section 2.

226. The following section appraises the costs and benefits of each of these options, and provides an additional assessment of these options against the range of factors the Act requires are taken into account. This assessment also considers the options in the context of the detailed advice of the Committee on Climate Change, and against the representations of the Devolved Administrations.

4.1 Cost-benefit analysis

227. The direct costs and benefits of setting legislation on the level of the fifth carbon budget alone are negligible, as no specific emissions reductions actions occur as a direct result. Nevertheless, the budget level imposes a requirement on the UK Government to ensure the UK net carbon account does not exceed the level of the budget for the years 2028-2032. After the budget is set, the Government has the freedom to choose appropriate policies to ensure the budget is met, and therefore the costs and benefits of these future actions will be unknown at the time of setting the budget level. This means the analysis presented here is an illustration only of the potential scale of impacts of these future policies. As a result, there is significant uncertainty around the aggregate costs and benefits to the UK, and even greater uncertainty over their composition and distribution across the economy.

228. The 2006 Stern Review[79] estimated that the cost of inaction on climate change would significantly outweigh the expected cost of coordinated global mitigation action. Without effort to tackle climate change, the Review predicted that the loss of gross domestic product (GDP) from climate change could cost the global economy significantly more than the global cost of action to stabilise atmospheric concentrations of greenhouse gases (at 450-550ppm CO_2e). This cost-benefit analysis takes into account the benefits of avoided climate change at high level only through the use of carbon values (further detail is available in Annex 7.6.1).

229. In order to provide an illustrative assessment of the costs and benefits, impacts are quantified using the static MACC evidence presented in section 3.2. Importantly, this means any dynamic costs and benefits of earlier action will not be taken into account, for example reducing risks around meeting the 2050 target, developing nascent UK low carbon industries, and reducing the costs of low carbon technologies.

230. The extent of non-traded emissions reductions required to comply with the target is calculated as the difference between the budget level and the counterfactual estimate of the UK net carbon account (see section 2.3). It is assumed here that only domestic emissions abatement action is undertaken to comply with the budget level. Abatement opportunities are assumed to be undertaken in static cost order, starting from the most cost-effective.

231. To understand the precise costs and benefits would require identifying the full mix of technologies used to meet the budget, and the range of policy levers used to deliver this mix. It is highly likely the mix of measures included in this cost-benefit analysis will be different to that deployed in practice, which will be based on a wide range of other considerations besides static cost-effectiveness. Furthermore, it is possible the final budget could be met through some use of the available flexibilities explained in section 1.1 (e.g. use of international credit purchases, and the banking and borrowing of emissions from other carbon budgets). Therefore, the figures presented here can be considered as providing an illustration only.

232. The costs presented based on UKTM analysis of emissions pathways to 2050 in section 3.2 offer a sense-check of the cost-benefit analysis presented here. While not directly comparable, the scale of costs is found to be of a similar order of magnitude. The pathways analysis also allows an assessment of how the overall long-term emissions pathways costs are affected. The analysis in section 3.2 demonstrates it is possible to meet the range of carbon budget levels without having a substantial impact on the overall cost of the pathway to meeting the UK's 2050 target, although this would require realising the optimal actions chosen within the model.

233. While the UKTM analysis gives an illustration of the impact on the overall pathway to 2050, this is highly dependent on decisions made on subsequent carbon budgets, and the evolution of the availability and cost of low-carbon technologies. The static cost-benefit analysis presented in this section therefore focuses on the short-term costs and benefits of solely complying with the fifth carbon budget, which is best assessed using the MACC evidence database explained in section 3.2.

Costs and benefits of domestic emissions reductions

234. Costs and benefits are calculated using HMG Green Book appraisal methodologies, and with energy prices, emissions factors, and other core assumptions taken from Green Book supplementary guidance. Further details can be found in Annex 7.2. One-off and annual costs are included on an amortised basis, with costs of finance applied at sector-specific rates reflecting the real social cost of providing finance for investments. Energy consumption and greenhouse gas emissions impacts are also valued, in addition to air quality and wider environmental impacts where these are possible to quantify. Rebound effects[68] are also captured in the domestic buildings and transport sectors, and utility and health impacts from changes in road congestion are quantified. Carbon cost-effectiveness is calculated in accordance with government guidelines and is explained in Box 2.

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79 Stern, N. (2006); 'The economics of climate change: the Stern review'; Cambridge University Press, Cambridge. http://webarchive.nationalarchives.gov.uk/20100407172811/http://www.hm-treasury.gov.uk/stern_review_report.htm

Limitations

235. This cost-benefit analysis approach based on static MACC evidence has several important limitations, in addition to those relating generally to MACC-based analysis described in section 3.3.2.1. These include:

- The actual measures used to comply with a given budget level are highly likely to be different to those selected solely in order of static cost-effectiveness, which will affect the actual costs and benefits of meeting a budget level.
- It is likely the defined counterfactual overstates the size of the UK's net carbon account for the period, in the absence of any further policies specifically implemented to meet the fifth carbon budget. In particular, it is likely additional emissions reductions policies will be implemented to help meet the fourth carbon budget, which would likely result in additional savings in the fifth carbon budget period. This will tend towards an overstatement of the scale of impacts of undertaking additional action to specifically meet the fifth carbon budget.
- Distributional impacts are not captured through this method. These will be highly dependent on any policy lever used to realise the technical emissions reductions. Energy cost savings are likely to benefit the operators and owners of the relevant energy using equipment, for example homeowners in the case of domestic solid wall insulation installations, and shareholders in the case of more energy-efficient machinery used in the manufacture of goods. However, exposure to the capital and installation costs will depend on policy, for example if fiscal incentives are provided.
- These cost and emission savings estimates are calculated for the five year period of the fifth carbon budget, 2028-2032. Costs (and benefits) associated with the lifetime of measures outside the fifth carbon budget period are not included. The costs therefore represent an estimate of the marginal cost of the emissions constraint over the five year budget period.
- Policy costs (e.g. costs of administering and monitoring implementation of a policy) are also not included in the cost-estimates suggesting that for any budget option costs may be underestimated.
- There is no exploration of alternative methods for meeting budgets using banking or borrowing or international credits. An explanation of these additional flexibilities is provided in section 1.1. Constraints on the delivery of abatement measures are not factored in the core analysis. However, the impact of constraints around the deliverability of these measures is considered in sensitivity analysis presented in Table 20.

Static cost-benefit analysis results

236. Applying this analytical approach, the estimated costs and benefits of the different budget level options are presented in Table 19. There is sufficient technical potential for emissions reductions (when compared with the Government's carbon values) to meet the equivalent of a 53% reduction on the 1990 level in a statically cost-effective way. Meeting budget level option 2 (straight line emissions trajectory, equivalent to a 54% reduction on 1990) may therefore require a small amount of abatement action which is statically cost-ineffective.

237. In net social cost terms, this means that budget level option 2 (straight line emissions trajectory) has the potential to be met at a net benefit to society of around £12.6bn[80], including a valuation of avoided non-traded greenhouse gas emissions.

238. For the CCC's advised budget level (option 3), the analysis shows this could be met at a net discounted social benefit of around £5.5bn over the fifth carbon budget period if met domestically. As shown in Table 20, utilising available international credits at mid-price estimates would mean there is potential for the CCC's budget level to be achieved at a higher net benefit to the UK of around £9.8bn including the value of domestic non-traded carbon savings.

239. From a static costs perspective, the most stretching budget level (Option 4) could potentially be met at a small static net cost of around £100m during the fifth carbon budget period. There could potentially be substantial longer-term cost-reductions in meeting the 2050 target from undertaking this option not captured in the cost-benefit analysis. For example, reducing the rate of deployment required to meet the 2050 target after the period of the fifth carbon budget,

[80] All NPVs are expressed in 2015 prices, discounted to 2016, and represent costs attributable to the costs and benefits realised in the five years covering the fifth carbon budget period only.

increasing the rate of technology cost-reductions, and the value of additional exports of UK low carbon technologies.

Table 19: Cost-benefit analysis of fifth carbon budget level options

	Budget level option:	1) Non-binding	2) Straight line from CB3	3) CCC's advised level	4) Equal % reduction from CB4
Budget level	MtCO2e	**2,100**	**1,830**	**1,725**	**1,670**
Abatement required	MtCO2e	**0**	**206**	**311**	**366**
Cost-benefit analysis, £m 2015, 2028-2032, discounted	Technology & Finance Costs	£0	-£10,400	-£31,200	-£43,600
	Net fuel impacts	£0	£11,300	£23,600	£28,400
	Other impacts	£0	£1,400	-£2,400	-£3,000
	Traded carbon	£0	£400	£400	£300
	Non-traded carbon	£0	£10,000	£15,100	£17,700
NPV (£m 2015, 2028-2032)	Excluding non-traded carbon	£0	£2,700	-£9,600	-£17,800
	Including non-traded carbon	£0	£12,600	£5,500	-£100

240. The most significant contributions to the overall costs and benefits are the technology and finance costs of the measures[81], as well as the impacts on energy consumption. For the looser budget options, fuel savings tend to outweigh the costs of the measures, while with tighter budgets the reverse holds. This is because tighter budgets generally require less cost-effective measures with greater up-front costs to realise a given level of energy savings.

Sensitivity analysis of non-traded emissions abatement

241. The analysis presented above is highly sensitive to underlying assumptions. The sensitivity to the overall NPV presented in Table 19 to some of the key assumptions is presented in Table 20, with figures showing the overall change in NPV relative to the core scenario. The assumptions considered within this analysis include:

- changes to the baseline emissions scenario (e.g. through revisions to GHG inventory methodologies, economic growth, and current policy performance);
- the availability of measures facing the highest barriers to deployment (level 4). Two scenarios have been tested, with a limit of either 25% or 75% on the realisable savings from these measures[82];
- energy prices, based on latest published assumptions;[83]
- variations in technology costs (specific to the technology); and
- carbon values, based on latest published government assumptions.

242. Certain combinations of these individual factors are likely to result in NPV estimates outside the range presented. More detail on these assumptions is explained in annex 7.2.

243. Based on the analysis undertaken, the NPV over the fifth carbon budget period of the options is sensitive to each of the factors considered. Generally-speaking, the NPV will be worsened by a higher emissions baseline; a reduced ability to deploy measures with strong non-cost barriers; low energy prices; high technology costs; and low carbon values. However, since there are some NPV-positive technical opportunities, a higher emissions baseline can improve the NPV of looser budget levels, as additional positive NPV measures are additionally assumed to be deployed.

244. The assumption taken on the deliverability of those measures facing strong deployment barriers has a very substantial impact on the NPV: if only 25% of measures with the highest barriers to deployment were deliverable, this could reduce net social benefits during the fifth carbon budget period by around £8.3bn for the straight line trajectory scenario (option 2), or by

[81] Including capital, maintenance, and non-fuel operating costs
[82] This has been implemented proportionately across each measure with a barrier rating of 4. The cost-effectiveness of measures (and underlying costs and benefits) per tonne of carbon saved remains unchanged, but the extent of emissions abatement achievable is scaled down proportionately.
[83] The energy price sensitivity varies gas, oil, electricity, coal and road and rail fuel prices (including biofuels) as well as biomass except for domestic applications where this is assumed constant.

nearly £33bn for the CCC's advised level (option 3), assuming budgets are met domestically. This is as a result of undeliverable measures with the highest barriers being replaced with more costly measures with lower non-cost barriers.

Table 20: Sensitivity of the cost-benefit analysis to underlying assumptions

Budget level option				1) Non-binding	2) Straight line from CB3	3) CCC's advised level	4) Equal % reduction from CB4
Budget level			$MtCO_2e$	2,100	1,830	1,725	1,670
Abatement required			$MtCO_2e$	0	206	311	366
NPV £m	**Core scenario**			**£0**	**£12,600**	**£5,500**	**-£100**
Change in NPV £m 2015 against core scenario, 2028-2032, Including non-traded carbon	Emissions baseline	Low (-50 MtCO		£0	+£400	+£4,300	+£5,100
		High (+50 MtC(		£0	-£2,500	-£5,100	-£7,700
	Availability of measures with strongest barriers	75%		£0	-£1,400	-£2,900	-£4,800
		25%		£0	-£8,300	-£32,900	Not Possible
	Energy prices	Low		£0	-£2,300	-£5,900	-£7,500
		High		£0	+£4,800	+£10,000	+£12,100
	Technology costs	Low		£0	+£3,600	+£13,300	+£18,000
		High		£0	-£3,400	-£14,100	-£20,900
	Carbon values	Low (£39/t)		£0	-£5,200	-£7,700	-£9,000
		High (£118/t)		£0	+£5,200	+£7,700	+£9,000
	Allow use of international credits. Price:	Low (£15/t)		£0	+£300	+£6,500	+£11,500
		Mid (£40/t)		£0	-£200	+£4,300	+£8,500
		High (£65/t)		£0	-£800	+£2,200	+£5,500

245. The sensitivity analysis also reveals the importance of the availability of international credits (or other flexibilities) in mitigating considerable uncertainty in the underlying assumptions. For tighter budgets, the flexibility to use credits can significantly improve net social costs in the short-term, as it potentially allows some of the most costly forms of domestic emissions abatement to be avoided in favour of lower-cost emissions abatement undertaken in other countries. This could be particularly important where there are increases in baseline emissions, or where measures facing the strongest barriers cannot be delivered. However, the resulting reduction in action will require increased emissions reductions in subsequent budget periods, the costs of which are not included in the table above.

Estimates of potential investment costs

246. The MACC data can be also used to estimate the total investment from 2016 up to the fifth carbon budget period that could be needed in order to deliver the measures to meet the fifth carbon budget level (taking 2030 as the central year). Investment costs are the total capital costs required to install the abatement capacity. Not all abatement measures will have investment costs, for example substituting use of fossil fuels for biofuels or emissions reductions based on behavioural change.

247. The investment costs are indicative only as they depend on the assumption that measures are adopted in order of static cost-effectiveness, in line with the approach assumed in the cost-benefit analysis above. The actual measures used to comply with a given budget level are highly likely to be different to those selected solely in order of static cost-effectiveness, which will affect the investment costs required to meeting a budget level.

248. Table 21 shows an estimation of the required cumulative investment to 2030 for the four different budget levels considered. The figures are undiscounted as the analysis does not stipulate at which point in time the investment is made. Importantly, the costs to consumers and businesses may in practice be amortised over the lifetime of the measure, for example through the use of financing. Not only this, the investment will for most measures result in benefits outside the fifth carbon budget period; considering investment costs solely in the context of the emissions savings during the fifth carbon budget period may be misleading.

The required investment is sensitive to changes in the emissions baseline (a higher baseline will require more abatement and hence more investment and vice versa), and also to the assumed costs of the technologies. These sensitivities are shown alongside central estimates in

249. Table 21.

Table 21: Indicative investment costs to 2030 with sensitivities

Budget level option				1) Non-binding	2) Straight line from CB3	3) CCC's advised level	4) Equal % reduction from CB4
Budget level			MtCO2e	2,100	1,830	1,725	1,670
Abatement required			MtCO2e	0	206	311	366
Estimate of required investment (2016-2030, £m undiscounted)	**Core Scenario**			**£0**	**£33,100**	**£87,700**	**£120,400**
	Emissions baseline	Low		£0	£18,600	£58,400	£91,400
		High		£0	£56,100	£118,800	£144,400
	Technology costs	Low		£0	£25,100	£55,000	£75,300
		High		£0	£40,900	£121,500	£171,100

Indirect impacts in the traded sector

250. Due to the formulation of the UK Net Carbon Account, against which performance towards carbon budgets is measured, the fifth carbon budget only has direct influence on emissions in the non-traded sector. However, abatement action in the non-traded sector could affect emissions and costs in the traded sector, particularly in the power generation sector. For example, the electrification of heat and transport would reduce emissions recorded in the non-traded sector but would result in increased electricity demand, the emissions from which would fall under the EU Emissions Trading System and therefore be captured within the traded sector. In addition, there are measures that could offset some of this increase in demand for electricity (e.g. through improvements in how efficiently electricity is used), however these actions generally do not contribute to meeting carbon budgets.

251. The cost-benefit analysis presented in Table 19 and Table 20 includes a high-level valuation of the impact of changes in electricity demand. This is based on published long-run variable costs of electricity supply (see Annex 7.2), and assumes electricity prices and the emissions intensity of power supply are not significantly affected. However, if the scale of electricity demand impacts of meeting the fifth carbon budget is large enough, a more significant change in the power sector might be required to meet this demand. To give some insight into the potential scale of resulting power system impacts, bespoke modelling of the power sector has separately been undertaken.

252. The specific mix of measures that would be delivered to meet budget levels is highly uncertain, and any impact on electricity demand is very sensitive to this mix. There is therefore insufficient certainty to undertake specific power sector modelling for each of the budget level options listed above. Instead, an illustrative set of electricity demand scenarios has been considered reflecting the range of impacts on electricity demand that could occur. These scenarios are compared to the counterfactual scenario set out in section 2.3.

253. Estimates of impacts on electricity demand from reducing GHG emissions have been taken from the data underpinning the MACC evidence base, and are used to create the range of electricity demand scenarios. The power sector's response to these different demand scenarios has then been modelled using DECC's Dynamic Dispatch Model described in Box 3.

254. The following scenarios have been modelled[84] . These do not correspond directly to the budget level options as it is not possible to assess the specific impact of these options on electricity demand. Instead, they give a sense of the full range of potential impacts on electricity demand, depending on the actions taken to reduce emissions. These scenarios are:

A. **Cost-effective non-traded abatement only**: A small reduction in demand resulting from statically cost-effective non-traded sector measures only. No direct action to reduce traded sector emissions is undertaken.

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[84] Scenarios B-D were modelled with DECC's DDM. For Scenario A, given the small impacts on electricity demand of this scenario (see Annex 7.9), rather than carrying out detailed modelling, we have simply calculated the change in net welfare based on the approach set out in the HMG Green Book supplementary appraisal guidance on the valuation of energy use and emissions for appraisal (https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal).

B. All non-traded abatement: An increase in demand from deployment of the full maximum technical potential of all non-traded sector measures, mainly driven by electrification of heat and transport. No direct action to reduce traded sector emissions is undertaken.

C. Maximum theoretical traded and non-traded emissions reductions: A substantial reduction in electricity demand resulting from the deployment of the full maximum technical potential of all emissions reductions measures (i.e. including those in the traded sector). This represents action substantially beyond what would be required for all budget level options and therefore is an extreme scenario. Generally, reductions in electricity demand from efficiency improvements in electricity use are greater than the increases in electricity demand from electrification of heat, transport and other energy services. This scenario excluding options to decarbonise the supply of power, and also excludes more uncertain reductions from behaviour change in how electricity-consuming products are used.

D. CCC cost-effective pathway: A stylised representation of the CCC's cost-effective pathway scenario presented in its advice to government.

Total of electricity supply

255. Increased electricity demand typically results in overall increases in marginal costs of power supply, due to the need to dispatch more expensive generating technologies to meet demand[85] . The precise impacts depend on a range of factors, including the technology mix, technology costs, and fossil fuel and carbon prices. The estimated impacts on net social welfare within these scenarios provide a comparator for the top-down estimates presented in the main cost-benefit analysis and should not be interpreted as additional cost impacts. These estimates are set out in Table 22: below and show that the impact of measures taken to meet carbon budgets could have a combined impact, in NPV terms, of between -£1.3bn and £10.1bn.

Table 22: Central estimate of change in net welfare due to potential changes in electricity demand

	Scenario A Cost-effective non-traded abatement only	**Scenario B** All non-traded abatement	**Scenario C** Maximum theoretical traded and non-traded emissions reductions	**Scenario D** CCC cost-effective pathway
Change in UK net social welfare from electricity demand changes (£m, 2015 prices, NPV over 2028-2032, discounted to 2016) [86]	1,800	-1,300	10,100	4,200

[85] In this analysis, we have only considered effects on overall electricity demand, and not whether the measures deployed might have an impact on the profile and/or flexibility of electricity demand. While this could affect the costs and benefits of the scenarios presented, the impacts at this stage are uncertain and depend on a range of factors, including developments in underlying electricity system flexibility, including demand-side response, storage and interconnection.

[86] The Dynamic Dispatch Model simulates the supply market and captures changes in costs associated with supply and required investment in the power sector. The model also makes provision to capture the impacts on network operation and investment costs. There may be impacts before and beyond this time horizon. However, given uncertainty around the pathway that will be taken to meet the fifth carbon budget and illustrative nature of this analysis, we have taken a proportional approach and limited the time horizon of the analysis. Note also that due to differences in the methodology used and in underlying assumptions, impacts presented here are not directly comparable to those included in Table 19 above.

256. In scenario A, where only statically cost effective non-traded sector actions are undertaken, the overall effect is a small reduction in demand. This has a positive effect on welfare, firstly because more there is less frequent need to use more expensive generation technologies, and less capital investment is required. Scenarios C and D also show a net benefit reflecting reductions in electricity demand. In scenario B, where all non-traded action is considered, electrification rates for heat and transport are higher leading to an overall increase in electricity demand relative to the counterfactual scenario. This increase in demand leads to extra costs, firstly from generating additional electricity from existing plants and secondly from additional investment to ensure that power fleet can meet demand.

257. This analysis demonstrates that while substantial action to reduce non-traded sector emissions may increase electricity demand, there is sufficient potential for improvements in the efficiency of electricity use to offset this and result in a lower electricity demand relative to the baseline.

Electricity price impacts

258. The modelling also provides an estimate of potential impacts on wholesale electricity prices for each scenario. The impact of changes on average retail electricity prices will be highly dependent on energy policy over the period, however an illustrative assessment has been made using this analysis with DECC's Prices and Bills model. These illustrative impacts are based on the assumption there is no change in market or policy structure. The results of this analysis are presented in Table 23.

Table 23: Central estimate of electricity retail price impacts[87] compared to counterfactual[88]

Type of consumer	**Impact on retail electricity price (2028-32)**	**Scenario A** Cost-effective non-traded abatement only	**Scenario B** All non-traded abatement	**Scenario C** Maximum theoretical traded and non-traded emissions reductions	**Scenario D** CCC cost-effective pathway
Household	£/MWh (2015)	0*	-1	+7	+2
	%	0%*	-0.4%	+3.7%	+1.1%
Medium Business	£/MWh (2015)	0*	-0	+3	+0
	%	0%*	-0.3%	+2.3%	+0.1%

*Assumed to be negligible, given small impact on electricity demand.

259. The impact on retail prices is small across the range of scenarios. Since electricity demand impacts are estimated to be small in Scenario A, where only cost-effective non-traded abatement is undertaken, it is assumed there would be negligible impact on electricity prices. In Scenario B, higher electricity demand over the fifth carbon budget period drives higher wholesale electricity prices than in the baseline. However, retail prices are lower than in the baseline. This is because fixed elements of network and policy costs are spread over a wider base and the costs of

[87] The estimates of price impacts for the scenarios considered do not take account of any additional policy costs associated with installing the measures that give rise to a change in electricity demand, as these are subject to future policy development. The precise bill impacts also depend on which types of consumer take up measures affecting electricity demand. Given the uncertainties, it would be inappropriate to present an estimated impact on final bills. However, it is important to note that changes in demand could mean that, in some years, the final bill impacts go in the opposite direction to the estimated price impacts presented here.

[88] Illustrative impacts are presented here for households and medium-sized businesses only. The impacts on energy intensive industries (EIIs) are not included – the majority of emissions from EIIs are captured by the EU ETS, and are not directly influenced by carbon budgets. These sectors will be subject to other policies targeting emissions reductions, and these will likely have greater impacts on energy prices faced by EIIs.

Government support for low-carbon generation is lower due to higher underlying wholesale prices. Broadly speaking, the estimated impacts are reversed in Scenarios C and D, due to demand being lower over 2028-32. While average unit retail prices are higher in scenarios C and D, average bills will likely be lower as consumption of electricity is smaller.

260. The potential impacts of electricity price changes on competitiveness and fuel poverty is also considered, and is presented in sections 4.3.3 and 4.3.5 respectively.

261. Further explanation of the analysis of power sector impacts is explained in Annex 7.9.

4.2 Direct costs and benefits to business

262. Setting the fifth budget level in itself does not result in any direct costs or benefits to business. Instead, it introduces a target binding on the Government, which is then required to introduce appropriate policies to ensure the budget is met. Setting the fifth carbon budget at a tighter level than emissions are currently projected to be will likely require a range of policies to be introduced. All costs and benefits, both to business and society, will be assessed and quantified within their own Impact Assessments, according to standard HMG Green Book appraisal methodologies as and when these policies are developed.

263. In order for the UK to meet its 2050 emissions target, there will almost certainly be a requirement for new policy in the business sector, and actions undertaken in other sectors can have indirect impacts on the businesses. However, the scale, scope, and timing of the impacts of these policies will remain unknown until the policies are developed. As an illustration of the potential impacts, a high-level assessment has been undertaken in section 4.3.3 below, covering the potential share of abatement undertaken by different economic sectors to meet the budgets, and the potential impacts on energy prices.

264. The portfolio of measures resulting from the binding targets could also include regulatory measures. Where regulation will be considered among the alternative solutions, it will be assessed against the Government's commitment to reduce regulatory burden on businesses and relevant targets. These considerations will include future commitments to achieve Business Impact Targets and targets on the impacts of regulatory and deregulatory measures, such as the current One-In-Three-Out rule[89]. This means considering wherever possible alternatives such as non-regulatory or self-regulatory approaches, and appraising the impacts of any regulation introduced according to established appraisal methodologies[90].

265. The Committee on Climate Change in its advice on the level of the fifth carbon budget did not explicitly assess the regulatory impacts on business of the recommended level of the budget. However, it did provide an assessment of the potential impacts on competitiveness, which it assessed to be manageable. This Impact Assessment considers impacts on competitiveness in section 4.3.3.

4.3 Climate Change Act factors

266. The Climate Change Act 2008 provides direction on how the level of a carbon budget should be set, including a minimum set of factors that must be taken into account by the Secretary of State when making the decision, and by the Committee on Climate Change when providing its advice on the level. These factors are set out in section 10 of the Act ("Matters to be taken into account in connection with carbon budgets"), and include:

- Scientific knowledge about climate change;
- Technology relevant to climate change;

[89] https://www.gov.uk/government/news/government-going-further-to-cut-red-tape-by-10-billion

[90] For more information, please see the Impact Assessment Toolkit within the Better Regulation Framework Manual (under revision). https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/468831/bis-13-1038-Better-regulation-framework-manual.pdf

- Economic circumstances, and in particular the likely impact of the decision on the economy and the competitiveness of particular sectors of the economy;
- Fiscal circumstances, and in particular the likely impact of the decision on taxation, public spending, and public borrowing;
- Social circumstances, and in particular the likely impact of the decision on fuel poverty;
- Energy policy, and in particular the likely impact of the decision on energy supplies and the carbon and energy intensity of the economy;
- Differences in circumstances between England, Wales, Scotland, and Northern Ireland;
- Circumstances at the European and International level; and
- The estimated amount of reportable emissions from international aviation and international shipping for the budgetary period or periods in question.

267. Section 10 of the Act also provides that "nothing in this section is to be read as restricting the matters that the Secretary of State or the Committee may take into account". In particular, 13(3) of the Act requires the subsequent package of policies and proposals to meet the budgets to contribute to sustainable development. The natural capital component of sustainable development is considered in section 4.3.10, with impacts on fuel poverty considered in section 4.3.5.

268. Where not covered by these factors, the insights obtained through the application of the three perspectives in section 3 have also been taken into account, and overall conclusions are summarised in section 6.

269. The sections below consider the evidence behind each of these factors in turn, and assess the implications for the different budget level options.

4.3.1 Scientific knowledge about climate change

270. The Climate Change Act requires consideration of:

"Scientific knowledge about climate change".

271. Climate science underpins the UK's 2050 target to reduce emissions by 80% on 1990 base levels. The UK's 80% target was advised by the Committee on Climate Change as an appropriate share of global action to limit global surface warming to around 2° Celsius above pre-industrial levels by 2100. In its advice for the fifth carbon budget level, the CCC reaffirmed the appropriateness of the UK's 80% target for a global 2° Celsius pathway. The 1.5° Celsius aspiration from the recent Climate Conference in Paris underwrites the global long term goal to keep global temperature increase well below 2° Celsius.

272. 2050 emissions pathways modelling (presented in section 3.2) indicates that the UK could achieve its 2050 target domestically with each of the four budget levels being considered. Global efforts to limit warming to 2° Celsius above pre-industrial levels by 2100 depend on the cumulative stock of carbon in the atmosphere. Climate science suggests that tighter fifth carbon budget levels are preferred on the grounds that they result in marginally lower cumulative global emissions. However, the UK's contribution to global emissions is small, at around 1% of estimated 2014 emissions.

273. Scientific knowledge about climate science does not directly point to a particular budget level but does suggest that tighter budgets offer advantages in terms of marginally reduced global risk of harmful climate change.

4.3.2 Technology relevant to climate change

274. The Climate Change Act requires consideration of:

"Technology relevant to climate change".

275. The technology choices which the UK must make are system-wide, covering all parts of the economy and all greenhouse gas emissions. The scientific and engineering realities which underpin these choices, including what is physically and technically possible in each sector, are

considered in detail throughout the evidence base underpinning this Impact Assessment, described in sections 7.3, 7.4, and 7.5.1.

276. Knowledge of technology underpins the assessment of feasible emissions reductions, and plausible budget levels set out in section 3. The cost-benefit analysis presented in section 4.1 depends on estimates of the costs and availability of different technologies. Reflecting uncertainty around these estimates, sensitivities of the static cost-benefit analysis to technology costs and availability are presented in section 4.1.

277. The analysis of emissions pathways to 2050 presented in section 3.2 highlights the critical role of uncertainty around key emission reductions technologies. Where uncertainty is present, there can be value in deploying a diverse range of technologies at some scale in the short and medium-term.

278. To the extent that knowledge of technology underpins the analysis presented throughout this Impact Assessment, it can point towards a range of different levels of the fifth carbon budget that could be considered appropriate. This will, however, depend on the relative weight attached to the different assessments.

4.3.3 Economic circumstances

279. The Climate Change Act requires consideration of

"Economic circumstances, and in particular the likely impact of the decision on the economy and the competitiveness of particular sectors of the economy"

Economic outlook

280. The UK has recorded robust GDP growth in recent quarters. However, according to the World Bank's Global Economic Prospects report,[91] GDP growth globally fell short of expectations in 2015 due to low commodity prices, low capital flows and weak trade. Global economic growth is expected to be stronger in 2016-2018 although there are significant downside risks resulting from increased geopolitical tensions, reduced growth in major emerging economies, and remaining financial turmoil. The Office for Budget Responsibility projects UK growth of 2.0% in 2016, and averaging 2.1% per annum until 2020.[92] Stronger UK growth can result in higher underlying emissions, although the UK has seen more decoupling of GDP and emissions in recent years. In 2014, emissions fell by an estimated 8.4% against the backdrop of a growing economy. Strong growth can increase investment in low-carbon technologies to reduce emissions and stimulate greater spending on innovation in these technologies, with the potential to reduce long-term costs.

Economic impacts from decarbonisation

281. Meeting the UK's 2050 target is likely to result in a range of impacts on the UK economy. These impacts will differ by sector, and will be dependent on the types of policy levers introduced by government to meet carbon budgets. Impacts will also depend on how UK action compares to action in other countries.

282. In the long-term, through the 2015 climate change agreement in Paris[93], countries have committed to regularly reviewing their climate plans and collectively ensure that necessary action is being taken to tackle climate change. These commitments, together with long established cross-border trading systems such as the EU ETS, help provide a degree of certainty for UK business in the global transition to a low-carbon future. The commitments also mitigate (to a certain extent) the risk of carbon leakage of new investments or business. The UK's ambition in meeting its emissions target is considered in a European and global context in section 3.1.

283. Domestic emissions abatement action to meet the fifth carbon budget can have a range of impacts on growth in the wider UK economy. These include, but are not limited to:

[91] World Bank, Global Economic Prospects. http://www.worldbank.org/en/publication/global-economic-prospects

[92] Office for Budget Responsibility, Economic and Fiscal Outlook (March 2016) http://cdn.budgetresponsibility.org.uk/March2016EFO.pdf

[93] Paris COP, December 2015

- Impacts on the timing and scale of investment spending;
- Impacts on business output resulting from improvements in energy efficiency, and changes in expenditure on capital assets;
- Reorientation of consumption patterns away from emissions-intensive products and towards more energy-efficient products;
- Impacts from changes to energy prices as a result of energy demand changes, and any changes in the costs of policy delivery mechanisms included in energy bills;
- Long-term benefits from innovation, including the development of nascent industries, associated spillover benefits into other sectors, and the increase in exports of knowledge and new technologies;
- Indirect effects on growth through changes in exposure to energy price volatility and supply disruptions;
- Transition costs that could materialise, for example the potential impact of stranded assets and any transitional unemployment; and
- Multiplier effects associated with the above impacts, including any impacts on employment.

Modelling of overall macroeconomic impacts

284. The 2006 Stern Review[94] estimated that the cost of inaction on climate change significantly outweighs the expected cost of coordinated global action. Without effort to tackle climate change, the Review predicted that the loss of GDP from climate change could cost the global economy significantly more than the global cost of action to stabilise atmospheric concentrations of greenhouse gases (at 450-550ppm CO_2e).

285. The Government has commissioned analysis of UK economic growth impacts of meeting the options for the level of the fifth carbon budget. This analysis has been undertaken using HM Revenue and Customs' (HMRC's) Computable General Equilibrium (CGE) environmental model[95]. It captures many of the (gross) economic impacts of meeting the fifth carbon budget. It does not, however, take account of any avoided costs of climate change detailed in the Stern Review.

286. CGE models provide a top-down, long-run perspective of the economy and simulate the behaviour and economic interactions between households, firms and the Government, assuming rational decision making by each of these. These models have been widely used by various governments, multilateral organisations and academics to model the economic impacts of climate policy.

287. In practice, the economic impacts of meeting the fifth carbon budget will depend on the policies implemented to meet the budget. The precise details of policies which will be implemented to meet the fifth carbon budget have not yet been decided, therefore a pragmatic approach has been adopted in this modelling. An economy-wide carbon price has been implemented in the model to drive the required amount of emissions reductions, rather than adopting an alternative approach of directly specifying policies.

288. This modelling approach estimates that as a result of meeting the CCC's budget level (Option 3, 1,725 $MtCO_2e$) through domestic action alone (as opposed to, for example, buying international credits), GDP in 2030 could be 0.2-0.7% lower compared to what GDP would be if only existing climate policies are implemented.

289. The model estimates a static GDP impact in 2030. It is not designed to estimate annual growth impacts; however, as a rough illustration the equivalent reduction in annual growth over a 10-year period would be between 0.02-0.07 percentage points for the CCC budget. Given GDP in 2030 is projected to be around £2.5 trillion in real terms, the impact translates to a cost of around £5-18 billon in 2030 (real, undiscounted) for the CCC budget level.

290. The range of potential in-year GDP impacts depends on the extent to which there will have been underlying improvements in energy efficiency not directly driven by government policy. The

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[94] Stern, N. (2006); 'The economics of climate change: the Stern review'; Cambridge University Press, Cambridge. http://webarchive.nationalarchives.gov.uk/20100407172811/http://www.hm-treasury.gov.uk/stern_review_report.htm

[95] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/263652/CGE_model_doc_131204_new.pdf

greater the degree of efficiency improvement driven by the market (independently of policy), the closer to the low end of the range the actual impact on GDP will be. There are other factors which can further widen this range, including the extent to which policy realises the most cost-effective opportunities.

291. There are several limitations to the modelling:

- The CGE modelling captures the (gross) economic impacts of meeting the fifth carbon budget. However important benefits from tighter greenhouse gas targets and measures to tackle climate change are not captured in the modelling. In particular, it does not directly capture the short-run impacts of increased investment and associated multiplier impacts; employment impacts; innovation impacts; and energy security. Benefits from improvements in energy efficiency are only partially captured[96] .
- Other benefits not captured include improved air quality, health benefits, as well as avoided negative impacts on UK economic growth from global climate change.
- The model also does not capture all of the transition costs that could materialise from the move to a low-carbon economy, for example the potential impact of stranded assets and any transitional unemployment (as workers transition from higher to lower carbon intensive industries).

Potential impacts on the business sector and on the competitiveness of firms

292. The evidence on emissions reductions opportunities presented in section 3.3 indicates where there are emissions reduction opportunities across the non-traded sectors of the economy (agriculture, waste, forestry, transport, domestic buildings and non-domestic buildings). In industrial sectors, a large proportion of emissions are covered by the EU Emissions Trading System and are not directly influenced by carbon budgets.

293. Industry sectors most likely to be susceptible to competitiveness impacts and carbon leakage are trade-exposed firms for whom energy forms a large part of their cost base. However, for many of these firms compensation or support mechanisms are in place.[97] The Government is also in the process of finalising compensation schemes for the indirect effects of the Renewables Obligation and Feed-in Tariffs on the UK's most electricity-intensive businesses. In addition, emissions from these firms are more likely to be within scope of the EU ETS. Since carbon budgets only directly influence non-traded emissions, the direct impact of carbon budgets on these firms is likely to be limited. However, indirect impacts on traded sector emissions can occur for example due to changes in electricity demand.

294. The majority of non-traded emissions from businesses are from less energy intensive firms, for example those operating in agriculture, services, and light manufacturing. The impacts on these businesses will depend on the range of policies implemented to meet budgets. There will be opportunity for businesses in these sectors to take up cost-effective energy efficiency measures that can contribute towards meeting the budget. These measures can help reduce wasteful energy use, reducing business costs, boosting productivity and increasing competitiveness.

295. As set out in section 4.1, energy price impacts solely from meeting the options for the fifth carbon budget are expected to be small. Any impact on the competitiveness of UK businesses from energy price changes will similarly depend on the extent of climate action and energy prices in other countries.

[96] Increases in economic output due to reductions in production costs resulting from efficiency increases resulting from additional action to meet the fifth carbon budget are not captured. In addition, where energy cost savings outweigh the capital costs of improving energy efficiency, these net cost savings are also not captured.

[97] Compensation packages and support mechanisms include: free allowances for industrial sectors judged as being at risk of carbon leakage under the EU ETS; the carbon price support rate capped at £18/tonne from 2016-2020; Climate Change Agreements; and cash compensation administered by BIS for the indirect impacts of various policies on electricity costs, including EU ETS and Carbon Price Floor.

296. At this point, the competitiveness impacts on individual sectors are unknown, as these impacts depend on the specific policies introduced to meet carbon budgets. The strategy for meeting carbon budgets, to be published as soon as reasonably practical after the level of the fifth carbon budget is legislated, will set out in more detail potential impacts on business competitiveness.

4.3.4 Fiscal circumstances

297. The Climate Change Act requires consideration of

"Fiscal circumstances, and in particular the likely impact of the decision on taxation, public spending and public borrowing"

298. As in all other areas, the Government will need to consider decisions on policies to meet carbon budgets alongside other pressures on public finances and in light of the fiscal mandate.

299. Consistent with the assessment of economic impacts, the types of policy levers introduced will determine the fiscal impacts. The details of policies to meet the fifth carbon budget have not yet been determined, therefore only a high-level assessment of the fiscal impacts can be made.

300. Tax receipts are broadly correlated with GDP, and if the fifth carbon budget creates the pressure on GDP that is set out above then this may have a follow-on impact of reducing public sector receipts. That reduction in receipts would likely increase in line with the scale of any negative GDP impact. More specifically, in the absence of policy change, it would be expected that receipts from energy and environmental taxes (for example Carbon Price Support, Vehicle Excise Duty and Landfill Tax) in particular would decrease as the economy becomes more energy-efficient and emissions are reduced further. However, in practice the tax regime could be reformed to offset the described impacts on receipts.

301. The design and relative mix between different types of domestic policy (regulation, tax, and subsidy) will be an important determinant of the overall fiscal impact. There would also be fiscal impacts if the Government were to decide to purchase international credits to help achieve our carbon budgets.

4.3.5 Social circumstances

302. The Climate Change Act requires consideration of

"social circumstances, and in particular the likely impact of the decision on fuel poverty"

303. The definition of fuel poverty varies by nation. While the analysis below is based on an assessment of impacts in England, it would be expected that the impact of the fifth carbon budget on fuel poverty and the energy efficiency of fuel poor homes would be comparable in other nations. The Devolved Administrations did not make representations regarding the specific impacts on fuel poverty, although the Scottish Government highlighted the importance of fuel poverty through energy-efficiency schemes and that further work needs to be developed in this area.

304. In England, fuel poverty is measured using the Low Income High Costs (LIHC) indicator.[98] Under this indicator a household is considered to be fuel poor if:

- it has *required* fuel costs[99] that are above average (the national median level)
- were it to spend that amount, it would be left with a residual income below the official poverty line.

305. This means fuel poverty in England is measured on a relative basis, which can change over time as the distribution of incomes and fuel costs change. Energy requirements are driven by dwelling characteristics, such as insulation levels and the specific heating system, but also by

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[98] This was metric was adopted in 2012 following an independent review. https://www.gov.uk/government/publications/final-report-of-the-fuel-poverty-review

[99] "Required fuel costs" are an estimation of the spend on fuel needed by a household to reach a set temperature and energy use standards. In reality, many households under-heat their home, relative to the recommended adequate standard of warmth.

household characteristics such as the occupancy pattern. In Scotland, Wales and Northern Ireland, fuel poverty is measured on the basis of whether a household needs to spend more than 10% of their income on energy needs.

306. The Government has a statutory target to raise as many English fuel poor homes as is reasonably practicable to energy efficiency Band C by 2030,[100] with milestones of Band E by 2020 and Band D by 2025. The Devolved Administrations in Scotland and Wales have separate legal fuel poverty targets.

307. Carbon budgets can affect our fuel poverty targets in the following three main ways:

- Through affecting energy prices: changes in energy prices will have a larger impact on fuel poor households as they have higher energy requirements than the average household.
- By affecting the energy needs of households: if the fabric of homes with fuel poor occupants improves more than other dwellings, this will have a positive impact on fuel poverty.
- By affecting the means by which heat is supplied: For example, the extent to which fuel poor households replace gas boilers with heat pumps compared to the wider population will affect the fuel costs of the fuel poor compared to the national average.

308. Illustrative analysis of the impact of the fifth carbon budget on fuel poverty has been undertaken by considering these three types of impacts across abatement scenarios that vary electricity prices and the installation of fabric improvements and low carbon heating technologies. These are measured against a Reference scenario of the 2015 Energy Emissions Projections.

309. Analysis presented in section 4.1 suggests that the impact on electricity prices from undertaking abatement to meet the range of budget level options is generally small. This will be highly dependent on the policies used to deliver abatement and any evolution in the landscape of power sector markets and policy levers. A similar assessment on gas prices was not possible at this stage.

310. This analysis shows that depending on the approach to decarbonising domestic heat, there is significant potential for the size of the fuel poverty gap to be reduced compared to the reference scenario, where this gap represents the difference between the required fuel costs for each household and the national median required fuel costs. This would depend on the approach to decarbonising heat supply, for example whether there is a focus on reducing the carbon content of gas supply (for example through injection of biomethane into the grid) or through installing heat pumps. Focussing on electrification of the grid through the installation of heat pumps has a smaller impact on reducing the size of the gap due to the assumed running costs of heat pumps being relatively higher than gas systems. The reduction in the overall fuel poverty gap would be expected to be largely due to improvements in the average fuel poverty gap per fuel poor household. This is because the expected impact on the number of fuel poor homes in England from either approach would be expected to be relatively small without specific targeting of measures towards fuel poor households.

311. Depending on how the fifth carbon budget is met, there is potential for improvement in the number of fuel poor households in England in dwellings with an energy efficiency rating of Band C or better.[101] Under current assumptions, greater improvements would be achieved through a greater focus on decarbonising the gas supply over moving non-gas-fuelled fuel poor homes on to electrically powered systems such as heat pumps.

312. When interpreting the progress made against the fuel poverty target for England, it is important to bear in mind that carbon budget scenarios do not consider a number of interventions that can also help makes progress towards the statutory targets and milestones. These include energy bill rebates or Solar PV (which affects traded emissions and also the required energy

[100] As measured by the Fuel Poverty Energy Efficiency Rating (FPEER): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332236/fpeer_methodology.pdf

[101] As measured by the Fuel Poverty Energy Efficiency Rating (FPEER): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332236/fpeer_methodology.pdf

costs of fuel poor homes), which are two important elements in the fuel poverty strategy.[102] Had they been included in the analysis they would have shown additional progress towards our milestones and target.

313. Further details on the analysis can be found in Annex 7.10.

4.3.6 Energy policy

314. The Climate Change Act requires consideration of

"energy policy, and in particular the likely impact of the decision on energy supplies and the carbon and energy intensity of the economy"

315. Energy policy shapes how energy is supplied, how electricity is generated, and how consumers, businesses, government and the voluntary sector use energy. This in turn shapes the UK's primary energy mix, and emissions resulting from energy use.

Energy and emissions intensity of the UK economy

316. The energy and carbon intensities of the economy are measured as the ratio of total energy use or emissions of greenhouse gases respectively to the value of the UK's economic activity. Up to and including the fifth carbon budget period, deployment of cost-effective energy efficiency measures is expected to reduce final energy demand and therefore the energy intensity of the economy,[103] although the precise impact of the fifth carbon budget level on the energy intensity of the economy will depend on which energy policies are adopted. To the extent that actions to meet the fifth carbon budget reduce UK emissions, the carbon intensity of the economy during the fifth carbon budget period would be expected to fall.

317. The energy intensity of the UK economy in 1990, as measured through final energy demand was 2.29kWh/GDP£2015, with a corresponding emissions intensity of 739tCO_2e/£2015m. In comparison, the final energy intensity of the UK economy is estimated in 2030 to be around 0.57kWh/£2015, under the counterfactual emissions scenario reflecting existing and planned policy.[104]

318. Implementing the cost-effective abatement opportunities identified through the compiled MACC database (see section 3.2) has the potential to further reduce final energy intensity by around 9%, while implementing all opportunities identified regardless of cost-effectiveness could reduce energy intensity by around 30% relative to the emissions counterfactual scenario including the impacts of existing and planned policies only.

319. Table 24 presents the impact on the carbon intensity of the economy of meeting the fifth carbon budget through domestic emissions reductions. There is considerable uncertainty about the emissions from electricity generation during the period of the fifth carbon budget, for example due to interconnector capacity, and how the costs and deployment of low carbon generation evolve. Since carbon budgets do not directly affect these emissions, the projected emissions intensity of the economy has been based on estimates of the UK's net carbon account to isolate the impact. The percentage improvement in emissions intensity of the economy would be expected to be broadly similar if adopting a territorial emissions-based metric.

320. Under the counterfactual emissions scenario, the emissions intensity of the economy is expected to have fallen by 78% relative to the carbon budgets base year. Meeting the fifth carbon budget level options through domestic emissions reductions could further reduce the emissions intensity to an 82% reduction, depending on the budget level.

[102] Available here: https://www.gov.uk/government/publications/cutting-the-cost-of-keeping-warm
[103] This assumes no overall impact on growth from undertaking actions to meet the level of the carbon budget. For estimates of potential impacts of meeting the fifth carbon budget on GDP see section 4.3.3
[104] OBR GDP growth assumptions are used to estimate 2030 GDP. OBR forecast is extended assuming a 2.4% growth rate between 2020 and 2024, and a 2.5% trend growth rate thereafter.

Table 24: Carbon intensity for fifth carbon budget level options

	1990 base year	**Counter-factual** (existing and planned policy impacts only)	**1. Non-binding budget**	**2. Equal absolute reductions from CB3 to 2050**	**3. CCC advised level**	**4. Equal % reductions from CB4 to 2050**
5-year net Carbon Account $MtCO_2e$	**800** (1-year)	**2,036**	**e.g. 2,100**	**1,830**	**1,725**	**1,670**
GDP emissions intensity (tCO_2e/£m 2015)	739	161	161	144	136	132
% reduction on 1990 carbon intensity		-78%	-78%	-80%	-82%	-82%

Energy security

Energy security is about ensuring secure, reliable, uninterrupted supplies to consumers, and that the system can effectively and efficiently respond and adapt to changes and shocks. Energy security of supply is made up of three characteristics: flexibility, adequacy and resilience. The Government is committed to ensuring there are secure supplies for consumers whatever the energy mix.

321. The precise impact of the fifth carbon budget level on each of these elements will depend on what energy policies are implemented as a result of the carbon budget level, as well as any other policies implemented in the traded sector. Measures considered within the MACC evidence base have the potential to reduce demand for electricity, gas, coal, oil and transport fuels or switch to alternative energy sources. For example, loft insulation can reduce the demand for heating fuels while the use of biomass in heating reduces demand for gas while increasing demand for biomass. The MACC evidence suggests that undertaking measures to reduce UK emissions has potential to reduce demand for gas and coal by over 40% in 2030 relative to current projections, and over 25% for petroleum based products.

Impacts on fuel demand

322. Emissions reductions for the fifth carbon budget will require action across the economy, with action in the electricity, oil and gas sectors. In its advice the CCC highlighted that under its cost-effective scenario coal use will fall substantially in the period to the fifth carbon budget, particularly as a result of coal power station closures. The Government has committed to phasing out unabated coal in power generation by 2025. In the CCC's central scenario for the fifth carbon budget, oil use falls by around 24% and gas use falls by around 13% compared to today's levels. This is broadly supported by the pathways analysis presented in section 3.2. The overall impact should be to reduce both the UK's energy use and intensity.

323. Within the power sector, the EU ETS will continue to cap ETS-wide emissions and is expected to help bring down emissions from power stations. UK Carbon Price Support will also ensure there are incentives to switch to low carbon generation. Take-up of cost-effective abatement measures in the non-traded sector is expected to have a negligible net effect on electricity demand (see section 4.1). However, demand could be higher or lower than this, depending on the policies implemented.

324. Actions to meet the fifth carbon budget can also change the profile of electricity consumption, for example through electrification of heat and transport demand. This could require ensuring there is sufficient flexibility in the system. Existing and new gas generation will likely play an important role in maintaining electricity system adequacy and flexibility (as coal generation is phased out), together with increased interconnection and the continued development of demand side response and energy storage.

325. The influence of the level of the carbon budget on emissions in the non-traded sector will likely result in some transfer in demand for fossil fuels to low carbon sources, including direct consumption of renewables and possibly hydrogen, in addition to indirect consumption of low carbon electricity through electrification. This could increase fuel and fuel source diversity, and help enhance energy resilience, provided reliable supply chains for those alternative fuels are established.

326. These views are in line with the Committee on Climate Change which highlighted the security of supply benefits of diversifying away from fossil fuels towards low carbon fuels, whilst also reducing fossil fuel imports. The Committee also noted the role of maintaining electricity system security through gas generation, interconnection, demand-side response and storage.

4.3.7 Regional impacts

327. The Climate Change Act requires consideration of:

"Differences in circumstances between England, Wales, Scotland and Northern Ireland"

328. Collectively Scotland, Wales and Northern Ireland accounted for 22% of UK emissions in 2013 against a share of 14% of the UK's GDP.

Table 25: National emissions, population, and GDP[105]

Nation	**Share of UK Emissions** (2013)	**Share of UK Population** (2013)	**Share of UK GDP** (2013)	**Territorial emissions reduction** (1990-2013)
Northern Ireland	4%	3%	2%	16%
Scotland	9%	8%	8%	35[106]%
Wales	9%	5%	4%	12%

National emissions reductions frameworks

329. The Climate Change Act sets a long-term target to reduce emissions of GHGs by 80% in 2050 relative to 1990. Each of the Devolved Administrations are committed to the same end point as the UK Climate Change Act (an 80% reduction by 2050), however the level of ambition through the carbon budgets and annual targets set by the nations can vary.

330. Scotland introduced its own legislative framework through the Climate Change (Scotland) Act 2009 and has an interim target to reduce emissions by 42% in 2020 relative to 1990 (including international aviation and shipping). The Act also requires the Scottish Government to set annual emission targets from 2010-2050 and requires reducing greenhouse gas emissions by 3% each year from 2020.

105 Report: Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990-2013 Report link: http://naei.defra.gov.uk/reports/reports?report_id=810 Data tables link: http://uk-air.defra.gov.uk/reports/cat07/DA_GHGI_1990-2013_EmissionsData_v1.xlsx

106 The shares in this table do not account for emissions from international aviation and shipping. These emissions are measured for Scotland and when accounted for the reduction from 1990 to 2013 is 34%. Using either approach Scotland's share of total UK emissions is 9%.

331. Wales has a target to reduce greenhouse gas emissions by 3% each year from 2011, relative to a baseline of average emissions over 2006-2010. Wales has recently received royal assent for the Environment (Wales) Act 2016.

332. Northern Ireland has a target to reduce emission by 35% (from 1990 levels) by 2025.

Summary of national representations to the Secretary of State

333. The Devolved Administrations have forward their representations on the CCC's advice for the fifth carbon budget. These are given in more detail in annex 7.1. In summary:

- **Northern Ireland:** Northern Ireland agrees with the recommendations of the CCC. Northern Ireland's view is that the level of the fifth carbon budget should be set at 1,765 $MtCO_2e$, including emissions from international shipping, over the period 2028-2032.
- **Scotland:** The Scottish Government supports the recommendations of the CCC, that the level of the fifth carbon budget should be set at 1,765 $MtCO_2e$, including emissions from international shipping, over the period 2028-2032.
- **Wales:** Wales acknowledge the recommendations of the CCC, that the level of the fifth carbon budget should be set at 1,765 $MtCO_2e$, including emissions from international shipping, over the period 2028-2032.

Accounting for DA characteristics when estimating abatement potential

334. The unique characteristics of each nation will have a bearing on the technical maximum abatement potential in that nation and of the measures that will deliver carbon savings. For instance, agriculture accounts for a larger proportion of the economy in Northern Ireland, Wales and Scotland than in England, and so will account for a higher proportion of emissions that the UK average.

335. The Government has worked with Devolved Administrations to ensure that the estimates of technical potential for emissions reductions during the fifth carbon budget period presented in this Impact Assessment take account of the best available data and expert advice when assessing the distribution of potential across the UK. This approach to capturing UK-wide evidence as presented in section 3.3 varies between sectors. UK wide data sets have been used where possible. However, for some sectors assumptions have been agreed based on nation-specific evidence.

4.3.8 European and international circumstances

336. The Climate Change Act requires consideration of:

Circumstances at European and international level

337. Section 3.1 provided a detail assessment of the European and international circumstances. This section pointed to a carbon budget level that constrains future UK emissions below current projections (i.e. a budget level tighter than Option 1) but with a relatively wide range for how tight the budget level should be set, depending on the relative weight placed on different European and international factors.

4.3.9 International aviation and shipping

338. International aviation and shipping emissions are not currently formally included within the net carbon account and are therefore not included in the 2050 target as defined by the Climate Change Act, nor within the four carbon budgets that have already been set. The Climate Change Act says that the Government must "take into account" the "estimated amount of reportable emissions from international aviation and international shipping for the budgetary period or periods in question" when setting carbon budgets.

339. Section 2.1 sets out why emissions from international aviation and shipping are not being included within the fifth carbon budget.

340. In addition, section 3.2 explains that the emissions pathways analysis considers a 2050 target where international aviation and shipping emissions are included. The allowance made for international aviation and shipping emissions in 2050 in the CCC's analysis has been used as a modelling assumption when determining the level of emissions reductions that are required from

other sectors of the UK economy. The potential impacts of airport expansion are not explicitly reflected in this allowance, but it is considered the carbon impacts of airport expansion, as estimated by the Airports Commission, are not inconsistent with this allowance.

4.3.10 Natural capital

341. Section 13 of the Climate Change Act 2008 requires Government to ensure that its proposals and policies for meeting carbon budgets, taken as a whole, are such as to contribute to sustainable development. So it is essential to assess the environmental impacts of possible new measures. The Government has committed to using a natural capital framework to understand the impacts of future policies.

342. Building on conceptual developments in environmental economics, the independent Natural Capital Committee, established in 2012, has defined natural capital as 'those elements of the natural environment which provide valuable goods and services to people'[107]. It refers to stocks of natural assets (e.g., forests, clean air, soils, species, freshwaters, oceans and minerals) that provide flows of natural resource inputs and ecosystem services.[108] Other forms of capital (human, produced, social) are usually combined with natural capital in this process to generate goods and services that provide benefits of value to society and the economy.

343. An initial screening exercise to provide a qualitative assessment of the potential implications for natural capital has been undertaken for the abatement opportunities underpinning the MACC evidence explained in section 3.2. This suggests there is an overall significant potential for impacts on natural capital which will require an in-depth assessment when developing policies to meet carbon budgets. However, these impacts are determined by how the measures are implemented and are not dependent on the budget level.

344. Out of these, around half of abatement opportunities identified are expected to have positive impacts for the UK's natural assets but a significant number of opportunities are anticipated to have both positive and negative impacts. Many of the potential land use measures (agriculture, forestry, soils) are likely to have a range of positive impacts, particularly for land use, air and water quality and wildlife. However, the use of bioenergy measures present risks, particularly for land use and air quality, and as set out in section 3.2.6 there could be an important role for bioenergy in meeting the UK's 2050 target.

5 Committee on Climate Change advice

345. The CCC gave its advice on the fifth carbon budget level and the high-level proposals for how this should be met in November 2015. Further, the CCC wrote to DECC's Secretary of State on 27th January 2016, setting out the implications of the Paris Agreement for its advice on the level of the fifth carbon budget. The Government is required to take into account this advice in making a decision on the level of the fifth carbon budget.

346. The CCC recommends that the level of the fifth carbon budget is set at 1,765 $MtCO_2e$, including emissions from international shipping, over the period 2028-2032. The CCC upheld this advice in the wake of the outcome of the 2015 UNFCCC climate change negotiations, establishing the Paris Agreement. This overall recommendation comprises emissions of 1,175 $MtCO_2e$ for the non-traded sector (those emissions falling outside of the EU Emissions Trading System) and 590 $MtCO_2e$ from the traded sector (those emissions covered by the EU Emissions Trading System). If emissions from international aviation and shipping are excluded, the CCC's

[107] See https://www.gov.uk/government/groups/natural-capital-committee The Natural Capital Committee is an independent advisory body, set up in 2012. It provides advice to the government on the state of England's natural capital - that is, our natural assets includes forests, rivers, land, minerals and oceans.

[108] Natural Capital as a concept develops the ecosystem services approach in a number of ways: (i) it stresses the environment as a stock of assets (air, land, water, subsoil); (ii) final benefits are typically provided by combining natural capital with other capital inputs; (iii) these assets can be subject to depletion and degradation which will affect the quantity or quality of future benefits; whereas investment in natural assets will provide future returns to people and the economy.

recommended budget level for the fifth carbon budget is then 1,725 $MtCO_2e$ (1,135 $MtCO_2e$ for the non-traded sector).

347. The CCC assesses that this budget level balances the range of factors that the Climate Change Act prescribes must be taken into account in determining a cost-effective path to the UK's 2050 target. The CCC also provided advice on additional considerations besides the level of the fifth carbon budget. This Impact Assessment does not consider these additional recommendations.

6 Conclusion

348. Identifying a preferred budget level requires balancing a number of factors. Different budget levels may be considered consistent with the requirements of the Climate Change Act. The Act requires budgets to be set with a view to meeting the UK's 2050 target, and consideration must be given to a range of specific factors set out in section 10 of the Act (and presented in section 4.3 of this Impact Assessment). Furthermore, the advice of the Committee on Climate Change, and the representations of the Devolved Administrations must also be taken into account.

349. Table 26 provides a summary of the analysis contained throughout this Impact Assessment, comparing the budget levels against each of the considerations listed above. The summary also includes the headline cost-benefit analysis and an assessment of the opportunities and risks to natural capital.

Table 26: Summary of budget level options against relevant considerations.

Consideration	**Budget level option,** ($MtCO_2e$ and equivalent % reduction on 1990 base levels)			
	1. Non-binding budget	**2. Equal absolute reductions from CB3**	**3. CCC advised level**	**4. Equal % annual reductions from CB4**
Budget level	2,100 $MtCO_2e$	1,830$MtCO_2e$	1,725$MtCO_2e$	1,670 $MtCO_2e$
% reduction on base year	47.5%	54.3%	56.9%	58.3%
CCC advice	**Highly insufficient** action for CCC to consider it cost-effective to meet 2050 target.	**Insufficient** action for CCC to consider it cost-effective to meet 2050 target.	**CCC recommended level.**	**More ambitious than CCC's recommended level.**
Representations from Devolved Administrations	**Inconsistent** with preferred budgets from all DAs.	**Inconsistent** with preferred budgets from all DAs.	**Consistent** with the level of action required in the non-traded sector preferred by all DAs (excluding international shipping emissions).	**Inconsistent** with preferred budgets from all DAs.
Three perspectives				
Perspective 1: International and EU	**Insufficient** to deliver efficient share of global action, and **highly insufficient** to deliver action that could be considered internationally equitable. Likely to be **insufficient** to be in line with EU 2030 target.	**Sufficient** to deliver efficient share of global action, but **insufficient** in itself to deliver action that could be considered internationally equitable. Likely to be **sufficient** to be in line with EU 2030 target	**Comfortably sufficient** to deliver efficient share of global action and **approaching a level sufficient** to deliver action that could be considered internationally equitable. Highly likely to be **sufficient** to be in line with EU 2030 target	**Well beyond** necessary action to deliver efficient share of global action and **sufficient** to deliver action that could be considered internationally equitable. Highly likely to be **sufficient** to be in line with EU 2030 target
Perspective 2: Pathways to 2050	**Substantially reduced short-term action**, with higher risks likely around meeting the UK's 2050	**Broadly consistent** with undertaking steady emission reductions to meet 2050 target, and	**Broadly consistent** with undertaking steady emission reductions to meet 2050 target, and undertaking actions	**Reduced risk** pathway towards the UK's 2050 target, requiring greater emissions reductions in the short term.

	target. Pathway would require substantially increased emissions reductions later on.	undertaking actions by 2030 to deploy a range of technologies that may be critical for meeting the 2050 target.	by 2030 to deploy a range of technologies that may be critical for meeting the 2050 target. Could contribute to technology cost reductions.	Additional short-term costs are likely under this budget level, but could result in greater technology cost reductions to reduce future decarbonisation costs.
Perspective 3: Feasible and affordable action	**Insufficient** to require action known to be intrinsically cost-effective. **Highly feasible** to deliver as no action likely to be required.	**Broadly cost-effective**. Some higher cost actions are likely to be required, although this is likely to be necessary to adequately make progress towards 2050 target in key sectors and technologies. **Broadly feasible** to deliver, although some additional policy effort to overcome strong barriers likely to be required.	**Stretching** abatement required although many actions are likely to be important for ensuring adequate progress is made towards 2050 target. Some international credits could be purchased to avoid highest cost abatement. **Feasible, but challenging** to deliver, requiring adoption of measures with strong barriers to delivery.	**Very stretching** abatement required, necessitating action significantly beyond those measured cost-effective against the government's carbon values, and measures not required to adequately prepare for meeting the 2050 target. **Highly challenging** to deliver, requiring near full deployment of unfamiliar, unpopular, or otherwise difficult technologies facing the strongest of delivery barriers.
Cost-benefit analysis				
Indicative NPV (£bn, 2015, incl. valuation of carbon) Range based on uncertainty in energy prices and technology costs	0	12.6 (6.9 – 20.9)	5.5 (-14.5 – 28.8)	-0.1 (-28.6 – 30.0)
Indicative investment costs to 2030 (£bn, 2015, undiscounted) Range based on uncertainty in technology costs	0	33 (25-41)	88 (55-122)	120 (75-171)

Climate Change Act factors	
Climate change science	All budget levels potentially consistent with action to meet the UK's 2050 target (see perspective 2). Since the 2050 target was set as an indicative and appropriate UK contribution towards global action to limit warming to dangerous levels above pre-industrial times, each budget could plausibly be consistent with the stated climate ambition. However, tighter budget levels are likely to result in lower cumulative UK emissions.
Relevant technology	Each budget level option is assessed to be technically plausible to deliver, and would not prevent the UK from reaching its 2050 emissions reduction target. There are significant uncertainties around the costs and availability of emissions reductions technologies. Early deployment can help develop emergent technologies, and keep options open for later decarbonisation, thereby reducing the risk of failing to meet the 2050 target. However, earlier deployment of a wide range of technologies is likely to increase short-term costs. Placing greater weight on reducing short-term costs points to looser budget levels, whereas greater weight on reducing risks around meeting the 2050 target point towards tighter budgets.
Economic circumstances	Meeting the CCC's advised budget level (Option 3) through domestic emissions abatement could reduce GDP in 2030 by 0.25-0.7%, illustratively equivalent to a 10-year reduction in annual growth of 0.03-0.07 percentage points. Option 2 would likely have a smaller impact on GDP. These estimates exclude wider environmental benefits, impacts on innovation that could reduce long-term costs of emissions reductions, and exclude a consideration of the avoided costs of climate change resulting from global climate action. Any costs of transition are also not captured. Impacts on businesses will depend upon specific policies relating to these sectors, and will also not affect the most energy-intensive industries as budgets only directly place a constraint on non-traded emissions.
Fiscal circumstances	The details of policies to meet the fifth carbon budget are not yet determined, so these impacts are unknown, although the relative mix between regulation tax and subsidy will be an important determinant. As described above, tighter budgets are likely to put greater pressure on GDP, which would be associated with proportionately lower tax receipts. Receipts from energy and environmental taxes in particular are likely to decrease as the economy became more energy

	efficient and emissions were reduced further. However, in practice the tax regime could be reformed to offset the described impacts. There would also be fiscal impacts if the Government were to purchase international credits to help achieve our carbon budgets.	
Social circumstances	Impacts on fuel poverty are highly uncertain and will depend on the specific policies and levers used to implement budgets. Carbon budgets can affect our fuel poverty targets through affecting energy prices and by affecting the energy needs of households (e.g. through improved buildings insulation). The evidence on these two impacts is presented in section 4.3.5.	
Energy policy	Impacts on energy policy of different levels of the fifth carbon budget will depend largely on the policies and levers used to meet the budget level. However, tighter budgets will reduce the emissions and energy intensity of the economy, and could potentially reduce demand for imported fuels. Emissions reductions through increased electrification could require additional action to manage the reliability of the electricity system.	
Regional circumstances	Impacts of different levels of the fifth carbon budget will depend largely on the policies and levers used to meet the budget level. There are differences in the sectoral shares in underlying emissions between the nations, with generally greater emissions from agriculture in Scotland, Wales, and Northern Ireland. Responsibility for emissions reductions in several sectors is devolved to the individual nations.	
European and International circumstances	Options 3 and 4 are more consistent with the range of methodologies presented to estimate a fair UK contribution to global emissions reductions, although national commitments from all countries are not yet sufficient to meet this climate objective. Options 2-4 would likely be sufficient to be in line with current EU 2030 target.	
International aviation and shipping	International aviation and shipping emissions are currently not included within scope of the UK's 2050 target or carbon budgets. However, the Act states that in setting carbon budgets, the Government must take these emissions into account. The CCC considers that, in practice, the requirement to take IAS emissions into account when setting carbon budgets "means carbon budgets need to allow for emissions from IAS by ensuring that emissions from other sectors are at a level consistent with meeting the overall 2050 target when IAS emissions are included". It has made its recommendation on the level of CB5 on this basis.	
Other factors		
Natural capital	No further opportunities or risks to natural capital compared with counterfactual.	Some new abatement required. Risks and opportunities unknown, as these will depend on the policies and actions to meet the budget levels. Tighter budgets will require greater action, which will likely increase scale of impacts relative to those expected under existing and planned policies. However, these impacts could be positive or negative.

7 Annexes

7.1 The views of the Devolved Administrations (DAs)

350. Under the 2008 UK Climate Change Act (CCA) the Government is required to take into account representations made by the Scottish Government, Welsh Government and the Northern Ireland Executive. Collectively, the DAs account for 22% of the UK's emissions in 2013. Their territories are covered by the Act but they have also set their own two targets through their own legislative frameworks, set broadly in line with the legally binding 80% target.

351. All three devolved administrations agreed with the advice of the Committee on Climate Change (CCC) to set the level of the budget at 1,765 $MtCO_2e$, including from emissions international shipping, over the period 2028-2032.

The Scottish Government

352. The Climate Change (Scotland) Act puts in place targets similar to those set out in the UK Climate Change Act. Specifically, the Scottish Act requires that annual targets for the same period are set as soon as is practically possible after 31 October 2016. To support these timetables, the CCC has provided separate advice on Scottish targets in March 2016. The CCC recommended setting Scottish targets equivalent to an average 61% reduction below baseline levels over the period of the UK's fifth carbon budget. Scottish Ministers will consider this advice before they take a specific view on their appropriate targets for that period, and it will be for the Scottish administration to then bring forward proposals.

353. The Scottish Government has submitted its views on the CCC's advice on the fifth carbon budget. The Scottish Government agrees with the level of the fifth carbon budget, as proposed by the CCC of 1,765$MtCO_2e$ (equivalent to a 57% reduction against 1990 baseline), including emissions from international shipping and to be met without the use of the international carbon units. The Scottish Government believes the fifth carbon budget should represent the minimum level of UK ambition necessary following the agreement in Paris, Conference of Parties in December 2015.

354. The Scottish Government agrees with the CCC's analysis of the necessary scale of decarbonisation across the UK. The Scottish Parliament has already set a 42% emissions reduction target for 2020 and a requirement that emissions fall by at least 3% per annum thereafter.

Welsh Government

355. The Welsh Government is committed to a reduction of 40% in greenhouse gases in all sectors levels by 2020 from 1990 levels and an annual target to reduce GHG emissions by 3% each year from 2011, relative to a baseline of average emissions over 2006-2010. Work on climate change in Wales will be taken forward under the fresh legal framework set by the Well-being of Future Generations (Wales) Act 2015 and the Environment (Wales) Act 2016.

356. The Welsh Government responded to the UK Government's consultation on the CCC's fifth carbon budget report in March 2016. The Welsh Government acknowledged UK Government's consultation on UK Committee on Climate Change's advice on the setting of the UK's fifth carbon budget at 1,765 $MtCO_2e$, including emissions from international shipping, over the period 2028-2032. The Welsh Government noted the content of the Committee's advice regarding the devolved administrations and will take this into account as they move forward with policy development in Wales. In taking forward the implementation of the Environment (Wales) Act, Wales will be seeking expert advice, including from the Committee on Climate Change, on the setting of the carbon budgets levels in Wales. The Welsh Government also noted that the UK Committee believes that the budget should be met through domestic effort which will require new policies and plans to be set during this Parliament and would urge that this action fully takes into account the devolution context.

Northern Ireland

357. Northern Ireland does not have a comparable legislative framework beyond the Climate Change Act 2008, however it is committed to a long term goal of an 80% (from 1990 levels)

reduction in emissions by 2050, and contributes to achievement of UK targets and EU and International commitments.

358. The CCC's recommendations have been noted and there is agreement with the recommendations on the level of the fifth carbon budget put forward by the CCC. The level proposed by the CCC of 1,765MtCO_2e, including emissions from international shipping is fully endorsed.

7.2 Assumptions

359. The analysis in this Impact Assessment is consistent with standard government appraisal methodologies as laid out in HM Treasury's Green Book[109]. Specific supplementary guidance on "Valuation of energy use and greenhouse gas emission for appraisal"[110] has been applied for estimates of the scale and value of fuel and emissions impacts. A summary of the overarching assumption set used throughout this Impact Assessment (unless otherwise stated) is given in the following table.

Energy prices	The fossil fuel price assumptions[111] are produced by DECC analysts based on global market considerations and comparison with projections from other organisations such as International Energy Agency. These were last updated in November 2015. Based on these fossil fuel price projections, DECC also produces assumptions for UK retail prices (published as part of the supplementary guidance on the valuation of energy use and greenhouse gas emissions[110]). These are used when assessing the private value to individuals and businesses of changes in fuel consumption, as well as to value any rebound effects. Long-run variable costs of energy supply (LRVC) reflect the social resource costs of energy and are based the variable components of the retail price. These too are published by DECC as part of the supplementary guidance on the valuation of energy use and greenhouse gas emissions[110].
Emission factors	Emissions intensity factors used in the analysis are taken from the latest emissions inventory. They are published in the HM Treasury's Green Book supplementary guidance on the valuation of energy use and greenhouse gas emissions,[110] last updated in December 2015. The marginal electricity emissions factor is used to convert the impact of small sustained changes in electricity consumption into the corresponding impact on emissions.
Carbon prices and values	See Annex 7.6.
Economic growth	Economic growth forecasts are in line with assumptions included in DECC's 2015 Energy and Emissions Projections (EEP)[112] which in turn use the growth forecasts published by the Office of Budgetary Responsibility (OBR)[113]
Demographics	Population estimates and number of households are aligned with assumptions adopted in the DECC 2015 EEP, using data from the Office of National Statistics (ONS).
Discount rates and finance costs	When conducting social cost-benefit analysis, discount rates based on HM Treasury's Green Book guidance are applied. The discount rates used are 3.5% for the first 35 years of the appraisal period and 3% thereafter to reflect the social rate of time preference. Some analysis also considers a private sector-specific cost of finance based on the mid-point of ranges set out by the CCC.[114]
Price base	All monetised values, unless stated otherwise, are presented in GBP with a 2015 price base, discounted to 2016.

[109] https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent
[110] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal
[111] https://www.gov.uk/government/publications/fossil-fuel-price-projections-2015
[112] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2015
[113] http://budgetresponsibility.org.uk/
[114] http://archive.theccc.org.uk/aws/Time%20prefernce,%20costs%20of%20capital%20and%20hidden costs.pdf

7.3 UK TIMES model

360. For this analysis, model version v1.2.2_d0.0.6 has been used. Quality assurance of the model has included a review of assumptions by relevant stakeholders and a comprehensive formula audit of the calculations in the input database.

361. UK TIMES is a technology-rich (approximately 1,500 technologies) modelling tool which offers insight about some of the key interactions and future decision points for a complex and competing UK energy system. It provides information about the roles that technologies and resources could play under different pathways. UKTM uses a linear optimisation solver to identify the system that meets exogenous energy service demands with the lowest overall discounted system cost, subject to constraints such as GHG targets and build rate limitations.

Limitations

362. UKTM has a number of limitations.

- The model only takes account of a subset of the full costs and benefits of meeting a given carbon budget level. In addition, only technical factors are taken into account in the roll out choices (costs, maximum build rates etc.). Behavioural or other practical considerations that might make a certain pathways undesirable or difficult to achieve are not accounted for. In addition, the modelled solution will delay roll out of the more expensive options required for as long as is technically possible, given the assumed maximum deployment rate and overarching emissions constraint. This result is due to the discounting of future costs and because costs are then incurred for a shorter time period (the modelling ends in 2060).
- The results for each run of the model take no account of risk or uncertainty. The pathways modelled by UKTM are therefore only least-cost and achievable if all of the underpinning assumptions turn out to be correct over the whole period. It is unlikely in practice that all technologies would achieve the costs and performance assumed and that the availability and maximum build rate assumptions could all be achieved. This aspect also contributes to the model delaying the roll out of more expensive options, as it does not factor in the risk that some of these options may not be fully viable, and the impact this could have on achieving the UK's 2050 emissions target.
- The level of detail in UKTM varies across different sectors and, as with any model, is a simplified representation of the real world. Because it does not fully reflect the diversity in technology options and user choices it may understate the diversity of technologies that could contribute to achieving meeting targets at least cost. The coverage of technology options is broadly in line with those in the sector-specific models used to provide the affordability assessment in Section 3.3. UKTM does not include behavioural measures though, such as transport modal shifts or increased household recycling.
- Sectors where the majority of emissions are not related to energy use such as agriculture are modelled in less detail in UKTM than in the sector-specific models used for the affordability assessment in Section 3.3. Other sectors are *generally* more granular in UKTM in terms of the number of technology options but less detailed in terms of the factors that affect variation in costs. For instance, UKTM takes no account of variation in heat network costs due to geo-spatial factors, instead applying an average cost per unit of capacity. Competition for use of land, including diverting it from other uses such as agriculture, is also likely to be an issue in the higher biomass availability scenarios but these interactions are not taken into account within UKTM. It is important to note that UKTM does not price risk, or directly factor in uncertainty. Therefore each solution that UKTM finds is dependent on every assumption about each technology (e.g. cost, maximum build rate, maximum availability) coming true. UKTM effectively states the latest decision points to start mitigation actions, in a deterministic world under perfect foresight.

Sector representation and technology coverage

363. Each of the sectors has a variety of technical abatement opportunities at different costs. No behavioural measures are captured. Key model assumptions include efficiencies, availability dates, lifetimes, resource availability and cost, capital costs, operational and maintenance costs and the potential savings through installing measures. These are drawn from the best evidence available at the time of analysis. Details of some of the key assumptions and sector representations are below.

Table 27: Summary of key assumptions and sector representations in UK TIMES model

Assumption	Detail
Growth	There are 60-plus growth drivers which are exogenous to the model and based on a variety of factors including: • GDP growth consistent with assumptions listed above, with high and low variants of +/- 0.25%. • Population growth • Department for Communities and Local Government (DCLG) assumptions on numbers of households. • Household temperature demand variants. • Department for Transport (DfT) transport driver estimates.
Carbon Capture Storage (CCS)	CCS is assumed to become deployable at scale from 2035, and sensitivity analysis is undertaken around the subsequent availability of the technology.
Bioresource	Bioresource availability is based on model runs of the Bioenergy Feedstock Availability Model (Ricardo AEA, 2015). The assumed land area available for energy crops has been limited by excluding a wide range of sensitive sites on both landscape and biodiversity grounds. The reference case upper bound in 2050 for UK perennial energy crops (which unlike forestry are removable crops) is 158TWh. In the low scenario this is 31TWh. Of this, there is a 79TWh technical limit on woody domestic crops in 2050 (79TWh grass crops). 158TWh equates to about 2MHa, and this assumes that no more than 15% of grassland and 8% of arable land would be used for energy crops. These areas can often be found on farms as under-managed land neither economically or agriculturally productive due to field shapes and the size of modern machinery and other similar factors. The impact on food production, if well managed, need not be significant and is similar in size to the interannual variability in yield - around 10%. Annual change in land use is small compared to inter-annual variation in cropping areas. Bioresource prices reflect CCC Bioenergy Review (2011) assumptions.
Fossil fuel prices	Fossil fuel prices are sourced from Department of Energy and Climate Change (DECC) Fossil Fuel Price Projections 2015[115]. Fuel demand by sector is calibrated to DUKES (2012) 2010 statistics.
Electricity	Assumptions are aligned to the 2014 DECC Dynamic Dispatch Model (DDM) reference case. Updating to the 2015 costs would decrease the cost of wind and increase the cost of CCS but sensitivity testing has shown no significant impact on conclusions drawn from in the pathways section of this document.
Hydrogen	Hydrogen assumptions were developed by University College London. The costs are based on the assumption that a new network would need to be built to allow heating to be supplied by hydrogen. The option to re-purpose the gas grid is not available within the model.
Transport	Represented by nine vehicle groups (e.g. car, bus, lorry), each with a number of different types of vehicle choice (e.g. electric vehicle, hydrogen vehicle etc.). Cost and performance assumptions for key transport modes were aligned as far as possible with the latest evidence from DfT. Car and LGV assumptions were sourced from DfT analysis based on Element Energy's ECCo Cost and Performance Database. HGV assumptions were sourced from a report for the CCC (a review of the efficiency and cost assumptions for road transport vehicles to 2050).
International Aviation and Shipping (IAS)	IAS is not modelled explicitly in UKTM. In the UK TIMES analysis, the allowance made for IAS emissions in 2050 in the CCC's analysis has been used as a modelling assumption when determining the level of emissions reductions that are required from other sectors of the UK economy in order to achieve the 2050 target when IAS emissions are included.
Industry	Industry subsectors are either modelled as process orientated or energy demand orientated. Process orientated sector assumptions are primarily sourced from the Usable Energy Database (UED). Energy demand orientated sector assumptions sourced from ECUK (2012) and UK MARKAL

[115] https://www.gov.uk/government/publications/fossil-fuel-price-projections-2015 ("Fossil fuel price projections" workbook).

Non-domestic buildings	Represents all non-domestic and non-industrial buildings in the UK: split into high energy consumption and low energy consumption buildings.
Domestic buildings	Assumptions are aligned with those used in the National Household Model. Heat Assumptions have been developed from those used in the RHI 2016 Consultation[116]. Two dwelling types are available: existing and new. New dwellings can optionally be disaggregated into flats, houses, plus those with cavity walls and those with solid walls though have not been for this analysis.
Agriculture and land use	Represented by applying a fixed emissions profile with a series of mitigation options available. This profile combines components from land use, crops and livestock.

7.4 Overview of the GLOCAF model

364. Analysis of effort sharing of global emissions reductions has been conducted using DECC's Global Carbon Finance model – GLOCAF. The model allows the user to evaluate the impacts of different global emission reduction targets, burden sharing regimes as well as various specifications of the carbon market design. It covers the years 2020, 2025, 2030 and 2050.

Data underpinning GLOCAF

365. In order to calculate the impacts of a global deal, GLOCAF needs Business As Usual (BAU) emissions as well as Marginal Abatement Cost (MAC) curves for different regions and sectors. GLOCAF uses data from:

- The POLES energy model: this is a partial equilibrium energy model, which takes into account the costs of different technologies as well as the potential demand feedback effects within the energy system.[117]
- IIASA's G4M and GLOBIOM models for forestry emissions; these are partial equilibrium models of the forest sector; incorporating the opportunity costs of abatement from forestry.[118]
- The IMAGE model for non-CO_2 emissions; this is also a partial equilibrium model.[119]

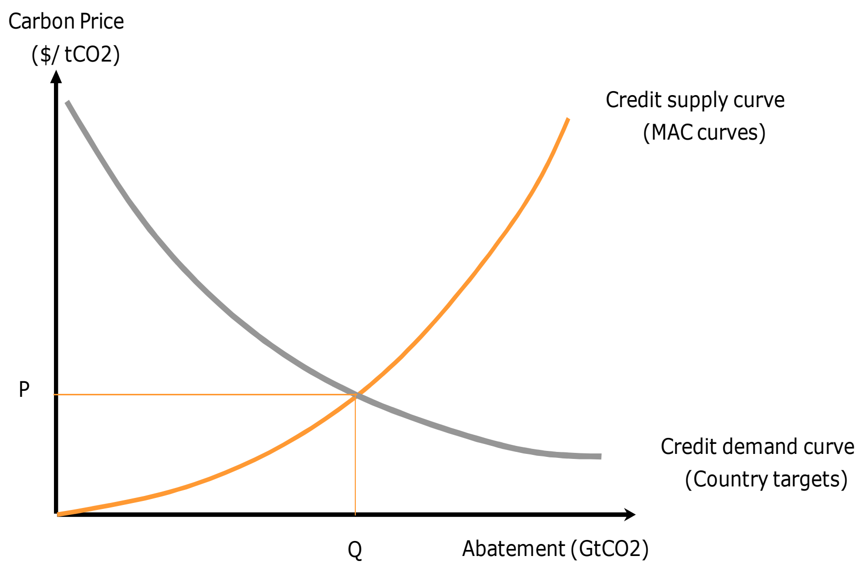
366. All datasets are at a sector level, and apply to a number of regions. GLOCAF models 24 world regions and 27 sectors although a different level of disaggregation is possible if the data supports it (the version used for this analysis model views the UK and the rest of the EU as separate regions).

How GLOCAF works

367. At the heart of GLOCAF is a model of the carbon market(s). It compares the supply of carbon abatement or International Carbon Units (driven largely by MAC curves) to the demand for mitigation, (determined by the difference between BAU and regional targets). The model finds the market clearing carbon price where the demand for carbon permits matches their supply for each market. This is done through an iterative process around the carbon price, shown by the chart below. These curves are constrained by trade restrictions around, for example, supplementarity (the requirement for a certain part of a target to be met domestically) and/or participation.

368. GLOCAF uses the market clearing carbon price to determine how much abatement each region and sector carries out and the associated incremental cost. Using the carbon price and associated trading of carbon permits GLOCAF also determines the resulting international financial flows.

[116] https://www.gov.uk/government/consultations/the-renewable-heat-incentive-a-reformed-and-refocused-scheme
[117] http://www.enerdata.net/enerdatauk/solutions/energy-models/poles-model.php
[118] http://www.iiasa.ac.at/web/home/research/modelsData/Models--Tools--Data.en.html
[119] http://themasites.pbl.nl/models/image/index.php/Welcome_to_IMAGE_3.0_Documentation



Limitations of GLOCAF modelling

369. There are a number of limitations of GLOCAF modelling:

- GLOCAF only models specific years (2020, 2025, 2030 and 2050), and as such GLOCAF results focus on 2030 rather than the whole fifth carbon budget period (and wider). This means that when dealing with carbon trading, GLOCAF is unable to model banking and borrowing of carbon offsets from year to year.
- GLOCAF marginal abatement cost curves only include direct costs of mitigation, and exclude wider macro-economic effects.
- Although GLOCAF models most major emitters individually, it aggregates many smaller emitters into regions, meaning that effort share calculations were done at regional rather than country level in many cases.
- GLOCAF assumes that countries will always choose least-cost mitigation options. This may not always happen in practice.

370. These limitations mean that GLOCAF results should always be considered to be illustrative rather than as forecast of real world outcomes.

Projections to 2020

371. GLOCAF data includes BAU projections which are calibrated to the WEO 2013 Current Policies Scenario and so do not necessarily take into account all the policies and measures countries have implemented or planned. The effort share analysis therefore uses a policy scenario to estimate emission in 2020, to ensure the analysis of post-2020 action uses an appropriate starting point.

International Bunkers

372. Emissions that come from international aviation and maritime, which cannot be allocated to a particular country, were given a target consistent with minimum cost approach (the economic efficient level of mitigation, based on the MACC analysis).

Effort share approaches

Table 28: Assumptions used in effort share approaches

Effort share approach	Assumptions
Carbon budget or carbon space based approach	All countries are allocated an emissions budget for 1990-2050, based on the share of the global population over the same period. Each country's remaining budget is calculated for the period 2021-2050 by subtracting their historical and projected emissions for the period 1990-2020 from their allocated budget. Each country is given a linear emission pathway for the period 2021-2050 which ensure the total emissions for the period 1990-2050 matches the global budget.
Historical emission index	The total mitigation needed is calculated as the difference between the global BAU emissions projection and the global target. Each country's share of historical emissions is calculated based on cumulative emissions from 1990 to 2020. Its share of total historical emissions from 1990 to 2020 is used to determine the quantity of mitigation (in Mt) each country needs to deliver. This is subtracted from their BAU projection to establish their 2030 target.
Contraction and Convergence	The 2050 convergence point is calculated by dividing the global emission target by projected population in 2050. Each country is given a 2050 target based on the convergence point multiplied by their projected population, and a linear emissions path from 2020 to their 2050 target.
Common but differentiated convergence	The 2050 convergence point is calculated by dividing the global emission target by projected population in 2050. Countries with emission per capita above the global average are allocated a linear trajectory to their 2050 targets (based on the target per capita emissions multiplied by their projected population). Countries with emissions per capita below the global average continue with their BAU emissions pathway, until they cross the threshold, at which point they also converge to the same per capita emission by 2050.
Cost proportional to GDP per capita	Under this approach all country targets are set so that all countries face the same cost as percentage of GDP. Mitigation costs per capita are proportional to GDP per capita, making this approach equivalent to a flat tax. An iterative process is used within the GLOCAF model to adjust each countries target up or down until its mitigation cost is within an acceptable tolerance of the global average and the required global emission target is met.
Income	This approach set targets on the basis of their cost as a percentage of GDP, but differentiates between high income and other countries, with the former facing costs twice those of the latter. The high income grouping is based on the World Bank income group classifications. An iterative function within the GLOCAF model is used to calculate the targets.
Minimum global cost	This approach allocates targets in a way that would minimise global mitigation costs in the absence of the global carbon market. The GLOCAF model is used to calculate the amount of abatement each country would deliver for a given carbon price. The model gradually raises the carbon price until enough abatement has been done to meet the global target. The end result is that the marginal cost of mitigation[120] is the same across all countries. With a full efficient and comprehensive global carbon market, all other approaches result in abatement happening in the same place as this approach, but countries with higher mitigation cost would purchase credits to meet their targets from others that have cheaper abatement available.

7.5 Marginal Abatement Cost Curve (MACC) analysis details

7.5.1 Evidence base

Table 29: Evidence base for the MACC analysis

Sector	Description of evidence base used for MACC analysis
Transport	The transport analysis has been developed using the Department of Transport's National Transport Model (NTM)[121] for road measures and the Rail Emissions Model for rail measures. The NTM forecasts emissions and traffic taking account of the impacts of transport measures on vehicle fuel efficiency and fuel mix. Assessments of maximum technical abatement potential

[120] The extra cost of reducing GHG emissions by 1t CO_2e.
[121] https://www.gov.uk/government/collections/transport-appraisal-and-modelling-tools

	are based on externally commissioned, published studies on the technical limits of currently available technologies and those under development. The penetration of ultra-low emission vehicles (ULEVs), for example, is in part based on a 2013 study by Ricardo AEA for the RAC foundation and UKPIA[122]. The ECCo model is used to develop uptake scenarios for ULEVs. The impacts of sustainable travel measures have been based on evidence from the evaluation of the Sustainable Travel Towns[123]. Scaling: the NTM covers all of Great Britain; an uplift of 3.6% has been applied by DfT to include Northern Ireland in the scope of the MACC data. This was done in agreement with the Northern Ireland Executive and is the approach usually taken by DfT when modelling impacts for the whole UK.
Domestic buildings	The analysis of domestic buildings is separated into retrofit and new build. For retrofit of domestic buildings four key areas were analysed: energy efficiency measures, heating measures, heat networks and behaviour change. The heat networks analysis is illustrative pathway that assumes all dense areas have a district heat network by 2050. The domestic building retrofit MACC evidence is based on illustrative pathways reaching zero non traded sector emissions in 2050. Two polarised pathways (full electrification and replacement of the natural gas grid with green gas) were analysed. The cost-effective pathway is likely to be a combination of these extremes. The ability to have deployed energy efficiency measures is assumed to reach 100% before the period of the fifth carbon budget. Buildings are then increasingly connected to a low carbon heat source (heat pump, district heating or green gas). Under the assessment of maximum technical potential the sector reaches zero non-traded sector emissions by 2050. The scenarios and deployment rates were then modelled through the DECC National Household Model. The new homes analysis assumes that from 2020 new homes achieve an 'energy performance' standard, excluding onsite renewables, that delivers 19% less emissions than the current requirements in the English Building Regulations Part L 2013[124]. Typical measures are likely to include energy efficient fabric (e.g. external wall U values of 0.15 or better, improved airtightness and construction joints to avoid thermal bridging), mechanical extract ventilation (MEV) or mechanical ventilation systems with heat recovery (MVHR), good double glazing with thermally efficient glass or triple glazing, efficient heating systems and controls and waste water heat recovery. The same build rate assumption as used in recent analysis for the housing standards review has been applied. Emissions reductions through low carbon heat supply are based on the evidence underpinning the analysis of the existing building stock.
Non-domestic buildings	The analysis of non-domestic buildings is separated into retrofit and new build. For retrofit modelling pathways for decarbonising the non-domestic sector were modelled, including: i) earliest possible decarbonisation, reflecting maximum technical potential; ii) plausible pathway reflecting a central scenario; and iii) the most emissions can be delayed while still decarbonising by 2050 reflecting a low scenario. The Digest of UK Energy Statistics (DUKES) and the Energy and Emissions Projections (EEP) were used alongside Energy Consumption in the UK (ECUK) and data from Sheffield Hallam University to reflect the heat demand and emissions in the sector through time. Technology level data came from expert input, the Renewable Heat Incentive and early findings from the Building Energy Efficiency Survey. For heat in non-domestic new build a single pathway reflecting technical potential was included, assuming a low carbon technology (heat pump) in all new builds by 2026 in the absence of further evidence. Heating technology assumptions were used from the retrofit analysis.
Energy-using products	The energy-using products analysis is derived from the DECC Products Policy model. The Products Policy model estimates the impacts of all agreed EU energy-using products standards. There are a number of different EU energy-using product standards. Therefore, the Products Policy model draws on a variety of sources, including information from manufactures on cost and sales data purchased from market research companies. The energy-using products analysis extrapolates the impacts of agreed energy-using product

[122]Powering Ahead: the future of low carbon car's and fuels, April 2013, Ricardo AEA for RAC foundation and UKPIA, http://www.racfoundation.org/assets/rac_foundation/content/downloadables/powering_ahead-kay_et_al-apr2013-embargoed_copy.pdf

[123] https://www.gov.uk/government/publications/the-effects-of-smarter-choice-programmes-in-the-sustainable-travel-towns-full-report

[124] https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l#history

	standards (as estimated in the Products Policy model) order to estimate potential impacts from possible future energy-using product standards. Analysis has also been carried out to estimate the potential impact of behavioural change. The report "How much energy could be saved by making small changes to everyday household behaviours?"[125] has been used to estimate a percentage change in consumption through behaviour change related to energy-using products. That percentage change has then been applied to the Energy and Emissions Projections in order to estimate the change in consumption. A similar approach has been taken for behaviour change in the non-domestic sector. Evidence from the Building Energy Efficiency Survey has been used to estimate a percentage change which was then applied to the energy and emissions projections.
Industry	MACC evidence has been prepared using DECC's Industry Pathways Models, which is split into eight industry sectors and broadly use the same technology assumptions as UK TIMES. A number of sectors have been modelled in a process-oriented manner, where actual production steps are modelled. These are iron and steel, paper, cement and some chemicals, with the main original evidence source being the Usable Energy Database[126]. The remaining sectors are split into the different energy service demand categories (high temperature heat, low temperature heat, drying, motor drive, refrigeration and other) and generic technologies that produce these types of energy are modelled. Assumptions for the sectors modelled in this way (other chemicals, non-metallic minerals, non-ferrous metals, food and drink and 'other' industry) can largely be traced back to UK MARKAL (the UK TIMES predecessor). A capital cost uplift of 10% has been applied to reflect potential hidden costs in the sector. In calculating abatement potential across the fifth carbon budget period, the technology deployment assumptions across sectors are, as far as possible, consistent with the maximum technical potential scenario that was used in the 2050 Industrial Roadmaps project[127]. Where this has not been possible, UK TIMES constraints have been used (e.g. technologies that can be rolled-out only from 2025, have been). For the fifth carbon budget period, the key measures causing cost-effective abatement in the non-traded sector are energy efficiency measures in non-energy-intensive industries.
Waste	Waste MACC evidence has been provided by the Department for Environment, Food and Rural Affairs (Defra), whose evidence base and remit extends to England only. In order to cover the UK as a whole, the England only data has been scaled based on the Greenhouse Gas Emissions Inventory for England, Scotland, Wales and Northern Ireland (1990-2013)[128]. Waste management scenarios have been informed by a variety of sources. Landfill diversion was based on Defra's Wasteman model which is itself informed by multiple sources, and Landfill Gas Mitigation assumptions were elicited from the Environment Agency and industry leads from the landfill industry. Projections of waste arisings are a key input to the model.
Soils	Defra has also provided MACC evidence on soils, limited in geographical scope to England only. In order to cover the UK as a whole the England-only data has been scaled based on estimates of total UK peat land area[129].

[125] Cambridge Architectural Research (2012) https://www.gov.uk/government/publications/how-much-energy-could-be-saved-by-making-small-changes-to-everyday-household-behaviours
[126] http://data.ukedc.rl.ac.uk/cgi-bin/dataset_catalogue/view.cgi.py?id=15
[127] https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050
[128] http://naei.defra.gov.uk/reports/reports?report_id=810
[129] Evans, C., Thomson, A., Moxley, J., Buys, G., Artz, R., Smyth, M. A., Taylor, T., Archer, N. and Rawlins, B. (2014) Initial assessment of greenhouse gas emissions and removals associated with managed peatlands in the UK, and the consequences of adopting Wetland Drainage and Rewetting as a reporting activity in the UK Greenhouse Gas Inventory. Report to the Department of Energy and Climate Change (Unpublished); ASC (2013): Managing the land in a changing climate. Adaptation Sub-Committee Progress Report 2013; Graves, A. and Morris, J. (2013): For the Adaptation Sub-Committee. Restoration of Fenland Peatland under Climate Change. Cranfield University, Bedford, UK; Smyth, M.A., Taylor, E.S., Birnie, R.V., Artz, R.R.E., Dickie, I., Evans, C., Gray, A., Moxey, A., Prior, S., Littlewood, N. and Bonaventura, M. (2015) Developing Peatland Carbon Metrics and Financial Modelling to Inform the Pilot Phase UK Peatland Code. Report to Defra for Project NR0165, Crichton Carbon Centre, Dumfries.; Defra (2008): SP0556: A Compendium of UK Peat Restoration and Management Projects. Report to Defra; and Natural England (2015): Countryside Stewardship: Options and Supplements. NE606.

Agriculture	Evidence has been scaled from England to cover all of the UK Greenhouse Gas Emissions Inventory for England, Scotland, Wales and Northern Ireland (1990-2013)[130]. The scaling factor is based on a five-year average of the national contributions to overall agricultural emissions from the national inventory report (the 2014 common reporting format tables). From that data the average English contribution to agricultural GHGs is 63% and estimates are scaled up on this basis.
Forestry	Estimates and analysis has been provided by the Forestry Commission. Abatement potential is based on analysis of historical data and the possible mix of tree varieties available, include forestry for biomass production. Evidence has been scaled from England to cover all of the UK based on afforestation planting rates from the Forestry Commission. Current and historic planting rates were taken from Forestry Statistics (2015: http://www.forestry.gov.uk/forestry/infd-7aqdgc). Future MTP planting scenarios were based on the difference between the Low and High emissions scenario of the UK GHG Inventory projections (see: http://uk-air.defra.gov.uk/assets/documents/reports/cat07/1406021226_DA_LULUCF_2012i_pub_version_1.1_300514.pdf but updated in line with the unpublished 2013 inventory projections report). Carbon abatement (and biomass production) for different forest types has been based on the models presented in Broadmeadow and Matthews (2009) http://www.tsoshop.co.uk/gempdf/Climate_Change_Main_Report.pdf. Land availability for biomass production was based on Rushton et al., (2014: http://sciencesearch.defra.gov.uk/Document.aspx?Document=12146_ReviewandSynthesisofBioenergyandBiofuelsResearchFinalReportFINAL13_06_2014.pdf). Non-markets benefits were derived from EFTEC (2010: http://www.forestry.gov.uk/pdf/eng-pfe-econmicresearch-final.pdf/$FILE/eng-pfe-econmicresearch-final.pdf) scaled to 2015 prices.

7.5.2 Emissions abatement opportunities

Table 30: MACC abatement opportunities by sector with barriers

Measure and maximum technical potential (non-traded, 2028-2032 $MtCO_2e$)[131]		**Description**	**Main barriers to overcome**
Transport			
Car fuel efficiency	46	Technological improvements to reduce emissions from internal combustion engines and increase sales of electric vehicles and plug in hybrids.	Would require greater roll-out of recharging infrastructure, changes in public acceptance, and a degree of international agreement on stringent vehicle emissions regulations for 2030. Distance for which EVs can travel without recharging is a barrier.
HGV fuel efficiency	13	Combination of increased take up of gas and electric HGVs plus significant take up of fuel efficiency technology for conventional HGVs.	Likely to require financial support to overcome additional cost of technology plus changes in infrastructure (both rapid charging for electric vehicles and gas infrastructure). Greater certainty around fuel savings required to overcome operator mistrust.
Van fuel efficiency	17	Technological improvements to reduce emissions from vans with internal combustion engines and an increase in the sales of electric vans and plug in hybrids.	Would require greater roll-out of recharging infrastructure, changes in public acceptance, and a degree of international agreement on emissions regulations.
Sustainable travel	22	Reduced car trips by 25% through	Requires significant changes to

[130] http://naei.defra.gov.uk/reports/reports?report_id=810
[131] MTP abatement numbers may not sum to values used elsewhere in this document due to rounding

		increased provision of public transportation, more cycling & walking etc.	infrastructure to accommodate sustainable modes of travel as well as the associated finance e.g. increased cycle lanes and public transport. Behaviour change to reduce car use also a major barrier.
ULEV buses	3	Increased electrification of bus and coach travel.	The key factor will be how far the unit cost of electric buses can be reduced, and technological improvements on the reliability of these buses.
Rail electrification	3	Electrification of train lines and improvements to the efficiency of diesel trains.	Barriers include public acceptance of disruption to services during implementation, financing the upfront costs and changes to a limited supply chain.
Modal shift road to rail (passengers)	2	Increased peak hour capacity of trains for passengers to allow a modal shift.	Financing significant expenditure on infrastructure and technologies to deliver higher rail capacity. Public acceptance of new technologies and automation which may have safety concerns.
Modal shift road to rail (freight)	3	Increased use of rail for freight transportation.	Financing upfront costs for both infrastructure improvements and changes in operation for businesses.
		Buildings	
Heating Controls and behaviour change (domestic and non-domestic)	26	Provision of heating control systems that allow the ambient temperature inside buildings to be controlled effectively.	Evidence on the impact of improved controls on energy consumption is limited and very uncertain. Behavioural change required may be significant and difficult to implement.
Flue Gas Heat Recovery Systems for new domestic gas boilers	8	At the point of boiler replacement, a FGHR system integrated into their heating system to improve boiler efficiency.	Uncertainty with regard to costs and energy efficiency performance and whether savings payback upfront costs.
Retrofitting thermal efficiency measures (such as solid-wall and cavity-wall insulation, glazing, drought proofing) in domestic and non-domestic buildings	49	Existing domestic and non-domestic buildings are retrofitted with appropriate thermal efficiency measures according to building type.	Often requires considerable up-front costs with long term payback period. Misaligned incentives where owner pays but tenants benefit. Regulatory barriers around planning permission. Behaviour change – there is some evidence of inertia and myopic decision making where households place a higher value on up-front costs compared to future benefits.
Retrofitting low carbon heat sources (different types of heat pumps, biomass boilers) in domestic and non-domestic buildings	95	Existing domestic and non-domestic buildings are fitted with low-carbon heat sources. Note, this often requires as a prerequisite improvements to the thermal efficiency of buildings which is captured above.	Often requires considerable up-front costs with long term payback period. Requires change in public acceptance. The perceived lack of responsiveness in heat pumps and the change in heating behaviour required can lower demand.
District heating (domestic and nondomestic)	13	Increased implementation of district heating in domestic and non-domestic buildings.	Significant upfront costs with long payback period and access to capital are issues for some sectors. In domestic buildings coordination with wider community/ housing estate may be required.
Energy efficiency measures and heat pumps in new build	10	Increased implementation of heat pumps in new build (domestic and non-domestic), additional energy efficiency measures in non-domestic buildings (beyond baseline).	Regulatory challenges around reversing legislation on zero carbon homes.
Improved efficiency of ventilation in non-domestic buildings	14	Ventilation in non-domestic buildings is more energy efficient.	Would face financial barriers among firms and public organisations with limited access to capital. May face regulatory burden, requiring changes to current EU legislation

			on minimum standards.
Industry			
Improvements to industrial processes	12	Improvements to process heating and cooling and energy efficiency of specific production processes in all major UK industrial sectors (chemicals, food & drink, iron & steel, non-ferrous metals, non-metallic minerals, paper, cement).	Would require overcoming infrastructure and markets barriers including: 1) the long plant life for equipment results in infrequent capital investment; 2) Potential competitive disadvantage arising from the disruption to production from large scale changes to machinery; 3) Competition from international firms using cheaper substituting materials with higher emissions.
LULUCF			
Various peatland conservation measures	11	Measures include removal of livestock grazing, land management, moorland ditches as well as land-use change, rewetting and stopping peat extraction.	Misaligned incentives where farmers potentially loose long-term profits from land used for agriculture or livestock.
Afforestation	19	Afforestation would comprise a mixture of native and exotic species, meet the requirements of the UK Forestry Standard, and include a significant proportion of productive woodland. Woodland expansion acts as a carbon sink by absorbing greenhouse gases and provides other ecosystem services. Also includes afforestation for the purpose of providing woody feedstock for bioenergy.	Some woodland expansion covers farmland. Persuading farmers to afforest their land is one of the main challenges. Although upfront grants are available, it can reduce the long-term profitability of land. There are also a range of other cultural, environmental and regulatory barriers to take-up. Uncertainty in future demand for biofuels is a disincentive for land use change.
Agriculture			
Livestock Health - Low Cost	20	Cost-effective measures aimed at addressing endemic diseases of livestock that have large economic impacts.	Generally faces low to moderate levels of barriers for most segments of farmers, although changes in practices and upfront costs are barriers for smaller, struggling farmers.
Countryside Stewardship Schemes	8	Schemes which provide farmers with funding for crop and grassland environmental management.	Generally faces low barriers as existing schemes are in place. It would require a shift towards carbon reduction objectives rather than other ecosystem services.
Livestock Diets and Supplements - Low Cost	7	Improvements to livestock diets to reduce emissions from digestive gases.	Some segments of farmers resistant to change and lack access to capital for increased costs.
Reduced consumption of meat	19	Reduce Consumption of Carbon Intensive meat products.	There are very large economic and scientific uncertainties on the effectiveness of a consumption based intervention, e.g. on the potential for import/export of emissions and co-impacts on water use, fertilisers, biodiversity, etc. Behaviour change barriers as consumers unlikely to change diets for environmental reasons.
GM to Improve Crop Nitrogen Efficiency	6	Breeding and Genetic Modification for crops with enhanced Nitrogen Use Efficiency.	Costs of establishing viable UK GM lines and achieving FSA approval. Concerns over market for crop (unpopular with consumers). Requires change in public acceptability among farmers and consumers.

Measures to optimize fertilizer use	14	Includes making use of compost as a substitute for carbon-intensive fertiliser, precision farming techniques that better match fertiliser to crop requirements, growing of livestock forage crops that require less fertiliser input, soil testing, introduction of novel crops, use of nitrification inhibitors, use of band spreaders/injectors.	Behavioural barriers among some farmers who are resistant to changes in farming practices. Access to finance may be a barrier for measures requiring new technology, such as spreaders.
Measures to further reduce GHG emissions from livestock	5	Includes increased housing period for livestock, measures aimed at controlling less economically damaging endemic diseases of livestock that have productivity impacts and measures to breed more efficient livestock.	Measures that require additional livestock housing infrastructure may face financial barriers. Plus some public acceptance issues around indoor rearing of livestock having poor animal welfare reputation.
Measures to improve energy and fuel efficiency	5	Includes making use of low cost energy saving technologies, particularly with respect to heat generation and making use of energy saving technologies on farm such as more efficient engines for motive power.	Some segments of farmers already adopt these practices or would be willing to. However they may be less of a priority for financially challenged enterprises.
Waste & F-gases			
Measures to increase rate of recycling to 85%	63	Reducing the amount of waste sent to landfill through reuse and recycling of materials. Also includes food waste prevention.	Financial barriers for Local Authorities to change the waste collection and management infrastructure. Uncertainty over whether extent of behaviour change to increase recycling is achievable.
Reduce emissions from closed/historic landfill sites	7	Through the installation of Bio-covers, bio-windows and bio-filters on closed/historic Waste landfill sites without infrastructure.	Misaligned incentives and financial barriers as there would be no benefit to the Waste site operator. Ability to record emissions savings in the GHG inventory.
Other measures to reduce emissions from operational landfill sites	8	Includes installation of smaller landfill gas engines at sites with and without existing infrastructure, technical reviews on landfill sites to improve performance and encourage best practice, post combustion oxidation (additional processing of exhaust gases from engines to reduce the fraction of unburned methane emitted to atmosphere).	Main barriers include financing costs of new technology. Most measures have relatively low barriers if regulations are changed.
Reduction of F-gas emissions from asthma inhalers	2	Switching from gas to powder-based asthma inhalers to reduce F-gas emissions from these.	Requires significant research and development to deploy new powder-based inhaler technology to replace asthma inhalers. Clinical suitability for some applications will need to be assessed before introduction. Power-based inhalers likely to have higher costs.

7.6 Carbon prices and values

373. Carbon values are used within this Impact Assessment in three ways:

7.6.1 Valuing changes in greenhouse gas emissions

374. The value of increases and reductions in GHG emissions is included in the appraisal of the costs and benefits of different budget options. These are calculated using the Government's

GHG appraisal values,[132] and are distinct from estimates of market carbon prices. These are based on the methodology established in the 2009 Review of Carbon Valuation in Policy Appraisal.[133]

375. From 2030 onwards, these values are estimated to be consistent with the price of emissions permits under a functioning global carbon market on a global emissions pathway to reaching a 2° Celsius-consistent outcome, although the existence of such a market is not essential. 2020 values for the non-traded (non-EU ETS) sector are based on the estimated marginal cost of complying with the third carbon budget and meeting current EU 2020 emissions targets, with interpolation of values between these 2020 to 2030 points. Traded sector values up to 2020 are based on estimated prices of EUAs, with convergence thereafter to the 2030 value for all emissions. Further detail is set out in the 2009 Revised Approach.

376. The Government is currently undertaking a review of the approach to carbon valuation, which it plans to publish in conjunction with the forthcoming emissions reduction plan. Sensitivity of the analysis to the assumed carbon values within this Impact Assessment has been tested in section 4.1 above using the high/low published range of carbon values. There is some impact on the amount of abatement potential deemed to be cost-effective against the carbon values. However, this is relatively limited meaning the assessment of cost-effective abatement action is relatively robust to this assumption.

7.6.2 Valuing purchases of international carbon units (ICUs)

377. Currently there are two carbon crediting mechanisms regulated under the Kyoto Protocol (KP), which generate credits which can be used to meet international targets under the KP. However, the KP mechanisms are likely to end in 2020, or cease to issue credits to new projects. The Paris Agreement has provided for the development of both a new international crediting mechanism and guidance to enable countries to trade emissions reductions. However, there remains considerable uncertainty over the future size and shape of the carbon market, in terms of the countries using credits to meet their targets, the types of credit which will be permissible and how emissions reductions will be accounted for.

378. The price of CDM units (Certified Emission Reductions, or CERs) peaked at almost $30/t in 2008, was largely stable within a $5-$10/t range in the period 2009-2011, and then fell to around $0.4/t, where it has remained since late 2012. These variations were driven by the fall in demand from the EU due to the recession, oversupply, and changes in EU policy on the use of credit in the ETS (which reduced demand for credits). Although it is not known exactly how the credit market will develop, it is likely that the ending of the KP mechanisms and/or restrictions on the use of KP units after 2020 would reduce the current oversupply and result in an increase in credit prices.

379. Credit prices during the fifth carbon budget period are highly uncertain – they will depend on the level of action taken by other countries to reduce their emissions, the state of the global carbon market and the type of credits purchased. The GLOCAF model has been used to produce scenarios reflecting different levels of global ambition and participation in carbon markets, which provide the basis of the carbon price assumption used in section 4.1. More details on the GLOCAF model can be found in annex 7.4. The GLOCAF result have been adjusted to capture the fact that in an efficient credit market, expectations of future prices would lead market participants to purchase credits earlier, leading to a smoothing of prices over time[134].

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[132] Available in Table 3 of the Data Tables 1-20, supporting the published Green Book supplementary guidance on the Valuation of Energy Use and Greenhouse Gas emissions for appraisal: https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[133] DECC (2009), *Carbon valuation in UK Policy Appraisal: A Revised Approach*. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/245334/1_20090715105804_e____carbonvaluationinukpolicyappraisal.pdf

Most recent DECC carbon values - https://www.gov.uk/government/collections/carbon-valuation--2

[134] We approximate this by applying a cost of carry to average prices over the period, of 3.8% per year; the estimated rate of return we assume market actors would need to receive to make them

380. The sensitivity analysis in section 4.1 uses a 2030 credit price range of £15 to £65, with a central assumption of £40/t. The top end of the range (£65/t) is based on a scenario in which countries increase the ambition of current target to a level consistent with the 2° Celsius goal. The low end of the range (£15/t) reflects a scenario in which countries deliver the emissions implied by existing 2030 targets.

7.6.3 Modelling behaviour in response to market carbon prices

381. Where appropriate, estimates of opportunities for emissions reductions can depend on the market price of carbon, as this can determine the relative cost-effectiveness of different abatement technologies, and the relative attractiveness of these options to private consumers. Where applicable, modelling at the sector level incorporates an estimate of the market price of carbon faced by private individuals, businesses, and other organisations, through participation in the EU ETS. The prices used are the published 2015 updated short-term values for modelling purposes[135]. Power sector modelling undertaken for this Impact Assessment assumes generators participating in the EU ETS will be subject to any top-up payments through the Carbon Price Support, set in line with the intended trajectory of the Carbon Price Floor.

7.7 Further detail on analysis of EU ETS and ESD

7.7.1 Estimating the UK's potential share of the ETS cap during the fifth carbon budget

382. The EU ETS cap is EU-wide and binding for all EU member states, plus Norway, Iceland and Liechtenstein. There are two major routes for European allowances under the EU ETS cap to enter the market: they are either auctioned by the participating states or are distributed free to EU ETS participants. When allowances are auctioned by a member state, any market participant can buy them, including those from other member states. When allowances are allocated for free, they are allocated to only those market participants who operated in the previous compliance year and reflect their carbon leakage status as well as any capacity changes that may have occurred during that year. A new entrant can claim free allowances from the ETS-wide New Entrants Reserve (NER).

383. While there are no formal shares of the ETS-wide cap that are assigned to individual states, it is possible to construct a notional UK traded cap for carbon budget accounting purposes. This notional cap is built up of the allocations to the UK of each of the components of the overall ETS cap. The European Commission has published a proposal on the phase IV of the EU ETS covering the period 2021-2030 that included:

- Tightening the ETS-wide traded stationary cap via an increase of the linear reduction factor from 1.74% to 2.2%;
- Splitting the total EU ETS cap into auctions and free allocation in proportion 57% and 43% respectively; and
- A different slicing of the EU ETS cap into its constituent parts over 2021-2030: no fixed provision for the NER in Phase IV (new entrants who are eligible to receive free allocation would be funded by the unused Phase III, 2013-2020, allowances instead) and some allowances are allocated to the "modernisation" and "innovation" funds. Allowances allocated to the innovation fund and modernisation fund form part of the 43% free allocation and 57% auctioned shares of the total cap respectively.

384. On this basis, the CCC estimated a UK share of the ETS cap of around 590MtCO_2e. There is substantial uncertainty over what the actual share will be and will remain uncertain until well after the fifth carbon budget is set. DECC has undertaken analysis of the notional UK traded cap during the fifth carbon budget, which takes account of the changes in the 2030 GHG target and slicing of the total cap into its components: auctions, free allocation and innovation fund. The UK

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indifferent between buying/selling in different years. This has the effect of lowering prices in 2030 and increasing them in 2020.

135 DECC (November 2015), "Updated short-term values used for modelling purposes" https://www.gov.uk/government/collections/carbon-valuation--2

is not eligible to receive allowances from the modernisation fund. A separate component for domestic aviation is also included. The CCC's estimate is viewed to be well within the overall range of possible shares during the period (estimated to be between 490MtCO_2e and 660MtCO_2e, although in practice could be wider. Further details on the EU ETS are available online.[136]

385. Estimates of the UK notional traded cap over the fifth carbon budget are subject to the following assumptions and uncertainties:

- Any impacts on UK auction volumes as a result of the Market Stability Reserve (MSR) have not been taken into account. The MSR is a rule-based mechanism that is triggered by the level of the cumulative surplus of allowances in the EU ETS and is likely to limit future auction volumes over the fifth carbon budget period. However, its impact is difficult to estimate accurately.
- The EU ETS policy design features that were included in the European Commission's proposal, in particular the 57%/43% split on the total stationary cap in 2021-2030, are assumed to hold over the fifth carbon budget period. The EU ETS Directive for Phase IV is currently being negotiated by the EU Member States and its final text may change.
- The UK share of ETS-wide free allocation is uncertain and is assumed to remain broadly at the level of free allocation in 2013-2020. This will depend on the number installations eligible to receive free allocation in 2021-2030 and their distribution across participating Member States. The CCC has applied a "Phase IV adjustment" within its estimate reflecting the difference between the 2013 and 2015 free allocation – it is uncertain the extent to which this will have an impact in the fifth carbon budget period.
- The UK's share of the innovation fund is assumed to be the same as its share of total free allocation. This share is uncertain as will depend on the number of successful applicants to receive funding from the innovation fund.
- It has been assumed that the EU ETS cap is extrapolated linearly post-2030 and the EU ETS rules for phase IV remain beyond 2030.

7.7.2 Assumptions on the EU's "Effort Share Decision" (ESD) during the fifth carbon budget

386. . The Government estimates that under current commitments the UK's ESD could be equivalent to a non-traded sector budget of 1,350 to 1,240 MtCO_2e in carbon budget accounting terms. In addition to uncertainties about the outcome of the ESD negotiations, the estimates presented in this impact assessment make assumptions around the following to present EU targets and commitments in carbon budget accounting terms:

- **Timing** – The EU 2030 framework defines EU action to 2030 but not beyond it. As the fifth Carbon Budget period includes 2031 and 2032, to make a comparison between Carbon Budgets and EU 2030 requirements an assumption must be made as to EU action beyond 2030.
- **Geographical scope** - Gibraltar's projected 2021-30 NTS emissions are subtracted from the headroom estimates, as the UK's ESD target under current commitments will cover Gibraltar's emissions while Carbon Budgets only apply to emissions from the UK.
- **Historical Emissions** - The latest inventory currently available (2014) for 2005 emissions – the baseline for 2030 ESD targets - has been used to produce these estimates. The latest available inventory is likely to be used when targets are set. On the basis of the precedent of the 2020 ESD this could be 2018 inventory.
- **Treatment of LULUCF** – Emissions from soils and forestry, also known as Land Use and Land Use Change (LULUCF), are counted towards the UK's carbon budgets but are not currently counted towards current EU targets for 2020. Whether and how LULUCF might be included in the ESD for 2030 is yet to be determined.

[136] EU ETS: http://ec.europa.eu/clima/policies/ets/index_en.htm

7.8 Barriers to delivering emissions reductions

387. When assessing the barriers to take-up the following barrier category definitions, ratings scales, and evidence quality ratings listed in the tables below were used.

Barrier category definitions
Financial: Unable to access sufficient finance Assessment of businesses' or households' ability to finance a measure or behaviour change. The barrier does not assess their willingness to pay for the measure or whether the cost of the item is perceived to be too high. Resistance to the measure itself is captured in public acceptance.
Regulatory: Regulation needs to be created or changed Whether there is regulation which would make it more difficult for a measure to be taken up on an individual level, or prevent it altogether. Also covered is whether the existing regulation is preventing development in this area on a wider level.
Infrastructure & markets: Supply chain unable to deliver the measure and/or associated infrastructure (or at necessary scale).
Misaligned incentives: Where costs and benefits are not attributable to the same person.
Public Acceptance: The levels of opposition currently, or likely to be- due to factors like the unfamiliarity of technologies or practices and other perceptions of desirability.
Informational: Levels of knowledge about a technology or behaviour measure are there, and whether a lack of knowledge is a risk to take up.
Uncertainty: Confidence in the measure's ability to deliver the expected benefits, not only with regards carbon savings but also reliability, performance, initial cost, running costs, etc.
Behavioural: The extent to which the measure requires people to change their behaviour and the level of disruption to their normal routine that will be caused by replacing their existing technology with a low-carbon technology or changing their behaviour.
Overall feasibility: Taking all the barrier ratings into consideration, what is the overall strength of non-cost barriers to realising delivery?

Barriers evidence quality

388. The quality of the underlying evidence (used for the barrier ratings) was also scored using the A to D guide below:
A: Robust evidence source - rating is based on a nationally representative evidence source, which uses a well-established methodology e.g. Government commissioned quantitative survey.
B: Reliable evidence source - rating is based on a source which uses a standard methodology, but there are some analytical limitations or concerns about quality.
C: Insightful Analytical Source - evidence source is small scale, not representative or not entirely reliable e.g. focus groups.
D: Indicative source or expert opinion - no reliable evidence is available, so rating is based on the opinion of experts in this area.

389. The strength of evidence used in assessing the barriers to take-up varied. With respect to potential abatement, the ratings of the barriers for around 15 per cent of technical potential was taken from nationally representative quantitative studies (either Government-commissioned or from other reliable source). A further 28 per cent came from insightful, but not fully robust or reliable sources. The remaining 44 per cent of barrier ratings were based largely on the expert opinion. Measures where take-up was deemed more difficult tended to be based on expert opinion; this is most likely because the less feasible technologies are newer, so associated evidence is not as well developed as existing measures.

7.9 Power sector analysis

390. As explained in Section 4.1, Scenarios B-D have been modelled using DECC's Dynamic Dispatch Model (DDM), covering Great Britain. In the counterfactual for the power sector

analysis, electricity demand is equal to the "reference" scenario in DECC's 2015 Energy and Emissions Projections.[137] The evolution of the supply side (the "generation mix") to 2032 and beyond is subject to much uncertainty and depends on a range of factors, including fossil fuel prices, technology costs and UK and EU energy policy (including support mechanisms and carbon prices).

391. The DDM used for the analysis in the Impact Assessment has been updated since the publication of DECC Emissions Projections last year. Assumptions regarding the fuel prices and generation costs were also updated and assumptions about Government support are consistent with the strategy laid out by the Secretary of State for Energy and Climate Change in her speech on 18th November 2015 and decisions made in the Spending Review in November 2015[138].

392. For the purposes of this analysis the following assumptions were made:

- Central fossil fuel prices in line with recently published power sector analysis;
- DECC Central short-term carbon values for modelling purposes;[139]
- No unabated coal plants are in operation after 2025;
- Deployment of low-carbon capacity consistent with expected commitments under the Contract for Difference (CfD) mechanism, the Renewables Obligation (RO) and the Feed-in-Tariff (FiT) scheme to 2020;
- Continued support for low-carbon capacity through the 2020s including the CFD spend announced for 2021-2025; and
- The residual demand after taking into account demand met by supported plant is met by existing plant (accounting for retirements), and new build driven by market revenues, the capacity market , and additions of interconnection capacity, assumed to grow from a current level of 4GW to 15GW in the mid-2020s.

7.10 Fuel poverty analysis

393. The actual impact on fuel poverty will depend to a large extent on the policy choices. The impact of meeting carbon budgets on fuel poverty targets presented in section 4.3.5 has been modelled following the established fuel poverty methodology[140]. This provides an illustration of the impact of carbon emission reductions in the domestic buildings sector on fuel poverty. It considers illustrative impacts of:

- Installing the full range of identified potential for insulation measures from 2020 to 2032;
- Installing low carbon heating measures from 2020 to 2032 taking into account supply chain constraints using a quasi-random allocation where off-gas grid households have priority (reflecting the most cost effective approach to delivery these measures); and
- The impact of potential changes in electricity prices through changes in the amount of total electricity demand as a result of meeting the fifth carbon budget. The impact of the fifth carbon budget on gas prices was not considered as it would depend on the policy design which is unknown at this stage.

394. This analysis is based on the following inputs, methodologies and assumptions:

- Buildings data for the housing stock and household characteristics (including income) from the 2013 English Housing Survey;
- Income is considered after housing costs have been excluded. It is also adjusted by family composition to take into account purchasing power. It is assumed that family composition does not change over time. Income and housing costs are projected following the IFS

[137] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2015
[138] https://www.gov.uk/government/speeches/amber-rudds-speech-on-a-new-direction-for-uk-energy-policy
[139] https://www.gov.uk/government/publications/updated-short-term-values-used-for-modelling-purposes-2015
[140] https://www.gov.uk/government/publications/fuel-poverty-methodology-handbook-2013

methodology in its 'Child and working-age poverty 2010 to 2020' report[141] using OBR forecast data – for those years not covered by OBR forecast we assume the same rate of growth as the last year forecast; and

- Estimated required energy costs are based on meeting a given temperature level in the home (following the established fuel poverty methodology).

[141] http://www.ifs.org.uk/publications/5711