Title: Impact Assessment of Fourth Carbon Budget Level	Impact Assessment (IA)
Lead department or agency:	**IA No:** DECC0054
Department of Energy and Climate Change (DECC)	**Date: 16/05/2011**
	Stage: Final Proposal
Other departments or agencies:	**Source of intervention:** Domestic
	Type of measure: Secondary legislation
	Contact for enquiries: Stephanie Ockenden Stephanie.Ockenden@decc.gsi.gov.uk

Summary: Intervention and Options

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

Climate change is one of the greatest threats to both UK and global security, and there is an overwhelming scientific consensus that it is being caused by human activity. The global causes and consequences of climate change, coupled with the long term and persistent nature of the impacts, highlight the need for government intervention. The Climate Change Act 2008 and the accompanying Impact Assessment provide the rationale for taking action to reduce greenhouse gas emissions – and to reduce UK emissions by at least 80% by 2050. The latest scientific evidence reinforces this case alongside the global commitment achieved in Cancun (the 16th Conference of Parties to the UNFCCC 2010) to hold increases in average temperatures below 2 degrees Celsius.

What are the policy objectives and the intended effects?

Setting of the fourth carbon budget level covering 2023-7: The Climate Change Act requires the Government to set 'carbon budgets' (five-yearly cumulative limits on the level of the net UK carbon account) with a view to meeting the 2050 target and taking into account matters listed in the Act. The fourth carbon budget must be set in legislation by 30th June 2011 and fulfil the objectives of the Act: avoiding dangerous climate change in an economically sound way by establishing an economically credible emissions reduction pathway to 2050. The objective at this stage is not to outline what shares of the carbon budget different sectors may take on, or to say in any detail what policies will deliver the emissions reductions. Government will, as required under the Act, report on policies and proposals to meet the budget once it is set.

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

Option 1 (Do Nothing): e.g. 3000 MtCO_2e (23% below 1990 levels), a continuation of the current EU ETS cap trajectory and a non-constraining budget level in the non-traded sector.
Option 2: 2310 MtCO_2e (41% below 1990 levels), based on a continued EU ETS cap and non-traded sector target trajectory, under the current EU 20% reduction target.
Option 3: 2170 MtCO_2e (45% below 1990 levels), based on a continued EU ETS cap trajectory and a statically cost-effective level of UK territorial abatement in the non-traded sector, as defined by Government's carbon values for appraisal.
Option 4: 2120 MtCO_2e (46% below 1990), based on a continuation of the current EU ETS cap and the CCC's recommendation for the non-traded sector level.
Option 5: 1950 MtCO_2e (50% below 1990 levels), CCC's recommended budget level.
Option 6: 1800 MtCO_2e (54% below 1990 levels), CCC's estimated UK share of global target.

Will the policy be reviewed? It will be reviewed. **If applicable, set review date: Spring 2015**
What is the basis for this review? PIR-Post-Legislative Scrutiny. **If applicable, set sunset clause date:** -/n/a

Are there arrangements in place that will allow a systematic collection of monitoring information for future policy review?	Yes

Ministerial Sign-off Final Proposal Stage Impact Assessment:

I have read the Impact Assessment and I am satisfied that (a) it represents a fair and reasonable view of the expected costs, benefits and impact of policy, and (b) that the benefits justify the costs.

Signed by the responsible Minister: .... Date: 16/05/2011

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Summary: Analysis and Evidence — Policy Option 1

Description: **Option 1 reflects a scenario in which the budget level would not be constraining, even if emissions are higher than expected.** This level is based on a traded sector share of the budget which assumes a continuation of the UK share of the EU ETS cap on the current declining trajectory, and then an illustrative high-end non-constraining level in the non-traded sector. An illustrative budget level for the UK of 3000 $MtCO_2e$ over 2023-7 is presented.

The option is assessed relative to the counterfactual (outlined in page 98).

Price Base Year 2009	PV Base Year 2010	Time Period	Net Benefit (Present Value (PV)) (£m)		
			Low: £0bn	**High:** £0bn	**Best Estimate:** £0bn

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

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

There are no technical abatement costs associated with this option as Business as Usual emissions, even under a high emissions sensitivity are within budget.

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

There may be additional costs incurred in later years due to this budget level being inconsistent with a feasible and least-cost pathway to the 2050 target.

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

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

There are no benefits associated with this option as it is assumed under all emissions scenarios, UK emissions are within budget.

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

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.

Direct impact on business (Equivalent Annual) £m):			In scope of OIOO?	Measure qualifies as
Costs: £0m	**Benefits: £0m**	**Net: £0m**	Yes	IN ZERO IN

Summary: Analysis and Evidence — Policy Option 2

Description: **Option 2 assumes a continuation of the current declining trajectory of carbon budgets two and three – based on a continuation of the UK's share of the EU ETS cap and an extrapolation of the UK's EU non-traded sector target under current commitments (consistent with EU 20% reduction targets).** This represents a budget for the UK of 2310 $MtCO_2e$ over 2023-7.

This option is assessed relative to the counterfactual (outlined in page 99).

Price Base	PV Base	Time Period	Net Benefit (Present Value (PV)) (£m)		
Year 2009	**Year** 2010	**Years** 5	**Low:** £0bn	**High:** £0.9bn	**Best Estimate:** £0bn

COSTS (£m)	Total Transition (Constant Price)	Years	Average Annual * (excl. Transition) (Constant Price)	Total Cost (Present Value)
Low	N/A	N/A	£0bn	£0bn
High	N/A		-£0.2bn	-£0.9bn
Best Estimate	N/A		**£0bn**	**£0bn**

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

The counterfactual range of emissions projections is 2150 $MtCO_2e$ to 2340 $MtCO_2e$, which is below the budget level for all but the high end of the counterfactual emissions range.

Net costs include associated capital and operating cost, and benefits through reductions in energy demand and reduced purchase of EUAs, associated with abatement opportunities. The most significant costs are capital costs and the benefit of energy demand savings. Further costs associated with changes in air quality, comfort taking, hidden costs (e.g. hassle; time) and congestion have been included where available. These are the net resource costs over 2023-7 of meeting the non-traded sector budget level (and do not reflect cost implications to 2050). There are no additional costs to meeting the traded share of the carbon budget as it is set equal to the 'Business as Usual' UK share of the EU ETS cap over the fourth carbon budget period.

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

Costs do not take account of dynamic pathway considerations and costs to 2050 - setting the budget at this level could lead to costs being higher over the period to 2050 due to risks of lock in, pressures on supply chain and the risk of not meeting the 2050 target. There may be additional costs incurred in later years due to this pathway being inconsistent with a feasible and least-cost pathway to the 2050 target.

Costs reflect the least costs of meeting the carbon budget in the non-traded sector. Policy costs are not included in this assessment and there has been limited modelling of hidden and missing costs and any potential wider impacts (given policies to deliver emission reductions are not yet known).

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

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

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

This IA does not value the avoided damages from reducing GHG emissions over the period 2023-7. The Climate Change Act IA set out that the net benefits of action were large in the case where the UK acts in concert with other countries to mitigate climate change.

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

Costs reflect take up of the remaining net negative cost abatement in the non-traded sector. There are no costs associated with the traded portion of the budget relative to the counterfactual. Range of costs reflect the range of modelled uncertainty in non-traded sector emission projections. There is a large amount of uncertainty around the potential delivery and costs associated with abatement measures which has not been captured in the sensitivity analysis. Costs do not reflect uncertainty in assumptions underpinning the cost estimates; notably benchmark carbon prices, energy prices and capital costs. Best estimates are based on the central emissions scenario and central assumptions are based on the HMT/DECC GHG guidance.

Direct impact on business (Equivalent Annual) £m):			In scope of OIOO?	Measure qualifies as
Costs: £0m	**Benefits:** £0m	**Net:** £0m	Yes	IN ZERO IN

*Discrepancies between annual average costs and totals are due to rounding

Summary: Analysis and Evidence — Policy Option 3

Description: **Option 3 is based on a continuation of the current EU ETS cap trajectory and a statically cost-effective level of UK territorial abatement in the non-traded sector, as defined by Government's carbon values for appraisal.** This represents a budget for the UK of 2170 $MtCO_2e$ over 2023-7.

This option is assessed relative to the counterfactual (outlined in page 99).

Price Base Year 2009	PV Base Year 2010	Time Period	Net Benefit (Present Value (PV)) (£m)		
			Low: £0bn	**High:** -£2.7bn	**Best Estimate:** £0.1bn

COSTS (£m)	**Total Transition** (Constant Price)	Years	**Average Annual*** (excl. Transition) (Constant Price)	**Total Cost** (Present Value)
Low	N/A	N/A	£0bn	£0bn
High	N/A		£0.5bn	£2.7bn
Best Estimate	N/A			

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

Net costs include associated capital and operating costs, and benefits through reductions in energy demand and reduced purchase of EUAs, associated with abatement opportunities. The most significant costs are capital costs and the benefit of energy demand savings. Further costs associated with changes in air quality, comfort taking, hidden costs (e.g. hassle; time) and congestion have been included where available. These are the net resource costs over 2023-7 of meeting the non-traded sector budget level (and do not reflect cost implications to 2050). There are no additional costs to meeting the traded share of the carbon budget as it is set equal to the 'Business as Usual' UK share of the EU ETS cap over the fourth carbon budget period.

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

Costs do not take account of dynamic pathway considerations and costs to 2050 - setting the budget at this level could lead to costs being higher over the period to 2050 due to risks of lock in, pressures on supply chain and the risk of not meeting the 2050 target. There may be additional costs incurred in later years due to this pathway being inconsistent with a feasible and least-cost pathway to the 2050 target.

Costs reflect the least costs of meeting the carbon budget in the non-traded sector. Policy costs are not included in this assessment and there has been limited modelling of hidden and missing costs and any potential wider impacts (given policies to deliver emission reductions are not yet known). There are no additional costs to meeting the traded share of the carbon budget as it is set equal to the 'Business as Usual' UK share of the EU ETS cap over the fourth carbon budget period.

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

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

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

This IA does not value the avoided damages from reducing GHG emissions over the period 2023-7. The Climate Change Act IA set out that the net benefits of action were large in the case where the UK acts in concert with other countries to mitigate climate change.

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

Costs reflect take up of the remaining abatement in the non-traded sector up to the cost-effective level. Range of costs reflect the range of modelled uncertainty in non-traded sector emission projections. There is a large amount of uncertainty around the potential delivery and costs associated with abatement measures which has not been captured in the sensitivity analysis. Costs do not reflect uncertainty in assumptions underpinning the cost estimates; notably benchmark carbon prices, energy prices and capital costs. Best estimates are based on the central emissions scenario and central assumptions are based on the HMT/DECC GHG guidance.

Direct impact on business (Equivalent Annual) £m):			**In scope of OIOO?**	**Measure qualifies as**
Costs: £0m	**Benefits: £0m**	**Net: £0m**	Yes	IN ZERO IN

*Discrepancies between annual average costs and totals are due to rounding

Summary: Analysis and Evidence

Policy Option 4

Description: **Option 4 is based on the Committee on Climate Change's recommended level of emissions for the non-traded sector and a continuation of the UK share of the current EU ETS cap.** This represents a budget for the UK of 2120 $MtCO_2e$ over 2023-7.

This option is assessed relative to the counterfactual (outlined in page 100).

Price Base Year 2009	PV Base Year 2010	Time Period Years 5	Net Benefit (Present Value (PV)) (£m)		
			Low: £0.8bn	**High:** -£4.0bn	**Best Estimate:** -£1.2bn

COSTS (£m)	Total Transition (Constant Price)	Years	Average Annual * (excl. Transition) (Constant Price)	Total Cost (Present Value)
Low	N/A	N/A	-£0.2bn	-£0.8bn
High	N/A		£0.8bn	£4.0bn
Best Estimate	N/A		**£0.2bn**	**£1.2bn**

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

Net costs include associated capital and operating cost, and benefits through reductions in energy demand and reduced purchase of EUAs, associated with abatement opportunities. The most significant costs are capital costs and the benefit of energy demand savings. Further costs associated with changes in air quality, comfort taking, hidden costs (e.g. hassle; time) and congestion have been included where available. These are the net resource costs over 2023-7 of meeting the non-traded sector budget level (and do not reflect cost implications to 2050).

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

Costs do not take account of dynamic pathway considerations and costs to 2050 - setting the budget at this level could lead to costs being higher over the period to 2050 due to risks of lock in, pressures on supply chain and the risk of not meeting the 2050 target. There may be additional costs incurred in later years due to this pathway being inconsistent with a feasible and least-cost pathway to the 2050 target.

Costs reflect the least costs of meeting the carbon budget in the non-traded sector. Policy costs are not included in this assessment and there has been limited modelling of hidden and missing costs and any potential wider impacts (given policies to deliver emission reductions are not yet known). There are no additional costs to meeting the traded share of the carbon budget as it is set equal to the 'Business as Usual' UK share of the EU ETS cap over the fourth carbon budget period.

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

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

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

This IA does not value the avoided damages from reducing GHG emissions over the period 2023-7. The Climate Change Act IA set out that the net benefits of action were large in the case where the UK acts in concert with other countries to mitigate climate change.

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

Costs reflect take up of the remaining cost-effective abatement in the non-traded sector, with the remaining shortfall met through purchase of international carbon units. Range of costs reflect the range of modelled uncertainty in non-traded sector emission projections. There is a large amount of uncertainty around the potential delivery and costs associated with abatement measures which has not been captured in the sensitivity analysis. Costs do not reflect uncertainty in assumptions underpinning the cost estimates; notably benchmark carbon prices, energy prices and capital costs. Best estimates are based on the central emissions scenario and central assumptions are based on the HMT/DECC GHG guidance.

Direct impact on business (Equivalent Annual) £m):			In scope of OIOO?	Measure qualifies as
Costs: £0m	**Benefits: £0m**	**Net: £0m**	Yes	IN ZERO IN

***Discrepancies between annual average costs and totals are due to rounding**

Summary: Analysis and Evidence — Policy Option 5

Description: **Option 5 is based on the Committee on Climate Change's recommended budget level.** This represents a budget for the UK of 1950 $MtCO_2e$ over 2023-7.

This option is assessed relative to the counterfactual (outlined in page 100).

Price Base Year 2009	PV Base Year 2010	Time Period Years 5	Net Benefit (Present Value (PV)) (£m)		
			Low: £0.2bn	**High:** -£4.7bn	**Best Estimate:** -£1.9bn

COSTS (£m)	Total Transition (Constant Price)	Years	Average Annual * (excl. Transition) (Constant Price)	Total Cost (Present Value)
Low	N/A	N/A	-£0.04bn	-£0.2bn
High	N/A		£0.9bn	£4.7bn
Best Estimate	N/A		**£0.4bn**	**£1.9bn**

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

The non-traded sector costs are the same as in Option 4 (£1.2bn). The difference between the two options is that, in Option 5, a tighter EU ETS cap is assumed to be in place. The traded sector portion of the UK's net carbon account in the fourth carbon budget period will only become clear once negotiations at EU level are complete. However, for the purposes of this assessment, an assumption has been made about the UK's share of a future EU ETS cap under a more ambitious EU policy regime (30% reduction in emissions relative to 1990). The estimated resource costs of complying with the tighter cap add £0.7bn to the costs of the budget.

The counterfactual is constructed by taking UK territorial emissions projections over the fourth budget, subtracting half of the identified net negative cost abatement in the non-traded sector (with an associated net benefit of £1.2bn), and assuming that the net carbon account in the traded sector is equal to the UK's business as usual share of the EU ETS cap. The 95% confidence interval for the counterfactual range of emissions projections is higher (2180 - 2360 $MtCO_2e$) than the budget level under this option.

Net costs include associated capital and operating cost, and benefits through reductions in energy demand and reduced purchase of EUAs, associated with abatement opportunities. The most significant costs are capital costs and the benefit of energy demand savings. Further costs associated with changes in air quality, comfort taking, hidden costs (e.g. hassle; time) and congestion have been included where available. These are the net resource costs over 2023-7 of meeting the non-traded sector budget level (and do not reflect cost implications to 2050).

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

Costs reflect the least costs of meeting the carbon budget. Policy costs are not included in this assessment and there has been limited modelling of hidden and missing costs and any potential wider impacts (given policies to deliver emission reductions are not yet known).

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

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

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

This IA does not value the avoided damages from reducing GHG emissions over the period 2023-7. The Climate Change Act IA set out that the net benefits of action were large in the case where the UK acts in concert with other countries to mitigate climate change.

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

Costs reflect take up of the remaining cost-effective abatement in the non-traded sector, with the remaining shortfall met through purchase of international carbon units. Range of costs reflect the range of modelled uncertainty in non-traded sector emission projections. There is a large amount of uncertainty around the potential delivery and costs associated with abatement measures which has not been captured in the sensitivity analysis. Costs do not reflect uncertainty in assumptions underpinning the cost estimates; notably benchmark carbon prices, energy prices and capital costs. Best estimates are based on the central emissions scenario and central assumptions are based on the HMT/DECC GHG guidance.

Direct impact on business (Equivalent Annual) £m):			In scope of OIOO?	Measure qualifies as
Costs: £0m	Benefits: £0m	Net: £0m	Yes	IN ZERO IN

*Discrepancies between annual average costs and totals are due to

Policy Option 6

Description: **Option 6 is based on the Committee on Climate Change's recommended 'Global Offer' budget.** This represents a budget for the UK of 1800 $MtCO_2e$ over 2023-7.

This option is assessed relative to Option 1 the counterfactual (outlined in page 101).

Price Base Year 2009	PV Base Year 2010	Time Period Years 5	Net Benefit (Present Value (PV)) (£m)		
			Low: -£3.7bn	**High:** -£8.5bn	**Best Estimate:** -£5.7bn

COSTS (£m)	**Total Transition** (Constant Price)	Years	**Average Annual*** (excl. Transition) (Constant Price)	**Total Cost** (Present Value)
Low	N/A	N/A	£0.7bn	£3.7bn
High	N/A		£1.7bn	£8.5bn
Best Estimate	N/A		£1.1bn	**£5.7bn**

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

The non-traded sector costs are the same as in Options 4 and 5 (£1.2bn). The estimated resource costs of complying with the tighter EU ETS cap are the same as in Option 5 (£0.7bn). The difference between Options 5 and 6 is the additional purchase of 150$MtCO_2e$ of international carbon units (£3.9bn).

The counterfactual is constructed by taking UK territorial emissions projections over the fourth budget, subtracting half of the net negative cost abatement identified in the non-traded sector (with an associated net benefit of £1.2bn), and assuming that the net carbon account in the traded sector is equal to the UK's business as usual share of the EU ETS cap. The 95% confidence interval for the counterfactual range of emissions projections is higher (2180 - 2360 $MtCO_2e$) than the budget level under this option.

Net costs include associated capital and operating cost, and benefits through reductions in energy demand and reduced purchase of EUAs, associated with abatement opportunities. The most significant costs are capital costs and the benefit of energy demand savings. Further costs associated with changes in air quality, comfort taking, hidden costs (e.g. hassle; time) and congestion have been included where available. These are the net resource costs over 2023-7 of meeting the non-traded sector budget level (and do not reflect cost implications to 2050).

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

Costs reflect the least costs of meeting the carbon budget in the non-traded sector. Policy costs are not included in this assessment and there has been limited modelling of hidden and missing costs and any potential wider impacts (given policies to deliver emission reductions are not yet known).

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

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

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

This IA does not value the avoided damages from reducing GHG emissions over the period 2023-7. The Climate Change Act IA set out that the net benefits of action were large in the case where the UK acts in concert with other countries to mitigate climate change.

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

Costs reflect take up of the remaining cost-effective abatement in the non-traded sector, with the remaining shortfall met through purchase of international carbon units. Range of costs reflect the range of modelled uncertainty in non-traded sector emission projections. There is a large amount of uncertainty around the potential delivery and costs associated with abatement measures which has not been captured in the sensitivity analysis. Costs do not reflect uncertainty in assumptions underpinning the cost estimates; notably benchmark carbon prices, energy prices and capital costs. Best estimates are based on the central emissions scenario and central assumptions are based on the HMT/DECC GHG guidance.

Direct impact on business (Equivalent Annual) £m):			In scope of OIOO?	Measure qualifies as
Costs: £0m	Benefits: £0m	Net: £0m	Yes	IN ZERO IN

*Discrepancies between annual average costs and totals are due to rounding

Enforcement, Implementation and Wider Impacts

What is the geographic coverage of the policy/option?			United Kingdom		
From what date will the policy be implemented? **Secondary Legislation in place**			30/06/2011		
Which organisation(s) will enforce the policy?			N/A		
What is the annual change in enforcement cost (£m)?			N/A		
Does enforcement comply with Hampton principles?			N/A		
Does implementation go beyond minimum EU requirements?			Yes		
What is the CO_2 equivalent change in greenhouse gas emissions? (Million tonnes CO_2 equivalent) **Range based on options (**vs. central counterfactual**)**			**Traded:** 0-170	**Non-traded:**	
Does the proposal have an impact on competition?			Yes		
What proportion (%) of Total PV costs/benefits is directly attributable to primary legislation, if applicable?			**Costs:** N/A	**Benefits:** N/A	
Distribution of annual cost (%) by organisation size (excl. Transition) (Constant Price)	**Micro** N/A	**< 20** N/A	**Small** N/A	**Medium** N/A	**Large** N/A
Are any of these organisations exempt?	No	No	No	No	No

Specific Impact Tests: Checklist

	Impact	Page ref within IA
Statutory equality duties	No	P86
Economic impacts		**P83-5**
Competition	Yes	p85
Small firms	No	
Environmental impacts		
Greenhouse gas assessment	Yes	Throughout
Wider environmental issues	Yes	
Social impacts		p86
Health and well-being	No	
Human rights	No	
Justice system	No	
Rural proofing	No	
Sustainable development	Yes	p83-5

References

The main references for this Impact Assessment are listed below. References to specific elements of the evidence base are cited in information boxes or footnotes in the main document.

No	Legislation or publication
1	**The Climate Change Act 2008** 'Climate Change Act 2008' http://www.legislation.gov.uk/ukpga/2008/27/contents
2	**The Climate Change Act Impact Assessment** 'Climate Change Act 2008 Impact Assessment'; DECC (2008); http://www.decc.gov.uk/assets/decc/85_20090310164124_e_@@_climatechangeactia.pdf
3	**The Committee on Climate Change's Fourth Carbon Budget Advice** 'The Fourth Carbon Budget: Reducing Emissions Through the 2020s'; Committee on Climate Change (2010); http://www.theccc.org.uk/reports/fourth-carbon-budget
4	**The DECC/HMT Greenhouse Gas Guidance** 'Valuation of energy use and greenhouse gas emissions for policy appraisal and evaluation'; DECC (2010); http://www.decc.gov.uk/assets/decc/statistics/analysis_group/122-valuationenergyuseggemissions.pdf

Executive Summary

The Climate Change Act 2008 requires that Government sets the level of the fourth carbon budget by 30th June 2011. In doing so, the Government has to take into account the advice of the independent Committee on Climate Change (CCC) and the opinions of the Devolved Administrations.

This Impact Assessment presents the evidence for setting the fourth carbon budget - a cap on the level of net UK emissions over the period 2023 to 2027. Carbon budgets must be set with a view of meeting the UK's target to reduce net UK emissions by at least 80% by 2050 relative to the 1990 baseline[1].

Whilst the fourth carbon budget level must be set in legislation by the end of June 2011, the Climate Change Act requires government to report on the policies and proposals to deliver the fourth carbon budget 'as soon as is reasonably practicable[2]' thereafter. This will be published in October 2011 and will provide more in depth analysis of sectoral impacts. In the absence of the detailed policies and proposals to meet the budget, this Impact Assessment considers at a high level the impacts of different budget levels.

This Impact Assessment presents analysis on different options for the level of the fourth carbon budget. Whilst the legislated carbon budget is a single level set to cover all sectors of the economy[3], for the purposes of analysis this level is split into the traded and non-traded sectors – the traded sector being sectors covered by the EU Emissions Trading System (EU ETS) and the non-traded sector being those sectors outside of the EU ETS.

The options considered in this Impact Assessment are:

	Description	**4th Carbon Budget Level ($MtCO_2e$)**	**Average reduction in emissions relative to 1990**
Option 1	'Do nothing' scenario – a non-constraining budget. Level based on a continued EU ETS cap trajectory based on the current EU ETS directive and an illustrative non-constraining budget level in the non-traded sector.	e.g. 3000	e.g. 23%
Option 2	Level based on a continuation of the current EU ETS cap trajectory, and in the non-traded sector a continued downward trajectory from legislated second and third carbon budgets (2013-2017 and 2018-2022).	2310	41%
Option 3	Level based on a continuation of the current EU ETS cap trajectory and a statically cost-effective level of UK territorial abatement in the non-traded sector, as defined by Government's carbon values for appraisal.	2170	45%
Option 4	Level based on a continuation of the current EU ETS cap trajectory and the CCC recommended level of emissions in the non-traded sector.	2120	46%
Option 5	CCC recommended fourth carbon budget.	1950	50%
Option 6	CCC Global Offer Budget – the CCC's assessment of what the fourth budget might need to be amended to in the future to reflect the UK's share of a future global climate change deal.	1800	54%

The Impact Assessment begins with a background section highlighting the international context - the UK's commitment to global action, the latest scientific evidence, global emission pathways and the UK's role in a global effort to tackle climate change. The assessment does not look in depth at the case for

[1] 'The 1990 baseline' is defined in the Climate Change Act 2008 as 1990 emissions levels for carbon dioxide, methane and nitrous oxide and 1995 for the fluorinated gases.
[2] Climate Change Act 2008, Section 14(1).
[3] Those sectors included in the net UK carbon account. This excludes international aviation and shipping emissions, see Background Section page 25

action to tackle climate change overall, as this remains as set out in the Impact Assessment for the Climate Change Act 2008. However, the case for UK action is restated briefly, before outlining the background of the Climate Change Act and the conditions upon which a budget level must be set and assessed. The core section of this Impact Assessment outlines the analytical approach and evidence base.

The fourth carbon budget level options presented have been assessed relative to three different perspectives regarding setting an efficient level that minimises costs to society;

- **A Long term UK pathway perspective** - considering what a least-cost pathway to 2050 would be given considerations of the energy system and mix of technologies, balancing costs of action now with long-term costs to 2050 and ensuring the UK is on track over the 2020s to meet the 2050 target;

- **A global perspective** - considering what the efficient level of UK territorial emissions would be as part of a global effort to reduce emissions, consistent with meeting the objective of limiting temperature rises to 2 degrees Celsius above pre-industrial levels by 2100; and

- **A 'static' perspective** - considering how much the UK can feasibly and cost-effectively reduce emissions by over the 2020s.

The CCC's recommendation on the level of the fourth carbon budget and underpinning analysis is also summarised.

Business as Usual Emissions Projections and Budget Options

Over the fourth carbon budget (2023-7), UK territorial[4] emissions under a 'business as usual' scenario are forecast on central projections to be **2306 $MtCO_2e$**, on average 41% below the 1990 baseline, with non-traded and traded sector territorial emissions projected to be 1393 $MtCO_2e$ and 912 $MtCO_2e$ over the period respectively. These projections include the impact of current policies but reflect no extension of these policies beyond 2022. However, the projections do capture the legacy of these policies which continue to reduce emissions over the 2020s. A carbon price is assumed to continue in the traded sector, reflecting the assumption that the EU ETS continues based on its current trajectory, as provided for in the 2009 EU ETS directive.

Emission projections are uncertain. Over the fourth carbon budget period, modelled territorial emissions range **from 2195 $MtCO_2e$ to 2631 $MtCO_2e$**, however the true uncertainty range may be higher. Comparing emission forecasts to budget levels identifies the emissions gap and hence the level of effort required to meet given carbon budget options.

Long term UK pathway perspective

Carbon budgets have to be set with a view to meeting the 2050 target. It is important to consider the appropriate pathway that minimises costs over time of reaching this target. This section considers this dynamic perspective, taking into account costs now and in the future, and least-cost pathways to meet the 2050 target given available opportunities and technical considerations to meet long-term targets. The modelling evidence base is limited, and not sufficiently granular or tailored to answer the question "what is the optimal level of effort over 2023-7 consistent with the 2050 target?". Instead consideration needs to be given to views on technical feasibility, key technologies for the UK's pathway to 2050 and implications for investment and action over the 2020s given risks of lock in, considerations of supporting supply chains, incentivising innovation and the benefits of this, and feasible rates of uptake given consumer preferences and behaviour change.

The CCC's recommended budget level of 1950 $MtCO_2e$ is the minimum level of effort they consider to be consistent with the 2050 target following their assessment of prudent development and deployment of technologies needed to reduce emissions by at least 80% in 2050. A looser budget would imply less effort was required in these areas which, they concluded, would in turn increase risks to and raise costs of meeting the 2050 target. For example, their analysis showed

[4] GHGs emitted on UK territory – not taking into account emissions trading (i.e. the purchase or sale of international carbon units from overseas).

that a 5 year delay in their assumed trajectory for roll-out of electric vehicles would have an NPV cost of over £5 billion when the extra credit purchase incurred is included.

High level evidence on 'dynamic' least-cost pathway assessment to support this can come from the MARKAL model. Whilst this model cannot be used to prescribe a specific carbon budget level and there are limitations to the modelling, **it suggests that an 'early action' pathway – one that requires greater reductions in earlier years – is more cost effective over time than a 'delayed action' pathway when meeting a cumulative emissions constraint over the period to 2050**. Early action increases the emissions space that is available later in the period to 2050. Without the early action, very stringent action would be required in later periods at high marginal cost to meet the cumulative emissions constraint. This could lead to costs being higher over the period to 2050 due to risks of lock in, pressures on supply chain and the risk of not meeting the 2050 target.

In itself, this does not point to a single specific fourth budget level – there are degrees of early action. An emissions trajectory that follows equal annual percentage reductions would be one form of early action pathway, as it would require larger absolute emissions reductions in earlier years and smaller absolute emissions reductions in later years. **Illustrative equal annual percentage reduction trajectories from projected territorial emissions in 2020 to our 2050 target would imply an emissions level of around 1830 to 2020 $MtCO_2e$ over the fourth carbon budget period**. Note that this conclusion is dependent on assumptions around the level of emissions in the international aviation and shipping sectors, which are not currently included in the net UK carbon account. If international aviation and shipping were included, as the CCC recommend as important for the UK's climate change objective, an equal annual percentage trajectory in territorial emissions would imply a fourth carbon budget range of between 1830 and 1880 $MtCO_2e$[5].

The MARKAL model does not include the effects of learning and innovation and so may understate the benefits of early action through reducing costs and inducing technological change. The need for support for specific decarbonisation technology pathways needs to be considered on a case-by-case basis, balancing benefits (such as innovation and avoided lock-in to carbon intensive infrastructure) against costs (future cost reductions, risk of diverting resources from the least-cost path and potential lock-in to interim technologies).

For example, it is possible that abatement is not cost effective from a static perspective (i.e. it is costly in the fourth budget period) but nonetheless needs to be delivered in the fourth budget period as part of an overall cost effective pathway. Demonstration and deployment of technologies in the fourth carbon budget period can increase their availability and reduce their costs in future periods through learning by doing and innovation.

A further source of evidence regarding long-term pathways is the DECC 2050 Calculator, which was developed to explore a range of potential pathways from today to 2050, to meet an 80% reduction in UK greenhouse gas emissions. It sets out the physical solution space for what level of UK GHG emission reductions can technically be achieved whilst ensuring the UK's energy needs are met, based on the full range of technical possibilities. The calculator illustrates: the scale of the challenge (that single technologies cannot be relied upon and that all sectors need to contribute to decarbonisation); the considerable de-carbonisation effort needed across a large number of the UK's energy sectors to hit the 2050 targets; and that without early action there is a risk that the technology scale up needed would be very difficult to deliver due to these factors.

Global perspective

This section considers the efficient reduction of UK territorial emissions as part of an economically efficient global effort to mitigate climate change, which minimises the costs of achieving a level of global emissions reductions by exploiting least cost abatement opportunities wherever they are located. Assessments of the efficient level of reduction in UK territorial emissions provide no guidance on the appropriate burden share for the UK as part of an international mitigation effort. Additional effort can be made through the purchase of international carbon units in international carbon markets.

[5] Range is determined by uncertainty in emissions in International Aviation and Shipping; based on central underlying emissions projection

The analysis employs two models – GLOCAF and PRIMES – to firstly estimate the EU's cost effective share of global abatement (GLOCAF) and then how this might be most cost effectively shared out amongst EU Member States (PRIMES).

This analysis shows that the level of cost-effective global abatement that the UK should be taking on depends on what assumptions are made on global efforts to reduce emissions. In a scenario incorporating the United Nations Environment Programme (UNEP)[6] assessment of Copenhagen Accord offers in 2020 (i.e. global emissions of 49 $GtCO_2e$), and consistent with a 2 degree trajectory where beyond 2020, global emissions decline to 16 $GtCO_2e$ by 2050 and to 7 $GtCO_2e$ by 2100, this suggests **a 43% reduction in EU emissions in 2030, consistent with the recently published EU Roadmap.** DECC's analysis of the **UK's cost effective share of this would be equivalent to a fourth budget level of the order of 1940 $MtCO_2e$ to 2210 $MtCO_2e$**. This is derived from PRIMES **modelling results for the non-traded sector (1350 $MtCO_2e$)** and adding the estimated range of the UK share of a future EU ETS cap (which implies a range of net UK emissions in the **traded sector of 590 $MtCO_2e$ to 860 $MtCO_2e$** – see Section D.II on the EU ETS cap post-2020). It follows that the lower end of the range is the more likely as it might be expected that the EU ETS cap would be tightened (as part of an EU move to a more ambitious 2020 target) if other countries deliver comparative levels of ambition. The higher end of the range, assuming an EU ETS cap of 860 $MtCO_2e$ is based on an EU ETS trajectory that, if continued, is inconsistent with the UK's 2050 target.

If it is assumed that global emissions reductions are less ambitious or delayed, this would imply a lower level of UK abatement as an efficient share of lower global abatement. This in turn would imply a range for the fourth carbon budget level higher than the 1940 $MtCO_2e$ to 2210 $MtCO_2e$ range outlined.

Static perspective

Evidence on technical abatement potential from across all main sectors of the economy and associated technical costs - consolidated through Marginal Abatement Cost Curves - is used to assess the technical viability of required emission reductions and estimate illustrative costs of the various fourth budget options. These illustrative costs represent the minimum costs of meeting a certain fourth budget level by assuming that abatement is taken up in order of 'static' cost effectiveness, with the most cost-effective measures adopted first. It may be the case that abatement options that are statically not cost-effective are cost-effective and desirable from a long-term pathways perspective.

In the **non-traded sector just over 160 $MtCO_2e$ of additional abatement potential** has been identified over the period 2023-7, of which around **80 $MtCO_2e$ is cost-effective** relative to the Government's benchmark carbon price – which takes a static view of costs. On central emission projections taking up all cost-effective abatement suggests non-traded sector **emissions over the fourth budget period of around 1310 $MtCO_2e$.**

In **heavy industry covered by the EU ETS around 90 $MtCO_2e$ of additional abatement potential** has been identified over the period 2023-7, of which **around 80 $MtCO_2e$ has been assessed to be cost-effective**. On central emission projections taking up all cost-effective abatement suggests **traded sector emissions excluding power generation, of around 410 $MtCO_2e$ over the fourth budget period.**

In the power generation sector, the level of emissions and costs depend upon choices of the market structure and the type of low carbon generation. Instead of a marginal analysis, the sector has been modelled considering decarbonisation scenarios that reduce the average emissions intensity of electricity generation in 2030 to 50gCO_2/kWh and 100gCO_2/kWh. **The scenarios suggest power sector emissions could range from around 220 $MtCO_2$ and 360 $MtCO_2$ under 50gCO_2/kWh and 100gCO_2/kWh scenarios respectively** (on central assumptions).

In practise if some of the cost effective abatement is not deliverable (e.g. due to other barriers to uptake, such as supply chain capacity constraints) then more costly abatement would be needed to meet the same overall budget level. There are also a number of other caveats and uncertainties, such as the fact

[6] UNEP convened experts from 25 research centres to explore how the 2020 emission reduction pledges submitted to the Copenhagen Accord compared to the goal of keeping the increase in global temperatures to below 2 (or 1.5) degrees Celsius. This was documented in the following report: 'The Emissions Gap Report: Are the Copenhagen Accord Pledges Sufficient to Limit Global Warming to 2°C or 1.5°C?' United Nations Environment Programme(UNEP), December 2010. http://www.unep.org/publications/ebooks/emissionsgapreport/

that 'static' assessments neglect dynamic pathway considerations, which together mean that actual costs and potential may be either higher or lower than presented.

Committee on Climate Change View

The Committee on Climate Change (CCC) recommended that the UK should set a budget of 1950 $MtCO_2e$ over the fourth budget period, and for Government to aim to meet this through territorial emissions reductions alone (it therefore referred to the 1950 $MtCO_2e$ level as the 'domestic action budget'). In the event of an international agreement to reduce emissions over the 2020s, the CCC recommended that the budget should be amended down, and that the minimum UK burden share of such a deal would require a fourth carbon budget of 1800 $MtCO_2e$.

In developing its advice, the CCC started by considering a feasible target for UK emissions in 2030 (the midpoint between now and the 2050 target set in the Climate Change Act). This method allowed the CCC to present in the report a view of the detailed analysis to meet nearer term targets which was consistent with the longer-term analysis of the pathway to 2050. The CCC based its proposal for the Domestic Action budget on bottom-up modelling of potential abatement opportunities to reduce emissions over the fourth budget period. The inclusion of different abatement options was determined by their relative performance against four criteria set out by the CCC: feasibility; sustainability; cost-effectiveness; and consistency with the 2050 target.

Using the bottom-up analysis and the assessment of measures against the criteria, the CCC constructed three potential scenarios of emissions which differed depending on their level of ambition; setting out low, central and high ambition scenarios over the fourth budget which are estimated by the CCC to deliver a reduction in emissions of 51%, 60% and 69% in 2030 relative to the 1990 baseline.

Consideration of wider impacts

The evidence section concludes with a summary of **considerations of wider 'matters to be taken into account**' when setting carbon budgets[7] – such as macroeconomic and competitiveness implications. However, because this Impact Assessment does not consider policies and proposals to deliver the fourth carbon budget, wider impacts can only be considered at a high level. A more in depth analysis on sectoral impacts, wider impacts and cost to business will be presented in October 2011 once the budget level is legislated and decisions have been taken over policies and proposals to meet the fourth carbon budget.

Alternatives to regulation and one-in, one-out

As the Climate Change Act 2008 requires that the level of the fourth carbon budget be set in legislation by 30th June 2011, alternatives to regulation are not an option here. However, alternatives to regulation will be given due consideration when developing the policies and proposals to meet the fourth carbon budget.

The key criterion for setting the levels for all the carbon budgets is to allow the UK to meet the 80% 2050 target at least cost – as such setting the fourth budget level does not result in any 'new' costs or benefits beyond those that have been identified in the Climate Change Act 2008 Impact Assessment (though we are now better placed to estimate these costs and benefits).

From the perspective of one-in, one-out, setting the budget level does not lead to any direct costs or benefits on business, as these will be imposed when policies and proposals to deliver the budget come into force. This measure is therefore a zero 'in'. All costs and benefits, both to business and society, will be assessed and quantified as and when these policies are developed.

Options Assessment

Lastly, different options for the level of the fourth carbon budget are considered. A range of possible options for the fourth carbon budget level are assessed relative to the three key perspectives mentioned above and the CCC's advice. The conclusions of the assessment are shown in the summary table below. More detail can be found in Section G.

[7] Climate Change Act 2008, Section 10.

Figure 1. Summary of Options Assessment

Option	Global perspective	Long term UK pathway perspective	Static perspective	CCC View
Option 1 3000 $MtCO_2e$	Inconsistent with a view of an efficient level of UK emission reductions in the non-traded sector, and a more stringent EU ETS cap, under an ambitious global climate change deal.	Inconsistent with a feasible pathway to 2050 – delaying action to the extent that future reductions required to meet 2050 targets are unlikely to be possible, and unlikely to stimulate or support innovation and key technologies required to meet stringent long-term targets. EU ETS cap based on a trajectory that is inconsistent with the UK's 2050 target.	Budget level non-constraining. There are no associated additional technical abatement costs over 2023-7.	Inconsistent with CCC recommendations, no further action would be required to meet budget level which would illustratively sit around 1050 $MtCO_2e$ above the CCC's recommended domestic action budget.
Option 2 2310 $MtCO_2e$	Inconsistent with a view of an efficient level of UK emission reductions in the non-traded sector, and a more stringent EU ETS cap, under an ambitious global climate change deal.	Inconsistent with a feasible pathway to 2050 – delaying action to the extent that future reductions required to meet 2050 targets are unlikely to be possible, and unlikely to stimulate or support innovation and key technologies required to meet stringent long-term targets. EU ETS cap based on a trajectory that is inconsistent with the UK's 2050 target.	The budget option will constrain under a high emissions scenario. Action to meet the shortfall under a high emissions uncertainty delivers a net benefit of around £0.9bn over the fourth budget period (2023-7).	Inconsistent with CCC's recommendations, around 190 $MtCO_2e$ above the CCC's recommended domestic action budget for the non-traded sector.
Option 3 2170 $MtCO_2e$	Broadly consistent with an efficient level of UK emission reductions in the non-traded sector under an ambitious global climate change deal. Inconsistent with a more stringent EU ETS cap.	Consistent with a straight line trajectory to 2050 but inconsistent with more cost effective early action pathway. EU ETS cap based on a trajectory that is inconsistent with the UK's 2050 target.	Meeting the shortfall delivers a small net benefit of £0.1bn relative to the counterfactual over 2023-7 – based on a cost-effective level of UK abatement in the non-traded sector.	Inconsistent with CCC's recommended domestic action budget, around 60 $MtCO_2e$ above the CCC's recommended domestic action budget for the non-traded sector.
Option 4 2120 $MtCO_2e$	The non-traded sector portion of the budget can be met efficiently with the flexibility to trade. If the non-traded share of the budget is assumed to be met territorially this suggests the UK take on a greater level of abatement than efficient as defined by Government's carbon values.	Broadly consistent with an early action pathway (assuming that international aviation and shipping emissions are not included in carbon budgets in the future). EU ETS cap based on a trajectory that is inconsistent with the UK's 2050 target.	Technical abatement costs of at least £1.2bn relative to the counterfactual over the fourth budget period, based on a cost-effective level of UK abatement in the non-traded sector and the remaining abatement coming from purchase of international credits.	Inconsistent with CCC's recommended domestic action budget. But based on the CCC's recommendation in the non-traded sector.
Option 5 1950	Consistent with a view of an efficient level of	Consistent with a feasible and cost	Technical abatement costs of at least £1.9bn	**This is the level recommended by the**

$MtCO_2e$	UK emission reductions under an ambitious global deal assuming efficient trading (inconsistent with a view of an efficient level of UK emission reductions in the non-traded sector should this be met territorially).	effective pathway to 2050 – achieving territorially would require very significant decarbonisation of the power sector.	relative to the counterfactual over the fourth budget period, based on a cost-effective level of UK abatement in the non-traded sector and the remaining abatement coming from purchase of international credits	**CCC**
Option 6 1800 $MtCO_2e$	This might be a fair burden share for the UK under an ambitious global deal, however inconsistent with an efficient level of UK emissions reductions in the non-traded sector should this be met territorially. Assumes that additional abatement beyond 1950 $MtCO_2e$ is met through purchase of international carbon units.	Consistent with a feasible pathway to 2050 but likely to place significant costs if delivered territorially.	Technical abatement costs of at least £5.7bn relative to the counterfactual over the fourth budget period, based on a cost-effective level of UK abatement in the non-traded sector and the remaining abatement coming from purchase of international credits (and additional 150 $MtCO_2e$ of international carbon units above Options 4 and 5).	**This is the CCC's recommended global offer level.**

The table below presents the net cost associated with achieving the emissions reduction required under each option.

The costs represent current best estimates of the marginal cost of the emissions constraint over the five year budget period (2023-7), and are assessed relative to the counterfactual emissions scenario.

In the options assessment, the budget options are assessed relative to a counterfactual emissions scenario, as opposed to the 'business as usual' emissions projection (referred to on page 11 above). In the process of identifying additional abatement potential over the fourth carbon budget period, some negative cost abatement opportunities have been identified. This abatement potential is considered as having 'no regrets': even without the benefit of avoided damages from greenhouse gas emissions, exploiting these abatement opportunities delivers a net benefit for society and should be taken up, even under a budget option which is non-constraining over the fourth carbon budget period.

In practice, it could be that only by implementing a budget which constrains emissions that this abatement potential would be exploited. The counterfactual against which the options are assessed assumes that half of the negative cost 'no regret' abatement options are taken up (19 $MtCO_2e$ of a total of 38 $MtCO_2e$ identified in the non-traded sector is included in the counterfactual). The approach taken to assessing the options in this Impact Assessment is therefore conservative, in that half of the benefits accruing from negative cost measures are included in the counterfactual, and are not attributed to the options for budget levels.

For the net UK carbon account, as opposed to taking a territorial view of UK emissions, the counterfactual assumes that there is a continuation of the UK's share of the current EU ETS cap trajectory, which would lead to traded net emissions of around 860 $MtCO_2e$ over 2023-7. 'No regrets' measures have also been identified to abate emissions in the traded sector. Taking the 'business as usual' emissions projection and half of the negative abatement (estimated to be around 48 $MtCO_2e$ of a total 96 $MtCO_2e$ identified over the fourth budget period), and including the indirect impact of cost-effective abatement measures in the non-traded sector (which would increase emissions by around 5 $MtCO_2e$), would reduce territorial emissions to around 867 $MtCO_2e$ for the traded sector, implying that to reach the assumed continuation of the UK's share of the EU ETS cap, the UK would be a net purchaser of EUAs over the fourth budget period.

Taking into account the counterfactual assumptions in the non-traded and traded sectors, the resulting counterfactual scenario, against which the emissions shortfalls implied by the budget options are assessed, is 2234 $MtCO_2e$ on a net UK carbon account basis, of which 1374 $MtCO_2e$ would be non-traded and 860 $MtCO_2e$ would be traded sector emissions.

Figure 2. Net cost associated with non-traded and traded sector share of budget options over 2023-2027 above the counterfactual (£2009m prices, present value)

Option	Budget Level (2023-7) ($MtCO_2e$)	Average emissions reduction relative to 1990	Non-Traded Sector Share ($MtCO_2e$)	Traded Sector Share ($MtCO_2e$)	Cost of non-traded sector share (of which is purchase of ICUs) (£m)	Cost of traded sector share (of which is purchase of ICUs)(£m)	**Total cost of budget option (£m)[8]**
Option 1	3000	-23%	2140	860	£0 (£0)	£0 (£0)	**£0**
Option 2	2310	-41%	1450	860	£0 (£0)	£0 (£0)	**£0**
Option 3	2170	-45%	1310	860	-£100 (£0)	£0 (£0)	**-£100**
Option 4	2120	-46%	1260	860	£1,200 (£1,300)	£0 (£0)	**£1,200**
Option 5	1950	-50%	1260	690	£1,200 (£1,300)	£700 (£3,100)	**£1,900**
Option 6	1800	-54%	1260	690	£5,100 (£5,100)	£700 (£3,100)	**£5,700**

Source: Costs based on UK MACC evidence, as outlined in Section D.III. Current best estimates, based on central projections.

Costs do not reflect total costs of the UK's climate change policy – they reflect technical resource costs only; for example, technology costs and net change in energy costs, purchases of international credit units where applicable and some wider impacts that we are able to monetise. Costs associated with implementing specific policies are not reflected and there is no reflection of macroeconomic second-order impacts.

Further detail on the cost methodology and caveats can be found in Section D.III from page 62 onwards. Costs reflect the marginal cost of meeting the fourth carbon budget.

Costs reflect technical resource costs of abatement over 2023-7, including levelised technology/capital costs, operating costs, fuel savings, and savings from avoided allowance purchase under the EU ETS.

Other monetised costs are also reflected where available, including financing costs, costs of congestion, air quality impacts, hidden and administrative costs of installations and comfort taken.

Costs do not reflect policy costs, macroeconomic impacts or distributional implications from the additional UK effort required to meet the fourth carbon budget, nor the legacy costs of current policies to meet the first three carbon budgets.

Costs exclude any valuation of avoided damages from reduced GHG emissions.

Cost are best estimates, based on central projections and central assumptions on exogenous factors (i.e. fossil fuel prices, carbon prices, GDP growth).

Costs in present value 2009 prices.

[8] Costs have been rounded to nearest £100m. Costs for each sector may not sum to total costs for the budget option due to rounding.

Contents

Background

International Context

The global objective

The Committee on Climate Change (CCC) in its report on the fourth carbon budget (December 2010) concluded that the fundamental science remains robust[9]. The scientific evidence for recent global warming continues to strengthen year-on-year[10]. Whilst uncertainties remain in the detail of how the Earth's complex climate system will respond to human-induced warming, the case for taking action to tackle climate change remains compelling:

- Global climate change is already happening;
- It is very likely that this is largely a result of human activity; and
- Without action, there is a high risk of global warming well beyond a two degrees Celsius increase above pre-industrial temperatures.

It is because of the strong, internationally-agreed evidence base that **the objective of seeking to limit global temperature increases to 2 degrees Celsius above pre-industrial levels was reflected in the December 2009 Copenhagen Accord, and agreed formally at Cancun in December 2010.** The Cancun agreement also proposes a consideration, to be completed by 2015, of strengthening the long-term goal, including in relation to limiting temperature rises to 1.5 degrees Celsius. The UK and EU will contribute fully to this review. However for the time being, the conclusions of the CCC that limiting global greenhouse gas emissions so that the expected temperature increase is below 2 degrees Celsius remains the right objective to manage the risks of the most serious impacts of climate change.

Global emissions pathways and the UK approach

Temperature outcomes do not depend on emissions in any given year – but on the trajectory of global emissions over the coming decades. Current emissions have a long-term impact on the climate – particularly for long-lived greenhouse gases such as carbon dioxide, which remain in the atmosphere for around 100 years or more. The level to which greenhouse gases are allowed to accumulate in the atmosphere through time strongly correlates to the eventual temperature change we can expect. Theoretically, an emissions trajectory with less ambitious early emission reductions, followed by steeper emissions reductions, could have the same long-term temperature impact as a trajectory with much more ambitious earlier action, but lower rates of emission reductions thereafter (although the rate of temperature increase could be different, which would be likely to affect impact and adaptation costs). However this does not take account of other factors including economic or technical feasibility of specific rates of reduction (see below).

A suite of emission trajectories consistent with a 50% likelihood of keeping temperature increases below 2 degrees Celsius in 2100 have been generated through the AVOID[11] research programme[12]. Based on modelling by the Met Office Hadley Centre[13], these trajectories show that the four key parameters

[9] CCC (2010); 'The Fourth Carbon Budget – Reducing Emissions through the 2020s'; http://www.theccc.org.uk/reports/fourth-carbon-budget; based on CCC's assessment of the climate science, including a peer review of over five hundred recently published peer review papers (Chapter 1).

[10] This evolving evidence base is captured in the IPCC's Assessment Reports, most recently the 2007 Fourth Assessment Report, which consists of the following three working group contributions: 'Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007'; Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.); 'Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change'; *2007* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds); 'Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007'; B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds), all Cambridge University Press, and all available at www.ipcc.ch. Since 2007, this evolving evidence base has been captured in reports including the assessment of the National Research Council of the USA National Academies; *Advancing the Science of Climate Change*, PA Matson and T Dietz (eds), available via http://americasclimatechoices.org/panelscience.shtml

[11] AVOID is a research programme that provides key advice to the UK Government on avoiding dangerous climate change brought on by greenhouse gas emissions. www.avoid.uk.net

[12] Gohar L. and Lowe J., 2009: 'Summary of the emissions mitigation scenarios: part 1'; Workstream 1, Report 2 of the AVOID programme (AV/WS1/D1/R02). Available online at www.avoid.uk.net

[13] Details included in the AVOID documentation referenced.

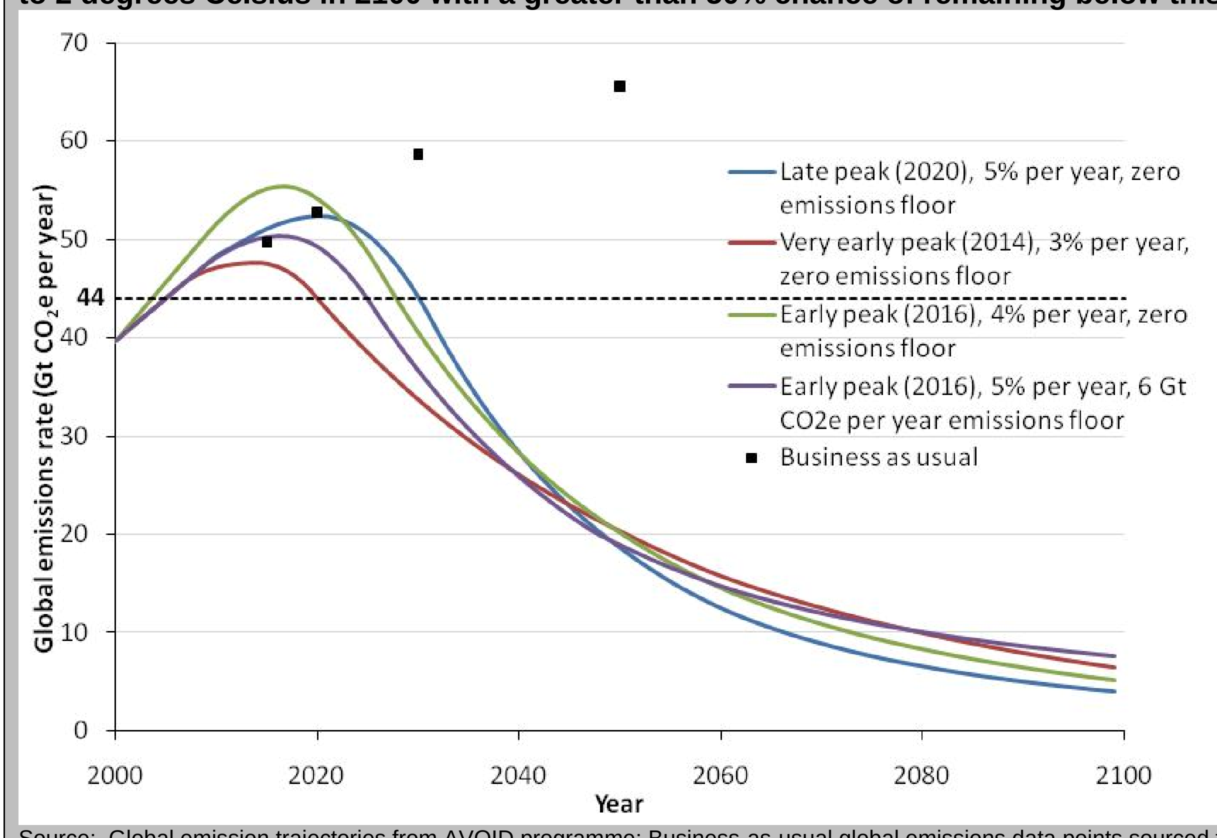
influencing global cumulative emissions are: the emissions leading up to the peak; the year in which global emissions peak; the rate of reductions beyond the peak, and; the emissions floor (the minimum level of emissions beyond 2050).

Information Box 1: The Avoiding Dangerous Climate Change (AVOID) Programme

Over 150 global emissions trajectories were investigated in the AVOID programme to examine climate response in terms of global temperature and greenhouse gas concentrations, as well as the probability of staying below specified temperature targets. These were constructed to explore the impact of varying four parameters: the emissions path leading up to a peak in emissions; the year in which emissions reach their peak (ranging from 2014 to 2030); the rate at which emissions decrease following the peak (ranging from 1% to 5% per year), and; the minimum level of net emissions that is attained in the very long term (0, 6, 11 and 16 $GtCO_2e$ per year). Using a version of the MAGICC simple climate model, a subset of around 20 trajectories were found to limit global mean temperature rise in 2100 to below 2 degrees Celsius above pre-industrial levels with a less than 50% chance of exceeding this limit. The figure below shows a small subset of these 2 degree trajectories.

An examination of these trajectories reveals that while limiting global temperature rise to below 2 degrees Celsius is challenging, it is possible. However, a delay in reaching a peak in emissions would necessitate stronger action in the future, which may be economically or technologically infeasible. This is illustrated below. A peak in 2014 would allow the 2 degree Celsius limit to be achieved with a 3% per year reduction rate. Delaying the peak increases the post-peak reduction rate that is required, such that a peak in 2020 would need to be followed by a 5% per year reduction rate and the long-term net emissions level to be zero (not shown in the figure below). Similarly, if emissions leading up to the peak are higher, or emissions in 2020 are at the lower end of the pledges made in the Copenhagen climate conference in 2009, stronger action in the future would be needed.

A subset of the AVOID suite of emissions trajectories which limit global temperature rise to 2 degrees Celsius in 2100 with a greater than 50% chance of remaining below this limit



Source: Global emission trajectories from AVOID programme; Business-as-usual global emissions data points sourced from GLOCAF model (described in section D.I).

These global emission trajectories and the modelling sensitivity around cumulative emission budgets are drawn on in the analysis section of this Impact Assessment to consider efficient UK shares of global effort (see section D.I) and sensitivities around implied UK cumulative emission levels (see section C).

The AVOID modelling shows that delayed action necessitates a higher rate of emissions reductions following the peak, and requires emissions to stabilise at lower levels in the long-term. For ambitious long-term targets in particular, strong early action is crucial to allow for relatively slower, and more likely cheaper, rates of reduction. Delaying the emissions peak significantly, for example beyond 2020, subsequently requires such rapid reductions that abatement costs rise dramatically as carbon intensive assets need to be retired before the end of their economic lives. This analysis does not include the social and political impacts of very rapid decarbonisation (such as the impact of carbon prices on fuel bills, and the political acceptability of rapid decarbonisation).

A review of the literature on the economics of aggressive emissions reductions by Bowen and Ranger (2009)[14], including the AVOID work, identified the main reasons why costs may be lower when early action is taken:

- Early action induces innovation sooner as learning, experience, economies of scale and networks are given time to evolve;
- Early action globally avoids piecemeal application of policies and the displacement of greenhouse gas emissions to late adopters of policies.
- Early action 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
- Early action allows more gradual and hence less expensive capital replacement and retrofitting.

Given the evidence on costs, a global emissions pathway involving strong early action would seem to be appropriate. Translating this into a specific single pathway is difficult but it follows that global emissions should peak before 2020. The targets and actions in the Copenhagen Accord are potentially consistent with this if all countries implement their pledged targets and mitigation actions in full and continued this mitigation action after 2020.

The global response to climate change and the UK approach

Climate change is a global challenge that requires a concerted global response. To prevent the worst of dangerous climate change the world needs to act to reduce emissions of the greenhouse gases that cause climate change. Important steps have been taken towards this goal, with progress being made at the UN climate negotiations in Cancun, December 2010[15].

However there is still much work that needs to be done. As set out in the UK's Carbon Plan[16] published in March 2011, the UK's approach will focus on:

- deploying UK and EU economic, technical, diplomatic and development assets to influence global political and economic conditions to secure action from other countries;
- helping developing countries build the climate resilience of their economies and move towards low carbon growth in the future, and;
- working for a comprehensive, global climate change agreement.

What this specifically means for the UK's equitable burden share of global effort will depend on the course of the international climate negotiations. However, equity arguments do point to the need for the UK and other developed countries to take the lead in delivering ambitious emissions reduction goals[17]. The relationship between domestic and international ambition is an issue to be kept under review as the international climate change negotiations progress.

The UK's efficient share of global effort is distinct from equitable burden share considerations, and reflects the cost-effective level of UK territorial abatement as part of an efficient global effort to mitigate climate change. This would minimise costs by exploiting least cost abatement

[14] 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

[15] 'Cancun breakthrough puts climate deal back on track'; DECC Press Release (2010); http://www.decc.gov.uk/en/content/cms/news/pn10_127/pn10_127.aspx and; 'Outcomes of Cancun Climate Conference (Oral Statement to Parliament)' Oral Statement to Parliament by Chris Huhne, Secretary of State for Energy and Climate Change, on 13th December 2010; http://www.decc.gov.uk/en/content/cms/news/os_cancun/os_cancun.aspx

[16] DECC, Carbon Plan, March 2011; http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/carbon_plan/carbon_plan.aspx

[17] Article 4 of the UN Convention on Climate Change specifies this as a requirement in determining international agreements on climate change; http://unfccc.int/resource/docs/convkp/conveng.pdf

opportunities wherever they are located. Through the flexibility afforded by international carbon trading, consideration of the efficient level of UK territorial emissions reductions can be reconciled with considerations of an appropriate UK burden share of global action to mitigate climate change – the UK could trade in international carbon units to make up any difference. Analysis of the efficient level of UK territorial emissions is presented in Section D.I.

The Case for UK Action

The Impact Assessment[18] for the Climate Change Act 2008 set out the rationale and supporting analysis for setting the UK's 2050 emissions reduction target, to reduce UK emissions by at least 80% relative to 1990 and the series of carbon budgets which set the trajectory towards this long-term target. The Climate Change Act Impact Assessment looked at the costs and benefits of action to meet the 2050 target relative to business as usual (see Information Box 2); the benefits of action were calculated with reference to the value of the social cost of carbon under scenarios in which the UK acts alone or with others in concerted global action to tackle climate change. The latest scientific evidence, outlined above, reinforces this case.

This Fourth Carbon Budget Impact Assessment does not look again at the case for action to tackle climate change. Instead it considers different options for the level of the fourth carbon budget assessed against three analytical perspectives (outlined in the evidence base section); **a long term pathway perspective** considering least-cost pathways to 2050; **a Global perspective** in which the efficient level of UK abatement is considered under different levels of global action to 2027, and; a **static cost-effectiveness perspective** considering how much the UK can feasibly and cost-effectively reduce emissions by in the UK over the 2020s. These perspectives emphasise the efficiency principle of minimising costs to UK society, but also include considerations of technological feasibility over the 2020s and to 2050, the consistency of technology pathways from 2020 to 2050, and concerns for cumulative emissions and wider impacts.

Information Box 2: Climate Change Act 2008 Impact Assessment

The Climate Change Act Impact Assessment[19] set out the rationale for taking action on climate change: there are external costs associated with the emission of greenhouse gases and those who produce them do not face directly the full consequences of their actions. In addition, the Impact Assessment noted that climate change has a number of features that together distinguish it from other environmental problems:

- it is global in its causes and consequences;
- the impacts of climate change are long-term and persistent;
- there are uncertainties and risks in the economic impacts; and
- there is a serious risk of major, irreversible change with non-marginal economic effects.

The fundamental rationale for the setting of the 2050 target (and a series of carbon budgets to gradually set a pathway to 2050) in the Climate Change Act rested on analysis of the costs of inaction (damage costs) versus the cost of action (abatement costs), allied to a clear understanding that the actions of individuals alone would not be sufficient to lead to an optimal reduction in the level of emissions.

The Impact Assessment drew upon the Stern Review[20] (2006), which 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 carbon dioxide equivalent (CO_2e)). The Stern Review also set out three essential elements of policy required for an effective global response that minimises the costs to society: (i) the establishment of a carbon price so that consumers and producers bear the full cost of consumption or production decisions; (ii) the promotion of innovation in low-carbon technologies; and (iii) overcoming market barriers and failures to increase cost effective mitigation potential in the short and medium run, particularly in relation to uncovering greater energy efficiency savings.

The Impact Assessment presented cost-benefit analysis of the long term target created by the Climate Change Act. It found that the net benefits of action were large in the case where the UK acts in concert with other countries to mitigate climate change.

[18] DECC (2009); 'The Climate Change Act 2008 Impact Assessment'; http://www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx

[19] Ibid

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

The Stern Review concluded that, based on an extensive review of the current literature, the long run costs of global action to stabilise atmospheric greenhouse gas concentrations at 550ppm CO2e are expected to be around 1% of GDP by 2050, within a range of +/-3%. Coordinated multilateral action, with good policy design and flexibility over where, when and what emissions are reduced are essential to keep costs this low. This range is substantially lower than the expected costs of "doing nothing" to reduce climate change, estimated at between 5% and 20% of global GDP now and forever.

In 2009, Lord Stern stated that he now thinks that the damage cost estimates should be larger than those reported in the Stern Review. Since the publication of the Review, others have made arguments based on the scarcity of environmental resources (Sterner[21]) and the impact of low probability high impact events (Weitzman[22]) to justify strong action. More recently, Lord Stern has updated his conclusion[23] stating that a more ambitious trajectory consistent with a 2°C goal would cost around 1-2% of GDP.

The Climate Change Act 2008

The Climate Change Act 2008 establishes a long-term legislative framework to cut greenhouse gas emissions. It does this in two ways: by setting a target for 2050 to reduce greenhouse gas emissions by at least 80% below the 1990 baseline, and by requiring a system of legally binding five-year 'Carbon Budgets' to be set with a view to meeting the 2050 target. Carbon budgets and targets can be met through a combination of action in the UK and trading of carbon units overseas (up to limits to be specified). Carbon budgets are set on a rolling basis. The first three carbon budgets (2008-2012, 2013-2017 and 2018-2022) were set in 2009. Subsequent carbon budgets must be set eleven and a half years before their start. The fourth carbon budget, which runs from 2023-7, must therefore be set by the end of June 2011.

The Act established an independent body, the Committee on Climate Change (CCC), to provide advice to Government and report on progress[24]. It lays a duty on the CCC to advise on the level of a carbon budget, on the extent to which the carbon budget could be met through the purchase of carbon units from overseas and the respective contributions that different sectors should make (Section 34 of the Act).

The CCC provided its advice[25] **on the level of the fourth carbon budget on 7th December 2010. The Climate Change Act states that the Government has to take into account this advice before proposing a carbon budget level for agreement by Parliament.** As soon as practicable after the budget has been set, the Government must report on the **policies and proposals to meet the budget**. The Government[26] has said it will do this in October 2011.

The Climate Change Act sets out a list of matters that have to be taken into account by the Government when setting a carbon budget level (Section 10 of the Act). These are:

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

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[21] Sterner, T. and U. M. Persson (2007) "An even sterner review: Introducing relative prices into the discounting debate," Working draft, May 2007; www.hgu.gu.se/files/nationalekonomi/personal/thomas%20sterner/b88.pdf

[22] Weitzman M (2007); 'A review of the stern review on the economics of climate change'; Journal of Economic Literature 45(3):703–724

[23] In his 2009 publication "A Blueprint for a Safer Planet", the cost of mitigation is updated from 1% of world GDP by 2050 for concentrations around 550 parts per million (ppm), to 1-2% of world GDP by 2050 to achieve a more ambitious concentration of around 500 ppm CO2e (with scope for further reductions after 2050 to meet a 2 degree Celsius goal).

[24] The CCC must produce annual reports to Parliament on the progress that has been made towards meeting budgets. Government must publish a response to each report.

[25] CCC (2010); 'The Fourth Carbon Budget – Reducing Emissions through the 2020s'; http://www.theccc.org.uk/reports/fourth-carbon-budget

[26] DECC Business Plan; http://www.decc.gov.uk/assets/decc/About%20us/decc-business-plan-2011-2015.pdf

g) Differences in circumstances between England, Wales, Scotland and Northern Ireland;
h) Circumstances at European and international level;
i) The estimated amount of reportable emissions from international aviation and international shipping for the budgetary period or periods in question.

Legislated Carbon Budgets

The first three legislated carbon budgets were presented as *interim* budgets, aligned with the UK share of the current EU target to reduce emissions by 20% below 1990 levels by 2020. There is therefore a commitment to tighten them following an EU move to a more stringent reduction target. These tighter *intended* budgets were estimated by the CCC at the time to be equivalent to a 42%[27] reduction against 1990 **levels by 2020, based on the UK's expected share of an EU-wide 30% emissions reduction target for** 2020.

Figure 3. UK Legislated and 'Intended' Carbon Budgets ($MtCO_2e$)

$MtCO_2e$	First Carbon Budget (2008-12)	Second Carbon Budget (2013-17)	Third Carbon Budget (2018-22)
Legislated *Interim* Budgets	3018	2782	2544
Percentage reduction from 1990[28]	22.9%	28.9%	35.0%
CCC's *Intended* Budgets	3018	2679	2245
Percentage reduction from 1990	22.9%	31.6%	42.7%

The UK is pressing hard in Europe to encourage an early move to the 30% target. However, it cannot be said with any certainty what the UK's burden share of this level of EU-wide target would be as this will be subject to further negotiation.

The Climate Change 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).

Scope of UK Carbon Budgets and the Net UK Carbon Account

The UK's performance against its legislated carbon budgets is assessed relative to the net UK carbon account (Section 27 of the Act). The net UK carbon account covers;

- Emissions from the UK (not including Crown Dependencies and UK Overseas Territories) of the 'Kyoto basket' of greenhouses gases (GHGs) which includes all carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), Hydrofluorocarbons (HFCs) , Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6) emissions;

- Including net emissions/removals[29] from Land-Use, Land-Use Change and Forestry (LULUCF); and
- Is net of the purchase and sale of international carbon units. Carbon units include allowances issued under cap and trade systems, such as the EU ETS (see below), and international carbon units representing developing country emissions reductions issued under the Clean Development Mechanism.

[27] These percentages have changed since 2008 when the CCC gave advice on the first three carbon budgets (CCC (2008); 'Building a low carbon economy'; http://www.theccc.org.uk/reports/building-a-low-carbon-economy) owing to a update in the GHG Inventory which revised total 1990 baseline UK GHG emissions from 777.4 $MtCO_2e$ to 783.1 $MtCO_2e$. This number is the denominator in this calculation, hence whilst the budget levels (in $MtCO_2e$) have not changed, the 1990 baseline and percentages have.

[28] These percentages have changed since 2009 when legislated and quoted in the Low Carbon Transition Plan ('The UK Low carbon Transition Plan – National Strategy for Climate and Energy'; DECC (2010); http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/lc_trans_plan/lc_trans_plan.aspx) owing to a update in the GHG Inventory which revised total 1990 baseline UK GHG emissions from 777.4 $MtCO_2e$ to 783.1 $MtCO_2e$. This number is the denominator in this calculation, hence whilst the budget levels (in $MtCO_2e$) have not changed, the 1990 baseline and percentages have

[29] In this context, 'removals' refers to where emissions are taken out of the atmosphere. The full definition of LULUCF emissions are included in information box 4.

Each carbon budget sets a maximum level for the total net UK carbon account over a five year period, in tonnes of carbon dioxide equivalent (tCO_2e). More information on the net UK carbon account and carbon accounting rules can be found on the DECC website[30].

International Aviation and Shipping

The Climate Change Act, and therefore by definition the net UK Carbon Account, currently excludes emissions from international aviation and shipping. The Act states that in setting carbon budgets, government must take these emissions into account[31].

In its December 2010 advice to Government regarding the fourth carbon budget, the CCC recommended 'that Government should accept the principle that international aviation and shipping emissions of CO_2 will be included in carbon budgets', but that 'further assessment is required in order to determine the appropriate approach to potentially significant non-CO2 emissions and effects'[32].

The Act requires the Government either to make regulations to specify the circumstances in which, and the extent to which, emissions from international aviation or international shipping [33] are to be included in carbon budgets and the 2050 target, or to lay before Parliament a report explaining why such regulations have not been made, by the end of 2012[34].

The European Union Emissions Trading System (EU ETS)

The European Union Emissions Trading System (EU ETS) covers direct emissions from power generation and heavy industry (and aviation from 2012) and sets a cap at the EU level for these emissions. In the UK this represents around 40%[35] of the UK emissions (referred to as the traded sector). For the purpose of calculating the net UK carbon account, emissions in the traded sector are taken to be equal to the UK's share of the EU ETS cap. Whilst there is volatility in these UK territorial emissions, driven by variables such as the carbon price and fossil fuel prices, there is certainty over the traded sector share of the net UK carbon account, which derives from the established level of the cap on UK emissions.

The UK share of the EU ETS cap is the sum of the allowances allocated for free to UK installations covered by the EU ETS and the UK's share of auctioned allowances. Once negotiated, this share of the fixed cap is relatively stable[36]. This certainty over the traded sector component of the net UK carbon account provides a significant advantage in managing carbon budgets, and the EU ETS is an important instrument for guaranteeing emission reductions.

The overall environmental outcome (total EU-wide emissions from the traded sector) is fixed, although the level of territorial emissions in the UK or any other EU Member State may vary:

- If the UK went further and reduced territorial emissions below the UK share of the EU ETS cap, this would not lead to an additional reduction in global emissions. Going further would, in the absence of other measures, result in a net outflow of allowances from the UK, increasing the availability of allowances to installations outside of the UK, whose emissions could increase within the overall EU ETS cap. The net UK carbon account would be unchanged because the increased export of allowances from the UK would cancel out the reduction in UK territorial emissions.

[30] 'Guidance on Carbon Accounting and the net UK carbon account' http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/carbon_budgets/carbon_budgets.aspx
[31] Climate Change Act 2008, Section 10.
[32] CCC (2010); 'The Fourth Carbon Budget – Reducing Emissions through the 2020s'; Page 33.
[33] Note that international aviation emissions associated with all flights arriving at and departing from European Economic Area (EEA) airports will be included in the EU ETS from 2012. The European Commission have also committed to introducing legislation to limit international maritime emissions from 2013 in the event that an international approach from the International Maritime Organisation (IMO) is not forthcoming by this time.
[34] Climate Change Act 2008, Section 30.
[35] On average over the first three carbon budgets.
[36] Varying only with small changes to the distribution of allowances resulting from closures and new entrants to the system, and uncertainty associated with the historical production data for UK and other EU installations, which will determine levels of free allocation and levels of UK auction volumes but will not be known until after all Member States have submitted their National Implementation Measures (NIMs) Plan in September 2011.

- Likewise, if UK territorial emissions exceed the UK share of the cap, then compliance requires that UK installations covered by the scheme purchase allowances from other installations with a surplus in other member states, or (subject to strictly defined limits) international offset credits.

Beyond 2020 the evolution of the EU ETS is uncertain. This is considered in Section C.II of the evidence base.

Information Box 3: The European Union Emissions Trading System (EU ETS)
The EU ETS covers installations whose emissions make up around 40% of UK GHG emissions. This includes power generators and heavy industry, such as manufacturers of iron and steel, mineral processing industries (for example, cement manufacture) and pulp and paper processing industries. Domestic and international aviation will enter the EU ETS in 2012.

As a cap-and-trade system, the EU ETS sets an emissions limit (the cap) for installations covered by the system, thereby ensuring a set volume of emissions reductions over the period of operation. By allowing trading between installations, the system enables an organisation to decide when and how they will reduce emissions, ensuring emissions are reduced where the cost of the reduction is lowest. Operators with a low abatement cost will choose to reduce emissions by more than the required amount and sell excess allowances to those operators with higher abatement costs. Additional flexibility is provided to installations by allowing them to purchase a limited number of project credits from those projects that reduce emissions outside of the EU ETS (mostly in developing countries) through the Kyoto Protocol.

Baseline Emission Levels and the 2050 Target

The baseline level of UK greenhouse gas emissions from which the emission reduction targets in the Climate Change Act are referenced is recorded as 783.1 $MtCO_2e$. This is referred to as the 1990 baseline and consists of net UK emissions in 1990 for CO_2, methane and nitrous oxide GHGs, and 1995 for fluorinated gases[37], recorded in the latest GHG emissions Inventory[38] (calculated according to the latest international reporting practice as required by the Act).

The long-term target enshrined in the Climate Change Act, to reduce emission levels by at least 80% below the 1990 baseline, would therefore require the net UK carbon account to reduce to at most 156.6 $MtCO_2e$ by 2050.

Should international aviation and shipping emissions be included in the Climate Change Act, an accounting basis for inclusion would need to be determined. One allocation methodology is the emissions from bunker fuels sold in the UK to the international aviation and shipping sectors. This is the method the EU has used to include international aviation in the EU's GHG targets. On this basis in 1990, UK international aviation and shipping emissions amounted to 24.9 $MtCO_2e$[39]. This would imply that if international aviation and shipping emissions were included in the Act, by 2050, net UK carbon emissions including international transport would need to reduce to 161.6 $MtCO_2e$ or lower by 2050. There are, however, a number of possible ways to determine a UK share of international emissions. The CCC will provide advice on the appropriate methodology for allocating international emissions to the UK before the decision on whether or not to include these emissions must be taken in 2012.

The Fourth Carbon Budget

This Impact Assessment concerns the level of the fourth carbon budget, which covers the period 2023-7.

The Committee on Climate Change's Fourth Carbon Budget Advice

The CCC advice on the fourth carbon budget is that, owing to the uncertainty surrounding the shape of a future global climate change deal beyond 2020, it is appropriate for the time being to set a fourth carbon

[37] Under the Climate Change Act 2008, Section 25, 'the 1990 baseline' means net UK emissions in 1990 for CO_2, nitrous oxide and methane and in 1995 for the other greenhouse gases.
[38] National Statistics - UK Greenhouse Gas Emissions Inventory (DECC, February 2011): http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/uk_emissions/2009_final/2009_final.aspx
[39] UK GHG Inventory, February 2011 – figure relates to United Kingdom, Isle of Man, Jersey and Guernsey. Excludes all overseas territories.

budget level that can be met territorially. The Government should then consider amending the fourth budget downwards (i.e. make it more ambitious) to reflect the outcome of a future international climate deal that extends beyond 2020.

The CCC's advice is that the Government should legislate now for a fourth budget of 1950 $MtCO_2e$. This was based on its medium abatement scenario, where territorial emissions in the traded sector amounted to 690 $MtCO_2e$ and territorial emissions in the non-traded sector amounted to 1260 $MtCO_2e$. Overall this is equivalent to an average reduction in emissions of 50% relative to 1990 over the budget period. It proposes that the Government should aim to meet this budget level through territorial emissions reductions, i.e. without recourse to purchasing international carbon units (including through the EU ETS).

The CCC also provided an assessment of the minimum UK contribution for the fourth carbon budget period likely to be appropriate to a future global deal covering the 2020s. They suggested that an amended fourth carbon budget, to reflect a future global deal, could be around 1800 $MtCO_2e$. This is equivalent to an average reduction in net UK emissions of 55% relative to 1990 over the budget period. They suggested that the purchase of international carbon units could form part of a strategy for meeting a more stretching fourth budget level.

Further detail on the CCC's advice and underpinning analysis is presented in Section E.

Basis for Setting the Fourth Carbon Budget Level

The options explored in this Impact Assessment for the fourth carbon budget consider levels set on a net UK carbon account basis, i.e. taking into account trading in accordance with existing carbon accounting rules for carbon budgets. The CCC advised that the Government should plan to meet their 'Domestic Action Budget' of 1950$MtCO_2e$ on a territorial emissions basis – before any credit from the purchase of international carbon units is considered.

The Climate Change Act allows carbon budgets to be amended after they have been set if the circumstances under which they were set change. Once the UK's share of the EU ETS cap for the period is known, and following any developments in the international domain around a UK burden share of a global deal or future EU targets, it may therefore be necessary to amend the fourth budget to reflect these changes. The same is true for the second and third carbon budgets currently set in legislation. **The working assumption for this Impact Assessment is that the traded sector share of the fourth carbon budget is set at, or amended to be, at a level which is consistent with the UK share of the EU ETS cap. Uncertainty over the future UK share of the EU ETS cap does not therefore impact on the level of emissions reductions required in the non-traded sectors.**

The option levels presented in this Impact Assessment exclude emissions from international aviation and shipping, consistent with the Climate Change Act 2008. However, the inclusion of international aviation and shipping emissions (outlined in the section above) is considered alongside the many uncertainties surrounding the 2050 target.

The Evidence Base

Introduction

In considering the evidence for setting the fourth carbon budget level emphasis has been placed on the efficiency principle – to set a budget level that minimises costs to society overtime. Different perspectives exist on how to assess this principle in this context, all of which warrant consideration:

- **A long term pathway perspective** – considering what a least-cost pathway to 2050 would be given considerations of the energy system and mix of technologies, balancing costs of action now with long-term costs to 2050;

- **A global perspective** – considering what the efficient level of UK territorial emissions would be as part of a global effort to reduce emissions, consistent with meeting the objective of limiting temperature rises to 2 degrees Celsius above pre-industrial levels by 2100; and

- **A static technical feasibility and cost-effectiveness perspective** - considering how much the UK can technically and cost-effectively reduce emissions by in the UK over the 2020s given available technical abatement measures.

This evidence base is divided into five main parts. Part I outlines the evidence on UK emissions and projections. Part II presents the evidence on the three analytical perspectives highlighted above. Part III summarises the recommendations and analysis of the CCC. Part IV considers wider matters outlined by the Climate Change Act (Section F) and finally Part V concludes by assessing the fourth carbon budget level options considered in this Impact Assessment against the analytical perspectives.

Structure of evidence section

Part I: UK Emissions and Projections

A. Historic Reductions
B. Business as usual Emission Projections

Part II: Assessment Criteria: The Three Perspectives

C. Geometric Trajectories from 2020 to 2050 and Long Term UK Pathways to 2050
D. The Cost-Effective Level of UK Abatement:
    I. Globally Efficient share of UK Territorial Emissions
    II. International circumstances, the EU ETS and the Net UK carbon account
    III. Analysis of Static Abatement Potential and Costs

Part III: The CCC's Advice

E. Recommendations of the Committee on Climate Change regarding the Fourth Carbon Budget

Part IV: Wider Impacts

F. Consideration of wider impacts

Part V: Conclusions

G. Assessment of Options against the Evidence Base

Uncertainty and Limitations of the evidence base

The evidence base used to inform this analysis is subject to inherent uncertainty in forecasting forward into the future – in the 2020s and over the period to 2050, in the UK and globally. Uncertainty in emission projections and forecasts of abatement potential and costs to society result from uncertainty over future temperatures, fossil fuel prices, economic growth, technology development and associated costs, innovation and demographic trends. This uncertainty affects both emission projections and the marginal abatement cost curve analysis presented in subsequent sections. If fundamentals turn out to be different than forecast, emissions projections, abatement potential identified above these baseline levels and costs could turn out to be higher or lower than expected. There is also modelling uncertainty surrounding the ability to forecast economic relationships, for example the relationship between economic growth and emissions. These types of uncertainty are likely to increase over time as the structure of the UK economy and economic relationships evolve.

Results presented in this evidence base are best estimates based on the suite of models available and of standard practise in DECC. These are based on central uncertainty assumptions around exogenous factors such as GDP growth, fossil fuel prices, and carbon prices. (See Annex 2 and 3 for the set of these assumptions).

The evidence base is not sufficiently granular or robust to currently prescribe a precise level of ambition for the fourth carbon budget, but it can suggest which budget options may be closest to an efficient level. The options for the fourth carbon budget level are framed around different analytical approaches and the appropriateness of the options for the level of the fourth carbon budget can be judged in light of this evidence. However, because each perspective is partial, the perspectives are not necessarily perfectly consistent in their conclusions. For instance, the global perspective makes a comparison of the cost-effectiveness of abatement across regions of the world in each time period, which therefore does not consider dynamic or pathway issues. **The concluding section of this Impact Assessment will consider the appropriateness of the potential budget levels in light of all three perspectives together, in addition to the advice of the CCC.**

The following six carbon budget levels, covering all UK GHG emissions over the period 2023-7, have been considered.

Figure 4. Fourth Carbon Budget Level Options

	Description	**4th Carbon Budget Level ($MtCO_2e$)**	**Average emissions reduction relative to 1990**	**Traded Share** ($MtCO_2e$/% total)	**Non-Traded Share** ($MtCO_2e$/% total)
Option 1	'Do nothing' scenario – a non-constraining budget. Level based on a continued EU ETS cap trajectory based on the current EU ETS directive and an illustrative non-constraining budget level in the non-traded sector	Non-constraining budget, e.g. 3000	23%	860 (29%) (estimated EU ETS cap)	2140 (71%)
Option 2	Level based on a continued EU ETS cap trajectory and in the non-traded sector, a continued downward trajectory from legislated second and third carbon budgets (2013-22)	2310	41%	860 (37%) (estimated EU ETS cap)	1450 (63%)
Option 3	Level based on a continued EU ETS cap trajectory and a cost-effective level of UK territorial abatement in the non-traded sector defined by Government's static carbon values	2170	45%	860 (40%) (estimated EU ETS cap)	1350 (60%)
Option 4	Level based on a continued EU ETS cap trajectory and the CCC recommended level of emissions in the non-traded sector	2120	46%	860 (41%) (estimated EU ETS cap)	1260 (59%) implied CCC medium abatement scenario
Option 5	CCC recommended fourth carbon budget	1950	50%	690 (35%) implied CCC medium abatement scenario	1260 (65%) implied CCC medium abatement scenario
Option 6	CCC Global Offer Budget – the CCC's assessment of what the fourth budget might need to be amended to in the future to reflect the UK's share of a future global climate change deal	1800	54%	690 (38%) minus 150 (-8%) international credit purchases	1260 (70%) implied CCC medium abatement scenario

Part I: UK Emissions and Projections

This section begins by considering historic emission reductions and near–term emissions projections for the UK. Further details from these projections and the assumptions underlying them are published alongside this Impact Assessment[40].

Section A: Historic Reductions

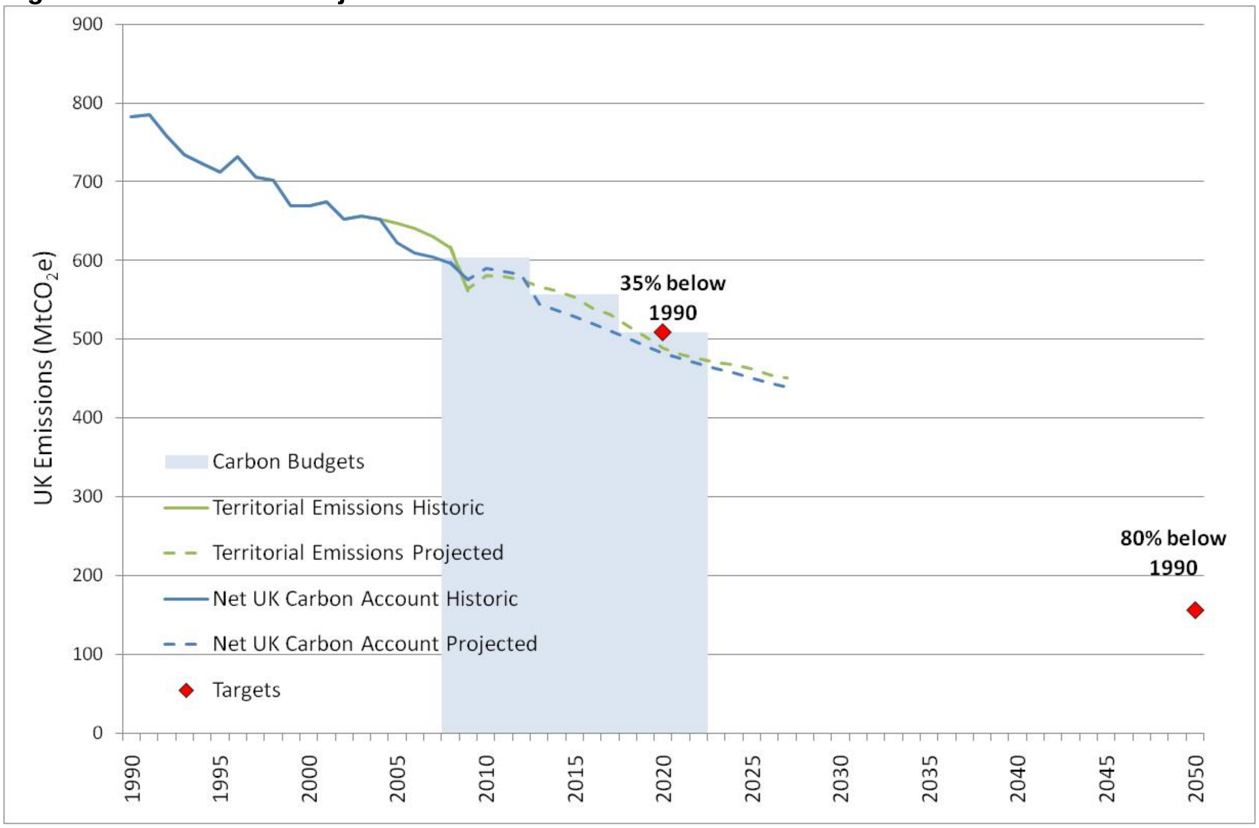
Summary:
Since 1990 historic territorial emission levels have fallen consistently. More recently, the 2008-9 recession had a significant impact. Pre-recession the average annual reduction in GHG emissions was 1.3% p.a. This decline was predominately driven by a decline in non-CO_2 GHGs, which fell faster than CO_2 emissions.

UK emission forecasts from 2009-27, on central projections forecast a decline in UK territorial emissions by on average 6.3 $MtCO_2e$ per year or 1.2% per annum. There is however uncertainty around these projections. Taking the 95% confidence interval around the emissions projections varies the average annual projected reduction in emissions from 7.6 $MtCO_2e$ to 3.3 $MtCO_2e$ under low and high emissions projections respectively.

Historic Progress and Projected Emissions relative to 1990

In 1990 UK GHG emissions on a net UK carbon accounting basis were 783.1 $MtCO_2e$.

Figure 5. Historic and Projected UK GHG Emissions



Source: Historic data - DECC UK GHG Emissions Inventory (DECC, February 2010).
Projections – DECC Energy and Emissions Model, DECC Non-CO_2 GHG Projections, DECC LULUCF Projections .

[40] DECC, Emission Projections, 2011: See Annex 3

In 2009[41], UK territorial emissions were 561.8 $MtCO_2e$ (a 28.3% reduction on 1990 levels). The net UK carbon account emissions level was higher, at 575.3 $MtCO_2e$ (a 26.5% reduction on 1990 levels), indicating that in 2009, the UK was a net seller of international carbon units under the EU ETS.

Since 1990, historic territorial emission levels have fallen on average 1.7% per year , or 11.6 $MtCO_2e$ per year. The 2008-9 recession had a significant impact on UK emissions (as illustrated in Figure 5). Territorial emissions fell by 8.8% between 2008 and 2009. In limiting the period under analysis to 1990-2007, pre-recession average annual reductions were 1.3% per annum.

By comparison, since 1990 the UK's net carbon account has fallen on average by around 1.6% per annum, or by around 10.9 $MtCO_2e$ per year. Limiting the period under analysis, pre-recession average annual reductions were around 1.5% per year.

The decline in UK territorial GHG emissions has been driven by reductions in non-CO_2 GHG emissions; methane emissions fell 61% from 1990, nitrous oxide emissions by 49%, and combined F-gases by 16%. In comparison energy related CO_2 emissions (excluding LULUCF) fell by 20% on 1990, but form a significant share of UK territorial emissions, 84% of total UK GHGs in 2009.

UK emission forecasts to 2027, on central projections taking into account current policy up to 2022 and their legacy of savings to 2027, project a reduction in UK territorial emissions by on average 6.3 $MtCO_2e$ per year or 1.2% p.a., within which non-CO_2 GHG emissions are forecast to decline 0.9% p.a. There is however uncertainty around these projections. Taking the 95% confidence interval around emissions projections over the period 2009-2027, the forecasted annual decline in emissions ranges between 7.6 $MtCO_2e$ and 3.3 $MtCO_2e$ under low and high emissions projections uncertainties respectively.

Section B: Business as Usual Emission Projections

DECC last published updated emissions projections in June 2010[42]. The projections presented here should be interpreted as projections under a 'do nothing' scenario over the fourth carbon budget period rather than an update to the June 2010 projections. Further detail on the projections presented in this Impact Assessment can be found in Annex 3. A full emissions projections update will be published in October 2011.

Note that these emission projections are not the counterfactual from which the fourth carbon budget options are assessed – but are the 'business-as-usual' emissions projections, and form a key part of the counterfactual. The detail of the counterfactual is described in Section G.

<u>Summary:</u>
In 2020, UK territorial emissions are forecast, on central projections, to be 488 $MtCO_2e$, 38% below 1990 baseline levels.

Over the fourth carbon budget (2023-7), UK territorial emissions are forecast, on central projections, to be 2306 $MtCO_2e$, on average 41% below the 1990 baseline.

Emission projections are uncertain. Over the fourth carbon budget period, modelled territorial emissions range from 2195 $MtCO_2e$ to 2631 $MtCO_2e$. The true uncertainty range may be higher.

UK emission projections reflect no extension of existing climate change policies beyond 2022, but capture the legacy of policies which continue to reduce emissions over the 2020s so as to determine emission levels for the fourth carbon budget analysis.

The projections assume a continued carbon price in the traded sector, reflecting the business-as-usual assumption that the EU ETS continues based on its current trajectory, as provided for in the 2009 EU ETS directive, and the announced Carbon Price Support in the Power sector.

[41] Latest reported inventory emission levels.
[42] 'Updated Energy and Emissions Projections'; DECC (June 2010); http://www.decc.gov.uk/assets/decc/Statistics/Projections/67-updated-emissions-projections-june-2010.pdf

In the assessment of options in this impact assessment, the 'business-as-usual' emissions projections are used to form a counterfactual emissions scenario against which the options are assessed. Taking into account half of the net negative cost abatement identified in the non-traded sector and a view of the UK's share of the EU ETS cap over the fourth budget period, the counterfactual emissions scenario has an emissions level of 2234 $MtCO_2e$ over the fourth budget period, split 1374 $MtCO_2e$ and 860 $MtCO_2e$ between non-traded and traded sector shares respectively.

The emission projections presented in this section reflect business as usual forecasts up to 2027, should no further action be taken by Government other than through the policies and proposals announced to date[43], and given current assumptions on key exogenous drivers of UK emissions (such as economic growth, population growth and fossil fuel prices, summarised in Annex 2 and 3). The projections take account of changes to policy announced since DECC last published emissions projections in June 2010[44] and also of updates to key economic drivers.

These projections shape the baseline from which additional abatement potential is assessed (detailed in Section D.III), and to estimate the emissions gap required to be met through abatement or credit purchase in order to meet different fourth carbon budget levels (the difference between budget levels and emission projections). This is drawn together in the concluding section of the Impact Assessment (Section G).

No assumptions have been made to extend existing policies and proposals into the 2020s. However many existing policies and measures continue to have a legacy, reducing emissions over the 2020s, thereby contributing to reductions over the fourth carbon budget period. For example, the current EU target for new car CO_2 emission standards only extends to 2020, but emissions reductions beyond then will continue as more new cars purchased up to 2020 will remain in the vehicle fleet until they are replaced.

In the traded sector, the business-as-usual assumption is that the EU ETS continues to exist with a continuation of the current cap trajectory (as set out in the 2009 EU ETS Directive, which imposes an annual 1.74% decrease in the cap from 2013 onwards, with no sunset clause), and that installations and firms covered by the scheme continue to face a carbon price which affects their production decisions (for example, electricity generation decisions. See Annex 2 for more detail on carbon price assumptions). Electricity generation decisions are also influenced by the Carbon Price Support (CPS), announced in the Fiscal Budget 2011. The carbon price faced by electricity generators is modelled as the CPS.

Information Box 4: DECC's Emission Projections

The DECC Energy and Emissions model projects energy demand using econometric equations and models the UK energy market. Key drivers of CO_2 emission levels, through their impact on both the level of demand and the type of energy supplied, are exogenous factors such as GDP growth, international fossil fuel prices, carbon prices and size of the UK population. Assumptions on expected policy savings from the range of Government's policies feed into these projections, reducing energy demand or changing the generation mix.

The input data and assumptions in the model are subject to uncertainty which increases over time. For example;
- the exogenous inputs (GDP, fossil fuel prices and UK population growth) are all subject to their own assumptions and levels of uncertainty around what the actual level may be in the future;
- expected policy savings are uncertain - numerous factors can affect whether policies will deliver as expected, and;

[43] Policies included are: EU ETS, Carbon Price Support (announced Fiscal Budget 2011), Renewable Heat Incentive (as announced March 2011), Climate Change Agreements, Carbon Reduction Commitment Energy Efficiency Scheme, Small and Medium sized Enterprise loans scheme, Salix and PBR loans, Green Deal, Smart Meters, Community Energy Savings Programme, Carbon Emissions Reduction Target, Buildings Regulations 2002 and 2005, Buildings Regulations 2010 and Zero Carbon Homes, Energy Performance of Buildings Directive, Products policy, Warm front and fuel poverty, Carbon Trust measures, CO_2 from cars 95g/km by 2020, EU new van regulation, Eco driving, Low Carbon Buses, Complementary measures for cars, Low rolling resistance tires, Landfill tax and Agricultural savings.

[44] Some of the main changes relate to the ambition set out by the previous Government in documents such as Greener Homes, Warmer Homes (2010) (http://www.decc.gov.uk/assets/decc/what%20we%20do/supporting%20consumers/household%20energy%20management/1_20100331101157_e_@@_warmhomesgreenerhomeshemstrategy.pdf), which has been superseded by the Green Deal (http://www.decc.gov.uk/en/content/cms/what_we_do/consumers/green_deal/green_deal.aspx).

- the parameters in the model are uncertain, particularly in the longer-run. For example, the energy demand responses to prices and output are estimated from analysis of past data.

In order to take account of some of the sources of this uncertainty in the emissions projections, ranges for emissions levels are produced based on statistical techniques (Monte Carlo simulation) to capture the likely frequency of different levels for some of the key input factors (fuel prices, GDP, temperatures, policy impacts, power station capital costs and non CO_2 emissions). Results presented in this section show the impact of capturing this uncertainty modelled from a reduced form of the model, consisting of simple econometric equations for consumption of oil, gas, coal and electricity, the electricity demand then being met by a one-pass solution of the electricity supply sub-model. The method also takes some account of modelling uncertainty caused by errors in the demand equation estimates, but does not take account of the potential increase in forecast error over time. Uncertainty arising from internal modelling assumptions are also not taken into account.

The model is calibrated to the UK GHG inventory and DUKES data, the former currently based on 2009 levels (published February 2011, the latest available to carry out this modelling exercise).

The DECC non-CO_2 GHG projections use the methodologies from the national Greenhouse Gas Inventory report. Projections are calculated using forecast activity statistics, emissions factors and various other sector specific assumptions for each of the main sources of emissions. Greenhouse gas emission projections are disaggregated by sector and aggregated to provide an estimate of total projected emissions. The projections system is designed to be transparent, flexible and easy to update. Uncertainties are calculated by running a simplified Monte Carlo model at National Communication aggregation level – expert opinion informs the uncertainty calculation inputs.

The DECC LULUCF projections (land use, land use change and forestry) cover CO_2 emissions from forestry, crop and grassland management, and other land uses. It is the only sector where CO_2 can be removed from the atmosphere (due to photosynthesis). LULUCF can therefore show net emissions, net removals or zero change, if emissions and removals are in balance. Projections are estimated by the Centre for Ecology and Hydrology under contract to DECC, using methods consistent with the UK greenhouse gas emission inventory, coupled with projections of future land use and land-use change, based on what has happened historically and possible future scenarios. Uncertainties are estimated using Monte-Carlo Analysis, projected forward where necessary. The LULUCF projections have been recently revised to reflect the latest survey and Inventory data available.

'Business-as-usual' UK Emission Projections 2008 to 2027

UK emission forecasts, on central projections of policy savings and central assumptions on exogenous factors, place the UK on track to meet current legislated carbon budgets[45]. The figures for the net UK carbon account, on central projections, place net emissions below the first three budget levels (2008-12, 2013-17, and 2018-22) by a margin of 85 $MtCO_2e$, 114 $MtCO_2e$, and 96 $MtCO_2e$ respectively .

UK territorial[46] emissions however track close to the legislated carbon budget levels for carbon budgets two and three (2013-22), as territorial emissions in the traded sector are forecast to be higher than the UK's share of the EU ETS cap and thus the traded sector share of the net UK carbon account. This means that the UK is forecast to be a net purchaser of allowances.

The UK territorial emissions are forecast in 2020, on central projections, to be 488 $MtCO_2e$, a 38% reduction on the 1990 baseline. The fourth carbon budget will be assessed on a net UK carbon account basis (i.e. taking account of trading under the EU ETS). However given the uncertainty surrounding the UK share and the EU level of the future EU ETS cap (discussed in Section D.II), the focus of this section is on UK territorial emissions.

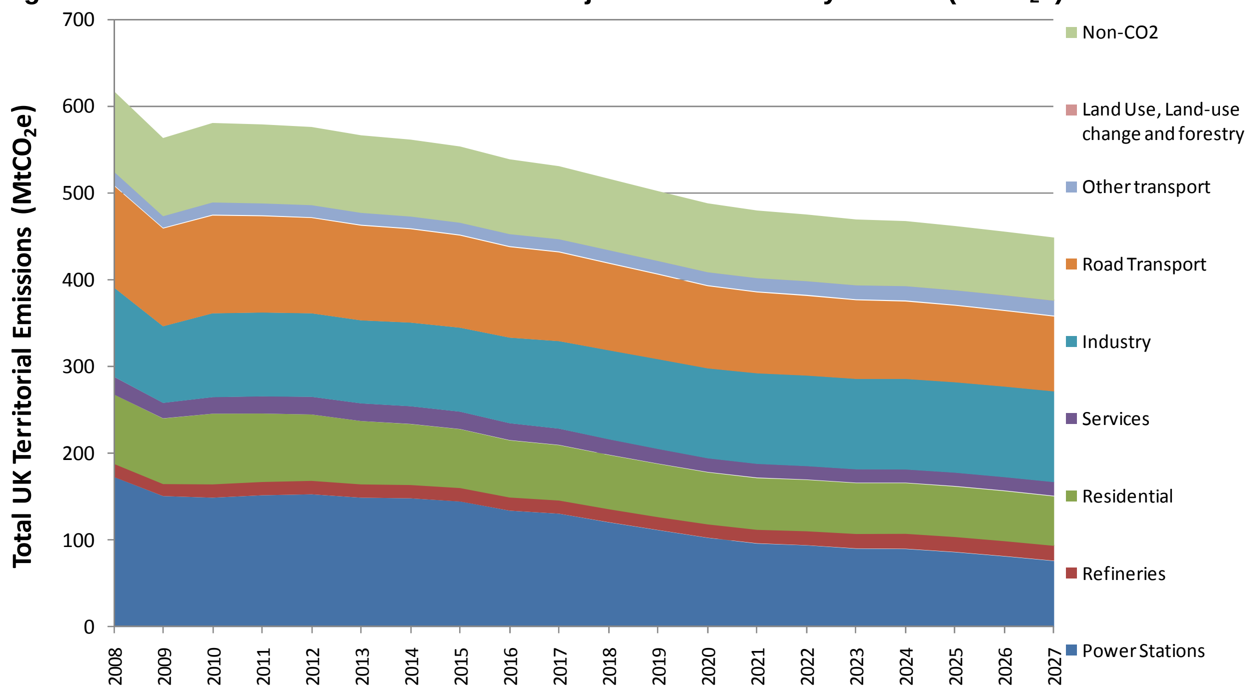
The projections imply a UK territorial emissions level of 2306 $MtCO_2e$ on central projections over the fourth carbon budget period, with annual emissions declining on average 1.2% p.a. 2009-27 owing to current policy and the legacy of these policies. On average over the budget period, emissions are 41% below the 1990 baseline (461 $MtCO_2e$).

[45] Emissions projections include policy savings in the baseline projections to account for policies which are anticipated to have an impact on emissions over the projected period. Those included are those policies which have been agreed and are either in place or anticipated to be put in place, over the emissions projection period.
[46] GHGs emitted on UK territory – not taking into account emissions trading (i.e. the purchase or sale of international carbon units from overseas).

Total territorial emissions for the UK show a steady declining trend from 2008 to the end of the fourth budget period. Reductions in road transport, residential, non-CO_2 GHG and power sector emissions are the key drivers of declining emissions over time, whilst emissions from industry are anticipated to show no decline over the period. The dip in emissions in 2009 and the subsequent increase to 2010 shows the anticipated impact of the economic downturn at the end of the 2000's.

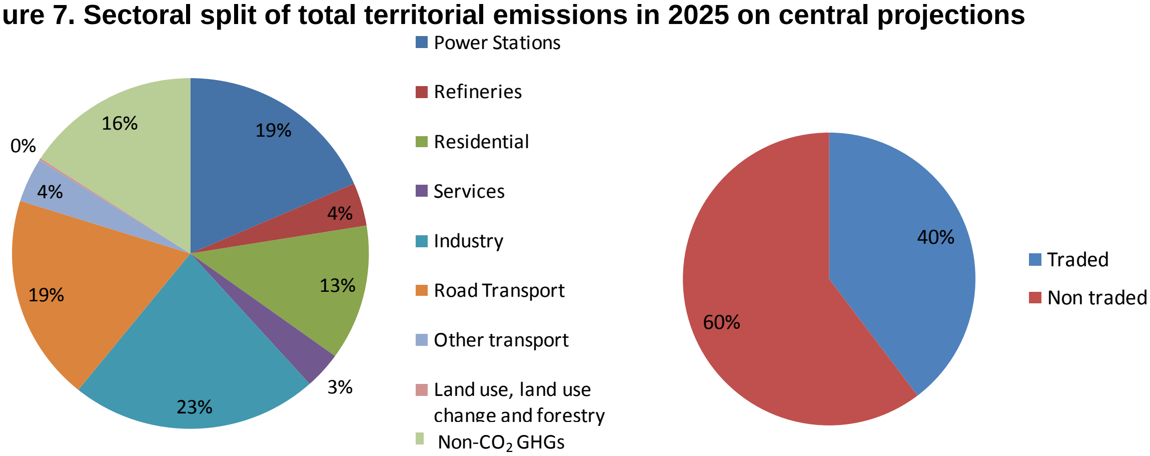
In 2025, the industry (27% - industry and refineries), transport (23% - road and other transport), and power (19%) sectors are projected to account for around 68% of total emissions, on central projections.

Figure 6. Central UK Territorial Emission Projections 2008-27 by Sector (MtCO$_2$e)



Source: DECC Energy and Emissions Model, DECC Non-CO_2 GHG projections and DECC LULUCF projections

Figure 7. Sectoral split of total territorial emissions in 2025 on central projections



Source: DECC Energy and Emissions Model, DECC Non-CO_2 GHG projections and DECC LULUCF projections

Figure 8. Central Forecasts of UK Territorial Emissions (MtCO$_2$e)

MtCO$_2$e	2023	2024	2025	2026	2027	Total 2023-7
Traded sector	187	187	183	180	176	**912**
Non-traded sector	283	281	279	276	274	**1393**
Total Territorial emissions	470	468	462	455	450	**2306**

Source: DECC Energy and Emissions Model, DECC Non-CO_2 GHG projections and DECC LULUCF projections

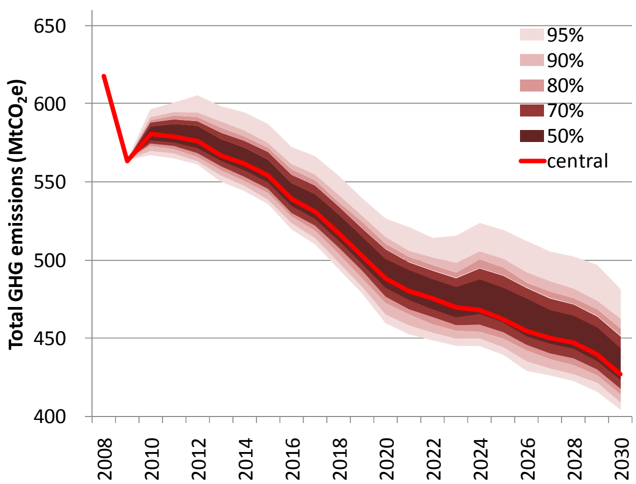
The coverage of the traded and non-traded sectors[47] are assumed to be the same as under the first three carbon budgets, where the traded sector includes major power producers, heavy industry and domestic aviation from 2012 (see information box 3 on the EU ETS). In 2025 60% of UK territorial emissions are projected to fall within the non-traded sector, 40% under the EU ETS.

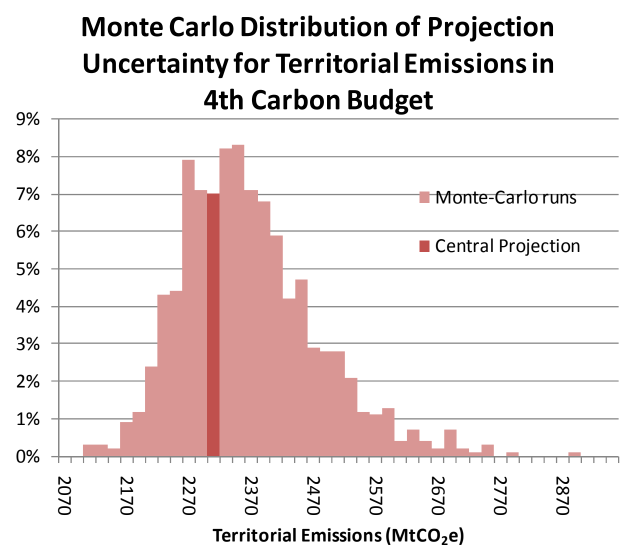
Non-traded sector emissions are estimated, on central projections, to be 1393 $MtCO_2e$ over the fourth budget period, a reduction of 5% on the level of expected non-traded sector emissions over the third budget period. Territorial traded sector emissions are estimated, on central projections to be 912 $MtCO_2e$ over 2023-7.

Uncertainty in Projections

Projecting emission levels into the 2020s is subject to uncertainty and depends upon modelling correctly the link between economic activity and GHG emissions, modelling and anticipating future drivers (such as temperatures, fuel prices, power station capital costs, economic growth and population) and accurately forecasting emission reductions due to climate change policy.

Figure 9. UK Territorial Emission Projections 2008-27 and distribution of uncertainty, per year and over 2023-7





Source: DECC Energy and Emissions Model, DECC Non-CO_2 GHG projections and DECC LULUCF projections.

The DECC emission projections capture some of this uncertainty through the use of Monte Carlo simulations, which use different assumptions and assumed distributions of the levels of key variables to provide a range of outcomes. This analysis provides an indication of the impact of uncertainty in fossil fuel prices, economic growth, temperature, policy delivery, power station capital costs, non-CO_2 GHG emissions and LULUCF emissions and removals[48]. This does not account for all sources of uncertainty – in particular modelling uncertainty (which will increase over time is only partially reflected; see Information Box 4) and scientific uncertainty.

Figure 9 illustrates the distribution of uncertainty ranges based on the Monte Carlo analysis. The outer confidence intervals presented are banded to reflect the middle 95% of simulation outcomes that fell into the given ranges. The true uncertainty range may be larger, and increasingly larger over time, than those presented below.

- **Modelled uncertainty increases overtime:** Over the first carbon budget, the 95% confidence interval is plus 57 $MtCO_2e$ or minus 33 $MtCO_2e$ around the central estimate, whilst over the

[47] The non-traded sector simply means all emissions outside of the EU ETS, and includes surface transport, emissions from heating homes and workplaces, emissions from agriculture etc.

[48] Uncertainty ranges around the LULUCF and non-CO_2e GHG emissions projections are produced independently to the uncertainty ranges for other emissions sectors, and incorporated into the wider uncertainty ranges using Monte Carlo analysis to form uncertainty ranges for different confidence intervals. The LULUCF and non-CO_2e emissions uncertainty ranges are assumed to be additive and independent from uncertainty around the wider emissions projections.

fourth carbon budget the range increases three to six times. This is depicted in the fan chart (on the left) by the increasing variance of emissions around central projections overtime.

- **The distribution of uncertainty is negatively skewed – emissions are more likely to be higher than lower around central projections** (as illustrated by the frequency chart on the right), which is in part driven by the assumption that policy under-delivery is more likely than over-delivery, but also an asymmetric range of fossil fuel price assumptions.

Figure 10 presents central projections and uncertainty ranges for total UK territorial emissions, and by non-traded and traded sectors, for each carbon budget period. It shows, for example, that over the fourth carbon budget, 95% of the outcomes from the Monte Carlo simulations for the non-traded sector fell into the 1319 $MtCO_2e$ to 1502 $MtCO_2e$ range, around the central projection of 1393 $MtCO_2e$. These modelled uncertainty ranges are drawn on in the concluding section of the Impact Assessment (Section G) in order to assess the sensitivity around the emissions gap to meeting different carbon budget options in the non-traded sector, and for estimating sensitivity around cost estimates.

Figure 10. Central UK Territorial Emission Projections and Uncertainty Ranges ($MtCO_2e$)

$MtCO_2e$	Budget 1	Budget 2	Budget 3	Budget 4
Central UK Territorial GHG Projection	**2917**	**2752**	**2464**	**2306**
Upper range 95%	2974	2909	2652	2631
	(+57)	(+157)	(+189)	(+326)
Lower range 95%	2884	2677	2335	2195
	(-33)	(-75)	(-129)	(-111)
Central Non-Traded Sector Projection	**1700**	**1590**	**1463**	**1393**
Upper range 95%	1734	1675	1566	1502
	(+34)	(+85)	(+103)	(+109)
Lower range 95%	1677	1536	1394	1319
	(-23)	(-54)	(-68)	(-74)
Central Traded Sector Projection	**1217**	**1162**	**1001**	**912**
Upper range 95%	1243	1247	1112	1154
	(+26)	(+85)	(+111)	(+242)
Lower range 95%	1203	1128	915	840
	(-14)	(-34)	(-86)	(-72)

Source: DECC Energy and Emissions Model, DECC Non-CO_2 GHG projections and DECC LULUCF projections.

The counterfactual emissions scenario

In the impact assessment, the budget options are assessed not relative to the business-as-usual emissions projections generated by the DECC Energy Model, but relative to a counterfactual scenario for the net UK carbon account.

The evidence collated on additional abatement potential (section D.III below) identifies a number of ‘no regret’ abatement measures in the non-traded sector. These measures are of net benefit to UK society even without valuing the emissions reductions that they achieve. These measures would be beneficial to pursue, irrespective of the carbon budget level and have an associated net benefit to society (though policy may be required to unlock this potential and there may be associated policy costs).

In the counterfactual emissions scenario, it is assumed that half of the net negative cost abatement is taken up, to present a conservative approach to the assessment of costs (the benefit of the measures included in the counterfactual would not be included in the cost estimation as a result). The rationale for this and sensitivity analysis is presented in later sections. In the non-traded sector, 38 $MtCO_2e$ of ‘no regret’ negative cost abatement identified, and hence 19 $MtCO_2e$ is assumed to be taken up to form part of the counterfactual for this analysis. This would reduce non-traded sector emissions to 1374 $MtCO_2e$ on central projections.

In practice, it is likely that hidden barriers or other non-monetised costs have prevented the take up of these measures to date. Assuming that only 50% of this net negative cost abatement will be taken up in the counterfactual reflects that it is likely that some of the existing barriers to take up this net beneficial abatement would still exist in the 2020s, and as such, the abatement potential would not be taken up without intervention.

For the net UK carbon account, as opposed to taking a territorial view of UK emissions, the counterfactual assumes that there is a continuation of the UK's share of the current EU ETS cap trajectory, which would lead to a traded sector of around 860 $MtCO_2e$ in 2023-7 (outlined in section D.II below) based on a continuation of the current cap trajectory (as set out in the 2009 EU ETS Directive, which imposes an annual 1.74% decrease in the cap from 2013 onwards, with no sunset clause). It is assumed that coverage of the EU ETS over the 2020s is the same as in 2020.

Taking into account the negative net cost abatement in the non-traded sector and taking the UK share of the EU ETS as the traded sector emissions scenario, the counterfactual emissions scenario against which the options are assessed is 2234 $MtCO_2e$ over the fourth budget period, with 1374 $MtCO_2e$ and 860 $MtCO_2e$ of emissions in the non-traded and traded sectors respectively. Hence, the business-as-usual emissions projections are not used as the counterfactual against which the budget options are assessed, but are an important part of its formation.

Part II: Assessment Criteria: The Three Perspectives

Section C: Geometric trajectories from 2020 to 2050 and Long-term UK Pathways to 2050

The Climate Change Act requires that carbon budgets are set with 'a view to' the UK's 2050 emission reduction target – to reduce net emissions by at least 80% on 1990 levels.

This section begins by presenting simple geometric trajectories of emissions trends to 2050 to inform a high-level take on potential emission trajectories to 2050 target levels.

The section then moves onto consider physically possible UK pathways to 2050 – drawing on evidence from the DECC 2050 Calculator and MARKAL model, before considering evidence on least-cost pathways – smoothing marginal abatement costs over time to undertake emission reductions when most cost-effective and inter-temporally efficient. This is followed by consideration of 'pathway' arguments for individual technologies and the implication for the rates of emission reductions over the 2020s.

Summary:

The appropriateness of and importance placed on the geometric trajectories depends on views of feasible annual reductions, future abatement options, costs of emission reductions and effort required.

A straight-line trajectory from projected territorial emissions levels in 2020 to the 2050 target requires constant absolute reductions of 11.1 MtCO_2 per year, whilst a concave equal annual percentage reduction trajectory requires reductions of 3.7% per year. These illustrative trajectories imply territorial emissions over the fourth carbon budget of around 2170 MtCO_2e or 2020 MtCO_2e respectively over 2023-7.

If international aviation and shipping emissions are included in the 2050 target in future, taking the CCC's range of 'likely' to 'speculative' scenarios for international aviation and a baseline projection of emissions for international shipping, reductions across other sectors may need to increase to 5.1-5.7% p.a. or 12.9-13.5 MtCO_2e p.a. to reach an overall 80% reduction by 2050. This suggests an emissions level ranging from 1830 to 2120 MtCO_2e[49] over 2023-7.

Even without the inclusion of international aviation and shipping, it may be prudent to set a budget at this level given the risks of us needing to reduce emissions by more than 80% by 2050, and the risks presented by the uncertainties about the level of emissions from agriculture, which could be higher or lower than currently estimated.

An economically efficient distribution of abatement minimises costs by exploiting least cost abatement opportunities over time, equalising abatement costs as far as possible based on available opportunities given technical constraints to meet long-term targets.

Results from the DECC 2050 Calculator and MARKAL model indicate that pathways with early action over the 2020s are technically feasible.

Emissions from non-energy sources (agriculture, waste and LULUCF) and international transport are likely to be more difficult to abate by 2050 - suggesting energy related CO_2 emissions take on a greater emissions reduction by 2050, of around 90% on 1990 baseline levels.

Modelling results for energy related CO_2 emissions suggest a least-cost pathway to 2050 based on early action and a concave trajectory similar to an equal annual percentage reduction – given the marginal cost of reducing emissions in the short- to medium-term is likely to be considerably lower than that in the long-term.

[49] The low end of the range represents the low end of the equal percentage range, with the high range representing the high range of the straight line trajectory, representing the widest range across both methodologies

All sectors need to contribute to decarbonisation. There is some path dependency - decisions now can affect pathways in future decades. Support for specific technology pathways need to be considered on a case by case basis, balancing arguments of avoided lock-in and benefits of innovation, with the risk of committing to interim technologies and increasing overall costs through inefficiency.

Pathway arguments may justify investing to push the development and uptake of key technologies even when they do not appear cost effective in the short term.

Geometric Trajectories from 2020 to 2050

Simple territorial emission trajectories to the 2050 emissions target require consideration of both the starting and the end point.

The third legislated carbon budget, covering emissions from 2018 to 2022, reduces the net UK carbon account to 35% below 1990 levels by 2020 – on average 509 $MtCO_2e$ p.a. over the period. The UK is forecast to meet this level, on central projections, through territorial abatement in the non-traded sector, and through the EU ETS, where on central projections the UK is a net buyer of allowances in 2020. Overall on central projections the UK's territorial emissions are forecast to be 488 $MtCO_2e$ in 2020 – the overachievement in the non-traded sector relative to the third carbon budget largely offset by the purchase of international carbon units in the EU ETS.

This level provides the **starting point** to the geometric trajectories presented below. However, this point is subject to uncertainty in the underlying emissions projections, where modelled uncertainty ranges from 459 to 527 $MtCO_2e$ in 2020, and also ambition level (should the EU and so UK move to more stringent targets, UK territorial emission levels may be lower due to greater policy ambition and a higher carbon price).

In considering the **end point** there are various uncertainties regarding the exact scope and ambition of the 2050 target level:

- **The role of international carbon units:** The following section on global perspectives presents stylised analysis of where the most cost-effective abatement is located globally. This analysis suggests an efficient level of EU territorial emissions reductions in 2050 of around 76-79% on 1990 levels. There is no analysis of how this level of EU territorial emissions reductions would be distributed across EU member states – however analysis for 2025 and 2030 suggests the UK will take on an efficient share above the EU average, indicating that the UK should plan to meet the 2050 target to reduce emissions by at least 80% through territorial emissions reductions. This planning assumption will need to remain under close scrutiny depending on international progress.

- **The uncertainty in ambition level:** the Climate Change Act outlines a target by 2050 of at least 80% lower than the 1990 baseline, but with a clause that this may be revised following developments in climate science or international agreements. Whilst the latest evidence reinforces the case for action, it does not at this stage suggest the 2050 target needs to be revised downwards.

- **The inclusion of international transport:** The Act states that government must, in making decisions on carbon budgets, take into account the estimated reportable emissions from international aviation and shipping emissions[50]. The introductory section above explains that, whilst emissions from international aviation and shipping are not currently included in the scope of carbon budgets, they may be included in future. This should be viewed as an uncertainty in considering a level of the fourth carbon budget that would be consistent with a pathway to the 2050 target.

The rate of emission reductions over time can be defined in either percentage terms, or absolute terms. A trajectory based on equal percentage reductions will mean greater absolute reductions ($MtCO_2e$) in

[50] Climate Change Act 2008, Section 10.

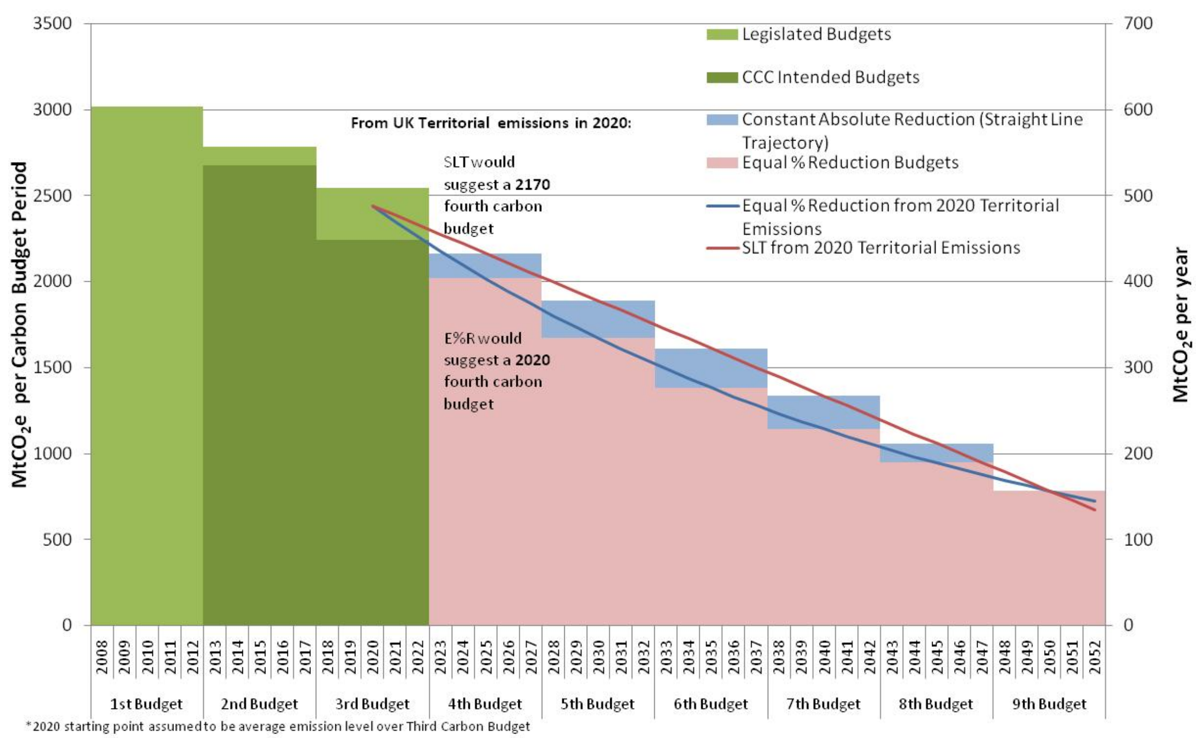
earlier years than later years, whereas a simple straight line trajectory requires constant reductions year on year, but those reductions become greater in percentage terms as the level of total emissions declines.

Simple geometric trajectories from the central forecast of UK territorial emissions in 2020 – to a 2050 target of at least 80% lower than the 1990 baseline - illustrate the rate of emission reductions required in the UK to meet the 2050 target territorially:

- **A straight-line trajectory requires constant absolute reductions from 2020 to 2050 of 11.1 $MtCO_2e$ year on year, with carbon budget levels declining** 280 $MtCO_2e$ each period. The degree of percentage reduction required year on year increases over time, from 2.4% p.a. in 2022-3 increasing to 6.6% p.a. by 2050 as the stock of UK emissions declines overtime.
- This illustrative straight line trajectory would imply territorial emissions over the fourth carbon budget of around 2170 $MtCO_2e$ over 2023-7.
- Uncertainty around the starting point of territorial emissions in 2020 creates an uncertainty range around this budget of 2040 $MtCO_2e$ to 2320 $MtCO_2e$ under low and high emissions projections respectively[51].

- **A concave, equal percentage reduction trajectory requires from 2020 to 2050 reductions of 3.7% per year**. The degree of reduction in absolute terms falls over time – from 17 $MtCO_2e$ per year initially, down to 6 $MtCO_2e$ p.a. by 2050.
- This illustrative equal percentage reduction trajectory would imply territorial emissions over the fourth carbon budget of around 2020 $MtCO_2e$ over 2023-7.
- Uncertainty around the starting point in 2020 would imply an uncertainty range around this budget level of between 1920 $MtCO_2e$ to 2150 $MtCO_2e$ over the fourth budget period, under low and high baseline emissions projections respectively

Figure 11. Geometric Trajectories from 2020 to 2050 (excluding international aviation and shipping emissions)



Source: Illustrative trajectories – starting point based on central UK emissions projections for 2020 (outlined in section B).

Compared to historic and near-term projected levels, these illustrative trajectories imply a significantly greater rate of reduction (in terms of percentage change year on year).

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51 Uncertainty ranges around the baseline emissions projections in this section represent 95% confidence interval around emissions projections in 2020

These illustrative geo-metric trajectories can also be considered on a net UK carbon account basis:

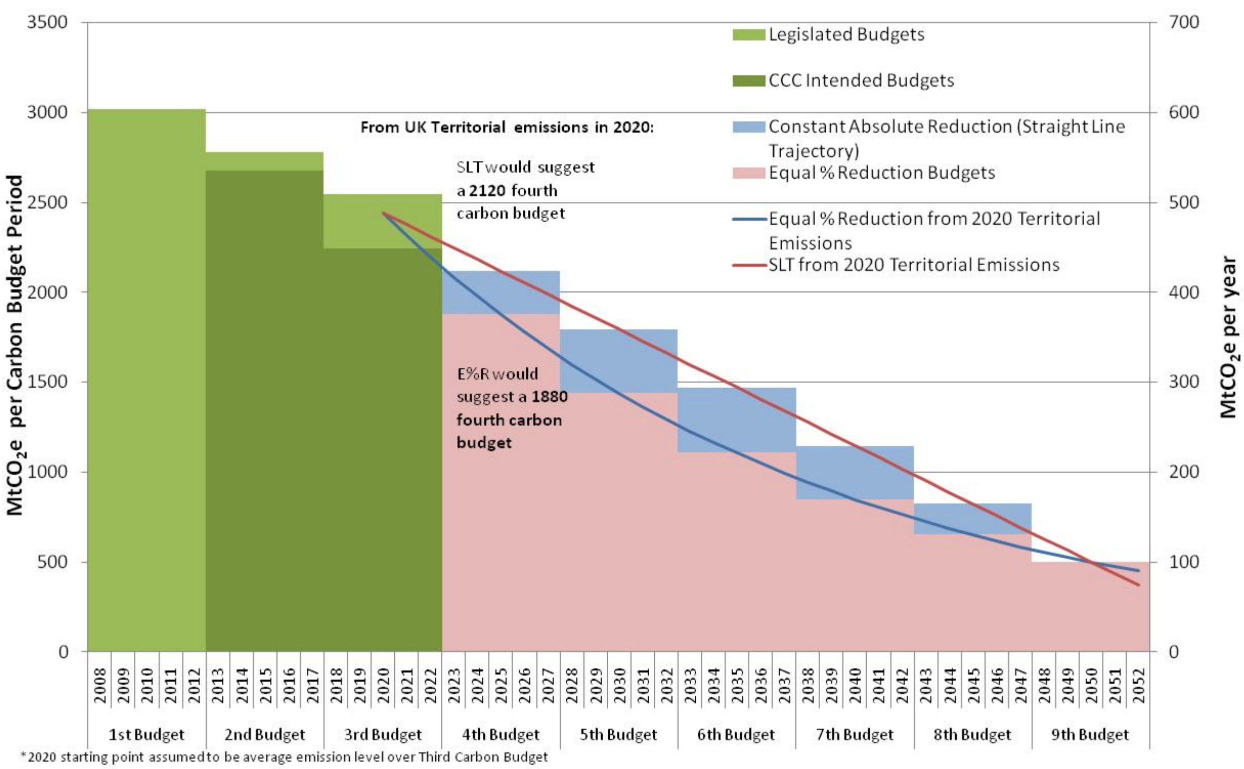
- **A straight line trajectory to the 2050 target from the net UK account level of emissions in 2020** would require a reduction in emissions of around 11 $MtCO_2e$ per annum to 2050. The degree of percentage reduction over time would increase from around 2.4% per annum at the beginning of the fourth budget period to 6.5% per annum by 2050.
- This straight line trajectory implies a net UK carbon account emissions over the fourth budget of around 2150 $MtCO_2e$. The uncertainty around this net UK carbon account emissions level as a result of an uncertain starting point would range from 2090 $MtCO_2e$ to 2240 $MtCO_2e$ under low and high emissions projections respectively.

- **A concave, equal annual percentage trajectory from 2020 to 2050 starting from the forecasted emissions under the net UK carbon account in 2020** would require an annual reduction in emissions of 3.7% over the period, with the absolute reduction in emissions per annum falling over the period from 16.7 $MtCO_2e$ to around 6.0 $MtCO_2e$ per annum reduction by 2050.
- This trajectory would imply a level of emissions under the net UK carbon account of around 2010 $MtCO_2e$ over the fourth budget period. Uncertainty around the starting point would create a range of emissions trajectories between 1960 $MtCO_2e$ to 2090 $MtCO_2e$ over the fourth budget period under low and high emissions projections respectively.

Inclusion of international aviation and shipping

The potential inclusion of international aviation and shipping into the 2050 target and future carbon budgets also needs to be considered, and treated as an uncertainty in the assessment of different fourth budget options.

Figure 12. Geometric Trajectories from 2020 to 2050 (including international aviation and shipping emissions)



Source: Illustrative trajectories – starting point based on central UK emissions projections for 2020 (outlined in section B).

Forecasts for international aviation emissions from the CCC[52] have been considered that reflect a continuation of policy (as at December 2009) including the EU ETS (the CCC's 'likely' scenario); and a forecast where significant additional abatement is undertaken (the CCC's 'speculative' scenario), such as a greater uptake of biofuels and greater fuel efficiency improvements.

For international shipping an illustrative scenario for emissions[53] has been used in both cases given the lack of better evidence for this sector. It should be noted that this projection is inconsistent with the calculation of the target level of UK emissions in 2050 given that the 1990 level of emissions is based on UK bunker fuel sales. It is included here only for illustration and completeness.

- When the CCC's 'likely' scenario for international aviation emissions is used along with the illustrative international shipping projection, reductions in territorial emissions across other sectors may need to increase to 5.7% p.a. (under a concave trajectory) or 13.5 $MtCO_2e$ p.a. (under a straight line trajectory) to reach an overall 80% reduction by 2050. This suggests emissions levels of 1830 and 2110 $MtCO_2e$ over 2023-7 for the concave and straight line trajectories respectively.
- Assuming the CCC's 'speculative' scenario for international aviation emissions along with the illustrative international shipping projection implies reductions across other sectors may need to increase to 5.1% p.a. or 12.9 $MtCO_2e$ p.a. This suggests emissions levels of 1880 and 2120 $MtCO_2e$ over 2023-7 for the concave and straight line trajectories respectively.

The Rate of Emission Reductions

The appropriateness and importance placed on the geometric trajectories depends on views of feasible annual reductions, future abatement options, costs of emission reductions and effort required. These are considered in more detail in the next part of this Section.

In summary, there are some arguments to suggest that an equal annual percentage reduction trajectory would be preferable. It **would result in lower cumulative emissions than a straight line trajectory over both the period to 2050 and the fourth carbon budget period.** Furthermore**, early action could avoid the possibility of locking in to carbon-intensive long-lived assets**, which could make it technically difficult and more costly to decarbonise sufficiently in future years, when targets become more stringent. Early action could help to stimulate innovation, induce technological change and drive down technology costs, strengthening the case for such a trajectory.

In the context of UK unilateral action these arguments may however be less strong, as they will depend upon the extent to which UK leadership is likely to induce other countries to act. There could be benefits from first mover advantage, but these can only exist if the rest of the world eventually chooses to decarbonise, otherwise there will be limited demand for the low carbon goods the UK produces. If the rest of the world does not follow the UK's lead, significant unilateral action could harm the competitiveness of the economy. **A straight line trajectory, requiring greater percentage reductions in later years might be more appropriate if there is an option value in waiting.** Later action would avoid the possibility of locking in to interim technologies or higher costs if further innovations, cost reductions or transformative technological shifts occur in future. Under a concave trajectory, new investments in less innovative technologies might be encouraged, tending to lock in earlier technological vintages.

Long-term UK Pathways to 2050

The 2050 Pathways Physical Solution Space

The DECC 2050 Calculator was developed to explore a range of potential pathways from today to 2050 to meet an 80% reduction in UK greenhouse gas emissions. It sets out the physical solution

[52] "Meeting the UK aviation target – options for reducing emissions to 2050"; CCC (December 2009); available at http://www.theccc.org.uk/reports/aviation-report.

[53] Illustrative scenario based on an International Maritime Organisation (IMO) scenario of global international shipping CO_2 emissions, assuming the UK's share of the IMO's global (activity-based) totals is equal to the UK's share of global CO_2 emissions from international shipping on the basis of International Energy Agency (IEA) fuel statistics for 2007, which was around 1.2%.

space for what level of UK GHG emission reductions can technically be achieved whilst ensuring the UK's energy needs are met, based on the full range of technical possibilities. The calculator allows users to choose from a full range of technical possibilities to meet the 80% target with no cost or wider policy-type constraints imposed.

Of the six illustrative pathways to 2050 presented in the DECC 2050 July 2010 report[54] and the seventeen published in the March 2011 report[55], all but one[56] of the illustrative pathways successfully meets the 80% emissions reduction by 2050 target whilst also meeting or reducing emissions below the CCC's recommended fourth carbon budget of 1950 $MtCO_2e$. These pathways are not necessarily desirable ways to achieve the UK's long-term goals, and do not reflect an exhaustive list of all possible pathways – instead the pathways serve to map technical pathways to 2050 without seeking to explicitly consider costs, financial constraints, or policy feasibility.

The calculator illustrates the scale of the challenge, that single technologies cannot be relied upon and that all sectors need to contribute to decarbonisation. For example, two of the pathways describe efforts balanced across all sectors, five examine the omission of a key technology driver, three scrutinise major reductions in energy demand, three look at heroic ambitions on electrification, three check different prioritisation strategies for bioenergy, six place emphasis on particular supply side technologies and one offers a hedging strategy which meets a 90% target to control for major technological failure.

The calculator illustrates the considerable de-carbonisation effort needed across a large number of the UK's energy sectors to hit the 2050 targets. The 2050 Pathways analysis gives some indication of the deliverability risks of back loading efforts in sectors, which often have constraints on the entry of low carbon technologies. This is due to the speed in scaling up technology production, natural lifetime and replacement cycles of energy using products.

Without early action there is a risk that the technology scale up needed would be very difficult to deliver due to these factors. However, it should be noted that the 2050 Calculator uses only 4 scenario trajectories for the major energy sectors and low carbon technologies rather than an optimising function, therefore the risk of back-ending may be over-stated in the absence of cost-optimisation.

Information Box 5. DECC 2050 Calculator

The 2050 Calculator reflects a set of physically possible outcomes. Pathways are user defined, given consideration of technical feasibility and stakeholder consensus rather than the economically optimal solution –as costs and views on feasibility are not considered explicitly and the calculator does not model pathways based on such criteria.

The DECC 2050 Calculator and Pathways Analysis was developed with input from many experts in businesses, NGOs, technical fields, and academics, through workshops and other discussions. Therefore, trajectories in sectors represent a consensus of decarbonisation given different levels of effort and incentives across sectors, but the analysis does not consider costs of the trajectories or other barriers to delivery.

The illustrative pathways presented in the July 2010 report identified some common elements of successful pathways to 2050, and drew out some of the implications and uncertainties associated with different choices.[57] In summary the common messages from that analysis were:

- Ambitious per capita energy demand reduction is needed
- A substantial level of electrification of heat and transport is needed
- The electricity supply needs to be decarbonised, while supply may need to double
- A growing level of variable renewable generation increases the challenge of balancing the electricity grid
- Sustainable bioenergy is a vital part of a low carbon energy system

[54] 2050 Pathways Analysis, DECC, July 2010 http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/2050/2050.aspx.
[55] '2050 Pathways Analysis; Response to the Call for Evidence Part 1'; DECC (March 2011);
http://www.decc.gov.uk/assets/decc/Consultations/2050/1343-2050-pathways-analysis-response-pt1.pdf
[56] The one pathway to miss is Pathway Zeta (published in July) which examines the effects of minimal behaviour change on efforts to reduce energy demand. It has emissions of 1,972 Mt during the fourth budget period.
[57] Page 34 of the report

- Reduction in emissions from agriculture, waste, and industrial processes will be necessary by 2050
- There will be an ongoing need for fossil fuels in our energy mix, although their precise long term role will depend on a range of issues such as the development of carbon capture and storage.

These headline messages listed above are broadly consistent with those of the MARKAL model (presented in the following section).

The UK MARKAL Model

Dynamic evidence on the cost-effective split of effort across sectors and over time can be drawn from long-term energy system models which optimise to provide least-cost solutions to meet the UK's 2050 target. The MARKAL model is a technology rich integrated energy system designed to develop insights on a range of future energy system evolutions, resulting technology pathways and sectoral trade-offs to meet given emission targets in a least-cost way.

Information Box 6. UK MARKAL - Mark**et** **Al****location Dynamic Optimisation Model**
MARKAL is a widely applied technology rich dynamic general equilibrium model which back-forecasts and linearly optimises to find least-cost pathways to meet various emission targets and trajectories.

There exist many versions of the MARKAL model. The analysis commissioned by DECC to form part of this evidence base employs the MARKAL Elastic Demand version.

The model is continually updated by a range of experts to reflect new assumptions on technologies, abatement potential and cost (defined as supply curves). Revisions have been made under the recent DECC project to revise the underlying levels of energy service demand, in particular in the services and industry sector, and to incorporate the DECC's Mott MacDonald electricity generation costs, alongside a variety of other small revisions.

The key advantage of the MARKAL model is that it is a dynamic optimisation MACC model and overcomes the many shortcomings of static MACCs in modelling interactions across sectors and over time. These considerations are particularly important for modelling abatement options beyond the short-term and considering long-term pathways to a 2050 target – especially for the power generation, heat and transport sectors.

MARKAL is a perfect-foresight, perfect markets model – fit to provide insight into 'what should be done' . This however is a limitation for the model in how DECC would ideally like to use it, as the model ignores short-term transitions, inertia, and barriers to uptake, such that without additional constraints it would delay and then model significant technology shifts and decarbonisation – within the technical constraints of the model, but beyond rates of reduction considered plausible in reality. As a deterministic optimisation model with perfect foresight MARKAL is also prone to 'penny switching' - sensitive to assumptions on costs and discount rates – such that small changes in technology costs can lead to significant switches in results to different technology pathways.

The UK MARKAL model has been set up for the purpose of this project to incorporate the current UK 2020 target (equivalent to a 30% reduction in energy related CO_2 emissions on 1990), an emissions pathway to this, and key abatement identified in the UK carbon plan (i.e. CCS demonstrations, renewable generation to meet the Renewables Obligation, and take up of heat pumps and conservation measures), as part of the baseline. Emission levels to 2020 are fully constrained.

Additional constraints have also been imposed; limiting demand response to 1% p.a.; constraints on levels of investment in renewable heat measures (heat pumps, biomass and wood boilers); constraints on levels of solar thermal in both residential and services sectors; and limits to industry CCS uptake rates and market shares of various transport technologies.

Modelling results need to be carefully interpreted, with appropriate sensitivity analysis carried out, and with these caveats in mind insights can be gained for the UK energy system to 2050.

It is also important to note that the UK MARKAL model does not include any endogenised learning/innovation (though there are exogenous learning rates) and so may understate the benefits of UK early action in reducing costs and in induced technological change.

The UK MARKAL (Elastic Demand) model has been used to provide insight into technically feasible pathways. MARKAL cannot be run to determine or give direct recommendation on the fourth budget level *per se*, as it cannot be meaningfully run with only a single long-term target to determine a least-cost pathway. Founded on the structures of perfect foresight and perfect markets the model would choose to delay investing in low carbon technologies and delay abatement until the final opportunity, reducing emissions at close to the maximum rate of technical reductions across all sectors, technologies and energy carriers[58] at the last chance (even investing in low carbon technologies to avoid lock-in but not using them until bound to by the final target). These results could not be achieved in the real world, where the rate of technology uptake is constrained through inertia and barriers, and where there is a need to demonstrate key abatement technologies before they are deployed at scale.

Convention is to run MARKAL through imposing a constrained emissions trajectory (for example an equal percentage reduction over time). Through this approach the results could then not provide insight into least-cost emissions pathways for the UK (as these are input assumptions) but the analysis provides invaluable insight into the implied least-cost energy system and technology pathway to achieve the imposed emissions constraint.

MARKAL Modelling

The UK MARKAL model covers only UK territorial CO_2 emissions from energy use and does not model non-CO_2 GHGs, LULUCF and international aviation and shipping sectors. As a consequence, the 2050 target needs to be translated to a 'MARKAL equivalent'.

The global perspectives section in this evidence base outlined that the 2050 target ought to be considered as an efficient share of global effort, and therefore for this analysis, it is assumed that it is met territorially. Translating the 2050 target to a MARKAL basis therefore just requires judgement on the level of emissions from non-CO_2 GHGs and LULUCF sources in 2050, and consideration to take into account international transport for sensitivity analysis where these sectors are in future included in the UK target.

Details are presented in Annex 4 on the target adjustment with assumptions in Annex 5 on non-CO_2 GHG emission forecasts, and assumptions on international transport emissions are as those considered earlier in this section. From this assessment, given the uncertainty range of non-CO_2 GHG projections, reductions of 85% and 90% in CO_2 emissions by 2050 on 1990 levels are considered.

Results

MARKAL model runs constrained to meet an equal annual percentage reduction emissions trajectory from 2020[59] to 2050 target reductions 85% and 90% in energy related CO_2 emissions on 1990 levels show pathways are technically feasible. Modelling results are dependent on the technology choices and build rate constraints assumed in the model. Under a recent project commissioned by DECC[60] key assumptions were reviewed by government analysts and considered to be in line with governments best view.

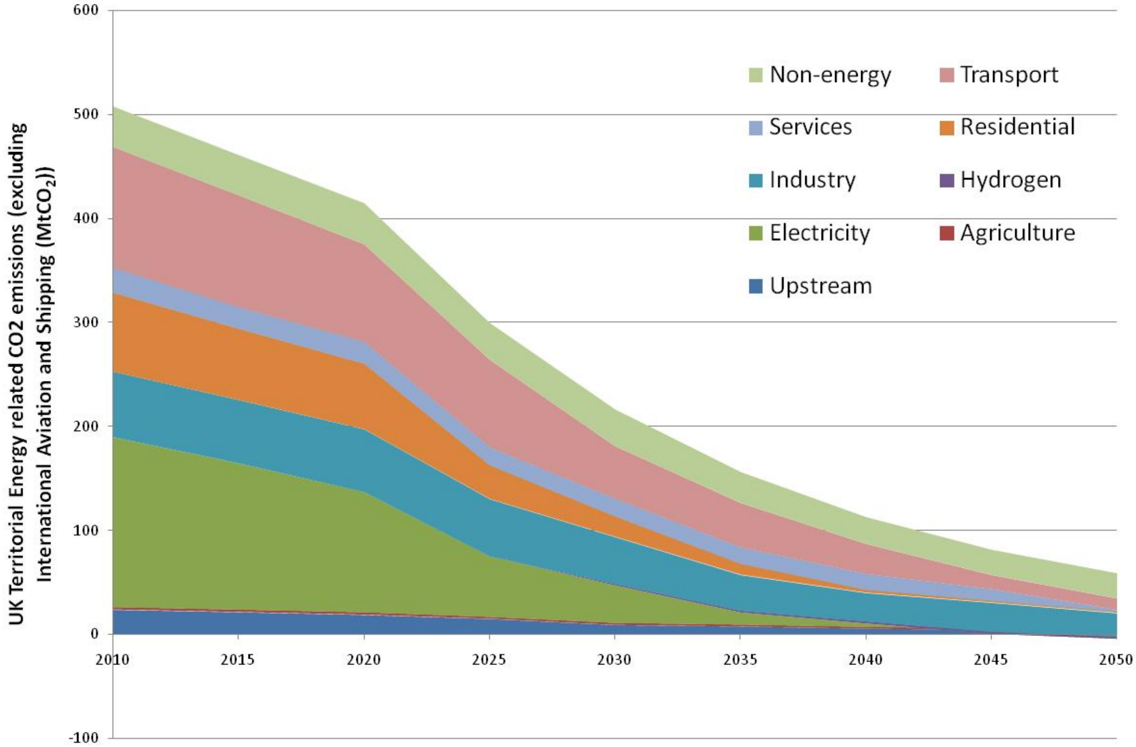
Figure 13 below illustrates the overall and sector level emissions trajectories for a 90% reduction by 2050. Figure 14 presents a range of modelling results for different sector emission levels in 2050, presented against 2010 and 2020 levels.

Pathways were found to be technically feasible and robust to sensitivities around high and low fossil fuel prices, and high and low levels of demand. Modelling different scenarios, such as a scenario with high demand, low fossil fuel prices, greater barriers to uptake, and with no CCS also gave insight and reiterated that under various assumptions it is technically feasible to reduce emissions following an equal annual percentage reduction trajectory to a 2050 target.

The modelling results – a sample of which are presented below - provide insight into the least-cost energy system and distribution of residual emissions in 2050.

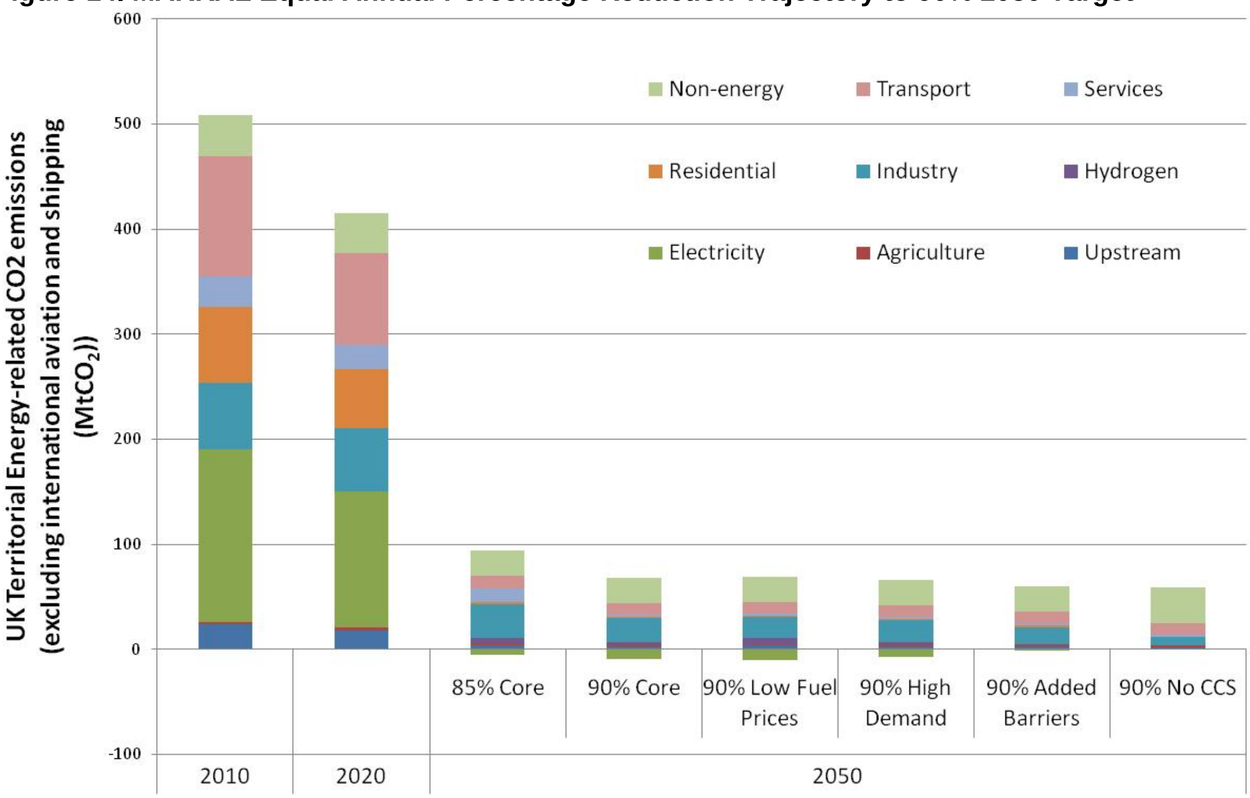
[58] Insight gained from DECC commissioned run of the model
[59] Based on June 2010 DECC Energy and Emissions Model Projection for energy-related CO2 emissions in 2020.
[60] AEA (2011); 'Pathways to 2050: MARKAL Model Review and Scenarios for DECC's fourth Carbon Budget Evidence Base'

Figure 13. MARKAL Equal Annual Percentage Reduction Trajectory to 90% 2050 Target[61]



Source: MARKAL modelling, AEA project for DECC (2011)

Figure 14. MARKAL Equal Annual Percentage Reduction Trajectory to 90% 2050 Target



Source: MARKAL modelling, AEA project for DECC (2011)

[61] Non-energy emissions account for fuels used for non-energy purposes (e.g. fuels used in processes, mechanical uses, etc) limited to diesel, natural gas, LPG and miscellaneous oils.

These results support well established pathway arguments surrounding the power sector and the view that decarbonisation of the grid will be important to meet the 2050 target. Electricity decarbonisation is a key factor in overall system decarbonisation, given the significant share of total emissions (around a third of energy related CO_2 emissions over 2010-20). Mitigation action in this sector is always closely related to the overall emissions reduction trajectory, and the range of results are consistent in their broad degree and timing of decarbonisation. For example across a range of equal annual percentage reduction pathways to meet both 85% and 90% CO_2 targets, varying demand and fossil fuel price assumptions[62] results suggest the grid may need to decarbonise by around 60-120gCO_2/kWh[63] by 2030 (from around 500gCO_2/kWh today), and to fully decarbonise and even generate negative emissions (brought using carbon capture and storage with biomass) by 2050.

Other key technologies identified as important to decarbonise heat and transport sectors by 2050 are;

- Ultra low emission and zero emission
- Renewable Heat; heat pumps and biomass boilers
- Industrial CCS

Alongside considerations of technologies, other important issues are the best use of bioenergy across the economy, and the degree of demand reduction; both of which have been highlighted to be important in recent modelling. For example, MARKAL assumes it is cost-effective to reduce demand by up to 25% in some end use sectors by 2050 in order to meet targets (though in some end uses demand reductions are much lower, 5-15%).

Economy-wide Least-cost Emission Reduction Pathways

Evidence on least-cost pathways to meet a given emission target is critical to informing the debate on the appropriate emissions reduction trajectory to the UK's long-term 2050 target.

The previous section highlighted outputs from MARKAL runs which optimise to provide a least-cost mix of energy system and demand reductions to meet an equal annual percentage reduction emissions trajectory. Whilst important insight can be gained from these scenarios, these results cannot be used to infer cost-effective pathways.

Insight can however be gained from reviewing the distribution of marginal abatement costs in these scenarios over the time horizon of the model to explore whether UK abatement is occurring at least cost overtime. From the results of all modelled runs, the marginal costs are considerably lower in the short-term than in the long term. For example, in the model run with an equal annual percentage reduction to a 90% 2050 target, the marginal cost in 2020 is around £60/tCO_2e and by 2050, around £600/tCO_2e (both prices in 2009 base, undiscounted).

This result suggests that the timing of required emissions reductions in the 90% run is not economically optimal. In all time periods up to 2045, the present value of the marginal abatement cost, using a 3.5% social discount rate, is lower than the 2050 marginal cost. This suggests that increasing the amount of abatement in the near-term, at the expense of abatement near 2050, would be a most cost-effective approach - **there may be some benefits to early action to enable greater 'cost smoothing'** given marginal costs increase with abatement effort over-time as low-cost options are exhausted.

In order to gain insight on the dynamic least cost pathway to our 2050 target, the MARKAL model has been run limiting cumulative emissions between 2020 and 2050 to levels consistent with our climate objectives. This is more prescriptive than the framework of the Climate Change Act 2008, which specifies only 2020 and a 2050 target. However, the Act requires the setting of carbon budgets for each five year period to 2050, implying, along with the scientific research outlined in the Background section above, the importance of cumulative emissions. Therefore this approach can be seen to be in the spirit of the Act, and permits some limitations of the MARKAL model, outlined above, to be circumvented. This enables the model to freely choose when to abatement over 2020-50 and **to minimise discounted costs over time, taking up abatement when most cost-effective.**

[62] Based on DECC's fossil fuel price scenarios outlined in Annex 2.
[63] Emission intensities reflect losses associated with storage and transmission and distribution. The assumed load factor on back-up plants in MARKAL is 0-3%, Indicatively load factors back-up plants of around10-15% would increase average carbon-intensity of up to around 25 g/kWh in 2030. –but would need to be treated on-model to properly consider.

Information Box 7. MARKAL Modelling Approach for Cumulative Emissions Analysis

In the period from 2020 to 2050, in this set up, the model is run to meet a given cumulative emissions level. This has been calculated as the cumulative level of emissions realised under an equal percentage reduction trajectory from the 2020 to 2050 target (5714 $MtCO_2$). This is in line with the global emissions pathway analysis discussed in Section D.I.

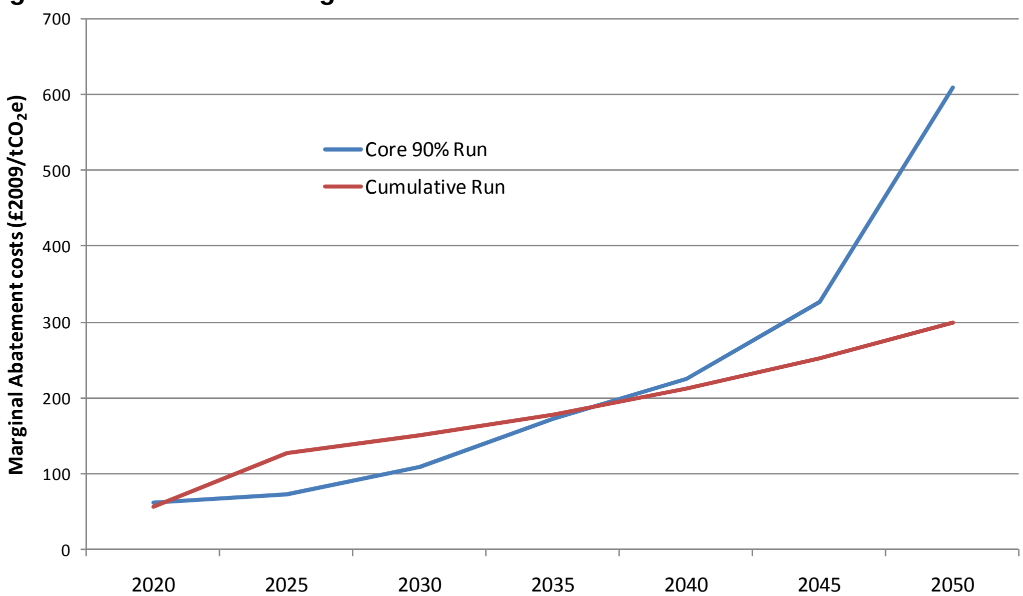
Sensitivities around this cumulative emissions level have been modelled. Uncertainty ranges of 10% above and below have been considered in line with the sensitivities considered in the AVOID project which looked at global cumulative emissions (see information box 1). As a consequence uncertainty ranges of 5142 to 6285 $MtCO_2$ are shown here, and the result on early action has been found to be qualitatively robust against a wider range.

The basic model run was set assuming a single discount rate based on the HM treasury's Green Book social time preference rate. A sensitivity was also carried out - applying higher discount rates to reflect costs of capital (which would imply a greater preference to delay action), and removing user defined constraints to limit annual investment levels (which intuitively would allow faster abatement to occur later).

Results

The modelling results provide evidence to support the view that the UK should follow a pathway of early action. In comparing marginal costs of a cumulative emissions run against an equal percentage run is it evident that the cumulative run smoothes costs overtime – as illustrated in the figure below. **The model smoothes costs given technical constraints such that the marginal abatement costs increase** overtime at the Green Book discount rate[64]**.**

Figure 15. Cost Smoothing Under Cumulative Emission Run



Source: MARKAL modelling, AEA project for DECC (2011)

Equalising the present value of marginal costs over time given the availability of abatement opportunities, and minimising overall costs, the results suggest the UK should do more earlier – as illustrated by the concave emissions trajectory from cumulative scenario and sensitivities around this run below.

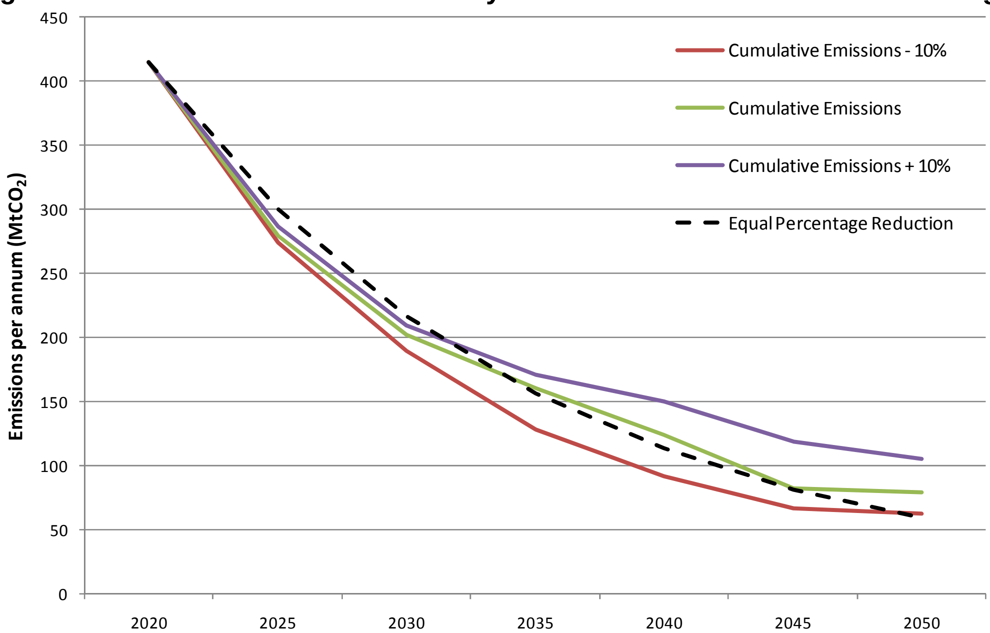
Results support an equal annual percentage trajectory: Modelled MARKAL runs with equivalent cumulative emissions track closely with the corresponding equal percentage reduction pathway – and results suggests it is more inter-temporally efficient to undertake greater emission reductions earlier, undertaking abatement beyond that implied by an equal annual percentage trajectory up to around 2035.

[64] Assumed to be constant at rate of 3.5%.

Given the MARKAL model structure of perfect foresight and perfect markets and associated limitations of the model in ignoring short-term transitions, inertia, and barriers to uptake, such that without additional constraints it would delay and then model significant technology shifts and decarbonisation –this is a strong result. The model would, if abatement opportunities were equally distributed, have bias to delay. (See Information Box 6 for more details of the limitations of model).

The CCC undertook similar analysis, drawing also on MARKAL, for their fourth carbon budget advice and came to a similar concave result[65] supporting early action.

Figure 16. Least-cost Emission Pathways for Given Cumulative Emission Targets



Source: MARKAL modelling, AEA project for DECC (2011)

Key implications for the 2020s and the fourth carbon budget are however harder to extract from both the MARKAL model and 2050 Calculator. The section below considers technology specific pathway arguments.

Technology specific pathway arguments

Whilst considerations of economy-wide trajectories and physically possible and technically feasible reductions in emissions are informative, it is how government plans to meet its near-term carbon budgets and the implementation and timing of uptake of key technologies that matter most in considering levels of action over 2023-7 and consistency with the least-cost pathway to 2050.

Least-cost/maximum-benefit pathways across the economy to the 2050 target are difficult to identify given the underlying uncertainty concerning, for example, the future structure of the economy, future technology costs, technical performance, wider impacts, and the dynamic interactions within the economy. However, **there is some path dependency; decisions now can affect the costs and availability of abatement potential in future decades. It is therefore important to try to understand the drivers of overall aggregate abatement costs, and what can be done to avoid diverging significantly from the least-cost pathway.**

Investment in the research, development and demonstration (R,D&D) of emerging low carbon technologies is likely to be crucial in ensuring the availability of key technologies, such as carbon capture and storage. It is also important in developing new enabling technologies, such as in heat and electricity storage, and for bringing down the costs of low carbon technologies that reach the deployment stage

[65] CCC (2010); 'The Fourth Carbon Budget – Reducing Emissions through the 2020s'; http://www.theccc.org.uk/reports/fourth-carbon-budget; page 122

(the final D of R,D,D&D). As well as incentivising early-stage investment, market-pull policies can enable/accelerate deployment and dramatically bring down the costs of emerging technologies. **There is a case for adopting and pushing the development and deployment or uptake of specific technologies before they are considered statically cost-effective** (i.e. cost effective in a given year), on the basis that by doing so the costs of the technology could be reduced in future periods through learning by doing or induced innovation, and the availability could be increased through the development of the supply chain.

It could make sense to be deploying statically cost-ineffective technologies in the fourth carbon budget period if they are at the deployment stage of their maturation, and through supporting their early deployment their costs can be brought down for future periods. This could apply to a range of critical technologies, for instance, heat pumps and low carbon vehicles.

There may be hedging strategy arguments for early action. The UK could set out a strategy to develop more abatement technologies than will be needed to meet the 2050 target to hedge against the risk that some of these currently immature technologies don't work. Hedging is advocated by the CCC and cited in their recommendations in chapter 3, where they emphasise the importance of flexibility and keeping a range of abatement scenarios in play.

However given future uncertainties support for particular technologies or sectors may be beneficial in some states of the world, but not in others. For example, support for a technology may be cost-effective over the long-term in the absence of a viable substitute technology, but cost-ineffective if substitutes are available. A technology may have a positive 'option value' if there is a good chance of states of the world in which it has a positive payoff which outweigh the states of the world where it does not.

In network industries, such as the energy supply sector (and large parts of energy demand), technologies may become 'locked in' as standards. In the short-term, it may be important to avoid lock-in to high carbon technologies, such as new infrastructure with long lifetimes. Some relatively low-carbon technologies may be useful for decarbonising over the next few decades, but not part of the long-term technology mix in the least-cost pathway. It may be important to avoid lock-in to such interim technologies.

In an uncertain world, there can be value in having a diversity of potential abatement solutions, in case some of those solutions do not work or prove very costly. This has to be balanced against the cost of developing more solutions and the risk of diverting resources from the right technology families to the wrong technology families on the basis of flawed information.

In conclusion, pathway arguments may justify investing to push the development and uptake of key technologies even when they do not appear cost effective in the short term. Consideration must be given to pathway arguments to consider the role for technologies and scenarios over the 2020s, and any potential planning implications for individual sectors; Government will set out more detail on this in its report on policies and proposals to meet the fourth carbon budget, to be published in October 2011.

Section D: The cost-effective level of UK Abatement

<u>Summary:</u>
An economically efficient global effort to mitigate climate change minimises the costs of achieving a specified level of global emissions reductions by exploiting least cost abatement opportunities wherever they are located, equalising marginal abatement costs across world regions.

Where there is a functioning global carbon market, the efficient level of abatement to be undertaken in the UK is separable from any consideration of the UK's equitable burden share of a future international agreement. The efficient level provides a planning benchmark for the level of territorial action.

Results from the GLObal CArbon Finance (GLOCAF) model suggest that where the world reduces emissions in a manner that is consistent with the high end of pledges made under the Copenhagen Accord and then follows a 2 degree consistent trajectory the EU would efficiently reduce emissions in 2030 by around 43% on 1990 levels. Where there is less ambitious global action, efficient reductions in EU emissions would be considerably lower.

Results from the PRIMES model suggest, as an upper bound consistent with an EU 43% reduction, that the UK would efficiently reduce emissions to around 1350 MtCO_2e over the fourth carbon budget period in the non-traded sector and around 550 MtCO_2e in the traded sector. Overall the analysis in this section could be used to assess from a global perspective the efficient level of UK emissions in the non-traded sector, with the traded sector part of the budget determined by the UK share of the EU ETS cap. There is uncertainty surrounding the future EU ETS cap and UK shares – estimates ranging from between 590 MtCO_2e and 860 MtCO_2e over the fourth budget period. Taking the efficient level of non-traded sector emissions in the context of a high global action, the implied range for the level of the fourth carbon budget is between 1940 MtCO_2e to 2210 MtCO_2e. If there is a lower level of global action, the efficient level of the budget would be higher.

GLOCAF analysis points to an efficient level of EU effort in 2050 of around 76-79% on 1990 levels. PRIMES analysis suggests the UK will take on an efficient share above the EU average, indicating that the UK should plan to be able to meet the 2050 target to reduce the net UK carbon account by at least 80% territorially.

This section then moves on to present the current best estimates of abatement potential and cost-effectiveness in a single given time period, which can be used to infer least-cost levels of abatement up to a given benchmark carbon price, or the least cost mix of abatement to meet a given emission reduction target from a static perspective. The cost-effectiveness benchmarks suggested by the global analysis are broadly consistent with the Government's carbon values for appraisal. These carbon values have been used as a comparator in the static assessment of cost-effective abatement potential available in the UK.

Section D.I: Globally Efficient level of UK Territorial Emissions

This section considers evidence on the efficient UK share of global effort to reduce emissions given a range of different global outcomes. This is based on the efficient level of abatement to be undertaken in the UK and is separate from any consideration of the UK's equitable burden share of a future international agreement which may include a role for international carbon units (discussed in the following section).

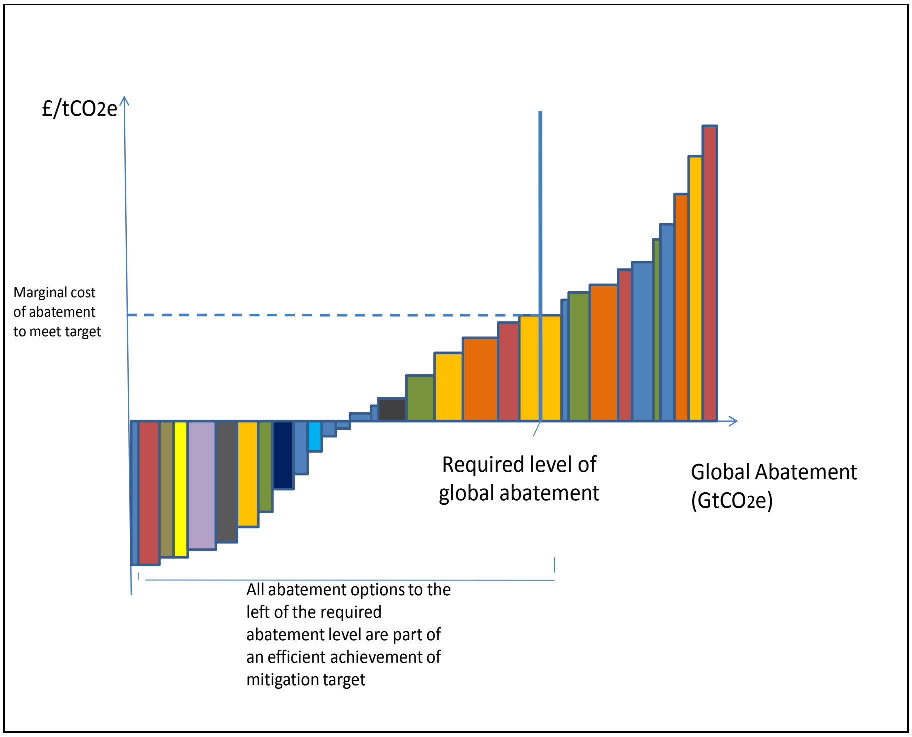
An economically efficient global effort to mitigate climate change minimises costs by exploiting least cost abatement opportunities wherever they are located. A global Marginal Abatement Cost Curve (MACC), which places all global abatement opportunities in order of their cost-effectiveness, can be used to identify an efficient approach in a given year (see Figure 17 for a simplified illustration). A level of abatement can be achieved at least cost by progressing left to right along the MACC up to the desired level of emissions reductions. If the geographical locations of the abatement options are known, then for a given quantity of abatement, a global MACC can identify the efficient abatement options, the marginal cost of achieving the level of abatement and the distribution of cost-effective abatement effort around the world. This approach can be used to estimate for a particular time period the extent to which globally cost-effective abatement is located in the UK. In particular, given a level of global abatement in 2025[66], and a global MACC for 2025, it can be used to estimate the globally efficient level for a reduction in UK territorial emissions in the fourth carbon budget.

These estimates for a Domestic Action globally efficient level for UK territorial emissions reductions cannot alone determine the level of the fourth carbon budget. The analysis is stylised; it assumes it will be possible for the world to act with perfect economic efficiency and with perfect co-ordinated action to exploit abatement opportunities which are unevenly distributed across the world, implying the implementation of policy which perfectly targets and delivers only the lowest cost abatement. The analysis also relies on uncertain estimates of the level of abatement required and the future cost-effectiveness and availability of abatement, and abstracts from dynamic considerations (i.e. which emissions pathways are more cost effective over the longer term). The analysis can therefore only suggest an order of magnitude for the efficient level of territorial emissions reductions. The analysis is nevertheless useful, because consideration of where the lowest cost abatement is located and what the efficient emissions reductions would be for particular regions in a particular year provides a useful benchmark with which to compare emissions reductions targets.

The globally efficient reduction in UK emissions does not provide a guide for the UK's burden share as part of a global deal. Cost-effective abatement is distributed unevenly across the regions of the world owing to geographical differences (such as climate or renewable energy potential), specialisation in production and differences in the stock of long lived infrastructure. The distribution of cost-effective abatement will not necessarily mirror negotiable or equitable burden shares of a global mitigation effort. For some nations, a burden share will require levels of effort that are greater than their efficient level of territorial emissions reductions. The additional burden share can be shouldered efficiently through the purchase of International Carbon Units, through which additional abatement can be funded in other countries. Through the flexibility afforded by international carbon trading, consideration of the efficient level of UK territorial emissions reductions can be separated from considerations of an appropriate UK burden share of global action to mitigate climate change.

Figure 17. An Illustrative Global Marginal Abatement Cost Curve

[66] On the basis that the efficient level of UK territorial emissions for 2025 is representative of the average level of efficient emissions over the period 2023-7.



The Analytical Approach

To perform this analysis and assess the globally efficient level of a territorial fourth carbon budget, estimates are needed for:

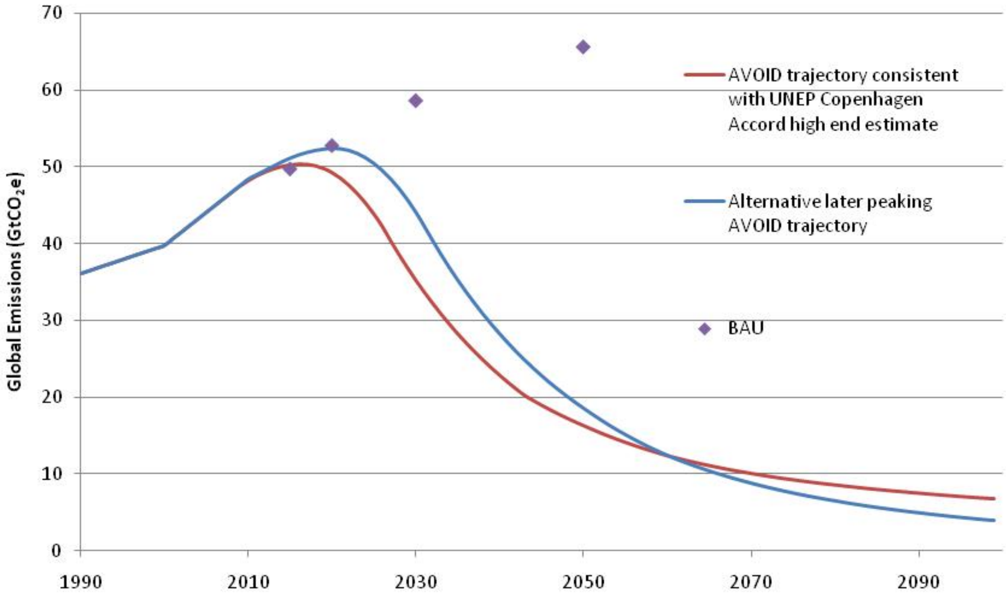
- The required quantity of global abatement in 2025; and
- A global MACC which identifies the availability and cost of abatement by nation/region.

In principle the required quantity of global abatement for a particular year can be calculated by comparing a global Business As Usual (BAU) emissions trajectory with a 2 degree consistent global emissions trajectory (the global objective as outlined in the background section above). In practice this raises a number of issues. Projecting a global BAU emissions trajectory without action to reduce emissions is uncertain, requiring many assumptions including over future economic growth, the future structure of the global economy, technological developments and fossil fuel prices. There are also numerous potential global emissions trajectories which are 2 degree consistent.[67]

The analysis for this Impact Assessment has been carried out using two models: the GLObal CArbon Finance (GLOCAF) model and PRIMES. These models provide international marginal abatement cost analysis but at differing levels of spatial coverage and resolution. GLOCAF covers abatement potential for the whole world, divided into 24 regions. However, the model treats the whole of the EU as one region and therefore cannot on its own provide an insight into the efficient level of territorial emissions for the UK. PRIMES provides greater spatial resolution, with abatement potential identified by individual European Member State, but it only covers abatement potential for the EU region. Combined, the two models can be used to provide an insight into the globally efficient level of UK territorial emissions; using GLOCAF to estimate the efficient level of EU territorial emissions and then using PRIMES to estimate the efficient distribution of these emissions across the EU. Box 8 and Box 9 provide more detail on the two models.

Figure 18. AVOID 2 degree Trajectories

[67] Which is taken to mean an emissions trajectory where the cumulative emissions are low enough that the concentration of greenhouse gases in the atmosphere do not exceed 450ppm of CO_2e.



Source: Two AVOID programme trajectories (detail on AVOID outlined in background section)

Two different 2 degree consistent global emissions trajectories have been considered in this analysis. Both trajectories are consistent with the AVOID[68] programme and are based on global abatement effort relative to BAU emissions consistent with the IEA's WEO 2009 reference scenario[69]. One trajectory incorporates the United Nations Environment Programme (UNEP)[70] assessment of Copenhagen Accord offers in 2020 (i.e. global emissions of 49 GtCO_2e) and is consistent with a 2 degree trajectory where beyond 2020, global emissions decline to 16 GtCO_2e by 2050 and to 7 GtCO_2e by 2100. The other trajectory peaks slightly higher and later and makes up for the later, higher peak by getting to a long term emissions floor of 0 GtCO_2e (i.e. after 2100). Both trajectories are illustrated in the chart below which also shows the action required relative to BAU up to 2050.

Information Box 8. The GLOCAF Model

The Global Carbon Finance (GLOCAF) model was developed by the Office of Climate Change with the aim of providing estimates of costs and international financial flows that could arise under various post 2012 global deal scenarios. The model allows the user to evaluate the impacts of different global emission reduction targets and burden sharing regimes, as well as various specifications on the carbon market design. It also includes functionality to set up funds for abatement outside the carbon market and generating market related finance.

GLOCAF models the carbon market and uses data on Marginal Abatement Costs (MAC) for 24 regions of the world[71], Business As Usual (BAU) emissions projections as well as user inputs of regional targets and carbon market design. For this analysis GLOCAF used BAU and MAC data from 3 sources:

- Energy CO_2 emissions from the POLES model calibrated to the IEA's World Energy Outlook (WEO) 2009 report;
- Non-CO_2 GHG emissions from PBL's IMAGE model calibrated to WEO 2009; and
- Forestry CO_2 emissions from IIASA's G4M and GLOBIOM models[72].

The Energy CO_2 and non-CO_2 GHG emissions data were updated in early 2010 and take into account the impacts of the recession. As the WEO 2009 report includes all policies in place at the time this is not a pure BAU free from policies. It includes a number of climate policies such as the EU's 20-20-20 package and major policies in China, USA and Japan.

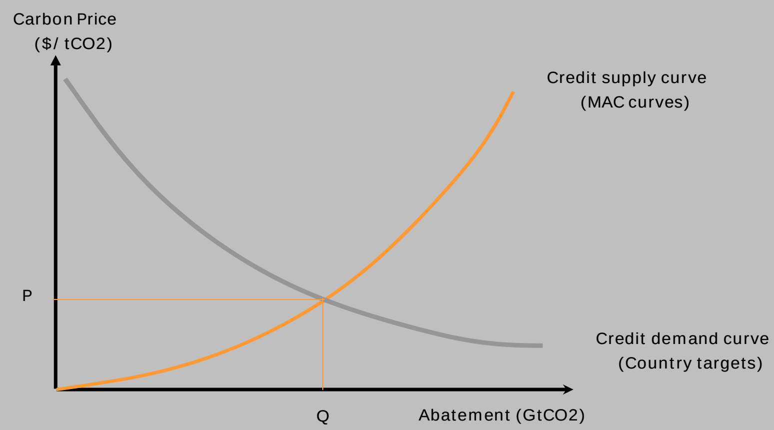
By comparing the supply curve of carbon credits (driven by MAC curves) to the carbon credit demand curves (driven

[68] See Background Section for Detail – including information box 1.

[69] International Energy Agency World Economic Outlook 2009; http://www.worldenergyoutlook.org/2009.asp

[70] UNEP convened experts from 25 research centres to explore how the 2020 emission reduction pledges submitted to the Copenhagen Accord compared to the goal of keeping the increase in global temperatures to below 2 (or 1.5) degrees Celsius. This was documented in the following report: 'The Emissions Gap Report: Are the Copenhagen Accord Pledges Sufficient to Limit Global Warming to 2°C or1.5°C?' United Nations Environment Programme(UNEP), December 2010. http://www.unep.org/publications/ebooks/emissionsgapreport/

by regional targets) the model finds the equilibrium carbon price where the demand for carbon credits matches their supply for each market.



GLOCAF uses the equilibrium carbon price to determine how much abatement each region and sector carries out and the associated incremental cost. Using the carbon price and associated demand for carbon credits GLOCAF also determines the resulting international financial flows.

The model takes into account induced technological change whereby more early action leads to lower costs in later years as additional technology becomes available. It does this by using three sets of MAC curves representing different carbon price trajectories. GLOCAF then interpolates between these to determine the appropriate costs to use for the scenario being run.

Information Box 9. Summary of the PRIMES model

PRIMES is a partial equilibrium model for the European Union energy markets. It finds the equilibrium solution which balances energy supply and demand across the European Union (EU) member states for a given constraint on greenhouse gases (GHGs).

Emissions of non-CO_2 GHGs projections are an input to the PRIMES model and are based on calculations using Marginal Abatement cost curves (MACC) and projections from the GAINS model. The methodology adopted by the GAINS model follows the framework below:

(i) as a starting point, it adopts exogenous projections of future economic activities,
(ii) develops a corresponding baseline projection of greenhouse gas emissions for 2020 with information derived from the national GHG inventories that have been reported by Parties to the UNFCCC for 2005,
(iii) estimates, with a bottom-up approach, for each economic sector in each country the potential emission reductions that could be achieved through application of the available mitigation measures, and
(iv) quantifies the associated costs required for these measures under the specific national conditions.

The PRIMES model is organised by sub-sectors, each one representing the behaviour of a representative agent (energy supplier or energy user). In the supply side, the model is divided by energy production sub-sectors (oil, natural gas, coal, electricity and heat production, biomass supply, and others). In the demand side the model is divided by end-user (residential, commercial, transport, nine industrial sectors). These different sub-sectors interact via the supply and demand for different forms of energy and prices, leading to the overall equilibrium of the energy system.

Energy prices are calculated from supply costs and infrastructure costs given assumptions about the prevailing market competition regime and price regulations. It considers environmental and technology-related policies and standards and incorporates alternative policy instruments that are meant to influence energy demand, supply and

[71] Canada, EU, Rest of Europe, Japan, Oceania, Russia, Turkey, Ukraine, USA, Brazil, China, India, Indonesia, Mexico, South Africa, South Korea, Middle East, Northern Africa, Rest of Central America, Rest of FSU, Rest of South America, Rest of South Asia, Rest of South East Asia, Rest of Sub Saharan Africa

72 POLES: Kitous, A., Criqui, O., Bellevarat, E., Château, B. (2010). Transformation Patterns of the Worldwide Energy System – Scenarios for the Century with the POLES model. Energy Journal vol. 31 (Special Issue 1). The Economics of Low Stabilisation, pp. 57-90

PBL: Lucas et al. Long Term Reduction Potential of non-CO2 Greenhouse Gases. Environmental Science and Policy Volume 10 Issue 2 (2007) pp. 85-103

IIASA: G4M http://www.cbmjournal.com/content/1/1/15, GLOBIOM http://www.iiasa.ac.at/Research/FOR/globiom.html prices, such as: taxes and subsidies, tradable emission allowances, emission limitation and energy efficiency performance standards, obligations (e.g. for renewables, CHP, etc.) and technology-push mechanisms (e.g. promotion of energy savings, etc). These factors influence energy demand and so the model simulates a closed loop between energy demand, supply and prices.

The model computes emissions from energy use and production for the whole EU27 and individual Member States by sector in 5-year periods (2015-2030). It is also able to simulate different market-based environmental policy mechanisms to provide market price equilibrium.

The PRIMES energy system model has been developed by the Energy-Economy-Environment modelling laboratory of National Technical University of Athens[73] in the context of a series of research programmes of the European Commission. DECC commissioned runs of the model from researchers at Athens University to support this IA in January 2011.

Results

The results for the two GLOCAF modelling runs are shown below in Figure 19 for the efficient share of EU abatement for the two given global emission pathways. The results suggest that the efficient level of EU territorial emissions reductions in 2030 is highly sensitive to the global emissions trajectory, however by 2050 both scenarios indicate that it would be efficient for the EU to reduce territorial emissions by close to 80% relative to 1990.

This conclusion is supported by the recent European Commission Roadmap Impact Assessment[74], which assessed the efficient level of EU territorial emissions in order to limit climate change to below 2°C. Such an assessment, based on the POLES model (as also used by GLOCAF) and a review of similar literature, concluded that the efficient distribution of abatement would result in EU emissions in 2030 and 2050 being around 45% and 80% below 1990 levels, respectively. The Roadmap also considered the possible evolution of the EU energy system to 2050, as opposed to the static estimate of an efficient distribution of abatement as estimated by POLES. This suggested that the optimal EU pathway to 2050 would result in EU domestic emissions in 2030 being 40% lower than 1990 levels. Note that none of this analysis provides any indication as to the appropriate burden share in terms of net EU emission reductions. Such a target may be higher, reflecting the relative prosperity of the EU, with the shortfall made up through the purchase of international offsets; the European Council and Parliament have endorsed a target of 80 to 95% (net) greenhouse gas emissions reductions below 1990 levels by 2050.

Figure 19. Estimated efficient reductions in EU territorial Emissions from GLOCAF

Global trajectory	Efficient reduction in EU territorial emissions	
	By 2030	By 2050
AVOID with UNEP Copenhagen assessment	43% below 1990	79% below 1990
AVOID alternative later peaking trajectory	34% below 1990	76% below 1990

The sensitivity of efficient reductions in EU territorial emissions in 2030 to the global emissions trajectory is largely explained by the different levels of abatement that are required under the two AVOID trajectories relative to the BAU. In 2030, for the UNEP consistent trajectory, a reduction of over 23 $GtCO_2e$ of abatement is required below the Business as Usual trajectory. This compares to 14.5 $GtCO_2e$ for the alternative trajectory with a later peak. As a result, the marginal cost of abatement for an efficient achievement of the trajectory differs substantially between the two runs in 2030. Less mitigation in 2030 means a lower carbon price and higher emissions within the EU. For the alternative later peak trajectory the marginal cost in 2030 is about a quarter of the level of the UNEP consistent trajectory. The efficient level of abatement in the EU drops from 1.125 $GtCO_2e$ for the UNEP consistent trajectory to 0.635 $GtCO_2e$ for the alternative trajectory[75] in 2030.

[73] http://www.e3mlab.ntua.gr/e3mlab/

[74] SEC (2011) 288; 'A Roadmap for moving to a competitive low carbon economy in 2050; Impact Assessment' http://ec.europa.eu/clima/documentation/roadmap/index_en.htm

[75] EU BAU emissions in 2030 are 4.098 $GtCO_2e$ in the model.

Figure 20. Estimated marginal cost of meeting global emissions trajectory under efficient action.

Global Trajectory	Estimated Marginal abatement cost of meeting emissions trajectory ($2005)	
	In 2030	In 2050
AVOID with UNEP Copenhagen assessment	$153/t$CO_2$e	$406/t$CO_2$e
AVOID alternative later peaking trajectory	$55/t$CO_2$e	$358/t$CO_2$e

Chapter 8 of DECC's July 2009 paper "Carbon Valuation – a revised approach"[76] made an assessment of the marginal abatement cost in 2030 of meeting a variety of stabilisation goals for atmospheric concentrations of greenhouse gases. Sensitivity to the global emissions trajectory, and ultimate stabilisation goal were assessed using the GLOCAF model as well as using other analysis including McKinsey abatement cost curves. Again, the global marginal abatement cost was shown to be sensitive to assumptions about the global emissions trajectory. It was agreed that for appraisal purposes a value of £70/tCO_2e in 2030 should be used as a cost-effectiveness benchmark for UK territorial emissions reductions. The UK should plan to reduce emissions territorially where the cost of doing so is equal to or lower than £70/tCO_2e[77]. This value lies in between the results from the two GLOCAF runs presented above. Using the published 2030 Government carbon value as a cut-off for efficient abatement would result in an efficient level of EU emissions reductions in between 34% and 43% in 2030. For the UNEP consistent trajectory the carbon price is considerably above the published Government carbon value, and for the later peaking trajectory the carbon price is lower. This highlights the importance of sensitivity analysis when considering cost-effectiveness benchmarks. The Government carbon value has a sensitivity range of +/- £35/tCO_2e – giving a range of £35/tCO_2e to £105/tCO_2e.

Although the alternative trajectory incurs lower abatement costs over the period to 2050 this does not suggest that this trajectory should be preferred to an earlier peak in global emissions. Later peaking is inter-temporally inefficient, with marginal costs of abatement after 2030 increasing at a substantially faster rate than the social discount rate. In addition, for the trajectory to be 2 degree consistent it requires global emissions to fall to zero next century which is likely to imply very substantial costs in the longer term. The rates of reduction implied by this trajectory are faster than many models take to be feasible and there are significant risks that zero emissions would be prohibitively expensive making this a much riskier trajectory. An inter-temporally efficient global trajectory would do more sooner, exploiting more low cost abatement in the near term to save more cumulative emissions space for the longer term. However, if global action is inter-temporally inefficient, and there is less abatement globally in the 2020s, then in the context of a lower level of global action it would be efficient for the EU to make lower reductions in territorial emissions over the period 2023 - 2027, even in the context of a 2 degrees Celsius goal. This analysis highlights the uncertainty over the efficient level of territorial emissions reductions for the EU (and the UK) over the fourth carbon budget period within the wider context of the level of global action (which could be following an inter-temporally inefficient trajectory).

Information Box 10. Treatment of International Aviation and Shipping and LULUCF in GLOCAF and PRIMES

To provide a useful benchmark for the level of the fourth carbon budget, the modelling in this section must estimate the efficient level of UK territorial emissions in the sectors covered by carbon budgets. While the future level of emissions from the international aviation and shipping sectors was considered by the CCC when developing their advice on the level of the fourth carbon budget, international aviation and shipping emissions are not currently included in the net UK carbon account.

The different treatment of international aviation and shipping emissions across the GLOCAF and PRIMES models must be adjusted for when using these models together to estimate the globally efficient level of the fourth carbon budget. GLOCAF modelling does include emissions from international aviation and shipping to calculate the overall level of global emissions and the consistency of the emissions trajectory with 2 degrees. However, the emissions are not disaggregated and attributed to particular regions. Instead, they are treated as all coming from one separate international aviation and shipping 'region'. The efficient levels of emission reductions which

[76] http://www.decc.gov.uk/assets/decc/what%20we%20do/a%20low%20carbon%20uk/carbon%20valuation/1_20090715105804_e_@@_carbonvaluationinukpolicyappraisal.pdf
[77] This cost-effectiveness benchmark is to be revised in 2011.

GLOCAF estimates for the EU region therefore relate to efficient reductions in emissions excluding international aviation and shipping (on the same scope as carbon budgets).

In contrast, the PRIMES model includes international aviation emissions (but excludes international shipping emissions). To translate a result from GLOCAF for an efficient reduction in EU emissions onto a PRIMES model run requires an adjustment. Because international aviation emissions since 1990 are have and are projected to grow, the efficient percentage reduction on a PRIMES basis which is equivalent to the GLOCAF result will be lower.

The results from PRIMES indicate the efficient percentage reduction in emissions including international aviation. These results then have to be translated back into the carbon budgets scope, adjusting back to an efficient level for emissions excluding international aviation and shipping.

Similar adjustments must be made for differential treatment of emissions from Land Use, Land Use Change and Forestry (LULUCF) GLOCAF includes LULUCF within the regional abatement cost curves but the PRIMES model does not include LULUCF at all. LULUCF is included in the scope of UK carbon budgets.

PRIMES analysis

A run of the PRIMES model was commissioned by DECC in January 2011. A detailed description of this run is contained in Information Box 11. PRIMES provides an estimate of the cost-effective split of abatement effort across EU Member States in 2025 and 2030. The run has EU territorial emissions reducing in 2030 by 40% relative to 1990 (hereafter referred to as "40% PRIMES")[78].

The results of the 40% PRIMES run can be regarded as providing an **upper bound** for the efficient percentage reductions in UK emissions in 2025. If the global emissions trajectory is consistent with the high end of pledges made under the Copenhagen accord, then the GLOCAF results indicate that it is efficient for EU territorial emissions, excluding international aviation and shipping, to reduce by 43% in 2030 relative to 1990. The 40% PRIMES run maps closely to this result – on the scope of emissions included in PRIMES, a 40% reduction is equivalent to a 42% reduction on the GLOCAF basis (see Information Box 8 for more detail). The 40% PRIMES run provides results for the efficient distribution of abatement within the EU for a scenario in which the world is taking substantial action before 2020 to achieve a 2 degree consistent trajectory. The upper bound for efficient percentage reductions in UK emissions by 2025 can be translated into a lower bound for the efficient level of UK territorial emissions over the fourth carbon budget.

There are no PRIMES results that map to the 34% reductions in EU territorial emissions that GLOCAF results indicate would be efficient if global emissions peak in 2020 (substantially later than in the UNEP consistent trajectory). The 34% reduction in EU territorial emissions in 2030 on the GLOCAF basis, maps onto an approximate 31% reduction on a PRIMES basis. It can be surmised, however, that the efficient percentage reductions in territorial emissions for the UK and other member states would be substantially lower, and correspondingly the efficient level of UK territorial emissions over the fourth carbon budget period would be substantially higher in the context of less ambitious global action.

As an illustration of the potential size of the sensitivity; a 1 % reduction in UK emissions relative to 1990 is approximately equivalent to an 8MtCO_2e reduction in one year. Over a five year budget period a difference of 1% in the efficient level of UK territorial emissions translates into a difference of approximately 40MtCO_2e in the efficient 'domestic action' budget level. While there is no modelling of the efficient UK share of an EU 34% reduction in emissions in 2030, given that EU territorial emissions are 9% higher in this scenario in 2030, it can be concluded that the sensitivity of the efficient level of UK territorial emissions to the global emissions trajectory could be of the scale of hundreds of mega tonnes of carbon dioxide equivalent over the fourth carbon budget period.

Information Box 11. Scenarios for the PRIMES Model

The 40% PRIMES scenario looks at the cost-efficient distribution of abatement to achieve an overall 30% target in 2020 with flexibility for trading. It therefore considers a scenario in which 25% of the effort is done internally with 5% achieved through purchase of project credits. Beyond 2020 it continues finding the most cost-efficient distribution of abatement to achieve 40% emissions reductions by 2030. The effort split between ETS and NTS (-26% for ETS and -13% for NTS in 2020) in this scenario is an input to the model and was suggested by the Commissions' Staff Working

[78] Modelled emissions reduction is in line with the headline trajectory outlined in the EU 2050 low carbon roadmap: COM (2011) 112, 'A Roadmap for moving to a competitive low carbon economy in 2050'

Document of May 2010 however distribution of abatement across countries is derived in a least cost basis. This scenario leads to 32% emissions reductions in 2025 and 40% in 2030.

Implications for the UK's cost-effective share of EU territorial emissions reductions under the 40% PRIMES scenarios can be found in Figure 21.

Adjusting the PRIMES results by removing international aviation emissions and adding historical and projected LULUCF emissions, the percentage of emissions in the traded sectors and the non-traded sectors changes. Figure 22 presents the percentages after the adjustment is made. The percentage reductions in emissions from PRIMES can be converted to absolute levels of emissions[79].

There are substantial uncertainties associated with this analysis, and a divergence between these results and the results of bottom up assessments (presented in the following sections) of the distribution of cost-effective abatement between the traded and non-traded sectors. The CCC fourth carbon budget report[80] stated that under their medium abatement scenario emissions in the traded sector would make up 35% of emissions, and emissions in the non-traded sector 65%. The results from PRIMES therefore diverge substantially from the CCC's bottom up assessment of the efficient split of effort between the two sectors. The PRIMES results are also at odds with the Government's own bottom up assessment of abatement potential (presented below in section D.III) in which insufficient traded sector abatement was identified to reduce UK territorial emissions in the traded sector to this level.

Figure 21. PRIMES results consistent with EU 40% reduction by 2030, cost**-efficient reductions in UK territorial emissions**

	40% PRIMES
Efficient % reduction in UK emissions in 2025 (all sectors) relative to 1990	46.0%
% of UK emissions in ETS sectors in 2025 (including international aviation)	36%
% of UK emissions in NTS sectors (not including LULUCF)	64%

Figure 22. Adjusted PRIMES results, cost-efficient reductions in UK territorial emissions consistent with EU 40% reduction by 2030

	40% PRIMES
% of UK emissions in ETS sectors in 2025 (excluding International aviation)	29%
% of UK emissions in NTS sectors in 2025 (including LULUCF)	71%
Efficient level of UK territorial emissions over fourth carbon budget period[81]	1900
Efficient level of UK emissions ($MtCO_2e$) in the ETS sectors 2023-27 (excluding international aviation)	552
Efficient level of UK emissions ($MtCO_2e$)in the NTS sectors 2023-27 (including LULUCF)	1348

There are substantial uncertainties associated with this analysis, however mindful of these, some conclusions can be drawn.

From the global perspective the CCC advice for the level of a 'domestic action budget' (1950 $MtCO_2e$) appears efficient provided that the world is taking ambitious early action to reduce emissions. However,

[79] There are discrepancies between the baseline emissions levels included in the PRIMES model for 1990 and the UK inventory. To avoid this impacting on the absolute level of emissions, a percentage reduction in emissions between 2005 and 2025 was calculated from the PRIMES results. This percentage reduction was then applied to the 2005 UK inventory figure for UK territorial emissions within the scope of carbon budgets.
[80] CCC (2010); page 136
[81] Assumes that 2025 is an average year for the fourth carbon budget period 2023-2027.

this level of territorial action would be inefficient in the context of later global action to reduce emissions. When considering a commitment to this level of UK territorial emissions, the balance must be struck between leadership and the risk of locking in to inefficiently fast reductions in UK territorial emissions in the absence of reciprocal effort elsewhere in the world.

The analysis in this section could be used to assess from a global perspective the efficient level of UK emissions in the non-traded sector, with the traded sector part of the budget determined by the UK share of the EU ETS cap. The section below estimates a range for the UK share of the cap over the fourth budget period between 590 $MtCO_2e$ and 860 $MtCO_2e$. Taking the globally efficient level of non-traded sector emissions in the context of ambitious global action, the implied range for the level of the fourth carbon budget is between 1940 $MtCO_2e$ to 2210 $MtCO_2e$.

The GLOCAF analysis presented in this section points to an efficient level of EU effort in 2050 of around 76-79% on 1990 levels (depending on the shape of the global trajectory). There is no existing analysis on the UK efficient share of EU territorial emissions reductions in 2050 – however PRIMES analysis for 2025 and 2030 suggest the UK will take on an efficient share above the EU average, indicating that the UK should plan to meet the 2050 target to reduce emissions by at least 80% territorially: i.e. the UK should meet the minimum reduction in the net UK carbon account in 2050 relative to 1990 required by the Climate Change Act on a territorial basis. This is drawn on in section C for considering UK pathways to meet the 2050 target.

The following section moves away from considerations of the efficient level of UK abatement and territorial emissions discussed above and considers the level of the EU ETS cap which determines the net UK carbon account.

Section D.II: International Circumstances, the EU ETS and the Net UK Carbon Account

The emission goals that the EU and UK agrees internationally will depend on the course of international climate negotiations – at this stage it is impossible to predict what share of global emissions reductions the EU and UK would take on.

The above section outlined analysis on the UK's economically efficient share of global action – and that through the flexibility afforded by international carbon trading, consideration of the efficient level of UK abatement can be separated from burden share considerations. In principle the UK would undertake an efficient level of abatement territorially and thereafter purchase international carbon units to bridge any shortfall to deliver an equitable burden share.

The CCC recognised this in its advice in December 2010, where the Committee recommended that Government legislate for a fourth budget of 1950 $MtCO_2e$ now but be prepared to move to a more ambitious level in the future as part of a post-2020 global deal. They suggested that a more ambitious fourth budget as part of a global deal might be 1800 $MtCO_2e$ or lower – the difference between this and their recommended domestic action level made up through the purchase of international carbon units.

Setting the traded portion of the fourth carbon budget now will come with high uncertainty. The Climate Change Act allows for carbon budgets to be amended after they have been set, should the basis on which they were set change. The working assumption for this analysis is that the budget level recommended now is revised if and when necessary in the light of a future global deal.

The uncertainty is important to note - in particular **the UK does not have full control over the evolution of the EU ETS (as it will depend on EU negotiations) up to and beyond 2020, and therefore over the traded sector share of the net UK carbon account.** In practice if a carbon budget level is set on an assumption of the UK share of the EU ETS cap that does not materialise (for example if the UK share of the cap ends up being a larger volume of allowances), and the budget level is not revised, then on a net UK carbon account basis the difference would need to be made up. This could be done by a range of other options, including undertaking additional abatement in the non-traded sector, the purchase of international carbon units, retiring allowances under the EU ETS, etc. These options are not explored in this IA, and instead it is assumed that the budget level would be amended to reflect the UK share of the EU ETS cap.

The EU ETS Cap Post-2020

The EU ETS cap will reflect the outcome of an international deal for the 2020s. Estimates of potential EU ETS cap trajectories and the range of potential UK shares and traded shares for the fourth carbon budget are presented below in Figure 23. In practice the level of international action will translate into an EU burden share which will translate into an agreed split of effort between traded and non-traded sectors which will translate into the level of the cap. Hence, the ranges presented below are uncertain and should be interpreted as illustrative.

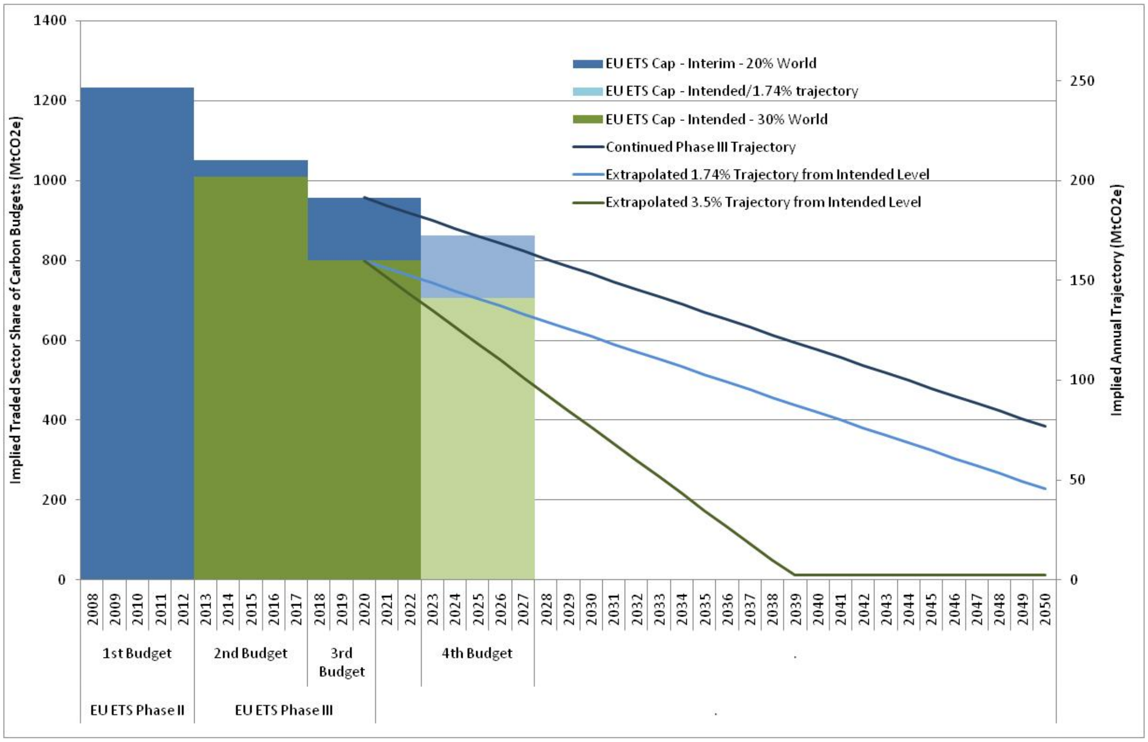
In the current EU ETS Directive, the Phase III cap from 2013 onwards will tighten by 1.74% of the average annual Phase II cap per annum – an estimated annual reduction across the EU of 37.4 MtCO$_2$e[82]. This is likely to translate to a reduction in the UK's share of the EU ETS cap from 2013 onwards by around 3.8 MtCO$_2$e p.a.. It was upon this basis that the second and third carbon budgets were set and a continuation of this trajectory is assumed in the counterfactual[83].

Should the EU move to a 30% reduction target for 2020, the EU ETS cap is likely to be tightened further. It is unclear to what extent, as this depends on the division of effort between the EU ETS and the non-traded sector. The CCC's interpretation at the time of its report[84] on the first three carbon budgets (December 2008) was that the EU ETS would take on around 64% of the additional effort required across the EU – an estimated tightening of the cap by 3.5% p.a. on 2010 levels (around a 73 MtCO$_2$ p.a. decline per year across the EU and a 8.3 MtCO$_2$ p.a. reduction for the UK). The recent publications from the European Commission[85] do not provide much clarity as to how the EU ETS trajectory might change. However, these publications do suggest a split in effort between the EU ETS and the non-traded sectors for any potential increase in ambition to the current 2020 greenhouse gas emissions targets, similar to that assumed by the CCC.

The ETS directive currently contains provision for a review of the 1.74% year on year reduction factor between 2020 and 2025, making it hard to predict the level of the cap much beyond 2020. However, extrapolating this '30% world' trajectory provides a speculative case for the evolution of the EU ETS, where by 2039 the non-aviation component of the cap falls to zero. An alternative scenario may be that post-2020 the trajectory reverts back to the 1.74% declining trajectory as set out currently by the Directive. The evolution of the EU ETS cap would also depend on the outcome of an international burden sharing agreement in the context of a global deal and then how the EU chooses to implement its burden share.

Figure 23. Legislated and Intended EU ETS shares of Carbon Budgets, post-2020 trajectories and implications for Fourth Carbon Budget Level Options

[82] http://ec.europa.eu/clima/policies/ets/cap_en.htm
[83] Note that this estimate is provision
[84] CCC December 2008 Report: http://www.theccc.org.uk/reports/building-a-low-carbon-economy
[85] COM (2010) 265 & COM (2011) 112



Source: DECC Analysis.
Note: EU ETS includes aviation from 2012 – however figures presented for carbon budget purposes exclude international aviation. Assumptions for domestic aviation are to assume the share of the cap remains constant over time.

This range of post-2020 EU ETS trajectories for the UK is presented below;

- Continuing the current EU ETS trajectory of around a 3.8 $MtCO_2e$ reduction per year up to and beyond 2020 implies net cumulative emissions in the traded sector over the fourth budget period of 862 $MtCO_2e$. The continued trajectory is inconsistent with the UK meeting its 2050 target – net traded sector emissions by 2050 would require almost full decarbonisation in the non-traded sector (or significant purchase of ICUs) which is not feasible.
- Taking the CCC's estimated EU ETS cap under an EU 30% target to 2020 then reverting back to the current cap trajectory after 2020, implies net traded sector emissions of around 700 $MtCO_2e$.
- Taking the CCC's estimated EU ETS cap under an EU 30% target to 2020 and extrapolating this trajectory of around a 8.3 $MtCO_2e$ reduction per a year beyond 2020 implies net traded sector cumulative emissions of around 590 $MtCO_2e$.

These ranges illustrate the uncertainty and magnitudes of difference over the fourth carbon budget period. These are drawn on in the concluding section of this Impact Assessment to assess how the fourth carbon budget level options compare with the range of potential future outcomes of the EU ETS cap. The true level of the traded sector emissions over 2023-7 will be determined by the EU ETS cap, and the working assumption for this analysis is that carbon budgets will be amended once this is known.

Section D.III: Analysis of Static Abatement Potential and Costs

This section presents static sector-by-sector analysis of additional abatement potential and cost-effectiveness relative to the emission projections (presented in section B) over the fourth budget period.

In the non-traded sector around 160 $MtCO_2e$ of additional abatement potential has been identified over the period 2023-7, of which just over 80 $MtCO_2e$ has been identified as cost-effective relative to the benchmark carbon price. The cost-effectiveness varies, ranging from -£740/tCO_2e up to £290/tCO_2e. Taking the abatement potential from central emissions projections would result in

total non-traded sector emissions over the fourth budget period of around 1230 $MtCO_2e$ taking all identified measures, and 1310 $MtCO_2e$ taking just statically cost-effective potential identified[86].

In heavy industry covered by the EU ETS, around 90 $MtCO_2e$ of additional abatement potential has been identified over the period 2023-7, of which approximately 80 $MtCO_2e$ has been assessed to be cost-effective. The cost-effectiveness of this potential varies from-£100/tCO_2e to £170/tCO_2e. Deducting this level of cost-effective abatement potential from central emission projections results in an emissions level across traded sectors, excluding power generation, of around 410 $MtCO_2e$ over the fourth budget period.

In the power generation sector, the level of emissions and costs depend upon choices of the market structure and the type of low carbon generation. Instead of a marginal analysis, the sector has been modelled as a whole under decarbonisation scenarios that reduce the average emissions intensity of electricity generation in 2030 to 50g CO_2/kWh or 100gCO_2/kWh.

Different scenarios imply different power sector emissions levels over the fourth carbon budget period: Under 50gCO_2/kWh[87] and 100gCO_2/kWh scenarios, emissions are estimated to be around 250 $MtCO_2$ and 360 $MtCO_2$ respectively (on central assumptions and central levels of electricity demand taking into account demand changes implied by heat and electricity measures identified).

In summary, if all cost-effective potential identified in the traded and non-traded sectors was taken up, alongside an illustrative ambition in the power sector of 100 g/kWh in 2030, relative to an emissions projection of 2306 $MtCO_2e$, resulting UK territorial emissions would be around 2080 $MtCO_2e$ over the fourth budget period on central projections. Increasing the level of ambition in the power sector to 50 g/kWh in 2030 would reduce emissions to around 1970 $MtCO_2e$.

There are a number of important caveats to place around this evidence; static assessments of abatement potential and cost may abstract from dynamic and path dependency considerations; there are a number of uncertainties affecting the analysis such that potential abatement and costs may be higher or lower than presented, and; the assessments may not comprehensively reflect all impacts (such as conventionally non-monetised and distributional impacts).

Whilst effort has been made to make this analysis as comprehensive as possible, there may be further cost-effective additional potential that has not yet been fully assessed. Beyond this, reducing emissions further would require uptake of measures not considered statically cost-effective.

Government will be considering measures to meet the fourth carbon budget in its report on policies and proposals, and will consider deliverability of the abatement potential identified in this analysis.

Marginal Abatement Cost Analysis

Marginal Abatement Cost Curves (MAC curves) rank abatement opportunities according to their associated cost-effectiveness for a given year.

On a MAC curve, each abatement opportunity is represented by a block. The height of the block represents the cost-effectiveness of the emissions savings (in terms of £/tCO_2e abated), and the width of the block measures the total level of abatement delivered through the measure.

The MAC curve orders the measures by their cost-effectiveness, starting with the most cost-effective (and hence delivering the lowest net cost associated with emissions savings) closest to the vertical axis. MAC curves are usually presented showing the total abatement potential across different sectors of the economy in a given year. The abatement potential identified in this analysis is additional to the central

[86] Abatement potential and resulting emissions over the fourth budget period in the summary box are rounded to the nearest 10 $MtCO_2e$
[87] Ambition under EMR represents the 50 g/kWh by 2030 without additional renewables

emissions projection (outlined in section B) and so reflects potential emission savings above the savings anticipated to be delivered through current and future policies included in the emissions projections.

Static MAC curves alone cannot be used to infer a socially optimal level of abatement – but can be used to infer least-cost levels of abatement up to a given benchmark carbon price, or the least cost mix of abatement to meet a given emission reduction target – from a static perspective, as opposed to a dynamic perspective which assessed abatement potential over time.

Information Box 12. UK MACC Database

An economy-wide UK MACC database has been developed, consolidating information on abatement potential through various technology measures, and the associated cost-effectiveness of measures.

Abatement opportunities have been analysed for technology types which could achieve emissions savings over the fourth budget period. Assumptions about the feasible roll out, emissions savings and costs of these technologies have been made to produce scenarios of potential abatement.

Analysts have provided scenarios of technical potential around a number of measures, for example, abatement opportunities in industry, through energy efficiency measures and renewable heat technologies, technology roll-out in transport, impact of emissions through new buildings, and emissions and abatement opportunities through agriculture, waste and LULUCF sectors. There has also been some consideration of behavioural change measures.

Additional abatement potential in the UK over the fourth carbon budget

To develop the MAC curves used in this analysis, a sector-by-sector assessment of the additional feasible technical abatement potential has been undertaken. This assessment has identified a range of measures across the economy which would deliver additional savings over the fourth budget period, relative business-as-usual technology trends and growth assumed in the central emissions projections.

Abatement potential has been identified taking into account the possible overlaps and inter-dependencies between abatement opportunities. The consistency of the costs estimated between different sectors of the economy have been considered and have been estimated following the advice of the HMT/ DECC GHG Guidance[88].

There are a number of input assumptions which are common to the analysis across sectors, for example, on central fossil fuel price projections, energy prices, growth assumptions. Further detail of the input assumptions is given in Annex 2 and 3.

There are several important caveats to place around this evidence:

- A single MAC curve presents only a static view of cost-effectiveness and abatement potential – and may abstract from how the cost of different technologies may develop with different levels of take-up within a period, and dynamically over time. It may also be limited in reflecting interdependencies across measures within a sector, across sectors and overtime (path dependency)
- The lack of granularity in the analysis may misrepresent individual increments and measures; some measures which appear in a relatively cost-ineffective block of abatement, could include a mix of measures which are relatively cost-effective and cost-ineffective, and vice-versa.
- Cost-effectiveness estimates may not reflect conventionally non-monetised impacts of abatement opportunities, such as impacts on competitiveness, distributional impacts and on other environmental and social considerations.
- Whilst every attempt has been made to be comprehensive in this analysis, some technical options and savings may be omitted, for example, potential opportunities for emissions abatement through district heating or forestry options, savings from improved landfill methane capture rates and demand reduction measures. Work will continue to identify further abatement opportunities and improve existing estimates.
- There may be a substantial difference in technical potential and cost identified in this analysis, and policy costs to deliver this for some measures. For example, negative cost abatement

[88] http://www.decc.gov.uk/assets/decc/statistics/analysis_group/122-valuationenergyuseggemissions.pdf

measures identified in this analysis are not always fully taken up without policy and government intervention. This may result in costs increasing substantially.

- There are considerable uncertainties over the development of technologies and their associated costs this far into the future. The estimated abatement potential and cost effectiveness presented are best estimates and are based on assumptions about technology uptake rates and costs that may need to be revised in future.
- MAC curves are limited in portraying the range of uncertainty surrounding abatement potential and cost-effectiveness (see Information Box 13 below). The analysis presented in this section reflects current best estimates based on central emission projections (outlined in section B) and central assumptions (outlined in Annex 2 and 3).

Sensitivity analysis around the estimates of costs associated with each fourth carbon budget option has been undertaken to gain a sense of the variance in costs due to uncertainty in both the abatement potential and cost estimates. Both high and low cost estimates have been assessed, by adjusting the implied shortfalls relative to the budget options, varying the estimated emissions reductions through different abatement opportunities and applying a range around the estimated net cost per measure of abatement.

Information Box 13. Uncertainty in UK MACC analysis

To assess potential abatement it is necessary to project emissions forward, making assumptions around the level and source of emissions, and the possible abatement technologies available. Closely associated with forecasting emissions and abatement potential into the future, is the large amount of uncertainty caused by a number of different factors, which could impact on the level of emissions and abatement potential available. The following key groups of uncertainties are inherent, and hence are important to consider, as part of the 'bottom-up' analysis:

- Modelling Uncertainty: Forecasting emissions into the future is inherently uncertain and relies on assumptions around the trends of many parameters which impact on emissions. Uncertainty in the underlying activity and emissions level implies uncertainty around potential abatement opportunities, which are assessed relative to this.

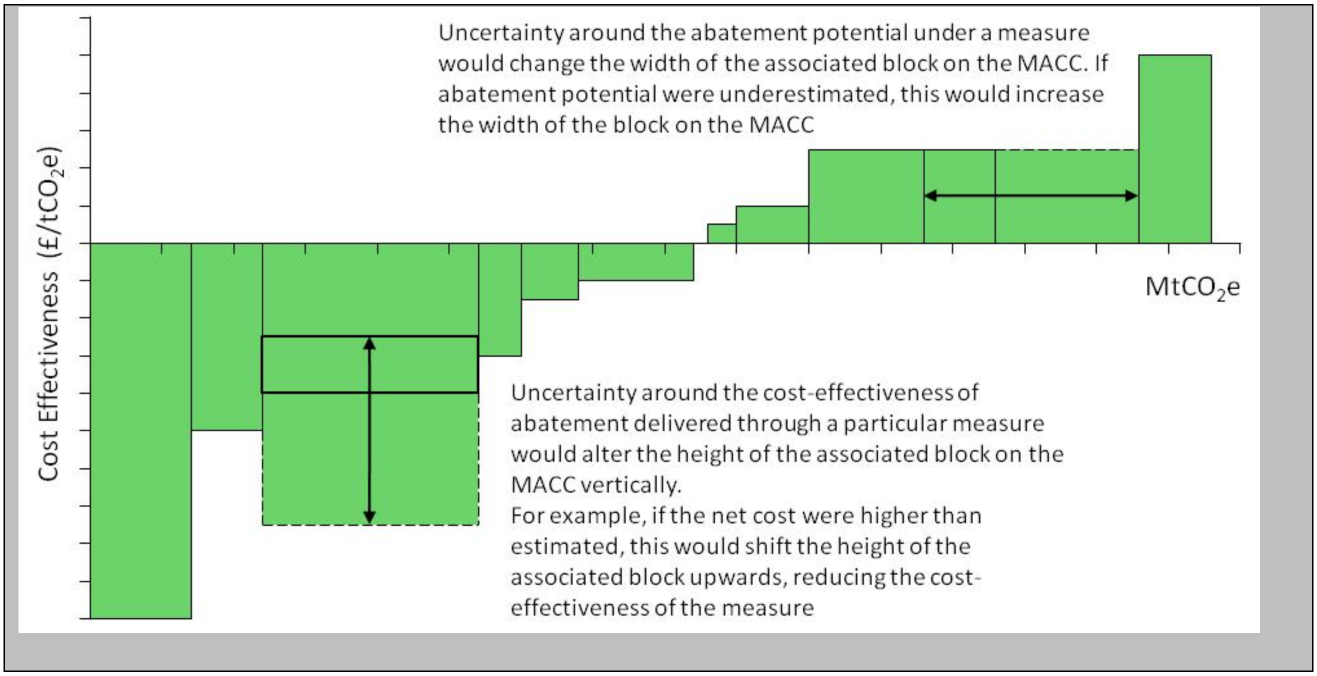
- Scientific uncertainty: Emissions from each sector depend on the emissions intensities assumed around activities in the economy, and around the levels of activity in each sector, both of which are uncertain, in particular around emissions in sectors which predominantly emit non-CO_2 GHG's, such as agriculture and waste.

- Uncertainty around deliverability: The abatement potential identified reflects technical potential and not considerations over implementing measures and delivering emission savings in practise. Different tranches of abatement potential, placing different assumptions on the availability of technology and activity levels, can provide more insight into feasibility considerations. These assumptions are however uncertain and there could be significant barriers to delivering abatement potential which is not identified.

- Cost uncertainty: Owing to uncertainty in underlying factors, such as fossil fuel energy prices, uncertainty around the development of technology costs over time, and uncertainty around the full impact of measures as some costs are non-monetised. Uncertainty around the abatement potential of opportunities would also have an impact on the estimated cost-effectiveness of these measures when calculated per tonne of carbon abated.

Uncertainty would impact on both the estimated abatement potential in the MAC curve, and on the minimised cost estimates associated with the achievement of each budget option - potentially increasing the cost of a budget option where emissions or the costs of abatement options are higher than estimated, or where potential deliverable abatement is less than that identified.

MAC Curve demonstrating how uncertainty could affect estimates of cost-effective abatement potential



Abatement potential in the Non-Traded Sector

A wide variety of measures has been considered which could deliver abatement in the non-traded sector. For example, energy efficiency measures applied to the existing building stock might deliver savings in the domestic and non-domestic sectors, renewable heat measures deliver savings across the domestic, industry and non-domestic sectors, and the roll out of ultra low emission vehicles and further efficiency improvements could deliver savings in the transport sector.

The measures and the MAC curves are used in this Impact Assessment to give illustrative figures for costs of abatement. The presence of specific measures in the table and MAC curve below does not mean that these measures will necessarily be taken forward by Government. Some of the measures may not be cost effective and others may have practical barriers to delivery and implementation. Further information on policies and proposals to meet the fourth budget are due to be published in October 2011.

The following table sets out the level of total abatement in each sector of the economy which has been identified, and contains a summary of the measures which are assumed to be taken up to achieve the emissions reductions.

The abatement measures which have been included under the above scenarios of feasible abatement potential in each sector include a number of measures with a wide range of cost-effectiveness. The cost-effectiveness of feasible measures ranges from cost-effective energy efficiency measures which are installed in the existing building stock and improvements to industrial processes, to relatively cost-ineffective measures such as additional new building standards, renewable heat measures and road transport technology measures.

The abatement potential of each measure can be presented as part of a MAC curve, ranking the cost-effectiveness of all measures across the economy. Figure 25 shows a MAC curve for the year 2025, where cost-effectiveness is measured with a base year of 2009 prices and is discounted to 2010.

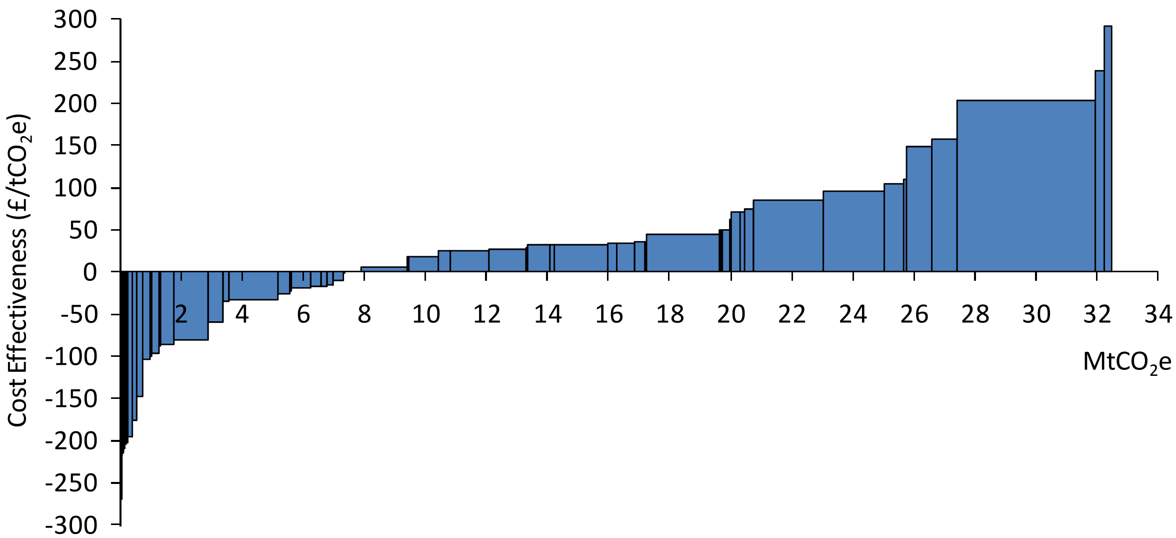
Figure 24. Additional Abatement and Cost Effectiveness[89] in the Non-Traded Sector over the fourth budget period

[89] See information box 16 for the methodology for estimating cost-effectiveness. The cost-effective benchmark is based on Governments central carbon values, detailed in the following section on benchmark carbon prices.

Sector	Non-traded sector abatement ($MtCO_2e$)	Discounted cost-effectiveness range of savings in 2025 (£2009/tCO_2e)	Cost-effective non-traded abatement ($MtCO_2e$)	Detail of sector abatement options
Domestic	40 to 54	-£100 to £290	18 to 27	Energy efficiency measures deliver relatively cost-effective abatement over the fourth budget period, with increasing building standards and renewable heat measures falling at the higher-end of the cost spectrum.
Industry	22 to 33	-£270 to £90	7 to 20	Industrial process improvements deliver relatively cost-effective abatement, renewable heat measures in industry tending to be more costly
Services	13 to 17	-£740 to £230	12 to 14	Retro-fit improvements to the fabric efficiency of existing buildings are estimated to be particularly cost-effective. Renewable heat and additional buildings standards which would improve the fabric efficiency of new buildings, tend to be costlier per tonne of carbon abated.
Agriculture	13 (uncertainty range 0 to 52)[90]	-£30 to £80	11 (uncertainty range of 0 to 46)	Improvements in on farm practices could deliver savings over the fourth budget period, however there is large uncertainty around the degree to which these practices are already taken up, emissions factors and the cost-effectiveness of measures.
Waste	0 to 1	*No estimates, policy options under consideration as part of Waste Review*	0 to 1	The effect of current policy measures and planned increases in the landfill tax are expected to deliver emission reductions over the fourth carbon budget period. Remaining abatement potential is limited as a result of these large changes already factored in to emission projections.
Transport	5 to 44	-£180 to £240	3 to 11	Further improvements in conventional vehicle efficiency and the roll out of zero and ultra low emission vehicles are among measures assumed to deliver emissions savings over the fourth budget period.
Total	**94 to 162**		**52 to 84**	

Source: HMG UK MACC Database

Figure 25. Marginal Abatement Cost Curve for the Non-Traded Sector in 2025



Source: HMG UK MACC Database

[90] Abatement potential in agriculture represents maximum technical potential in the sector, with an uncertainty range around what the abatement options identified could achieve. This uncertainty represents underlying scientific and activity uncertainty around agricultural emissions, and would be correlated with underlying agricultural emissions projections

Emission Reductions in the Traded Sector; Heavy Industry & Commercial

The abatement opportunities set out in this section reflect potential for both industrial process improvements and renewable heat installations in the heavy industry sector. The working assumption is that the current scope of the EU ETS remains the same over the fourth budget period. The detail of the identified traded sector emissions savings are included in the following table:

Figure 26. Additional Abatement and Cost Effectiveness[91] in Traded Sector

Sector	Direct traded abatement over 4th budget period ($MtCO_2e$)	Cost effectiveness of traded direct savings over fourth budget period (£2009/tCO_2e)	Amount of cost-effective direct traded abatement available over fourth budget period ($MtCO_2e$)	Detail of sector abatement options
Industry	54 to 91	-£100 to £170	48 to 83	Improvements to industrial processes and the roll out of renewable heat measures are assumed to deliver savings in the industrial sector. A small amount of savings from CCS are also assumed over the fourth budget period

Source: HMG UK MACC Database

The potential abatement opportunities display a range of cost-effectiveness. Improvements in industrial processes are estimated to be relatively cost effective, as they tend to deliver large resource cost savings through reductions in energy use for relatively small levels of capital investment in the measure. Renewable heat measures on the other hand, are relatively less cost-effective over the fourth budget period as they tend to deliver smaller energy and carbon savings per pound of investment in the measure.

Emission Reductions in the Traded Sector; Power Generation

Two factors will impact on the level of emissions from electricity generation over the fourth budget period:

- The net level of electricity demand across all sectors of the economy; and
- The average emissions intensity resulting from the power generation mix

A top down approach has been adopted for the power sector analysis to feed into the assessment of abatement, providing illustrative orders of magnitude on the potential level of emissions in this sector over the fourth carbon budget period, and costs for a range of ambition.

Information Box 14. Top-down modelling approach for the power sector
This takes forecasts of electricity demand (from the DECC Energy and Emissions Model) and nets off any changes due to abatement measures (from energy efficiency, and electrification of heat and transport). Broadly, increases in demand due to electrification of heat and transport are offset by decreases in demand through energy efficiency measures.

An emissions intensity (gCO_2/kWh[92]) per year is then applied to the net demand level (kWh) to calculate a range of overall power sector emission levels. This emissions intensity reflects the average intensity of the grid and will be dependent on the overall ambition for decarbonising the electricity sector and the generation mix.

The DECC Energy and Emissions model does not provide an estimate for energy system costs. Illustrative cost for abatement and a range of power sector decarbonisation trajectories has been provided by the Redpoint model - a market simulation model (see information box 15 below), framed around different decarbonisation levels in 2030 to provide an indicative range of results. Illustrative costs have also been provided from this analysis – reflecting the implied generation mix.

[91] See information box 16 for definition of cost-effectiveness.
[92] This is CO_2 only. Non-CO_2 GHG emissions from power generation are considered in the non-CO_2 baseline emission projections.

The net level of electricity demand

The static analysis has identified a number of measures which impact on electricity demand over the fourth budget period. Some of these measures would only impact on electricity demand, whereas other measures that reduce emissions in the non-traded and industrial sectors may also indirectly impact on the level of electricity demand.

The net change in electricity demand implied by downstream abatement options is marginal when considered across all sectors of the economy: The increase in electricity demand through the increased uptake of ultra low emission vehicles with hybrid and fully electric propulsion and heat pumps being generally offset through energy efficiency improvements in non-domestic buildings and in industry.

The range of electricity demand change is presented below relative to annual electricity generation over the fourth carbon budget period, forecasted to be around 370 TWh p.a. (based on the DECC Energy and Emissions model projections - with total generation for the period projected to be around 1850 TWh).

Figure 27. Range of net electricity demand changes from abatement options (2023-7)

Sector	**Range of net electricity demand changes from abatement options over the fourth budget period (2023-7)** (TWh, negative representing a reduction in demand)	**% change in total electricity demand from sector[93]**
Domestic	21 to 27	4% to 5%
Industry	-25 to -7	-3% to -1%
Services	-14 to 11	-3% to 2%
Transport	47 to 12	108% to 28%
Total	**29 to 44**	**2%**

Source: HMG UK MACC Database

The average emissions intensity of power generation

The emissions intensity of electricity generation is determined by a series of private sector investment and plant operation decisions within the policy framework set by Government. The optimal generation mix and emissions intensity is determined by feasibility given the legacy of existing infrastructure, and by shorter- and longer-term cost-effectiveness considerations given economy-wide pathways to meet 2050 reduction targets.

The CCC recommended (in its December 2010 report on the fourth carbon budget) that the carbon intensity of electricity generation decrease to around 50gCO_2/kWh by 2030 to be on the most cost-effective pathway to meeting the 2050 target.

The Government's December 2010 consultation[94] on Electricity Market Reform (EMR) presented a range of potential options to support the decarbonisation of power generation over the period to 2030. The outcome of the EMR will have a significant impact on the emissions from the power sector over the fourth carbon budget period. However, whilst options have been considered, no specific trajectory for decarbonisation has been set. The analysis underpinning the EMR consultation, based on Redpoint modelling (see information box 14) assumed a benchmark emissions intensity of 100gCO_2/KWh by 2030 as a basis to compare different mechanisms. This assumption was informed by earlier CCC advice which had suggested a 100gCO_2/kWh target in 2030.

In order to reflect an illustrative range for power sector emissions in this analysis, and without pre-empting any decision being taken on the EMR, two decarbonisation scenarios have been considered;

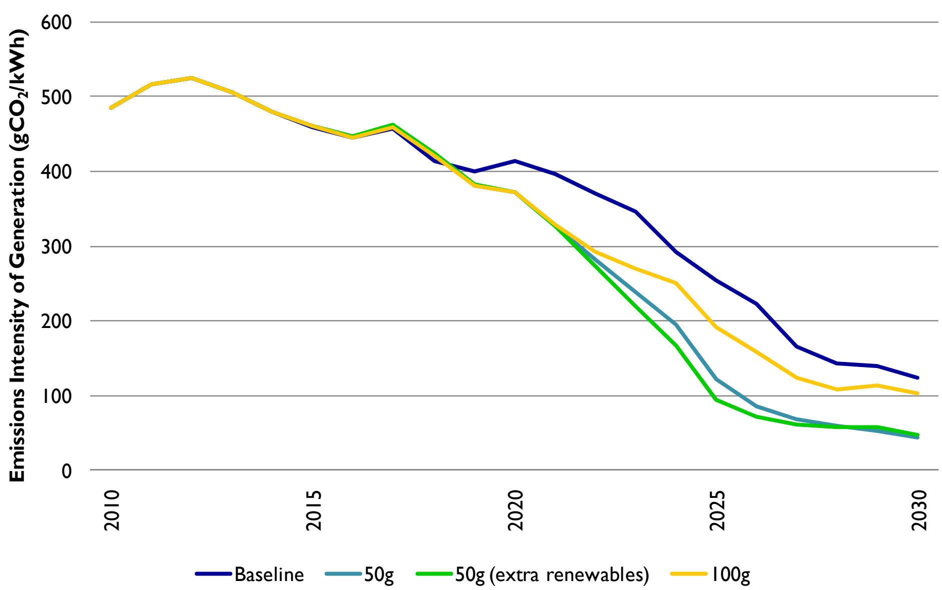
- A 100g CO_2/kWh scenario, corresponding to modelling of one of the combination packages in the EMR Redpoint modelling (Contract for Difference + Carbon Price Support + Targeted Capacity Tendering[95]).
- Two Redpoint model runs targeting a 50gCO_2/kWh 2030 grid emissions intensity.

[93] Assessed relative to central projection of final electricity consumption over the fourth budget period
[94] Electricity Market Reform: consultation document; DECC; December 2010; http://www.decc.gov.uk/en/content/cms/consultations/emr/emr.aspx
[95] Carbon Price Support places a minimum price (£30) on the cost of carbon paid by generators. Under Contracts for Difference, generators swap an electricity index price for a fixed strike price and receive a premium payment according to the technology type. Targeted Capacity Tender involves a system operator tendering for specific generation and demand-side capacity.

These scenarios together reflect an illustrative range for the analysis. In one run the renewables payment banding was adjusted to ensure renewables constituted about 70% of the additional low-carbon build needed to reflect the possibility of tighter build constraints on other low-carbon technologies.

All three runs are compared against a baseline of business as usual. The BAU scenario assumes the continuation of current policy, including 29% of the power-sector being large scale renewables in 2020 to contribute to the Renewable Energy Directive, rising to at least 35% by 2030. The BAU scenario corresponds to Scenario 2 from the Carbon Price Support Consultation Impact Assessment[96] and incorporates the carbon price floor announced in Budget 2011 (which means that costs will differ to those in the EMR Consultation Document).

Figure 28. Illustrative Average Grid Emission Intensities (gCO_2/kWh)



Source: Redpoint modelling

Information Box 15. Redpoint model
The Redpoint model simulates investment decisions in the electricity market based on given assumptions on fuel prices, supply curves, maximum build rates, and capital, financing and operating costs of electricity generating technologies.

Using these input assumptions, an investment decision simulator computes risk-adjusted long run marginal costs of all generation technologies and compares these to expected revenues to decide whether investment in the various generation technologies are economic or not. Based on this, the model computes annual outturn results in terms of energy demand, prices, generation output and carbon emissions.

Both the 50g and 100g scenarios involve a non-linear decarbonisation of the power sector and an ambitious increase in the amount of renewables, nuclear and CCS generation in the mix. The trajectories forecast by Redpoint are sensitive to assumptions about build constraints, levelised costs[97], the commercial attractiveness of low carbon investment and the availability of financing. If building rates of new low carbon generation are not technically feasible, or not feasible at the cost levels assumed in the Redpoint modelling, then the rate of decarbonisation as well as the mix of generation are liable to change. Likewise, if technological and engineering developments reduce the costs beyond the Redpoint assumptions, decarbonisation rates could be higher.

MARKAL modelling suggests that the power sector would need to decarbonise completely by 2050 to cost-effectively meet the UK's 2050 target (presented in Section C). Post-2030 decarbonisation of the power sector in a 100g scenario involves a constant decarbonisation trajectory towards 2050, whereas

[96] Carbon Price Floor: Impact Assessment for consultation; HMT / HMRC; December 2010; http://www.hm-treasury.gov.uk/d/consult_carbon_price_support_ia.pdf
[97] Capital costs averaged over the lifetime of the investment.

the 50g scenario involves a nonlinear trajectory. Existing analysis suggests that the decarbonisation trajectories following the fourth carbon budget period are achievable for both scenarios. However further analysis will be undertaken to support this assessment.

This analysis presents a range of emissions in the power sector, reflecting the large range of illustrative emission intensities: The 50g scenario implies emission levels that are around 30% lower during the fourth carbon budget period than the levels implied by the 100g scenario. There may be additional savings of non-CO_2 GHGs in the 50g and 100g scenarios, although these are likely to be small and are not considered here[98].

Figure 29. Total Power Sector Emissions over Fourth Carbon Budget Period[99]

Scenario	**Total CO_2 Emissions over Fourth Carbon Budget Period ($MtCO_2$)**	
	Taking final electricity demand net of cost-effective measures identified under static analysis	***Taking final electricity demand net of total ambition identified under static analysis***
DECC Energy and Emissions Model Central projection baseline	414	429
Redpoint baseline	477	n/a
50 g/kWh in 2030	255	263
50g/KWh in 2030 (extra renewables)	224	231
100 g/kWh in 2030	358	370

Source: HMG UK MACC Database

Costs for the power sector

The 100g/kWh and 50g/kWh scenarios provide orders of magnitude for net costs over 2010-2030. The generation costs are sensitive to assumptions on levelised costs across the different technologies; if capital costs differ, overall costs will also differ, and changes in relative costs may result in a different generation mix. Cost estimates would also change if the assumed deployment rates for different technologies are wrong in reality.

Figure 30. Cost-Benefit Analysis Relative to Baseline (£2010m, PV)

	NPV (2010-30) (£m)	**Capital & Operating Costs (£m)**	**Fuel Costs (£m)**	**EU Allowances (£m)**	**Cost effectiveness (£/tCO_2)**	**Weighted Average Discounted Carbon Price Comparator[100]**
50g Scenario	-£6,700	£27,100	-£11,000	-£9,300	£41	£25
50g Scenario (extra renewables)	-£16,400	£34,000	-£7,800	-£10,000	£62	£25
100g Scenario	-£5,400	£15,700	-£5,400	-£5,000	£45	£23

Source: Redpoint modelling

[98] The power sector emissions in this section and Figure 29 consider only the impact on CO_2 emissions from electricity generation. There are also a small amount of non-CO_2 emissions associated with power generation. It is likely that changes in generation sources which reduce CO_2 emissions would also impact on the non-CO_2 emissions. However, these savings are likely to be small and as such have not been considered in the analysis. The non-CO_2 emissions associated with power generation currently fall in the non-traded sector.

[99] Total emissions from the power sector over the fourth budget period are generated by netting off the net electricity demand changes from downstream abatement measures from the baseline forecast of electricity demand over the period generated by the DECC Energy Model. These resulting demand figures are then combined with the implied emissions intensity of power generation under different levels of ambition.

[100] See information box 17 below for detail on the weighted average discounted carbon price comparator and its uses. This cost comparator has been estimated over 2010-30, the appraisal period for the analysis but not the full lifetime of the appraisal option.

The costs presented below reflect generation (capital, fuel and operating) costs and resource cost savings from the avoided purchase of EU ETS allowances up to 2030. They do not reflect the wider impacts of higher energy prices and bills on consumers, businesses or competitiveness, or the wider benefits such as a more sustainable energy supply. The high penetration of inflexible low-carbon generation in the scenarios, particularly the 50g scenarios, will create challenges to System Operators around managing intermittency of electricity supply. There will continue to be carbon savings and generation costs beyond 2030; however the net effect of these is uncertain.

The costs of the three scenarios can be expressed in terms of £/tonne of CO_2 avoided relative to the baseline, and compared with different weighted traded carbon price comparators (see information box 17 for detail on this comparator).

Analytical Approach for use of MACC Evidence Base

This section outlines the methodology in which the MAC curve evidence is used in the concluding section of this Impact Assessment, in order to assess the cost-effective mix of abatement required to meet a given emissions shortfall and the technical costs of the fourth carbon budget options (Section G).

Each fourth carbon budget option can be considered from the perspective of meeting a required level of abatement (the difference between projected emissions and the budget level); **through undertaking an efficient share of action** (by adopting abatement that is cost-effective up to the benchmark carbon price and purchasing international credit units thereafter) **or through territorial action.**

- In undertaking an efficient share of effort, MAC curves can inform the cost-effective mix of territorial abatement potential, where all abatement up to the benchmark carbon price is taken up (illustrated by the green area in the diagram below), with any shortfall relative to a required abatement level met through the purchase of international carbon units (the amount equivalent to the red area in the diagram below).
- In meeting an emissions target through territorial action, MAC curves can inform the least cost mix of abatement potential, taking up abatement in order of decreasing cost effectiveness up to the level of abatement required (the shortfall implied from projections and the overall emission target). This is illustrated in the diagram below, where all abatement shaded green and red is taken up.

The analysis in this section presents a static view of cost-effective abatement. This method identifies the least-cost mix of technical abatement options to meet a given carbon budget – either with or without the purchase of international credits.

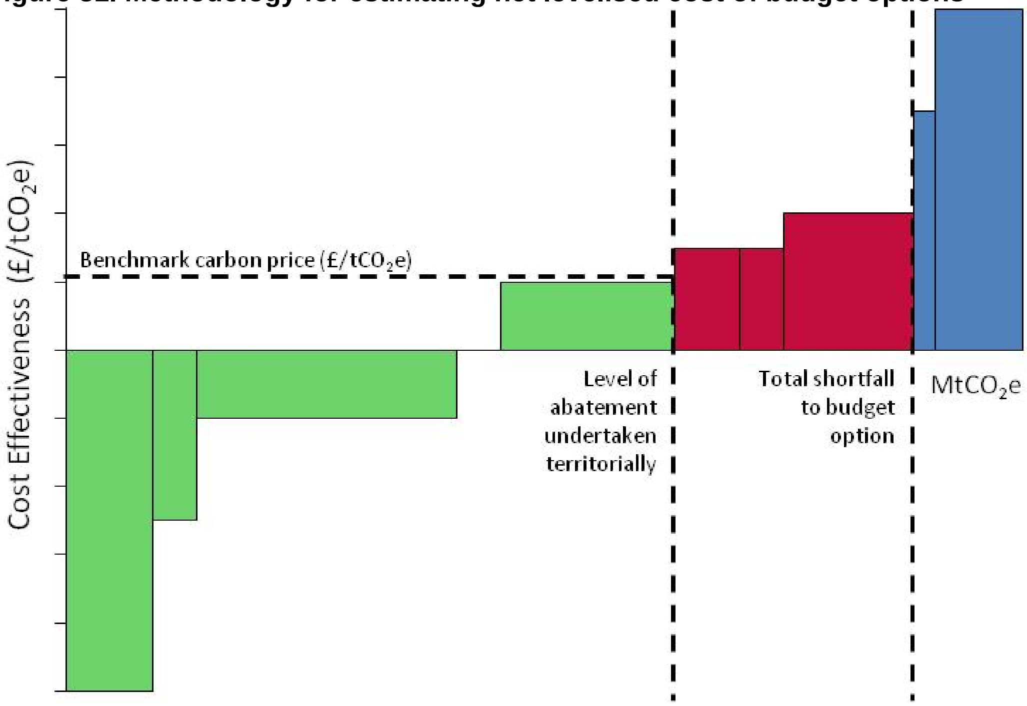
This method can be applied to provide indicative costs of meeting a given carbon budget in which the technical costs of identified abatement opportunities (either up to the abatement target, or up to the carbon price) are aggregated.

Cost estimates represent the net resource cost associated with the abatement identified over 2023-7. These reflect levelised technology (capital) costs (distributed over a technology's lifetime), operating costs and a monetised valuation of the net change in energy costs and purchase of allowances under the EU ETS (EU Allowances) – aggregated over the five-year fourth carbon budget period.

These cost estimates are calculated for the five year period of the fourth carbon budget, 2023-7. Costs associated with the lifetime of measures beyond the 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. They do not represent the total costs of the UK's climate change policy.**

Further costs and benefits have been included under some measures, for example, the value of the rebound benefit for domestic energy efficiency measures[101], the cost of congestion and air quality in transport measures and a private cost of capital reflecting the large investment costs associated with renewable heat measures.

Figure 31. Methodology for estimating net levelised cost of budget options



The cost metrics are not comprehensive. Some costs associated with abatement measures are not possible to monetise. Some impacts of measures are not captured in the net cost per tonne of emissions abated, for example, the air quality impact of renewable heat measures are not reflected in their cost-effectiveness analysis (as the impacts depend on the location of the technology and the modelling was not able to provide this breakdown), whilst air quality impacts for road transport measures have been assessed. Effort has been made to as far as possible provide a consistent view of the cost-effectiveness of abatement opportunities across different technology types. However, work continues to refine the estimates of abatement potential and cost-effectiveness, including ensuring that the types of costs included are consistent and non-monetised costs are considered and included as far as possible.

Costs do not reflect policy costs - at this stage the MACC analysis reflects technical abatement potential and costs and does not consider policy instruments, or associated policy costs, required to deliver the technical potential.

Macroeconomic second-order effects are not reflected in the total resource costs, for example from indirect impacts on the economy from investing in abatement opportunities or impacts from policy instruments.

The purchase of international carbon units is included in cost estimates for scenarios where a degree of trading is judged efficient. Credit units are monetised based on the traded carbon values from the DECC Carbon Valuation guidance (discussed in the section below).

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[101] The rebound effect occurs when individuals change their behaviour in response to an abatement measure, such that the anticipated emissions reduction of the measure may not be realised. For example, for a domestic energy efficiency measure, alongside delivering emissions savings through reductions in energy demand, households would also experience a reduction in fuel expenditure to maintain a given thermal comfort. In response, the household may choose to increase the amount of energy they consume to achieve a higher level of thermal comfort. This rebound effect reduces the potential emissions savings, but provides an additional benefit to the household through an improved thermal comfort, which is valued by the household at the cost of the increase in energy consumed. Rebound effects are valued as a welfare gain to consumers – estimated using retail prices as a proxy for the utility gained from increased energy consumption.

Information Box 16. Cost-effectiveness Metric
Cost-effectiveness - expressed in terms of net costs per tonne of CO_2e abated - is estimated according to the DECC/HMT guidance[102] and represents the net social cost of taking up an abatement opportunity. The guidance sets out a consistent methodology for estimating the net costs associated with a given level of emissions reductions. The cost-effectiveness indicator is a measure of the net cost of abatement associated with each measure. It is derived from the net present value associated with a given abatement measure, less the value of the carbon saved in either the traded or non-traded sector, depending on which cost-effectiveness indicator is being assessed. Considering lifetime cost effectiveness disguises changes in cost-effectiveness over time.

$$\text{Cost effectiveness } (£/tCO_2e) = \frac{\text{NPV – PVB carbon (either traded or non-traded)}}{\text{- (Total carbon saved in either traded or non-traded sector}(tCO_2e)}$$

For example: If an abatement measure which costs £10 and delivers £100 of fuel savings and 10 $MtCO_2$e of emissions saving in the non-traded sector at a value of £200, the cost effectiveness of the emissions savings delivered through this measure would be -£9/tCO_2e: -((100+200-10)-200)/10). 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.

Benchmark Carbon Prices

The benchmark carbon prices applied in this Impact Assessment are DECC's published carbon values for policy appraisal. These are based on a target-consistent approach outlined in the 'Carbon Valuation in UK Policy Appraisal'.[103] This has moved away from a valuation based on the damages associated with climate change, and instead linking to the cost of mitigating emissions. The values are set consistent with the UK short and long-term targets. In the near-term the presence of EU commitments and separate targets for the EU ETS and non-traded sectors imply different target consistent carbon prices for each sector up to 2020, whilst by 2030 the carbon valuation methodology assumes values based on a global carbon market price. Over the 2020s and the fourth carbon budget period price series for both the traded and non-traded sectors are considered. Below is a summary of the carbon values in 2025. (See Annex 2 for more detail).

Figure 32. Traded and Non-Traded Carbon Values for 2025 (£/ tCO_2e)

Traded (Undiscounted 2009 nominal)			Traded (Discounted to 2010)		
Low	Central	High	Low	Central	High
22	43	63	13	26	38

Non-traded (Undiscounted 2009 nominal)			Non-traded (Discounted to 2010)		
Low	Central	High	Low	Central	High
33	65	98	19	39	58

These benchmark prices can reflect the global perspective and be applied to infer a globally efficient level of UK abatement. Over 2023-7, the carbon values are assumed to converge from near-term target consistent prices in the traded or non-traded sector respectively to a common global carbon market price of £70/tCO_2e. Section D.I described the origin of this value, based on the GLOCAF model and other analysis. This value is consistent with the latest DECC GLOCAF analysis presented in this impacts assessment, where the value lies between the results from the two GLOCAF runs reflecting an efficient level of EU emissions reductions between 34% and 43% in 2030. Abatement measures identified up to this carbon price could be considered as cost-effective to undertake both from a static perspective and globally efficient perspective.

These benchmark prices are static, reflecting the market price or marginal abatement cost in a given year but not considerations of cost-effectiveness over the lifetime of an investment. In order to undertake such a comparison, lifetime costs per tonne abated would need to be assessed relative to a comparator defined as the 'weighted average discounted traded or non-traded sector cost of

[102] 'Carbon Valuation in UK Policy Appraisal', DECC, July 2010, http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/valuation/valuation.aspx
[103] 'Ibid

carbon'(see information box 17 below for an example). This considers the distribution of carbon savings over the lifetime of an investment, constructing a comparator weighted according to this distribution. This metric will be higher than the static benchmark carbon values for an investment that leads to emission savings in future where the carbon price is rising more quickly over time than the discount rate (as is the case with the published carbon values over the 2030s).

It is estimated that the appropriate cost comparators could be around 10-20% higher than the static benchmark prices used in this analysis – which suggests a larger proportion of abatement should be defined as cost effective when considering lifetime emission savings and dynamics.

For the valuation of international credit purchases the traded sector benchmark prices are applied on the basis that these are a good proxy for international credit unit prices currently (closely tracking the EU ETS EUA price) and would be the global market price in 2030.

Information Box 17. Example of using 'weighted average discounted' cost of carbon

The weighted average discounted (WAD) cost of carbon can be used to assess the cost-effectiveness of a measure over its lifetime, as opposed to using a static carbon price benchmark in a particular year, for example, £39/tCO_2e is the carbon price in the non-traded sector in 2025, discounted to 2010. This benchmark which captures the changes in the value of carbon over time is compared to the estimate of cost-effectiveness over the lifetime of the abatement measure. Examples of the weighted average discounted cost of carbon are generated below to demonstrate how this relative benchmark would change with the characteristics of the measure:

Example 1: Lifetime of the Measure: If an abatement measure were installed in 2025 and lasted 10 years, saving the same amount of emissions in each year, its WAD cost of carbon would be around £38/tCO_2e (2% lower than the static cost comparator in 2025). If the lifetime of the measure were extended to 20 and 30 years, the WAD cost of carbon would increase to £43/tCO_2e and £45/tCO_2e respectively (9% and 14% higher than the static cost comparator in 2025).

Example 2: Trend of savings over lifetime of measure: Taking the example of the measure which would save carbon over a 30 year lifetime, if the savings were assumed to rise over the lifetime of the measure, its WAD cost of carbon would increase to £48/tCO_2e. However, if its emissions savings were expected to fall over its lifetime, this would decrease the WAD cost of carbon to £42/tCO_2e (20% and 8% higher than the static cost comparator in 2025).

Example 3: Year of installation: If the measure with 30 lifetime is installed in 2015, and 2035 as opposed to 2025, assuming a constant level of emissions savings in each year, the WAD cost of carbon of the measure would be either £43/tCO_2e and £48/tCO_2e respectively over the lifetime of the measure (9% and 20% higher than the static cost comparator in 2025).

The WAD cost of carbon associated with a particular measure will depend on the trend of emissions savings over the lifetime of the measure, the lifetime of the measure and the point at which the measure is installed, as demonstrated by the above examples. These factors will then combine with the benchmark static carbon prices in each year over the lifetime of the measure to produce the WAD cost of carbon associated with this measure.

If a measure delivers savings over a period where the carbon price is rising below the discount rate, the WAD is likely to be below the static benchmark price in a given year over the lifetime of the measure. If carbon prices are rising at a rate above the discount rate, the WAD cost of carbon is likely to be higher than a relative static carbon price benchmark.

As an illustration of how the amount of cost-effective abatement may change under a WAD cost of carbon as opposed to a static benchmark in a particular year, the WAD cost of carbon under Example 1 for 30 years is taken as an illustrative benchmark. This benchmark is taken as many measures deliver emissions savings over the fourth budget and beyond and hence the appropriate WAD cost of carbon is likely to be higher than the static estimate of cost effectiveness in 2025.

Caveats to the Least-Cost Approach to estimate Technical Abatement costs

The MAC curves and abatement options identified in the bottom-up scenarios are used to derive illustrative technical costs around the fourth budget options considered in the concluding section of this Impact Assessment.

These costs will represent the minimum costs of a given budget level, as the approach will assume that all measures, starting with the most cost-effective, are taken up on the MACC until the given level of budget is reached.

This analysis does not mean that measures included in the 'least cost' mix of abatement will necessarily be taken forward and the presence of abatement from a particular sector should not be taken as meaning that level of abatement will necessarily be delivered. There may be barriers or risks to delivery that are not reflected in the analysis. Similarly, it is not necessarily the case that we would not implement any of the abatement that is shown to be less cost effective. It might be that some abatement is not necessarily cost effective when considered at a point in time, but represents action that we would need to take to be on the most cost effective pathway to our long term 2050 target (as outlined in section C). If some cost effective measures are not taken up, due to barriers to delivery, then other, more costly measures may be needed to deliver the same overall level of emissions reductions.

Some of the barriers or risks to delivery include the following:

- **Hidden costs** – some abatement might have hidden costs. One example is with home energy efficiency measures, where the 'hassle' factor involved in clearing out your loft could put someone off getting their loft lagged, even though doing so would save them money through lower fuel bills.

- **Supply chain barriers** – there might be restrictions on delivering the abatement seen in the MAC curve that stem from supply chain constraints, for example limited raw materials, lack of trained engineers or inadequate infrastructure.

- **Wider impacts** – some abatement that appears on the MAC curve may have wider implications, for example delivering the abatement might mean increased local air pollutants or negative impacts on biodiversity, or vice versa there may be co-benefits.

- **Financing constraints** – the market may not be able to provide financing on the scale required.

These are all key considerations that will need to be addressed when new policy is being developed.

Sensitivity analysis around the cost of options has been undertaken using this variance in carbon prices. As this analysis displayed a narrower range of costs relative to sensitivities around the emissions projections, only the wider range of costs have been presented in this Impact Assessment (in Section G).

Results

The following section outlines the distribution of the additional abatement potential identified in this analysis – relative to the central benchmark carbon prices and also the high and low sensitivities for the carbon values to consider the uncertainty in prices. These ranges reflect the uncertainty range around near term carbon price estimates and also ranges around global carbon prices arising from uncertainties over global emission trajectories.

Varying the carbon values redefines the level of abatement considered cost-effective, both directly, through changing the benchmark up to which measures are assumed to be 'cost-effective', and indirectly, through the valuation of resource savings or costs from the avoided purchase of allowances (EUAs) in the traded sector[104]. For example; a lower carbon price would lower the cost-effectiveness of measures which alongside reducing non-traded emissions, also reduce territorial traded sector emissions, increasing the cost per tonne of carbon saved in the non-traded sector.

The table below shows how the amount of cost-effective abatement potential, relative to the counterfactual emissions scenario, would vary under different carbon price sensitivities (in which traded and non-traded carbon prices are considered coupled, for example a low non-traded price would be consistent with a low traded price).

[104] A cost or benefit of EUA savings are included in a cost-effectiveness assessment for abatement in the non-traded sector where applicable, where for example, a measure will both save emissions in the non-traded sector and impact on electricity demand

The results presented reflect the level of cost-effective abatement potential identified in this exercise, relative to the counterfactual scenario of emissions, where it is assumed that half of the net negative cost effective abatement potential is assumed to be taken up. These results are drawn on in Section G to assess the budget options. There may be further additional abatement measures that have not yet been considered in this analysis and that may increase the levels of cost-effective abatement potential (as noted in the earlier section on caveats around this analysis).

Figure 33. Distribution of Non-traded Sector Abatement Potential relative to the counterfactual vs Range of Carbon Values[105]

Non-traded sector	**Non-Traded Sector Benchmark Carbon Values**				
	Up to £0/tCO_2e	Up to Low Carbon Values	Up to Central Carbon Values	Up to High Carbon Values	Total Technical Potential Identified
MtCO_2e abatement over 2023-7	19	32	65	81	143

Figure 34. Distribution of Traded Sector Abatement Potential relative to the counterfactual vs Range of Carbon Values

MtCO_2e abatement over 2023-7	**Traded Sector Benchmark Carbon Values**				
Traded sector	Up to £0/tCO_2e	Up to Low Carbon Values	Up to Central Carbon Values	Up to High Carbon Values	Total Technical Potential Identified
From direct abatements	40	40	43	51	51
From changes in electricity demand[106]	8	8	8	8	11

- In the non-traded sector - taking a central benchmark carbon price, up to around 65 MtCO_2e of abatement potential is identified as cost effective in the non-traded sector relative to the counterfactual. Deducting this level of abatement against central emission projections this would imply an emission level of 1310 MtCO_2e over the fourth carbon budget period.
- Under a low carbon price, the amount of cost effective abatement potential decreases to around 32 MtCO_2e. Taking up this abatement potential would reduce non-traded emissions over the period to 1342 MtCO_2e.
- Under a high carbon price, the amount of cost-effective abatement potential would be higher, with the potential to deliver 81 MtCO_2e of abatement over the fourth budget period, reducing non-traded sector emissions to 1294 MtCO_2e.

- In the traded sector, taking a central benchmark carbon price, around 43 MtCO_2e of additional abatement opportunities identified in heavy industry would be cost-effective relative to the counterfactual emissions scenario. This would reduce emissions in the traded direct sector to around 407 MtCO_2e over the fourth budget period.
- Different decarbonisation scenarios imply different power sector emissions levels over the fourth carbon budget period: Under 50gCO_2/kWh and 100gCO_2/kWh scenarios emissions are estimated to be around 255 MtCO_2e and 358 MtCO_2e respectively (on central assumptions and central levels of electricity demand taking into account demand changes implied by cost-effective heat and electricity measures identified).

[105] Levels of cost-effective abatement potential identified are expressed relative to the counterfactual, and hence remove half of the 38 MtCO_2e of negative net cost abatement potential in the non-traded sector, half of the 80 MtCO_2e in the traded sector through heavy industry and half of the 16 MtCO_2e of abatement potential through changes in electricity demand, which are included in the counter-factual

[106] Changes in electricity demand include the impact of all measures identified in the static assessment of abatement potential. This includes measures which only impact on electricity demand, and also those measures which impact on electricity demand in addition to reducing emissions in the traded industrial sector. The indirect impact on electricity demand of measures which reduce emissions in the non traded sector are not included here. Negative figures represent an increase in emissions in the sector. As ambition increases in the non-traded, the additional measures included may imply an increase in electricity demand (for example, measures which electrify heat sources and transport). The impact of these measures outweighs the impact of measures which reduce electricity demand, increasing net emissions.

The assessment of the amount of cost-effective abatement above takes as a relative benchmark the average carbon price over the fourth budget period for the appropriate sector. This relative benchmark is provides a static view of cost-effective potential, and does not provide a view of cost-effectiveness over the lifetime of abatement investments. To illustrate this, the table below presents the amount of cost-effective abatement under an indicative weighted average discounted (WAD) cost comparator that is 14% higher that the static benchmark carbon price (see information box 17 above).

Figure 35. Distribution of Traded Sector Abatement Potential vs Range of Carbon Values

Emissions Sector	**Total level of cost-effective abatement over fourth budget period under relative benchmark carbon price ($MtCO_2e$ over 2023-2027)**	
	Relative to average static carbon price over fourth budget period (central carbon prices)	*Relative to illustrative weighted average discounted cost of carbon (central carbon prices)*
Non-traded	65	79
Traded (Heavy Industry sector)	43	51

The illustrative WAD cost of carbon increases the relative benchmark of cost-effectiveness to around £45/tCO_2e in the non-traded and around £44/tCO_2e in the traded sectors, from around £39/tCO_2e and £26/tCO_2e respectively. This increases the amount of cost-effective abatement in the non-traded and traded sectors and decreases the abatement through changes in electricity demand, due to more non-traded measures assumed to be cost-effective which increase electricity demand.

Part III: The CCC's Advice

Section E: Recommendations of the Committee on Climate Change regarding the fourth carbon budget

The CCC gave its advice on the fourth carbon budget level and its proposals for how this should be met in December 2010.

This section summarises the CCC's advice and underpinning analysis. In developing the advice, the CCC started by considering a feasible target for UK emissions in 2030 (the midpoint between now and the 2050 target set in the Climate Change Act). This method allowed the CCC to present in the report a view of the detailed analysis to meet nearer term targets which was consistent with the longer-term analysis of the pathway to 2050.

The key messages of the CCC advice:

- **Global emissions pathway:** The CCC's analysis suggests that deep emissions cuts at a global and therefore UK level are required through the 2020s to be on a global emissions pathway consistent with the CCC's climate objective underpinning their first report recommendations. Further, this action would imply a rising carbon price (e.g. to £70/tCO_2e in real terms £2009, by 2030).

- **Domestic Action over 2023-2027**: The CCC recommended that Government should legislate what it refers to as a Domestic Action budget for the fourth budget period, limiting emissions to 1950 MtCO_2e, split 1260 MtCO_2e in the non-traded and 690 MtCO_2e in the traded sector. This budget reflects the CCC's assessment of feasible and cost-effective emissions reduction in the UK throughout the 2020s, consistent with the path to 2050. They recommended that the UK should aim to meet this budget through territorial action.

- **Global Offer fourth carbon budget**: In the context of a global deal covering the 2020's, the CCC recommended that the fourth budget may be amended in the future to reflect the UK's contribution to the global climate objective underpinning such a deal. The CCC suggested that such an amended budget level would be at least as ambitious as 1800 MtCO_2e, and could be met through territorial emissions reduction consistent with the Domestic Action budget, together with the purchase of international carbon units.

- **Costs and investment requirements**: The CCC estimates that the cost of meeting the Domestic Action budget is under 1% of GDP in 2025. Meeting the Global Offer budget is estimated to cost a further 0.1% of GDP in 2025, based on the purchase of international carbon units at projected prices.

Domestic Action Budget

The CCC based its proposal for the Domestic Action budget on bottom-up modelling of potential abatement opportunities to reduce emissions over the fourth budget period. The inclusion of different abatement options was determined by their relative performance against four criteria: feasibility; sustainability; cost-effectiveness;[107] and consistency with the 2050 target.

Using the bottom-up analysis and the assessment of measures against the criteria, the CCC constructed three potential scenarios of emissions which differed depending on their level of ambition; setting out low, central and high ambition scenarios over the fourth budget. These scenarios included different subsets of available measures, and hence met the four criteria above to differing extents:

- **Low abatement scenario:** This reflected the CCC's view on limited uptake of low-carbon technologies, either because promising technologies are assumed not to perform well or are

[107] Cost-effectiveness of abatement options was modelled relative to the projected carbon prices; assuming a carbon price rising to £70/tCO2e in 2030, consistent with the DECC IAG Guidance carbon prices.

more expensive than expected. This is anticipated to deliver an emissions reductions of 51% in 2030 relative to 1990.

- **Medium abatement scenario:** Is expected to deliver an emissions reduction of 60% by 2030 relative to 1990 and reflected significantly increased penetration of low-carbon technologies across the economy, requiring technological innovation, cost reduction and policy effort.

- **High abatement scenario:** Constructed assuming that the limits of what is feasible, sustainable and cost-effective were pushed such that an emissions reduction of 69% is delivered by 2030, relative to 1990.

The CCC concludes that the Medium scenario of abatement should form the basis of what the UK should plan to achieve over the fourth budget. This assumes that a large amount of the remaining cost-effective abatement potential is taken up over the fourth budget period; it is anticipated by the CCC to balance the risks of under-achievement against the risks of excessive costs during the 2020s and; is viewed to imply a feasible path to 2050.

The CCC considers its medium abatement scenario and 1950 MtCO_2e recommendation to be a form of domestic planning scenario, in which planning for a lower level of ambition would carry three risks:

1. It could result in investment in carbon-intensive assets in the period to 2020 which, while compatible with meeting the first three carbon budgets, would impede further progress in the 2020s
2. It could fail to adequately develop technologies that will be required in the 2020s.
3. It could fail to put appropriate policies in place far enough in advance of the fourth budget, resulting in limited investments with long lead times and limited supply chain expansion. It could therefore necessitate scrapping of high-carbon assets and/or the purchase of high cost carbon credits in the 2020s.

The CCC believe that their medium abatement scenario implies a feasible path to 2050 in terms of required annual emission reductions and abatement options beyond 2030. Lower cuts through the 2020s would not sufficiently develop abatement options required in subsequent periods, and would leave a need for very challenging and expensive emission reductions beyond 2030, whilst higher cuts do not appear necessary and would involve additional costs on the path to 2050.

These arguments are based on results of their internal 'stress testing' of scenarios – where considerations of deliverability, risks and alternative options were weighed up and the medium scenario considered to offer a reasonable balance.

Information Box 18. The CCC's Medium abatement scenario

Power[108]: To model the generation sector, the CCC developed scenarios based on projected future electricity demand from existing and new sectors with varying amounts of investment in low-carbon generation. Under the Medium abatement scenario, it is assumed that 30-40 GW of low-carbon capacity is added to the system through the 2020s. This results in a reduction in carbon intensity from around 300 gCO_2/kWh in 2020 to around 50 gCO_2/kWh in 2030. The scenario includes a 30% demand increase from 2020 to 2030, reflecting increased uptake of electric vehicles and heat. The scenario could be delivered through a mix of technologies including renewable (e.g. wind, marine), coal and gas CCS, and nuclear. This scenario also includes investments in smart meters and increased interconnection with Europe to provide greater system flexibility, therefore addressing potential problems associated with intermittency.

Buildings: The CCC modelled potential abatement in buildings by assuming different levels of take-up of energy efficiency measures, on top of the legacy savings over the 2020s of measures installed under their Extended Ambition scenario. In the Medium abatement scenario, there are ongoing energy efficiency improvements through the 2020s, including insulation of 3.5m solid walls in the residential sector. Heat pumps are assumed to reach a penetration rate of 25% in the residential sector, and around 60% in the non-residential sector by 2030. There is a limited assumed role for district heating, reflecting uncertainties around technical and economic aspects of, and non-financial barriers to, this option.

[108] Chapter 6 of the CCC Fourth Carbon Budget Report; 'The Fourth Carbon Budget - Reducing emissions through the 2020s'; CCC (December 2010)

Industry: In this sector, the CCC combine information on potential savings through improvements to industrial processes, with assumptions around the uptake of renewable heat measures in industry. Under the Medium abatement scenario, there is an increasing use of biomass and biogas, which together account for around 25% of total heat demand by industry in 2030. The CCC assumed there is a growing role for CCS in industry through the 2020s, which by 2030 reduces emissions by around 5 $MtCO_2e$.

Transport: A basket of measures was considered as potentially reducing emissions through surface transport over the fourth budget. Ongoing improvement of conventional vehicle efficiency (to 80 gCO_2/km for conventional cars and 120 gCO_2/km for conventional vans in 2030); was considered alongside a 60% penetration of electric vehicles in new car and van sales by 2030 under the Medium abatement scenario. Also under this scenario, the CCC considered that there is a role for hydrogen vehicles in niche sectors (e.g. 50% of new buses in 2030 are hydrogen), with the possibility of broader penetration. The CCC took a cautious approach to the sustainability of biofuels, with these remaining at levels recommended for 2020 in the Gallagher Review through the 2020s.

Agriculture, waste and LULUCF: The CCC based their advice around abatement in the agriculture sector around the research of the Scottish Agricultural College. Under the Medium abatement scenario, it assumed continuation of progress over the next decade in implementing soils and livestock measures[109]. This scenario also included emissions reduction potential from increasing afforestation in the 2020s.

Risk management and risk appetite, form a key part of the CCC approach, on the basis that:

- Risk appetite over the 2050 target should be very low, given the high damage costs and potentially very high carbon prices.
- A credible strategy should be based on realistic views as to progress with known technologies, not a reliance on as-yet-unknown options.
- The costs of aiming too high and then reducing effort are likely to be far lower than aiming too low and trying to ramp up. For example; putting in place a framework that facilitates extensive nuclear roll-out (e.g. 25GW) through the 2020s does not rule out alternatives if they prove to be cheaper, but if that option isn't developed and then carbon/gas prices are high then you may need to e.g. just bear those costs or revert to much more expensive offshore wind.
- Some options that look appealing now may not work out; only early action leaves room for a plan B. If the UK aims for an electric vehicle strategy, but finds that take-up barriers mean they are not acceptable then a back-up plan centred on hydrogen would probably need to be considered. That will take time itself in terms of product development, consumer acceptance and fleet roll-over. It will also imply a much larger burden than expected for the electricity sector (given efficiency loss in conversion). These will be surmountable with time, illustrating the value of moving relatively early (in both EVs and low-carbon power).

The CCC's abatement scenarios produce varying levels of emissions reductions over the fourth budget period. After accounting for the measures assumed to be taken up under the Medium abatement scenario, the anticipated emissions split by sector are included in the following table relative to the CCC emission projection under the CCC's Extended Ambition scenario[110] of action to 2020.

Under the CCC's bottom-up analysis used to construct their proposed fourth budget levels, the largest reduction in emissions is in the power sector, which exhibits significant decarbonisation over the 2020s. The power sector emissions reduce to 13% of total annual emissions on average over the fourth budget period under the Medium abatement scenario of abatement, relative to a sectoral share of emissions in 2008 of around 28%. Whilst a large emissions reduction is anticipated in the domestic and industry sectors, larger proportional reductions in emissions are estimated in the services sector.

Over the fourth budget, industry and refineries, surface transport and non-CO_2 GHG emissions sectors are anticipated to be the highest emitters. Further, the majority of emissions of the fourth budget period are anticipated to fall in the non-traded sector.

[109] The CCC recognised the possibility of consumer behaviour changes, both as regards to reducing waste and rebalancing diet to less carbon-intensive foods but did not include emissions reductions from these measures in the scenario.

[110] The CCC's 'Extended Ambition Scenario' represents an emissions abatement scenario which the CCC presented in 2008 to meet first three carbon budgets. Detail on this scenario can be found in their report: 'Building a Low Carbon Economy – the UK's contribution to tackling climate change'; Committee on Climate Change (2008); http://www.theccc.org.uk/reports/building-a-low-carbon-economy

Figure 36. CCC analysis relative to emissions projection baseline

Emissions Sector	Total baseline emissions in sector over fourth budget period (under CCC's Extended Ambition ($MtCO_2e$)	Total emissions in sector over fourth budget period under Medium ambition scenario ($MtCO_2e$)	Emissions reduction under Medium ambition scenario relative to baseline (% and total $MtCO_2e$)
Power[111]	460	252	45%
Domestic	304	263	14%
Services	70	44	37%
Industry and refineries	598	530	11%
Surface transport	413	396	4%
Other transport	79	79	0%
LULUCF	14	12	14%
Non-CO_2 GHGs	396	369	7%
Total	**2336**	**1945**	**-391**

Figure 37. Sectoral split of emissions over fourth budget period under CCC's Medium ambition scenario

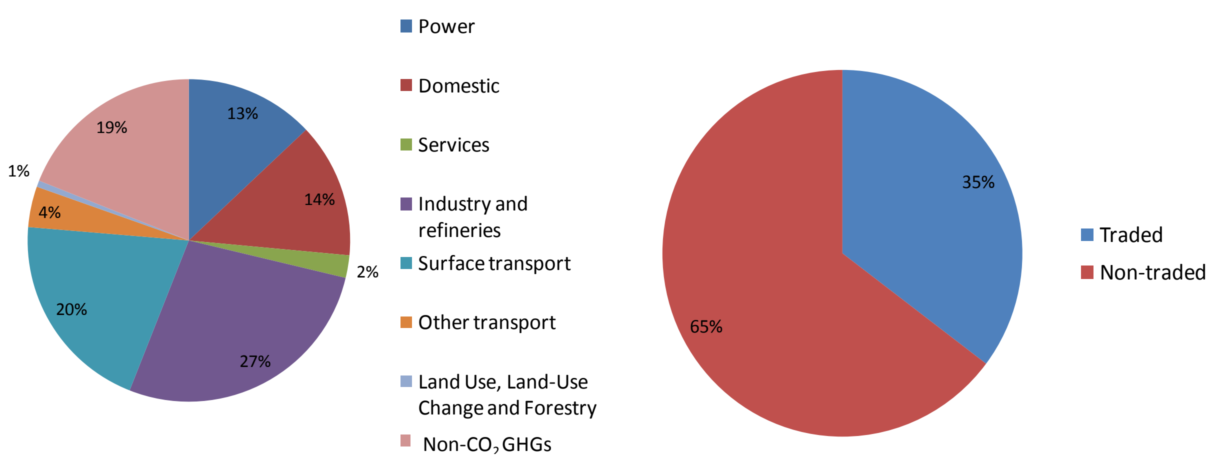

Figure 38. Proportional split of emissions between sectors under CCC higher ambition relative in 2025 relative to 2008

Emissions Sector	Sectoral share of total UK territorial GHG emissions in 2008 (%)	Sectoral share of total UK territorial GHG emissions in 2025 under medium abatement scenario (%)
Power	28%	13%
Domestic	13%	14%
Services	3%	2%
Industry and refineries	20%	27%
Surface transport	19%	20%
Other transport	2%	4%
Land Use, Land Use Change and Forestry (LULUCF)	0%	1%
Non-CO_2 GHGs	15%	19%

[111] Note that power sector emissions under Extended Ambition represent an illustrative estimate of emissions under this scenario. This takes into account reductions in indirect emissions through measures taken up through Extended Ambition assuming displacement of new gas-fired generation. However, further modelling would be required to estimate the precise impact on power emissions, including rebound effects, under this scenario

The CCC estimates that its Domestic Action budget - based on the medium ambition scenario - would imply a cost of under 1% of GDP in 2025. This cost represents the resource cost of the additional measures taken up to reduce emissions over the fourth budget period and is estimated by combining the emissions reduction under each measure with the abatement cost per tonne of emissions abated. The CCC notes that the estimates of resource costs are uncertain and would differ under changing fossil fuel prices. Sensitivity analysis around the capital costs of abatement options assumed to be taken up results in a variance of cost between 0.3% to 0.8% of GDP in 2025.

Global Offer Budget

The CCC's Global Offer budget was informed by a global pathway of emissions which is assumed to peak in 2020, followed by deep cuts through the 2020s, leading to a halving of emissions in 2050. The Global offer fourth budget proposal is derived from this pathway, taking into account the following implicit assumptions:

At a minimum the UK contribution to global effort should track the global pathway;

- It is difficult to envisage a situation where the UK is less ambitious than the global average, requiring other countries to be more ambitious;
- Beyond this minimum, more is likely to be required, depending on financing agreed under a future global deal; and

A UK emissions trend which tracks the global pathway is used by the CCC to estimate an indicative Global Offer budget of 1800 $MtCO_2e$ over the fourth budget period. The CCC recommends that the aim should be to meet the budget largely through territorial abatement given the estimated availability of cost-effective abatement potential and the sustainable pathway to 2050 target, with the purchase of international carbon units as an option to make up the difference between the domestic action budget and global offer budget.

Part IV: Wider Impacts

Section F: Consideration of Wider Impacts

Setting a constraining fourth carbon budget will require policy intervention. The degree to which this will lead to wider economic, environmental and social impacts is uncertain and cannot be determined ahead of any decisions on levels of effort in different sectors, and the different types of potential policy instruments or delivery mechanisms. These impacts will be assessed further when government reports in October 2011 on policies and proposals to deliver the fourth carbon budget, and will be more fully considered when individual policies are designed, whereby each policy will have its own individual Impact Assessment.

This following section outlines potential high-level wider impacts:

Economic Impacts

The transformation to a green economy will have significant impacts – providing both opportunities and challenges – across all households and all sectors in the UK. New low carbon and environmental industries will grow, with a rebalancing towards green investment and jobs, whilst other sectors will face significant challenges from increased prices of energy and other resources. The transition will unavoidably entail significant transitional costs in the near term, but these will be manageable, and acting now to address the environmental challenges will cost far less in the long term than acting later or not acting at all.

Investor certainty

Setting carbon budgets gives a strong signal to investors as to the future level of required emissions reductions. The EU Emissions Trading System provides such a signal for the power sector and heavy industry. However investment in the non traded sector is also crucial to bring forward key technologies to tackle climate change and the carbon budgets also provide an additional signal regarding the long term trajectory to those in the EU ETS. A strong signal to investors should increase the expected returns for investments in low carbon infrastructure and may stimulate additional investment. Such investment will be crucial to meet our longer term targets and to lower the cost of technologies required to tackle climate change at a manageable cost.

Macroeconomic Impacts

Adapting the UK economy to meet our climate change and energy goals will incur significant costs. However, the Stern report in 2006 demonstrated that the costs of action are likely to be less than the costs of not tackling climate change (see information box below). The Committee on Climate Change fourth carbon budget report concluded that meeting their proposed level of fourth carbon budget domestically (i.e. through emissions reductions in the UK) would cost under 1% of GDP in 2025. This is based on an assessment of resource costs – in other words the costs of introducing specific technologies, including upfront capital costs and operating costs, and also taking into account any benefits from fuel savings. The Government notes that resource costs can be an under-estimate of actual costs as they do not take account of wider macro-economic impacts. These could include competitiveness impacts if the UK decarbonises more aggressively than other developed economies, the cost of adjusting to the shifts in investment patterns implied, or any cost premiums from overcoming supply chain constraints. We will consider these issues further as we develop the proposals and policies for meeting the fourth carbon budget.

While some studies[112] focus on the negative impact on GDP of tighter greenhouse gas targets and the measures to tackle climate change, these studies often fail to account for a number of factors that may have a positive **impact on GDP.** These factors include gains from reduced exposure to volatile fossil fuel prices, co-benefits including improved air quality and impact of social health, reduction in the output gap, increased capital investment in the economy, move toward high growth sectors, double dividends and

[112] For example: European Commission: http://ec.europa.eu/environment/climat/pdf/26-05-2010working_doc2.pdf, OECD: http://www.oecd.org/dataoecd/6/5/45441364.pdf

innovation benefits. These impacts cannot be attributed solely to setting the fourth carbon budget, and the impacts will depend crucially on the policies implemented to meet the budget.

Recent trends have shown that the global low carbon and green sectors have been growing steadily in recent years, even during a period of economic downturn. By setting targets and signalling willingness to undertake early action on climate change, the UK may be able to position the economy to take advantage of these high growth rates by obtaining a first mover advantage in these sectors.

Finally, there may be additional benefits due to positive spill-over effects associated with innovation. Such innovation - which will be higher in immature low carbon technologies than existing infrastructure - is thought to be key to maintaining long term economic growth.

Information Box 19. Assessing the economic costs of inaction

Modelling the economic impacts of inaction on environmental objectives is very difficult because of the many feedback loops between economic activity and the environment. However, the available evidence indicates significant economic costs of inaction:

- The Stern Review considers the effects of increases in global temperatures on global consumption[113]. On the basis of a review of Integrated Assessment Model outputs, it was found that the negative impact of climate change could be equivalent to a fall in global per capita consumption of 5-20% now and forever under a business-as-usual climate change scenario[114]. This is as a result of adaptation costs (such as increased heating and cooling bills, and flood defences) and impacts which cannot be adapted to (such as health impacts and increased flood damages). It estimated the long-run costs of global action to stabilise atmospheric CO_2e and avoid catastrophic climate change to be around 1% of per capita consumption by 2050.
- There are significant risks to future growth, including through increased economic volatility, from ignoring environmental considerations. According to recent studies, the risk of the UK floods of 2000 (which damaged nearly 10,000 properties, with insured losses estimated at £1.3 billion) was recently found to have roughly doubled due to human induced emissions[115].
- There are also economic costs as a result of inefficient and unsustainable management of natural assets. For example, conserving forests avoids greenhouse gas emissions worth $3.7 trillion[116] while the net economic benefits from global fish catch is estimated to be $50bn/yr higher if stocks are better managed[117].
- The environment also indirectly supports and enables economic activity through its effect on other inputs. For example, the chronic health effects of particulate matter have been estimated to cost the UK £15 billion p.a.[118]. The value of storm buffering and flood control services from wetlands is estimated at over £1.5 billion a year[119], while the loss of pollination services would cost £440 million per year to agriculture alone[120]. Water scarcity and water restrictions are found to lead to significant losses in output through water supply restrictions on businesses.
- A recent study by UNEP attempted to capture the feedback from environmental outcomes to economic output by comparing the effects of a business-as-usual investment of 2% of global GDP to "green" investment of 2% of global GDP. The green investment scenario produced a higher global growth rate within ten years relative to the business-as-usual scenario, as a result of more sustainable farming and fishing as well as reduction in environmental risks to growth from climate change, water scarcity and other environmental factors[121].

Competitiveness

Many different factors, both domestic and international, determine the competitiveness of UK companies, including relative wage, energy and other variable costs, productivity, technological development, and exchange rates. Some policies to reduce emissions to meet the fourth carbon budget could enhance our

[113] Stern, N. (2006); 'The economics of climate change: the Stern review'; Cambridge University Press, Cambridge; http://www.hm-treasury.gov.uk/stern_review_report.htm
[114] The lower figure is a minimum. When the model incorporates non-market impacts and more recent scientific findings the total average cost is 14.4%. The 20% figure also reflects the disproportionate burden of impacts on poor regions of the world.
[115] Pall, P, Aina, T., Stone, D.A., Stott P.A., Nozawa, T., Hilbert, A.G.J., Lohmann, D., Allen, M.R., Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000; http://www.nature.com/nature/journal/v470/n7334/full/nature09762.html
[116] The Economics of Ecosystems and Biodiversity (2010), 'Mainstreaming the economics of nature'; http://www.teebweb.org/TEEBSynthesisReport/tabid/29410/Default.aspx
[117] World Bank (2009), Sunken Billions: The Economic Justification for Fisheries Reform; http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTARD/0,,contentMDK:21930578~pagePK:148956~piPK:216618~theSitePK:336682,00.html
[118] Defra (2010) http://www.defra.gov.uk/environment/quality/air/air-quality/
[119] National Ecosystems Assessment (2011)
[120] Biesmeijer, K (2010); ' Sustainable pollination services for UK crops'; (http://www.bbsrc.ac.uk/web/FILES/PreviousAwards/pollinators-biesmeijer.pdf
[121] UNEP (2011); 'Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication';

industrial competitiveness in some sectors, while others might have a negative impact, particularly in the short term if they increase costs. The report on proposals and policies in October 2011, which will set out how we will meet the fourth carbon budget, will consider the impact on industrial competitiveness in more detail.

An issue specific to energy-intensive industries and potentially other sectors such as agriculture is that they are potentially at risk from "**carbon leakage**", where industries relocate either production or investment to an area without similar carbon constraints, leading to an increase in overall global emissions. The risk of carbon leakage depends on the ability of the sector concerned to pass on costs without losing market share, its degree of exposure to international competition and the extent to which competitors face similar carbon costs. Published research[122] suggests that the risk of carbon leakage is confined to a limited number of sectors.

In the longer term, securing a strong international climate change agreement incorporating binding emissions reductions targets for developed economies and significant reductions in developing economies will be key to tackling the risk of carbon leakage. The UK supports the development of a global carbon market linked to ambitious targets as an important way to encourage emissions reductions in a cost-effective way.

Energy use and intensity

Further emissions reductions for a fourth carbon budget will require action across the economy, including the electricity, oil and gas sectors. The overall impact should be to reduce both the **UK's energy use and intensity**, though within that there is likely to be 'fuel-switching' to the extent that demand for electricity may increase, e.g. through the electrification of cars and trains, or advent of widespread ground source heat pumps instead of gas heating.

The EU ETS is expected to continue to cap emissions from fossil fuel fired power stations through the fourth budget period. The Electricity Market Review project is consulting on capacity mechanisms to ensure security of supply in spite of intermittent renewable generation, as identified in the Renewable Energy Strategy. Though consultation is ongoing, it is likely the UK will retain significant fossil fuel generation to be peaking plant (power generation capacity that can be brought on-line quickly to match peaks in demand), and the EU ETS will help minimise its use.

The level of the carbon budget set in the non-traded sector should help transfer demand for fossil fuels to renewables. This should increase fuel diversity, which would enhance energy security, provided reliable supply chains for those alternative fuels are established.

Alternatives to regulation and one-in, one-out

As the Climate Change Act 2008 requires that the level of the fourth carbon budget be set in legislation by 30th June 2011, alternatives to regulation are not an option in the setting of the fourth budget. However, alternatives will be pursued when considering the policies and proposals to meet the fourth budget, to enable the UK to meet its emissions reductions targets in a minimally burdensome way.

A key criterion for setting the levels of carbon budgets is to allow the UK to meet the 80% 2050 target at least cost – as such setting the fourth budget level does not result in any 'new' costs or benefits beyond those that have been identified in the Climate Change Act 2008 Impact Assessment (though we are now better placed to estimate these costs and benefits).

From the perspective of one-in, one-out, setting the budget level does not lead to any direct costs or benefits on business, as these will be imposed when policies and proposals to deliver the budget come into force. This measure is therefore a zero "in". All costs and benefits, both to business and society, will be assessed and quantified as and when these policies are developed.

[122] For example: Climate Strategies (UK) Reports (2007 – 2009) on: Tackling Leakage in a world of unequal carbon prices http://www.climatestrategies.org/research/our-reports/category/32.html, Öko-Institut (Germany), Fraunhofer ISI, DIW *(September 2008)* Impacts of the EU Emissions Trading Scheme on the industrial competitiveness in Germany http://www.umweltdaten.de/publikationen/fpdf-l/3625.pdf

Social Impacts

Delivering a constraining fourth carbon budget will incur costs and the **social implications of meeting the budget** will depend on how these costs are distributed. Policies to meet the fourth carbon budget could add to electricity and gas prices where the costs are passed on by energy suppliers to their customers.

DECC published an assessment of the impact of energy and climate change policies on gas and electricity prices and bills alongside the Annual Energy Statement in July 2010. While that assessment has not been updated to take account of the announcements in the Spending Review (an update will be published alongside the 2011 Annual Energy Statement later this year), funding the Renewable Heat Incentive through general taxation rather than a levy on gas prices will likely reduce the estimated impact of current and committed policies on gas prices and bills. Funding the capital cost of the first CCS demonstration through general taxation also will likely reduce the impact of CCS on electricity prices and bills. The recent policy proposals for electricity market reform, which the Government consulted on in December 2010, assuming a 100gCO_2/kWh decarbonisation scenario by 2030, would cause a small increase in electricity bills in the short to medium term (currently estimated to be a 2% increase in an average household electricity bill in the five year period to 2020 compared to continuing with current policies), however, by 2030 electricity bills are expected to be lower than they otherwise would be (in the absence of the reforms).

Moreover, the Government has a range of policies in place to improve the thermal efficiency of the housing stock and the energy efficiency of energy using products, meaning that any increases in average household energy bills will be less than they would otherwise have been. However, bills could still rise and potentially increase the risk of there being a significant number of households of fuel poverty. The Government is committed to providing support to the most vulnerable households in paying their energy bills and keeping warm at an affordable cost.

Equality Impact Assessment

This policy has been screened in line with the Public Sector Equality Duty, due to come into force from April 2011, considering the equality impacts on the protected characteristics of: age; disability; gender reassignment; marriage and civil partnerships; pregnancy and maternity; race; religion or belief; sex; and sexual orientation. The policy has been assessed using the specific screening questions set out in the EHRC guidance on Equality Impact Assessments[123]:

Figure 39. Equality Impact Assessment Screening Questions

Does the policy affect service users, employers or the wider community?	No, the policy is designed to set an overall emissions reduction target for the 4th Carbon Budget. Specific policies to deliver the Carbon Budget will be subject to individual Impact Assessments.
It is a major policy, with a significant effect on how functions are delivered?	The policy will not affect the delivery of functions.
Will it have a significant effect on how organisations operate?	No, the policy is designed to set an overall emissions reduction target for the 4th Carbon Budget. Specific policies to deliver the Carbon Budget will be subject to individual Impact Assessments.
Does it involve a significant commitment of resource?	No. Resource is already in place and no additional resource is expected.
Does it relate to an area where there are known inequalities?	No. The policy is designed to implement commitments for Government to deliver carbon savings.

Based on the answers to the specific questions above, we have decided that a full Equality Impact Assessment is not required. The overall fourth carbon budget policy will be monitored to ensure action is taken if unanticipated impact occurs. Individual Equality Impact Assessments will be carried out on specific policies designed to deliver the fourth carbon budget and these will set out any actions to be taken to mitigate against adverse equality impacts.

[123] See page 25 of http://www.equalityhumanrights.com/uploaded_files/eiaguidance.pdf

Wider Environmental Impacts

Tackling climate change, in part through the development of low carbon energy, is essential for maintaining a healthy, resilient natural environment. However, new energy infrastructure of the scale needed to play our part in achieving global reductions in greenhouse gas emissions can also have some adverse impacts on the natural environment.

The Government is committed to identifying a sustainable route to 2050, and to exploring the wider environmental impacts of our choices (including cumulative and indirect effects).

Impacts apply to a greater or lesser extent to a range of different technologies. For example, noise and landscape issues particularly effect onshore wind farms, water supply and water quality are relevant to hydro electricity, wave and tidal technologies operate in a sensitive marine environment, and soil quality and biodiversity impacts are apparent for a range of technologies.

All of this means, the potential wide-reaching and cumulative impacts of low carbon energy deployment to 2050, need to be recognised and addressed through a suite of measures. These include through the planning and consenting process, for example through Strategic Environmental Assessment (SEA), sustainability standards, and the design of incentives.

Sustainability of Bioenergy

For the purposes of this Impact Assessment a high-level assessment of the sustainability of potential demand and supply of bioenergy over the 2020s was considered.

The potential range of bioenergy demand was derived from the emission projections and analysis of additional abatement measures described in Sections B and D.III respectively. This consolidated the demand for biofuels from transport, and demand for biomass and biogas from renewable heat measures, and the use of waste and biomass in large and small scale electricity generation.

The available supply of bioenergy was considered drawing on three scenarios from AEA's UK and Global Bioenergy Resources report[124] and the BEAT[125] model and E4Tech's[126] biofuel supply projections.

The high-level conclusions were that the potential range of bioenergy demand is unlikely to exceed supply or sustainability constraints – though demand for biogas and biofuels considerations of supply and sustainability will need to be kept under review. In more detail:

Subject to international competition and the application of developing biomass sustainability criteria, for **woody biomass** there is a likely to be substantial import supply available to the UK in addition to the UK supply. Lower deployment trajectories to 2030 would require a greater proportion of the woodland resource being managed for wood fuel production, more woody feedstocks being harvested and, possibly, the establishment of new energy forests and short rotation coppice. Sustainability of supply for higher demand trajectories assumes a significant expansion of marginal land devoted to woody biomass production to meet the demand from domestic sources.

Throughout the period before and during the fourth carbon budget, demand estimates for **energy from waste** are somewhat closer to the lower end supply estimates. Even if strong demand materialises, it might be reasonable to expect a corresponding high supply scenario as more of the constraints are overcome. Demand for **biogas** may however prove more supply constrained. Demand for **biofuels** may prove constrained in low supply scenarios, however supply is likely to significantly outweigh the potential range of demand when compared against medium and high supply scenarios.

A cross-Government review of bio-energy, due to be published in July, will make a more thorough assessment of whether or not projected bio-energy demands beyond 2020 can be met sustainably.

[124] 'UK and Global Bioenergy Resource – Final Report'; AEA (2011); not yet published
[125] Environmental Assessment Tool for Biomass Energy (BEAT); http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=14484
[126] http://www.e4tech.com/en/consulting-projects.html#Bioenergy

Air quality

Many activities, especially transport and energy generation, contribute to both air pollution, at local and transboundary scales, and climate change, so our approach to meeting the fourth carbon budget will consider how the linkages between these policy areas can be managed to best effect.

Our commitment to building a low carbon economy as set out in the Climate Change Act will reduce air pollution, but choices about the route we take to 2050 will affect the scale of improvements to air quality. Factoring air quality into decisions about how to reach climate change targets results in policy solutions with even greater benefits to society. These air quality/climate change co-benefits can be realised by promoting ultra low-carbon vehicles, renewable sources of electricity which do not involve combustion, energy efficiency measures, and reducing agricultural demand for nitrogen. At the same time, we need to avoid policies that tackle climate change but damage air quality, and vice versa. The science is complex and the evidence base is developing.

A qualitative assessment of the likely impacts on air quality of some of the possible technologies for delivering the additional reductions in greenhouse gas emissions to meet the fourth carbon budget are set out below. The extent to which some of these options will be available will depend on technological development and costs, so this assessment is intended only to illustrate where policy choices could result in additional air quality benefits or costs.

Improving the fuel efficiency of conventional vehicles could have an adverse impact in air quality. This is an indirect impact from the reduced cost of driving which results in people driving more, relative to the base case. In contrast, the increased use of biofuels in liquid fuel is expected to result in air quality benefits as mileage reduces in response to the increased cost of driving. The impact of a reduction of car trips through smarter choices also has an air quality cost saving. The greater the reduction in trips, the higher the air quality benefits are assumed to be. The increased penetration of ultra low emission vehicles such as plug-in hybrid and fully electric vehicles should have a positive impact on air quality, as they replace conventional vehicles with higher tailpipe emissions and with a greater negative impact on air quality. There may be tensions in other areas too, notably between the combustion of bio-mass and air quality. The use of solid biomass (wood) as a fuel has benefits over fossil fuels in terms of carbon emissions; wood fuel is generally regarded as a low or zero carbon fuel (although carbon stock changes due to harvest are counted in the LULUCF sector). But depending on the fuel it is replacing, the locations in which it is used and the technology, the burning of wood can have positive or negative impacts on air quality. Wood fuel tends to emit a lower mass of particles than coal and often less than fuel oil but in comparison with natural gas, PM10 emissions from wood can be 10 – 100 times higher, based on emissions from current low emission biomass boiler plants. Future technological developments could greatly improve the emission performance of wood burning appliances.

Part V: Conclusions

Section G: Assessment of Options against the Evidence Base

The Counterfactual

The counterfactual from which the fourth carbon budget level options are assessed is outlined below. Abatement costs for options 1 to 6 are presented as additional to this counterfactual.

The counterfactual assumes that half of the 'no regret' abatement measures that have been identified are adopted. The evidence collated on additional abatement potential (section D.III) identifies 'no regret' abatement measures that are of net benefit to UK society even without valuing the emissions reductions that they achieve. These measures have a negative net cost per tonne of CO_2e abated. For example, energy efficiency measures where the discounted monetised fuel savings over the lifetime of the measure exceed the technology cost of the measure. **The assumption is that these measures are beneficial to pursue, irrespective of the carbon budget level and have an associated net benefit to society.**

There are a number of factors which, in practice, mean that these measures would not be taken up, even though they are of net benefit to society. For example, lack of information, lack of access to capital, inertia, hidden costs and high discount rates are some of these market failures (which have not been monetised as part of the assessment of cost-effectiveness). These factors could be preventing the full take up of these net beneficial measures and hence p**olicy may be required to unlock this remaining potential.** The influence of each market failure would vary according to sector and type of abatement opportunity.

It is however likely that some the 'no regrets' measures that have been identified would be taken up before the fourth budget period. A study by Element Energy anticipates that in the absence of Government policy, cost-effective abatement identified in the non-domestic, domestic and industrial sectors, would be taken up by private agents in the economy over the period to 2022[127]. However, barriers to take up of some abatement potential would still exist, leaving the remaining cost-effective abatement potential un-captured.

An assumption has been made that only half of the net negative cost abatement potential is exploited under the counterfactual, to reflect the likelihood that some of these barriers could continue to prevent take up into the 2020s, but that private agents are likely to take up some net beneficial abatement opportunities in the absence of Government intervention**.** Further consideration of this assumption and sensitivity analysis around this have been included at the end of this section**.**

In this Impact Assessment, the net negative cost abatement assumed to be taken up in the counterfactual, and any associated net benefit, is not attributed to the level of the emissions constraint. By attributing half of net negative cost measures to the counterfactual, the assessed cost of meeting the options for the budget level increases relative to the use of a counterfactual which includes none of the identified negative cost measures. **Assuming that half of the negative net cost abatement is taken up is a conservative approach to estimating costs**.

In the non-traded sector it is assumed that 19 $MtCO_2$e of the total 38 $MtCO_2$e of 'no regret' negative cost abatement identified is taken up and forms part of the counterfactual for this analysis. This would reduce non-traded sector emissions to 1374 $MtCO_2$e on central projections. The abatement options range from negative £740/tCO_2e up to £0/tCO_2e, with an associated net benefit of around £1.2bn over 2023-7 (best estimate on central projections, central assumptions, as identified by the MACC analysis outlined in section D.III).

[127] Element Energy (2009); 'Uptake of Energy Efficiency in Buildings';
http://downloads.theccc.org.uk/docs/Element%20Energy_final_efficiency_buildings.pdf
The report hypothesized that of a total amount of cost-effective abatement potential identified as available in 2008, in the absence of additional policies (over those existing before the Energy White Paper (2007)), around 48%, 35% and 16% of the cost-effective abatement in the non-domestic, domestic and industrial sectors would be taken up to 2022.

In the traded sector, it is assumed that 48 $MtCO_2e$ of 'no regret' negative cost abatement identified is taken up (half of the total 96 $MtCO_2e$ identified) and forms part of the counterfactual for this analysis, of which 8 $MtCO_2e$ is through changes in electricity demand and 40 MtCO2e is through 'no regret' measures in heavy industry sectors covered by the EU ETS. Of the abatement through electricity demand changes assumed to be taken up at negative net cost, 5 $MtCO_2e$ is associated with measures that only impact on electricity demand and 3 $MtCO_2e$ is associated with the indirect impact of negative net cost measures in the traded heavy industry sector The abatement options range from negative £290/tCO_2e up to £0/tCO_2e, with an associated net benefit of around £2.5bn over 2023-7[128].

For the net UK carbon account, as opposed to taking a territorial view of UK emissions, the counterfactual assumes that there is a continuation of the UK's share of the current EU ETS cap trajectory, which would lead to a traded sector of around 860 $MtCO_2e$ in 2023-7 (outlined in section D.II) based on a continuation of the current cap trajectory (as set out in the 2009 EU ETS Directive, which imposes an annual 1.74% decrease in the cap from 2013 onwards, with no sunset clause). It is assumed that coverage of the EU ETS over the 2020s is the same as in 2020.

Costs associated with meeting a traded portion of the budget of 860MtCO2e are included in the counterfactual as this is assumed to be the UK's costs of continuing participation in the EU ETS, where the cap follows a business usual trajectory. On a central emissions projection, the illustrative net levelised cost of meeting the EU ETS cap level would be around -£2.2bn, including thenet fuel saving and the capital costs associated with abatement action. These costs would half of the net negative abatement potential in the traded sector, alongside the adoption of industrial abatement measures up to the static carbon value over the period (average price of £26/tCO_2e over the fourth budget period), with the remaining shortfall to the budget option made up through the purchase of allowances at the relative carbon value.

The following six carbon budget levels – covering all UK GHG emissions over the period 2023-7 - have been considered.

Each Carbon Budget level option is assessed against the three analytical perspectives outlined in the evidence base section. Budget levels are:

- Compared to emissions forecasts and static abatement potential;
- Compared to the globally efficient level of UK abatement;
- Checked for consistency with feasible and least-cost pathways to the UK 2050 target.

The costs associated with the different budget levels are assessed assuming an efficient level of trading (the methodology as outlined in section D.III). This means that options for territorial abatement will be taken up, up to the traded or non-traded price of carbon, and thereafter any further required reductions met through the purchase of international carbon units. As a sensitivity an assessment is also made of the costs when the budget is met exclusively through territorial abatement (with no allowance for trading).

The non-traded and traded sector budget levels of the carbon budgets are considered first separately, before being combined into an economy wide perspective and option levels considered at the end of this section.

The options are constructed on a net UK carbon account basis. Whilst the uncertainty governing the EU ETS cap is recognised (as discussed Section D.II) **a working assumption for the purposes of this analysis is adopted – that the traded sector share of the budget is revised in future to be equal to the UK share of the EU ETS cap.**

The following sections consider budget levels in the non-traded and traded sectors in turn before combining options to consider a combination of economy-wide fourth carbon budget scenarios.

[128] The costs associated with net change in electricity demand through net negative measures taken up in the non-traded sector are included in the net cost of the non-traded counterfactual.

Figure 40. Fourth Carbon Budget Level Options

	Description	**4th Carbon Budget Level ($MtCO_2e$)**	**Average Reduction Relative to 1990**	**Traded Share** ($MtCO_2e$/% total)	**Non-Traded Share** ($MtCO_2e$/% total)
Option 1	'Do nothing' scenario – a non-constraining budget. Level based on a continued EU ETS cap trajectory based on the current EU ETS directive and an illustrative non-constraining budget level in the non-traded sector.	Non-constraining budget e.g. 3000	23%	860 (29%) (estimated EU ETS cap)	2140 (71%)
Option 2	Level based on a continued EU ETS cap trajectory and in the non-traded sector a continued downward trajectory from legislated second and third carbon budgets (2013-22)	2310	41%	860 (37%) (estimated EU ETS cap)	1450 (63%)
Option 3	Level based on a continued EU ETS cap trajectory and a statically cost-effective level of UK territorial abatement in the non-traded sector defined by Government's carbon values for appraisal	2170	45%	860 (40%) (estimated EU ETS cap)	1350 (60%)
Option 4	Level based on a continued EU ETS cap trajectory and the CCC recommended level of emissions in the non-traded sector	2120	46%	860 (41%) (estimated EU ETS cap)	1260 (59%) implied CCC medium abatement scenario
Option 5	CCC recommended fourth carbon budget	1950	50%	690 (35%) implied CCC medium abatement scenario	1260 (65%) implied CCC medium abatement scenario
Option 6	CCC Global Offer Budget – the CCC's assessment of what the fourth budget might need to be amended to in the future to reflect the UK's share of a future global climate change deal	1800	54%	690 (38%) minus 150 (-8%) international credit purchases	1260 (70%) implied CCC medium abatement scenario

Options in the Non-Traded Sector

The following options have been considered in the non-traded sector. These have been assessed relative to the non-traded sector emissions level counterfactual of 1374 $MtCO_2e$ on central projections. This takes into account half of the negative cost 'no regret' abatement measures as outlined above.

Of the four option levels set out above;

- Level A is non-constraining, set at a level that in principle, under no eventualities, will exceed the level counterfactual level of emissions.
- Level B is based on a continuation of the downward trajectory set by the second and third non-traded sector budget levels – on central and low projections this is also non-constraining, but under high emission projections there will be a small emissions shortfall (of 34 $MtCO_2e$) relative to the non-traded budget level.
- Level C is based on a cost-effective level of territorial action defined by DECC's non-traded sector carbon values. Relative to the central projection counterfactual there is an emissions shortfall of 64 $MtCO_2e$. On high projections this increases to 174 $MtCO_2e$, whilst on low projections there is an emissions surplus.
- Level D is based on the CCC's recommended level of action in the non-traded sector based on their medium abatement scenario. Under the modelled range of emission projections in all cases there is an emissions shortfall, ranging from 40 to 224 $MtCO_2e$.

Figure 41. Budget Levels and Emission Shortfalls ($MtCO_2e$, 2023-7)

		Non-Traded Sector Budget Levels	Emissions Shortfall (- surplus)		
			On Low Projections	On Central Projections	On High Projections
A	Non-constraining budget level	Non-constraining level e.g. 2140	n/a	n/a	n/a
B	Level based on a continuation of the downward trajectory set by the second and third non-traded sector budget levels	1450	n/a (-150)	n/a (-76)	34
C	Level based on a cost-effective level of UK territorial abatement defined by Government's non-traded sector static carbon values	1310	n/a (-10)	64	174
D	Level based on the CCC's non-traded sector recommendation	1260	40	114	224

Static Costs of Meeting Non-Traded Sector Budget Levels

The table below outlines the least cost estimates of technical abatement costs in the non-traded sector. This draws on the analysis and methodology presented in Section D.III on the static assessment of additional potential and cost effectiveness.

Figure 42. Non-traded Sector Technical Abatement Costs above counterfactual 2023-7 (PV, £2009m)[129]

	Non-traded Sector Level: MtCO2e	Fuel Cost (£m)	Technical plus other costs (£m)[130]	EUA Savings (from changes in electricity demand) (£m)	Credit Purchase (£m)	Total (£m)
Total cost associated with carbon budget option (with trading where cost-effective)						
On Central Projections	**A: 2140**	0	0	0	0	**0**
	B: 1450	0	0	0	0	**0**
	C: 1310	-£2,000	£1,700	£100	0	**-£100**
	D: 1260	-£2,000	£1,700	£200	£1,300	**£1,200**
On Low Projections	**A: 2140**	0	0	0	0	**0**
	B: 1450	0	0	0	0	**0**
	C: 1310	0	0	0	0	**0**
	D: 1260	-£900	£100	0	0	**-£800**
On High Projections	**A: 2140**	0	0	0	0	**0**
	B: 1450	-£900	£100	0	0	**-£900**
	C: 1310	-£2,000	£1,700	£200	£2,800	**£2,700**
	D: 1260	-£2,000	£1,700	£200	£4,100	**£4,000**
Illustrative costs assuming non-traded sector budget met domestically (with no trading)						
	Non-traded Sector Level: MtCO2e	Fuel Cost (£m)	Technical plus other costs (£m)	EUA Savings (from changes in electricity demand) (£m)	Credit Purchase (£m)	Total (£m)
On Central Projections	**A: 2140**	*0*	*0*	*0*	*0*	***0***
	B: 1450	*0*	*0*	*0*	*0*	***0***
	C: 1310	*-£2,000*	*£1,700*	*£100*	*0*	***-£100***
	D: 1260	*-£2,100*	*£5,400*	*£500*	*0*	***£3,800***
On Low Projections	**A: 2140**	*0*	*0*	*0*	*0*	***0***
	B: 1450	*0*	*0*	*0*	*0*	***0***

[129] Note: Costs are rounded to nearest £50m hence in some instances, the disaggregated costs do not sum to the totals due to rounding error

[130] Costs included in this category predominantly represent the capital costs associated with uptake of the measure. In certain circumstances, other costs, such as ongoing operating costs, the impact on air quality or congestion, have been monetised where appropriate.

	C: 1310	*0*	*0*	*0*	*0*	***0***
	D: 1260	*-£900*	*£100*	*0*	*0*	***-£800***
On High Projections	**A: 2140**	*0*	*0*	*0*	*0*	***0***
	B: 1450	*-£900*	*£100*	*0*	*0*	***-£900***
	C: 1310	*No net cost estimated as not enough measures identified on the central MACC. This does not strictly imply that there is not enough technical potential to meet budgets in these scenarios – the caveat is that there may be further opportunities that have not been considered as part of this analysis[131], and also that under a high emission projection the abatement potential of measures may increase inline[132].*				
	D: 1260					

The first section of the table illustrates least cost estimates in which an efficient level of trading is allowed, the second section of the table presents illustrative costs assuming the non-traded sector budget is met territorially with no trading. **It is clear that in scenarios where trading is cost-effective to meet a given target this can significantly reduce the costs. Decisions not to use the purchase of international carbon units and to undertake further UK abatement, would raise the costs of options.**

Sensitivity Analysis around the Counterfactual

In the counterfactual, it is assumed that half of the 'no regrets' measures identified in the evidence base would have been taken up over the period to the fourth budget period, with no additional intervention by Government. Hence these measures are included in the counterfactual. This assumption balances the considerations that some barriers to take-up are likely to remain by the fourth budget period, with evidence that private agents take up some emissions saving measures without Government intervention[133].

The evidence around what level of 'no regrets' measures to include in the baseline is not conclusive. Hence, sensitivity analysis has been carried out around this assumption, to explore how changing this assumption would impact on the cost estimates of the different budget options. The sensitivity analysis shows the costs of options including 25% and 75% of 'no regrets' abatement in the counterfactual.

Changing the assumption around the proportion of 'no regrets' included in the counterfactual does have an impact on costs. Including less in the counterfactual (as under the 25% sensitivity), results in more 'no regret' measures being available to be taken up to meet the budget option. These net beneficial measures therefore decrease the cost of the budget option, as this benefit is no longer included as part of the counterfactual.

The cost range above represents a sensitivity of 25% to 75% of the 'no regrets' measures being included in the counterfactual. The sensitivity range was selected to show a varying amount of the 'no regrets' abatement taken up, but also to maintain that barriers are likely to persist that would leave a proportion of the abatement un-captured. This assumption is evidently a key driver of costs. However, the range of costs presented above sits within the uncertainty range around the costs generated by uncertainty in the underlying emissions projections.

A range of cost sensitivities is presented to reflect uncertainty under different emission projection scenarios (consistent with emission projections presented in Section B). In practice a range of uncertainties, for example, surrounding abatement potential, technology costs, fossil fuel prices and carbon prices will affect total costs.

131 The analysis is not comprehensive, there may be more abatement opportunities and cost-effective abatement opportunities that have not been fully assessed.

132 If projections are higher because of lower energy prices, which increase energy demand in the counterfactual emission projections, per measure the potential savings may be higher as higher demand implies greater use of the technology. For example, lower energy prices lowers household energy bills and may lead to an increase in heating and the average temperature one heats their home. The installation of a more efficient boiler, or heat pump, would relative to central projections, would lead to greater savings, as is utilised to a greater extent.

133 'No regrets' measures in the evidence base include opportunities in sectors outside those considered in the Element Energy report – agriculture, waste and transport. Given this discrepancy, and the fact that the 'no regrets' measures are all negative cost-effective, as opposed to the cost-effective abatement considered by Element Energy report, half of the abatement potential is included as a working assumption

Figure 43. Sensitivity analysis around costs of budget options in non-traded sector

		Total cost of non-traded sector budget option (£m)		
Counterfactual assumption around the inclusion of 'no regret's measures		25%	50%	75%
Total cost associated with carbon budget option (with trading where cost-effective)				
On Central Projections	**A: 2140**	0	0	0
	B: 1450	0	0	0
	C: 1310	-£700	-£100	£500
	D: 1260	£600	£1,200	£1,800
Illustrative costs assuming non-traded sector budget met domestically (with no trading)				
On Central Projections	**A: 2140**	*0*	*0*	*0*
	B: 1450	*0*	*0*	*0*
	C: 1310	*-£700*	*-£100*	*£500*
	D: 1260	*£3,200*	*£3,800*	*£4,400*

Costs in this section are presented as relative to the counterfactual.

Of the four option levels set out above;

- Level A is non-constraining under all potential emission projections outcomes. There is no requirement for additional abatement under this scenario and no associated abatement costs.

- Level B is non-constraining in all but the modelled high range of emission projections. As a result, it is assumed that action would be taken only under the high emissions projection to meet the budget option. This additional abatement potential would deliver a net benefit of around £0.9bn over 2023-7.

- Level C is based on a cost-effective level of domestic action defined by DECC's non-traded sector carbon values and would be constraining under both central and high emissions projections. Under central emissions projections, the additional abatement assumed to be taken up delivers a net benefit of around £0.1bn. This is a consequence of taking up the remaining 19 $MtCO_2e$ of net negative cost abatement before taking up cost-effective abatement potential to fulfil the remaining shortfall. Under a high emissions uncertainty, the net levelised cost would be around £2.7bn relative to the counterfactual. If the non-traded sector budget level was to be met domestically with no credit purchase, the net benefit of Level C remains at around £0.1bn, as there is enough abatement potential available in the non-traded sector below the shadow price of international carbon units, such that no purchase of these units is required when trading is allowed. However, if emissions were higher than anticipated, there may not be enough cost-effective abatement potential available in the non-traded sector to meet the budget shortfall.

- Level D requires the uptake of additional abatement potential under the full range of emission projections to meet the budget level. On central emissions projections, the net levelised cost of additional abatement required to meet the budget is around £1.2bn relative to the counterfactual over 2023-7. This assumes an efficient level of trading. Under low and high emissions projections, net costs range from -£0.8bn to around £4.0bn - the variation driven by lower and higher emissions shortfalls bridged through the purchase of credits. Under the low, central and high emission projection ranges, around 0 $MtCO_2e$, 49 $MtCO_2e$ and 158 $MtCO_2e$ of credits are assumed to be purchased, at a value of £0m, £1,300m and £4,100m respectively.

- Meeting the 1260 $MtCO_2e$ budget level territorially, with no trading, would imply a higher net cost. Costs under a central emissions projection rise to £3.8bn, as cost-ineffective measures (up to £149/tCO_2e) are assumed to be taken up in the place of credit purchase. Whilst there is little additional increase in cost under low emission projections relative to the with trading scenario (given low levels of abatement required additional to that below the carbon price), no net cost can be estimated under a high emission projections as not enough potential abatement has been estimated – there is a further shortfall of around 80 $MtCO_2e$ once all domestic abatement measures identified as part of this analysis have been exhausted. It is however important to note that the abatement identified has been estimated on a static basis relative to the central emissions baseline. If baseline emissions were higher it may well be reasonable to expect abatement opportunities to be higher, and there are also some abatement options not considered under this analysis.

The cost of each budget option represents the technical resource cost of the abatement opportunities included to reach each budget option. The largest cost associated with the budget options is the capital cost of the abatement opportunities on the MAC Curve. This is offset against the energy demand savings of each opportunity which provide the most significant benefit. Further costs associated with changes in air quality, comfort taking and congestion, alongside hidden costs (e.g. hassle costs) and EUA saving have been included where available.

The breakdown of the total cost by different cost type varies between abatement opportunities, and is determined by a number of factors associated with that measure. For example, for abatement opportunities in industry, the most significant cost is the capital cost of the measure, whereas in the domestic sector, the hidden cost of energy efficiency measures may often be as significant as installation costs. In transport, the impact of measures on congestion can also provide a significant cost which may be as important as the capital cost associated with implementation. Energy demand savings are often the most significant benefit associated with abatement opportunities.

Costs reflect the marginal cost of meeting the fourth carbon budget – aggregating the total costs identified in the MACC analysis over 2023-7.

Costs reflect technical resource costs of abatement, including levelised technology/capital costs, operating costs, fuel savings, and savings from avoided allowance purchase under the EU ETS.

Other costs where available to monetise include financing costs, costs of congestion, air quality impacts, hidden and administrative costs of installation and comfort taken.

Costs do not reflect policy costs, macroeconomic costs or distributional implications from the additional UK effort required to meet the fourth carbon budget, not current policies to meet the first three carbon budgets.
Costs excluded any valuation of avoided damages from reduces GHGs.

Costs are best estimates, based on central projections and central assumptions on exogenous assumptions (i.e. fossil fuel prices, carbon prices, GDP growth).

Costs are in present value 2009 prices.

Global perspective

Analysis, outlined in Section D.I, suggests the UK's efficient level of abatement in the non-traded sector is of the order of 1350 $MtCO_2e$, consistent with a global emissions pathway consistent with limiting temperature rise to 2 degrees Celsius above pre-industrial levels by 2100.

Of the four option levels set out above;

- Level A is non-constraining, emission levels could be significantly above the globally efficient level.
- Level B is constructed on the basis of extrapolated UK shares of current EU commitments in the non-traded sector, with no tightening. This option leads to emissions of 1450 $MtCO_2e$ in the non-traded sector. This target is inconsistent with the globally efficient level of UK abatement as it permits non-traded emissions up to 1450 $MtCO_2e$.
- Level C is based on a cost-effective level of territorial action defined by DECC's non-traded sector carbon values – suggesting a budget level in the non-traded sector of 1310 $MtCO_2e$. This is consistent with the UK's efficient share of global abatement.
- Level D is based on the CCC's recommended level of action in the non-traded sector of 1260 $MtCO_2e$. If this level is met through trading, static analysis suggests that territorial emissions, on

central projections would be around 1340 $MtCO_2e$ with an additional 80 $MtCO_2e$ of credit purchase. This is aligned with the non-traded sector results of an efficient level of UK emissions suggested by GLOCAF and PRIMES analysis of 1350 $MtCO_2e$.

- A budget level of 1260 $MtCO_2e$ in the non-traded sector met territorially is significantly below the headline results for a globally efficient level of UK emissions - suggesting that the economy take on more effort in the non-traded sector than considered globally efficient in the context of an ambitious global deal. This option therefore does not necessarily represent the share the UK would or should take under a global burden sharing agreement.

Options in the Traded Sector

The traded share of the EU ETS cap and net UK carbon account determine and provide certainty over the traded share of the budget. While the working assumption is that the traded portion of the carbon budget will be amended to reflect the actual UK share of the EU ETS cap over the fourth carbon budget period, estimated costs to the UK of complying with a tighter share of the cap are presented for illustration – relative to the counterfactual.

Analysis, outlined in Section D.II, suggests the UK share of an EU ETS cap consistent with an EU 30% target is around 590-700 $MtCO_2e$ over the fourth budget period, whilst a continuation of the current cap trajectory (as set out in the 2009 EU ETS Directive, which imposes an annual 1.74% decrease in the cap from 2013 onwards, with no sunset clause) suggests a share of the UK cap of around 860 $MtCO_2e$ over 2023-7.

The traded cap scenarios considered in this analysis are:

- Level based on a continuation of current downward EU ETS trajectory; 860 $MtCO_2e$
- Level based on the CCC's traded sector recommendation; 690 $MtCO_2e$

Global Perspective

- A traded sector emissions level of 860 $MtCO_2e$ based on an estimate of a UK share of the EU ETS cap under the current trajectory is inconsistent with a more ambitious global level of ambition (an ambitious global deal to meet 2 degrees (unless the cap is amended). **This is the counterfactual level.**
- A traded budget level of 690 $MtCO_2e$ is consistent with the high end estimate of an EU ETS cap under a more stringent EU target (590-700 $MtCO_2e$) consistent with a potential future global deal.

Static Costs of Meeting Traded Sector Budget Levels

The traded share of the EU ETS cap and net UK carbon account determine and provide certainty over the traded share of the budget. The EU ETS determines to costs to UK participants and consumers, rather than carbon budgets.

In the counterfactual, it is assumed that the UK's share of the EU ETS cap over the fourth budget period is set at 860 $MtCO_2e$. The estimated net cost of achieving this cap would be around -£2.2bn under a central emissions projection. To reach this target, it is assumed half of negative net cost abatement would be taken up in the traded sector (around 48 $MtCO_2e$), in addition to further reductions through cost-effective abatement potential (around 2 $MtCO_2e$). Some measures which reduce non-traded emissions also impact on electricity demand: accounting for the take-up of measures under the budget options increases traded emissions by around 5 $MtCO_2e$. These impacts together reduce traded sector emissions to 867 $MtCO_2e$ on central projections, hence an additional purchase of 7 $MtCO_2e$ of international carbon units are required to reach the counterfactual emissions cap.

The cost, relative to the counterfactual, of a more stringent cap of 690 $MtCO_2e$ would be around £0.7bn. Reaching the more stringent target with trading assumes that the additional shortfall of 170 $MtCO_2e$ is met through the purchase of international carbon units (around 122 $MtCO_2e$), and through the take up of the remaining net negative cost abatement potential not assumed to be taken up in the counterfactual (around 48 $MtCO_2e$). It is assumed that there would be this amount of purchase of international carbon units as no further cost-effective abatement potential has been identified.

Figure 44. Traded Sector Technical Abatement Costs above counterfactual 2023-7 (PV, £2010m)

Traded sector level of UK share of EU ETS cap over fourth budget period	Traded Sector Budget Levels ($MtCO_2e$)	Costs of traded sector relative to counterfactual (£m)
Level based on a continuation of current downward EU ETS trajectory	860	0
Level based on the CCC's traded sector recommendation	690	£700

Meeting this more stringent cap without the use of trading would imply an additional cost relative to the counterfactual of around £3.2bn (i.e. an extra £2.5bn). Abatement costing more than the price international carbon units is required. In this scenario, the power sector would need to decarbonise to reach 50g/kWh generation intensity by 2030. Taking an ambition of 100 g/kWh would not allow territorial emissions in the traded sector to be reduced to $690MtCO_2e$, as not enough abatement potential has been identified in heavy industry.

Sensitivity Analysis around the Counterfactual

In the traded sector, varying the amount of 'no regrets' measures included in the counterfactual would vary both the cost of the counterfactual and the cost of the budget options. The counterfactual in the traded sector is assumed to be a continuation of the UK's share of the current EU ETS cap. The costs in the section above assume that half the 'no regrets' measures are included to meet the counterfactual share of the cap.

Taking instead an assumption that only 25% of the 'no regrets' measures are included in the counterfactual, the cost of meeting a stricter share of the cap efficiently would decrease to -£1.2bn (a net benefit), relative to a higher cost counterfactual of -£0.4bn. Meeting the stricter cap domestically would reduce the cost relative to the counterfactual to £1.3bn over the fourth budget period.

Figure 45. Sensitivity analysis around cost estimates for budget options

Budget option	Non-traded sector cost (£m)			Traded sector cost (£m)			**Total cost of budget option (£m)**		
	25%	50%	75%	25%	50%	75%	**25%**	**50%**	**75%**
1	0	0	0	0	0	0	**0**	**0**	**0**
2	0	0	0	0	0	0	**0**	**0**	**0**
3	-£700	-£100	£500	0	0	0	**-£700**	**-£100**	**£500**
4	£600	£1,200	£1,800	0	0	0	**£600**	**£1,200**	**£1,800**
5	£600	£1,200	£1,800	-£1,200	£700	£2,500	**-£600**	**£1,900**	**£4,300**
6	£4,400	£5,100	£5,700	-£1,200	£700	£2,500	**£3,300**	**£5,700**	**£8,200**

Assuming 75% of the 'no regrets' measures are included in the counter-factual would increase the cost of meeting the stricter cap efficiently, relative to the counterfactual, to around £2.5bn over the budget period and the cost of the counterfactual decreases to -£4.1bn. The cost of meeting the stricter cap domestically increase to around £5.0bn relative to the counterfactual.

Combining the sensitivity analysis around the costs of the budget options in the non-traded and traded sectors, the range of costs for each budget option is show in Figure 45. This presents the sensitivity analysis around costs through varying the amount of 'no regret's abatement potential which has been included in the counterfactual.

Changing the assumption around the proportion of 'no regrets' included in the counterfactual does have an impact on costs. Including less in the counterfactual (as under the 25% sensitivity), results in more 'no regret' measures being available to be taken up to meet the budget option. These net beneficial measures therefore decrease the cost of the budget option, as this benefit is no longer included as part of the counterfactual.

The cost range above represents a sensitivity of 25% to 75% of the 'no regrets' measures being included in the counterfactual. The sensitivity range was selected to show a varying amount of the 'no regrets' abatement taken up to maintain the view that a proportion of the abatement will be taken up, but that it is likely some barriers will remain. This assumption is evidently a key driver of costs. However, the range of costs presented above sits within the uncertainty range around the costs generated by uncertainty in the underlying emissions projections.

UK Pathways

Section C outlined indicative orders of magnitude for the fourth carbon budget based on illustrative geometric trajectories, and outlined considerations for UK pathways to 2050:

- A concave equal annual percentage reduction trajectory requires reductions of 3.7% per year, whilst a straight-line trajectory from projected emissions levels in 2020 to the 2050 target requires constant absolute reductions of 11.1 $MtCO_2$ per year[134]. These illustrative trajectories imply territorial emissions over the fourth carbon budget of around 2020-2170 $MtCO_2e$ respectively over 2023-7, or 1830 to 2120 $MtCO_2e$[135] over 2023-7 should international transport emissions be included within the UK net carbon account.
- Modelling results for energy related CO_2 emissions suggest a least-cost pathway to 2050 based on early action and a concave trajectory similar to, or more ambitious than an equal annual percentage reduction.

This analysis does not distinguish between the traded and non-traded sectors - hence economy wide options are considered as presented in figure 40.

Option 1: Non-Constraining e.g. 3000 $MtCO_2e$ (23% below 1990 levels)

Option 1 reflects a scenario in which the budget level would not be constraining, even if emissions are at the high end of emissions projections. This level is based on a traded sector share of the budget which assumes a continuation of the UK share of the EU ETS cap on the current declining trajectory, and then an illustrative high-end non-constraining level in the non-traded sector. An illustrative budget level for the UK of 3000 $MtCO_2e$ over 2023-7 is presented.

- This budget level does not constrain relative to the counterfactual - no additional abatement is required in the non-traded sector, even if emission levels turn out to be higher than central projections (up to the high-end range of modelled projection). Hence, this carbon budget level has no associated additional technical abatement costs over 2023-7.
- The traded portion of this budget level is set equal to the counterfactual level for the UK share of the EU ETS cap and therefore imposes no further costs in the traded sector.
- This budget level is inconsistent with a view of a globally efficient level of territorial emissions reductions in the non-traded sector and more stringent EU ETS cap, and is misaligned with an ambitious global deal.
- This level is inconsistent with current best estimates of a feasible pathway to 2050 – delaying action to the extent that future reductions required to meet 2050 targets are likely to prove costly, and unlikely to stimulate uptake of technologies critical to decarbonising the economy in later periods, such as zero and ultra low emission vehicles and heat pumps.
- Setting a non-binding fourth carbon budget risks failing to stimulate innovation, resulting in higher future abatement costs. There might also be risk of lock-in to high-carbon technologies making reductions challenging and costlier in future years and this option would not stimulate and learning benefits through the uptake of key technologies required to get to 2050 targets (such as zero and ultra low emission vehicles and heat pumps).

[134] On central emissions projections
[135] The low end of the range represents the low end of the equal percentage range, with the high range representing the high range of the straight line trajectory, representing the widest range across both methodologies

- This level is inconsistent with the CCC's advice; would bear a significant risk of undermining the UK's climate change programme and would give negative signals to low carbon technology investors.

Option 2 : 2310 MtCO_2e (41% below 1990 levels)

Option 2 assumes a continuation of the current declining trajectory of carbon budgets two and three – based on a continuation of the UK's share of the EU ETS cap and an extrapolation of the UK's EU non-traded sector target under current commitments (consistent with EU 20% reduction targets). This represents a budget for the UK of 2310 MtCO_2e over 2023-7.

- This budget level only constrains if emissions in the non-traded sector are significantly higher than the central counterfactual (i.e. over 76 MtCO_2e higher over 2023-7). As a consequence, it is assumed that action is taken up to meet the constraining budget level under the high emissions uncertainty. This potential delivers a net benefit of £0.9bn over the fourth budget period.
- The traded portion of this budget level is set equal to the counterfactual level for the UK share of the EU ETS cap and therefore imposes no further costs in the traded sector.
- This budget level is inconsistent with a view of a globally efficient level of territorial emissions reductions in the non-traded sector and more stringent EU ETS cap consistent with a global deal.
- This level is inconsistent with a current best estimates of a feasible pathway to 2050 – indicative analysis of least-cost pathways from MARKAL suggest it is inter-temporally efficient to carry out abatement earlier. This option delays action to the extent that future reductions required to meet 2050 targets are unlikely to be possible.
- This budget reduces emissions on average by 1.1 % p.a. from current central projections of emissions in 2020. This would require reductions of 4.2%-6.6% p.a. thereafter to reach the 2050 target. Compared to historical reductions (1.3% p.a.), this degree of reduction appears significantly challenging, and compared to reductions over the fourth carbon budget period delayed action would require a significant step change post 2025. Cumulative emissions would be significantly higher than a trajectory with some degree of action.
- Setting a non-binding fourth carbon budget risks failing to stimulate innovation; locking-in to high-carbon technologies and not stimulating learning benefits through the uptake of key technologies.
- This level is inconsistent with the CCC's advice.

Option 3: 2170 MtCO_2e (45% below 1990 levels)

Option 3 is based on an assumed continuation of the current EU ETS trajectory and UK share of the cap and a statically cost-effective level of territorial action in the non-traded sector defined by DECC's carbon values for appraisal. This represents a budget for the UK of 2170 MtCO_2e over 2023-7.

- This budget level has an implied emissions shortfall in the non-traded sector relative to the counterfactual of around 64 MtCO_2e on central projections. This option is based on the level emissions assuming a statically cost-effective UK abatement in the non-traded sector. The uptake of abatement to meet this shortfall would provide a net benefit of around £0.1bn over 2023-7.
- The traded portion of this budget level is set equal to the counterfactual level for the UK share of the EU ETS cap and therefore imposes no further costs in the traded sector.
- This budget option is consistent with the high-end range of illustrative geometric trajectories to 2050 (a straight-line trajectory), and is broadly consistent with a high-end range view of a globally efficient level of emission reductions in the non-traded sector. However, this option is framed with a traded sector EU ETS cap based on the current trajectory and hence in aggregate is not currently consistent with an ambitious global target.
- This option is inconsistent with indicative analysis of least-cost pathways, which suggest that it is inter-temporally efficient to carry out abatement earlier and generally support the case for an equal annual percentage reduction in emissions to 2050 under a cumulative emissions constraint. As with Option 1 and 2, there might be risk of lock-in to high-carbon technologies

and this level of budget is unlikely to drive investment in technologies critical to meeting the 2050 target. There may be an opportunity cost of not stimulating and supporting innovation, making reductions potentially less feasible and costlier in future years.
- This level is inconsistent with the CCC's advice.

Option 4 : 2120 $MtCO_2e$ (46% below 1990 levels)

Option 4 is based on the Committee on Climate Change's recommended budget for the non-traded sector and a continuation of the current EU ETS cap and UK share. This represents a budget for the UK of 2120 $MtCO_2e$ over 2023-7.

Summary
- This budget level requires significant effort in the non-traded sector of around 114 $MtCO_2e$ over the fourth budget period relative to the counterfactual (or around 133 $MtCO_2e$ relative to the baseline emissions projections on central uncertainty, not taking into account 'no regrets' measures that are included in the counter-factual).
- In the non-traded sector technical abatement costs are estimated at £1.2bn above the counterfactual over 2023-7 on central projections. The traded portion of this budget level is set equal to the counterfactual level for the UK share of the EU ETS cap and therefore imposes no further costs in the traded sector.
- The budget level is broadly consistent with an upper end range of a feasible pathway to 2050 and sits marginally above the upper end range simple geometric trajectories to 2050 – requiring an annual average reduction 2020 to 2050 of 3.7%-5.7%, with the high end of the percentage reduction range representing an equal annual percentage reduction including international aviation and shipping. However, as the option sits marginally above these trajectories, this option is inconsistent the pathways analysis from MARKAL which suggests it is inter-temporally more efficient to abate earlier. The degree of reduction required is high compared to historical reductions, but offers a more gradual transition for the economy.
- As a consequence, there might be risk of lock-in to high-carbon technologies and this level of budget is unlikely to drive investment in technologies critical to meeting the 2050 target.
- The global perspective analysis suggests it would be efficient to meet the non-traded sector portion of the budget level with some use of imports of international carbon units.
- If the non-traded share of the budget is assumed to be met territorially this suggests the UK will take on a significantly greater level of abatement than is globally efficient. However pathways arguments for the early adoption of renewable heat measures and zero and ultra low emission vehicles suggest going beyond the statically efficient level.
- The traded sector share is based on an EU ETS cap under the current trajectory and not currently consistent with an ambitious global target.
- This level is only partially consistent with the CCC's advice.

Option 5 : 1950 $MtCO_2e$ (50% below 1990 levels)

Option 5 is based on the Committee on Climate Change's recommended budget level. This represents a budget for the UK of 1950 $MtCO_2e$ over 2023-7. The CCC advised that the UK aim to meet this level territorially and suggested indicative shares of effort, based on its medium abatement scenario, of 1260 $MtCO_2e$ in the non-traded sector and 690 $MtCO_2e$ in the traded sector.

- This budget level requires significant effort in both the non-traded and traded sectors.
- There are technical abatement costs of the order of £1.9bn above the counterfactual. The costs associated with the non-traded sector are identical to those under Option 4 (£1.2bn). The more stringent constraint in the traded sector adds a further £0.7bn of cost relative to the baseline.
- The global perspective analysis suggests it would be efficient to meet the non-traded sector portion of the budget level with some use of imports of international carbon units. However, if the non-traded share of the budget is assumed to be met territorially this suggests the UK take on a significantly greater level of abatement than efficient.
- The traded share is at the high end range of an estimated UK share of the EU ETS cap under more ambitious global ambition.

- This level is consistent with a feasible and inter-temporally efficient pathway to 2050 if met territorially. In practice, meeting the budget territorially may be costly and challenging to achieve and would require significant decarbonisation of the power generation sector.
- With trading, if met efficiently, implies a territorial emission level of 2170 $MtCO_2e$[136] - i.e. Option 3 with additional purchase of International Carbon Units to reach the required budget option. This is broadly consistent with the upper end of the range of simple geometric trajectories to 2050. This is however inconsistent with the pathways analysis from MARKAL which suggests it is inter-temporally more efficient to abate earlier. The degree of reduction required is high compared to historical reductions, but offers a more gradual transition for the economy. As with Options 1-4, there might be risk of lock-in to high-carbon technologies and undertaking cost-effective abatement from a static perspective to meet this level of budget is unlikely to drive investment in technologies critical to meeting the 2050 target
- This level is consistent with the CCC's advice.

Option 6 : 1800 $MtCO_2e$ (54% below 1990 levels)

Option 6 is based on the Committee on Climate Change's recommended 'Global Offer' budget. This represents a budget for the UK of 1800 $MtCO_2e$ over 2023-7.

The CCC advised that the UK aim to meet part of this budget territorially (at the level of its 1950 $MtCO_2e$ budget recommendation based on its medium abatement scenario, as presented in Option 5). The CCC also suggest the purchase of international carbon units to the order of 150 $MtCO_2e$ as part of the UK's contribution to a global deal, resulting in a net emissions level of 1800 $MtCO_2e$.

This implies an equivalent level of emissions reduction effort as under Option 5, but with additional purchase 150 $MtCO_2e$ of international carbon units – estimated at an additional cost of around £3.9bn, taking the total cost associated with the budget option to £5.7bn.

[136] This figure assumes all cost-effective abatement potential identified in the static analysis is taken up, reducing emissions in the non-traded sectors to 1310 $MtCO_2e$ over the fourth budget period respectively, taking the counterfactual assumed cap in the traded sector of 860 $MtCO_2e$ over the fourth budget period.

Annexes

Annex 1: Post Implementation Review (PIR) Plan

Basis of the review:

Best practice. Deadline for post-legislative scrutiny of Climate Change Act set as spring 2015.

Review objective:

We propose submitting a memorandum on the Climate Change Act 2008, under which the requirement to set a fourth carbon budget comes, in Spring 2015. The main reason for this is that the impact of the key provisions will not be clear until mid-2014, but this timetable for a memorandum would also work in relation to other issues covered in the Act.

A review of the fourth carbon budget level is planned for early 2014. Government will review progress towards the EU emissions goal in early 2014. If at that point our domestic commitments place us on a different emissions trajectory than the Emissions Trading System trajectory agreed by the EU, we will, as appropriate, revise up our budget to align it with the actual EU trajectory.

Review approach and rationale:

The key provisions of the post-legislative scrutiny review are to:

- set a greenhouse gas emission reduction target of at least 80% by 2050;
- track/force progress towards this target through a set of five-year carbon budgets;
- establish the independent Committee on Climate Change to advise on the above process.

The first carbon budget runs from 2008 to 2012 inclusive. Whether or not we have met the carbon budget will only become certain in early summer 2014 (the legal deadline is May 2014) because of the time lags in acquiring the necessary emissions data. In order to provide a meaningful assessment of the implementation of this part of the Act, it would seem appropriate to prepare the memorandum once the data are available.

Baseline: No constraints on greenhouse gas emissions.

Success criteria: First carbon budget successfully met.

Monitoring information arrangements: The approach to the post-legislative scrutiny review will be to undertake ongoing monitoring of inventory and emissions projections data to assess the level of risk to carbon budgets. This is assessed formally on an annual basis currently. Monitoring is undertaken to conform with the reporting obligations under the Climate Change Act, 'Annual Statement of Emissions' in march each year and 'Government Response to the CCC progress report' in October each year, and as a part of the Government's overall Carbon Budgets Management (CBM). Monitoring arrangements for CBM require quarterly monitoring and assessment of progress on the Government's climate change policy development, implementation and outcomes through a cross Whitehall scorecard system. This tracks progress against key policy milestones, and the policy indicators designed to assess the impact of the policies. In addition CBM tracks wider information on risks to meeting carbon budgets, through reviewing policy savings and changes in external factors that affect emissions and feed through to the emissions projections.

Reasons for not planning a review:

N/A

Annex 2: Key Modelling Assumptions

Analysis commissioned from across key government departments (DECC, DEFRA, DfT and CLG) and from external sources, has been provided consistent with the guidance for valuing energy usage and greenhouse gas emissions and key parameter assumptions outlined in the DECC / HMT guidance 'Valuation of energy use and Greenhouse Gas emissions for appraisal and evaluation'[137]. This guidance supplements HM Treasury's Green Book[138] that provides general guidance on how to conduct appraisal and evaluation.

A summary of the main parameter assumptions underlying the analysis consolidated in this Impact Assessment is presented below:

Fossil fuel prices

The fossil fuel price assumptions 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 May 2009. In January 2010 these were reviewed but were left unchanged.

£2009	2020				2025				2030			
	Low	Central	High	High-High	Low	Central	High	High-High	Low	Central	High	High-High
Gas price (p/therm)	35	69	99	121	35	72	99	121	35	76	99	121
Oil price ($/bbl)	61	82	123	153	61	87	123	153	61	92	123	153
Coal price (£/tonne)	32	51	64	83	32	51	64	83	32	51	64	83

Energy costs (used to value energy savings)

These prices reflect social resource costs - the variable element of costs of energy provision (i.e. excluding fixed costs) – as required for social cost-benefit analysis and cost-effectiveness calculations. Below is the series of central prices, consistent with the central fossil fuel price scenario presented above. Low, high and high-high series consistent with the above fossil fuel prices are also available.

[137] http://www.decc.gov.uk/assets/decc/statistics/analysis_group/122-valuationenergyuseggemissions.pdf
[138] http://www.hm-treasury.gov.uk/data_greenbook_index.htm

	Use		2020	2025	2030
Electricity	Domestic	p/KWh (2009)	8.62	11.53	14
	Commercial	p/KWh (2009)	7.91	10.63	12.95
	Industrial	p/KWh (2009)	7.41	9.95	12.12
Gas	Domestic	p/KWh (2009)	2.53	2.69	2.86
	Commercial	p/KWh (2009)	2.38	2.52	2.66
	Industrial	p/KWh (2009)	2.38	2.52	2.66
Transport fuels	Petrol	p/litre (2009)	39.81	41.92	44.03
	DERV	p/litre (2009)	42.68	45.01	47.34

Carbon Prices and Sensitivities

- **Benchmark Carbon Prices for Appraisal**

Government's published carbon prices are based on a target-consistent approach outlined in the 'Carbon Valuation in UK Policy Appraisal'[139]. This has moved away from a valuation based on the damages associated with climate change, and instead linking to the cost of mitigating emissions. The values reported below are consistent with the UK short and long-term targets – where by 2030 prices are assumed to converge to a global market price.

The non-traded prices are based on the marginal abatement costs in the non-traded sector in 2020 in order to meet the UK's non-traded sector targets, and from 2020 to 2030 converges to a global market price.

£2009/ tCO_2e	Non-traded (undiscounted)			Non-traded (Discounted to 2010)		
	Low	Central	High	Low	Central	High
2020	30	60	90	21	43	64
2025	33	65	98	19	39	58
2030	35	70	105	18	35	53

The traded prices are based on DECC's forecasted EUA price – the carbon price in the EU ETS in 2020 and from 2020 to 2030 converges to a global market price.

£2009/ tCO_2e	Traded (undiscounted)			Traded (Discounted to 2010)		
	Low	Central	High	Low	Central	High
2020	8	16	21	6	12	15
2025	22	43	63	13	26	38
2030	35	70	105	18	35	53

- **Carbon Prices for Valuing International Credit Unit (ICU) Purchases**

ICUs are carbon units from offsetting carbon reduction projects outside of the UK. The main source of ICUs available to the Government is the CER credit.

For the purposes of this analysis the purchase of ICUs over 2023-7 is valued based on Government's published traded carbon price series. The price of ICUs is assumed to not be significantly different from the EUA price in 2020 – and over the 2020s the traded price series in the appraisal guidance is assumed to be converging to the global carbon market.

The table below presents a range for the forecast price of ICUs expressed as price per tonne of abatement, in GBP 2009 prices. The first line shows the DECC published traded EUA price series, consistent with the current EU ETS cap to 2020. The European Climate Exchange (ECX) quoted futures price for EUAs is lower by around £2 to £3 per tonne. The CER prices are given by two market forecasts,

[139] http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/valuation/valuation.aspx

one from Bloomberg New Energy Finance (BNEF) and the other again from the ECX futures quoted prices[140].

Comparison of international carbon unit price estimates (converted to £2009 prices)

	2016	2017	2018	2019	2020
EUA	16.0	16.0	16.0	16.0	16.0
ECX EUA	12.7	13.2	13.6	14.0	14.4
BNEF CER	12.5	12.3	11.0	10.8	10.7
ECX CER	8.9	9.0	9.1	9.2	9.4

- **Carbon Prices for Projections**

For use in the emission projections, the assumption is that in the traded sector EU ETS continues to exist based on the current EU ETS cap trajectory - it is therefore assumed that a traded carbon price (consistent with 20% reduction targets) continues.

The carbon price is based on DECC's forecasts of the EU ETS Phase III carbon price in 2020[141], and extrapolated forward based on the assumption of perfect foresight and the ability for firms to bank allowances into subsequent time periods, the carbon price rising year on year based on the cost of carry[142] - a term used to reflect the opportunity cost of holding allowances, estimated at the cost of money.

£2009/ tCO_2e	Traded (EU 20% world)			Traded (EU 20% world; discounted to 2010)		
	Low	Central	High	Low	Central	High
2020	8	16	21	6	12	15
2025	9	18	22	5	10	13
2030	10	19	24	5	10	12

- **Emission Intensity Factors**

Emissions intensity factors used in the analysis represent the scientific factors taken from the latest emissions inventory. The marginal electricity emission factor of 0.39kgCO_2e/kWh in 2025 based on CCGT from the DECC/HMT GHG guidance, is used to convert the impacts of abatement measures on electricity demand into impacts on emissions. For the power sector scenarios – average grid emissions intensities are taken from outputs of the Redpoint modelling, presented in Section D.III.

- **Power Generation Costs**

Power generation capital costs are taken from a study completed for DECC in 2010 by Mott MacDonald which reflects information regarding a variety of power generation technologies[143]. The study provides an assessment of current and forward power generation costs for the main large scale technologies applicable in the UK. These costs are used in the DECC Energy and Emissions Model, the UK MARKAL model and Redpoint models.

- **Growth**

The central scenario growth forecasts used in the DECC Energy and Emissions model are the Office of Budgetary Responsibility (OBR) short term forecasts to 2015. The model also uses a long term projection for real Gross Domestic Product (GDP) for the period beyond 2015.

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[140] ECX CER future prices: https://www.theice.com/marketdata/reports/ReportCenter.shtml?reportId=10&contractKey=81
ECX EUA futures prices: https://www.theice.com/marketdata/reports/ReportCenter.shtml?reportId=10&contractKey=20
DECC carbon values: http://www.decc.gov.uk/en/content/cms/statistics/analysts_group/analysts_group.aspx
BNEF: "Carbon Markets – Global – Deep Dive December 2011, Bloomberg New Energy Finance" This price series only applies to 'high-quality' CERs, i.e. credits that will be fully eligible for EU ETS compliance in Phase III. This specifically excludes CERs generated from HFC-23 and N2O adipic acid projects that are subject to EU ETS import restrictions. For the latter credit types prices are expected to be considerably lower over 2012-2020 as there is no price support provided by the EU ETS.

[141] This differs from the assumption underlying previously published emissions projections and DECC published carbon values for use in policy appraisal. These assume a global carbon market is in place from 2030 leading to higher carbon prices from 2021 onwards.

[142] DECC assumes a real (nominal) rate of cost of carry of 1.5% p.a. (3.5% nominal) for its carbon price and cost modelling based on the Euro Interbank Offered Rate (EURIBOR) - interest rate at which banks offer to lend unsecured funds to other banks in the euro wholesale money market (or interbank market). This is essentially a risk free interest rate which is used as the cost of money.

[143] http://www.decc.gov.uk/en/content/cms/statistics/projections/projections.aspx

These are assumptions are outlined in Annex 5.

- **Demographics**

The DECC Energy and Emissions model also relies on Office of National Statistics (ONS) data on UK population estimates. For these projections, ONS estimates are used that are based in 2008. These are an input into the household projection numbers provided by the Department for Communities and Local Government.

- **Discount Rates**

For the purposes of social appraisal, social discount rates are applied based on HM Treasury's Green Book guidance. This applied a discount rate of 3.5% p.a. for the first 35 years of appraisal to reflect social time preference (that one discounts future consumption over consumption today). In some modelling (such as in the power sector modelling) a private discount rate is also considered – to reflect the weighted average cost of capital where this might be considered a resource cost.

- **Price Base**

All monetised values, unless stated otherwise, are presented in GBP with a 2009 price base, discounted to today's (2010) values (£2009, Present Value (PV)).

Annex 3: Details of Fourth Carbon Budget baseline projection

Introduction

This note provides further details of the fourth Carbon Budget baseline projection presented in the Impact Assessment. The changes from DECC's last official emissions projection update, published in June 2010[144] are also presented.

This projection was produced to support the impact assessment for the fourth Carbon Budget. Therefore it does not include fourth Carbon Budget policies or extensions to existing policies beyond the third Carbon Budget period. In addition only a limited set of key outputs have been produced, focussing on those most relevant for the Impact Assessment. It is not the full update to the last official DECC projections that were published in June 2010. The next full updated emissions projections will be published in October 2011.

DECC is currently undertaking a review of the methodology used to project demand for energy for the emissions projections. Therefore it is possible that revisions to the projections will be larger than usually occurs between updates.

Greenhouse gas emissions projections

Projected net UK carbon account and territorial greenhouse house gas emissions and changes since June 2010

Table 1: Fourth Carbon Budget baseline projections ($MtCO_2e$)

$MtCO_2e$	June 2010			May 2011			
	Carbon Budget 1 2008-12	Carbon Budget 2 2013-17	Carbon Budget 3 2018-22	Carbon Budget 1 2008-12	Carbon Budget 2 2008-17	Carbon Budget 3 2018-22	Carbon Budget 4 2023-27
Traded sector[145]	1200	1128	1003	1217	1162	1001	912
Non-Traded	1756	1642	1512	1700	1590	1463	1393
Of which non-CO_2	462	441	409	452	429	389	363
Territorial Emissions	2955	2770	2514	2917	2752	2464	2306
Change in Territorial emissions				-38	-17	-50	
Traded Sector Cap[146]	**1233**	**1078**	**985**	**1233**	**1078**	**985**	
EUAs purchased (negative implies sold)	-33	50	18	-16	84	16	
Change in Traded/EUAs purchased				18	34	-1	
Net Carbon Account[147]	**2989**	**2720**	**2497**	**2933**	**2668**	**2448**	
Carbon Budget	**3018**	**2782**	**2544**	**3018**	**2782**	**2544**	
Shortfall (negative implies emissions under budget)	-29	-62	-47	-85	-114	-96	
Change Non Traded/Net Carbon Account				-56	-51	-49	

Table 1 provides a summary of fourth Carbon Budget baseline projections by carbon budget period and compares these to projections for the first three carbon budget periods published in June 2010. Under the latest central projections the UK continues to be on track to meet the first three carbon budgets with the margin by which the net UK carbon account is projected to be below the carbon budgets being

144 http://www.decc.gov.uk/en/content/cms/statistics/projections/projections.aspx

145 This is actual emissions from the traded sector unadjusted for any purchase or sale of EUAs. It therefore differs from the figures presented in Table 1 of the June 2010 projections as "Traded sector" which was set at the EU ETS cap.

146 The traded sector cap shown here is the UK legislated cap on traded emissions. This differs slightly from the cap applied in the June 2010 projections which was set at the projection EU ETS cap. As a result projected EUAs purchased and the net UK carbon account also differ slightly from those reported in June 2010.

147 The traded sector cap shown here is the UK legislated cap on traded emissions. This differs slightly from the cap applied in the June 2010 projections which was set at the projection EU ETS cap. As a result projected EUAs purchased and the net UK carbon account also differ slightly from those reported in June 2010.

larger. Emissions are projected to fall during the fourth Carbon Budget. This is due to several factors including the rising carbon price floor, legacy savings from existing policies and lower long term growth assumptions.

Projections for territorial and non-traded emissions are lower in a each of the first three carbon budget periods compared to projections published in June 2010. The latest projections of traded emissions are higher than those published in June for the first two carbon budgets, with little change in over the third carbon budget.

The main reasons for the reduction in territorial and non-traded emissions projections compared to the June 2010 publication are: lower GDP growth assumptions, incorporation of the 2009 Greenhouse Gas Inventory and updates to projections for non-CO_2 Greenhouse Gas and LULUCF emissions. The increase in emissions in the traded sector is due to an increase in emissions in the industrial sector which was driven primarily by an upwards revision to OBR manufacturing growth assumptions.

Methodology

CO_2 emissions (apart from those arising from Land Use, Land Use Change and Forestry), are projected using the DECC emissions projections model. Within this model demand for energy is projected using a series of equations that relate energy demand to its key drivers such as GDP growth. Demand is adjusted to take account of the policy impacts. The way in which electricity producers meet demand is projected using a model that in effect assumes providers know what future prices and demand will be and find the least cost method of meeting this demand under current policies. The basic methodology remains unchanged since June 2010 and is described in more detail in the June 2010 report[148].

Projections for non-CO_2 Greenhouse Gas emissions and LULUCF CO_2 emissions are projected using separate models. Updated non-CO_2 Greenhouse Gas projections were published in March 2011. These have been incorporated into the projections reported here. The methodology and changes in non-CO_2 Greenhouse Gas projections since the last projection are described in the March 2011 publication[149]. CO_2 emissions from Land Use, Land Use Change and Forestry (LULUCF) are estimated by the Centre for Ecology and Hydrology under contract to DECC using a methodology that is consistent with the UK Greenhouse Gas Inventory[150]. Updates to the LULUCF projections have also been incorporated into the updated projections presented here.

Updates to assumptions and data

The projections have been updated to take account of updates to official statistics and projections, March 2011 Budget announcements and other revisions to policy savings estimates.

- **Economic growth assumptions**

GDP growth assumptions have been updated to reflect the latest Office for Budget Responsibility (OBR) projections published at Budget March 2011. Manufacturing growth assumptions have been updated to the latest projections published by OBR which were released in June 2010.

Table 2: Economic growth central assumptions Fourth Carbon Budget baseline May 2011

Percent per annum growth	2009[151]	2010	2011	2012	2013	2014	2015	2016	2017-2025
GDP projection	-4.9%	1.3%	1.7%	2.5%	2.9%	2.9%	2.8%	2.4%	2.3%
Manufacturing projection	-10.9%	3.5%	4.1%	3.6%	3.6%	3.4%	3.2%	1.8%	1.7%

[148] http://www.decc.gov.uk/assets/decc/Statistics/Projections/67-updated-emissions-projections-june-2010.pdf
[149] http://www.decc.gov.uk/assets/decc/Statistics/Projections/1405-projections-nonco2-gh-gas-emissions.pdf
[150] http://ecosystemghg.ceh.ac.uk/docs/2009/Defra_Report_2009.pdf
[151] Note: 2009 and 2010 are actual past values

Table 3: Economic growth central assumptions June 2010 projections

Percent per annum growth	2009	2010	2011	2012	2014	2014 - 2016	2017-2025
GDP projection	-5.0%	1.3%	3.3%	3.5%	3.6%	2.4%	2.3%
Manufacturing projection	-10.8%	1.8%	3.8%	3.8%	2.4%	1.9%	1.7%

- **Carbon Price assumptions and carbon price floor**

The underlying traded carbon price assumptions were revised for the fourth Carbon Budget baseline. In June 2010 the carbon values used in the projections were the same as those used for the purposes of policy evaluation. These assume a transition to a global traded carbon price by 2030[152]. For the fourth Carbon Budget projection the traded carbon price is assumed to continue in line with the current EU ETS trajectory. The introduction of the carbon price floor announced at budget has been incorporated leading to the effective carbon price in the power sector being slightly higher than that assumed in the June 2010 projections.

Table 4: Carbon price central assumptions and impact of carbon price support

€/tCO_2 (2009 prices)	June 2010				May 2011				
	2010	2015	2020	2025	2010	2015	2020	2025	2030
Traded Price	15.8	17.0	18.3	48.5	14.5	17.0	18.3	19.7	21.3
Effective price with carbon price floor (Power Sector only)	N/A	N/A	N/A	N/A	14.5	21.7	33.0	54.7	77.1

- **2009 Greenhouse Gas Inventory**

The National Atmospheric Emissions Inventory (referred to as 'the inventory' in the remainder of this paper) is updated annually. It contains updated emissions factors for fuels and emissions data for the previous year. The June 2010 projections were based on inventory figures for 2008. The 4th Carbon Budget baseline projection has been updated to incorporate changes in the 2009 inventory published in February[153]. These lead to reductions in both traded and non-traded emissions as a result of changes in emissions factors and changes in accounting procedures for aviation and shipping.

- **Non-CO_2 Greenhouse Gas emissions and Land use, Land use change and Forestry (LULUCF)**

Non-CO_2 Greenhouse Gas emissions and LULUCF emissions are estimated separately. The latest projections have been incorporated into the fourth Carbon Budget projections. The LULUCF sector is different from other sectors in that it contains both sources of emissions and sinks that reduce greenhouse gas emissions.

Table 5: Changes to Non-CO_2 Greenhouse Gas Emissions projections[154]

$MtCO_2e$	2010	2015	2020	2025
May 2011	91.4	87.6	79.1	73.8
June 2010	91.7	89.6	83.0	80.7

The changes in LULUCF projections are primarily due to a new Countryside Survey becoming available[155]. This has changed our assessment of the current pattern of land-use change, and in

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152 http://www.decc.gov.uk/en/content/cms/statistics/analysts_group/analysts_group.aspx

153 http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/uk_emissions/2009_final/2009_final.aspx

154 The Non-CO_2 Greenhouse Gas projections used in the DECC model are the policy adjusted projections which are lower than the headline projections in the non-CO2 greenhouse gas emissions report. These are published on the DECC website in spreadsheet form at: http://www.decc.gov.uk/media/viewfile.ashx?filetype=4&filepath=Statistics/Projections/1676-nonco2-ghg-emissions-summary-policies.xls

155 http://www.countrysidesurvey.org.uk/reports-2007

particular reduced future estimated emissions from croplands. Details of this update will be published later this year in the LULUCF annual report[156].

Table 6: Changes to Land Use, Land Use Change and Forestry Emissions

$MtCO_2e$	2010	2015	2020	2025
May 2011	-4.4	-3.6	-2.6	-0.9
June 2010	-1.2	0.9	2.7	2.9

- **Policy savings assumptions**

The Fourth Carbon Budget baseline projections take account of changes to current policies that have been announced since the last published projections and of revisions to savings impact estimates resulting from improvements in modelling and evidence. Reductions in emissions factors due to updated appraisal guidance will also have led to some reductions in estimated policy savings. The baseline projection is for a scenario in which no new policies are introduced during the fourth Carbon Budget period and existing policies are not extended. Legacy savings after 2023 arising from policies introduced in earlier years are, however, included. Table 8 below shows policy savings assumptions for the non-traded sector included in the projections compared to those included in the June 2010 projections.

Savings resulting from the non-domestic Renewable Heat Incentive (RHI) have been updated to reflect March 2011 budget announcements. No savings have been projected for domestic installations, however, as whilst they will be eligible to claim the RHI from 2012, tariffs will only be consulted on later in the year. There remains a small amount of domestic energy savings due to domestic properties connecting to a new renewable heat district heating scheme.

Table 7: Updated non-traded sector policy savings estimates

$MtCO_2e$	Budget 1 2008-12	Budget 2 2013-17	Budget 3 2018-22	Budget 4 2023-27
Residential	27	73	109	125
Business/Public	9	23	54	63
Industry	4	14	19	22
Transport	23	56	114	161
Agriculture and Waste	23	34	54	62
Total non-traded policy savings	**87**	**200**	**351**	**433**
Change in non-traded policy savings since June 2010	**-16.4**	**-15.3**	**-14.2**	

Uncertainty in emissions projections

Projecting emission levels into the 2020s is subject to uncertainty and depends upon modelling correctly the link between economic activity and GHG emissions, and modelling and anticipating future drivers, such as temperatures, fuel prices, power station capital costs, economic growth and population and accurately forecasting the impact of climate change policy.

In order to take account of some of the sources of this uncertainty in the emissions projections, ranges for emissions levels have been produced based on statistical techniques (Monte Carlo simulation) to capture the likely frequency of different levels for some of the key input factors (fuel prices, GDP, temperatures, policy impacts, power station capital costs, non CO_2 Greenhouse Gas emissions).

Results presented in this section show the impact of capturing this uncertainty modelled from a reduced form of the energy model. The reduced form consists of simplified equations for consumption of oil, gas, coal and electricity that are similar to the structure of the actual equations used in the model. These equations are used to generate demand under many different simulated input data scenarios. Each simulated demand is entered into the electricity supply part of the model which is run under a different capital cost scenario for each demand scenario. The method also takes some account of modelling

[156] http://ecosystemghg.ceh.ac.uk/docs/2009/Defra_Report_2009.pdf

uncertainty caused by errors in the demand equation estimates but it does not take account of the potential increase in forecast error over time. Uncertainty arising from internal modelling assumptions are also not taken into account.

The lower and upper 95% confidence intervals in Tables 8 and 9 represent the value of emissions obtained from the lower 2.5% and upper 97.5% percentiles of the simulations respectively. As shown in Table 9, the results from this analysis of uncertainty suggest the risk that the UK will fail to meet any of its first three carbon budgets is low. The risk of not meeting Carbon Budget 3 based on this uncertainty analysis is estimated to be less than 5%.

Table 8: Uncertainty in net UK Carbon Account ($MtCO_2e$)

$MtCO_2e$		CB1 2008-12	CB 2 2013-7	CB 3 2018-22
Net UK Carbon Account	Central	**2933**	**2668**	**2448**
	Lower 95% CI	2910	2614	2379
	Upper 95% CI	2967	2753	2551
Carbon Budget		**3018**	**2782**	**2544**
Shortfall (negative implies under budget)	Central	-85	-114	-96
	Lower 95% CI	-108	-169	-165
	Upper 95% CI	-51	-30	7

Table 9: Uncertainty in Territorial Emissions ($MtCO_2e$)

$MtCO_2e$		CB1 2008-12	CB 2 2013-7	CB 3 2018-22	CB4 2023-27
Traded	Central	1,217	1,162	1,001	912
	Lower 95% CI	1203	1128	915	840
	Upper 95% CI	1243	1247	1112	1154
Non-Traded	Central	1700	1590	1463	1393
	Lower 95% CI	1677	1536	1394	1319
	Upper 95% CI	1734	1675	1566	1502
Total	Central	2917	2752	2464	2306
	Lower 95% CI	2884	2677	2335	2195
	Upper 95% CI	2974	2909	2652	2631

Annex 4: Energy related CO_2 emissions scope of MARKAL and a 2050 Target Equivalent

The UK MARKAL model covers only CO_2 emissions from energy use and does not model non-CO_2 GHGs, LULUCF and international aviation and shipping sectors. As a consequence the 2050 target on the net UK carbon account needs to be translated to a 'MARKAL equivalent'. This requires judgements to be made on the level of emissions from non-CO_2 GHGs and LULUCF sources in 2050, and consideration to take into account international transport for sensitivity analysis where these sectors are in future included in the UK target. The global perspectives section in this evidence base outlined that the 2050 target ought to be considered as an efficient share of global effort, and met territorially.

Assumptions have been taken to provide a central, high and low estimate of non-energy non-CO_2 GHG emissions in 2050. Deducting these emission levels from the overall 2050 target level (156MtCO_2e in 2050) implies energy related CO_2 emissions represented by MARKAL need to fall by at least 85% on central forecasts (83-87% when considering respective low and high emission sensitivities in agriculture and forestry). A 90% reduction could be interpreted as a sensitivity around the uncertainty in non-CO_2 GHG emissions.

The inclusion of international aviation increases the MARKAL equivalent 2050 target to 91% (87-94% sensitivities) for the non-CO_2 GHGs and domestic sectors, and including international shipping on top of this increases the target to 97% (92-99% sensitivity). This assumes no additional abatement from shipping, and current policy measures only for aviation (as at December 2009). From this assessment, given the uncertainty range of non-CO_2 GHG projections, and rounding to avoid spurious accuracy, it would seem prudent to consider a reduction of at least 90% in CO_2 emissions by 2050, alongside 85% reduction scenarios. This does not fully take into account all international transport emissions as projected – but with more stringent targets, if this turned out to be the case, one would expect more abatement to be occurring in the non-CO_2 GHG, LULUCF and international sectors than the current forecasted central trends (suggesting the low-end range), and that there could also be a role for international carbon trading.

Annex 5: Non-energy and Non-CO_2 GHG Emission 2050 Forecasts

Total non-energy, non-CO_2 GHG emissions from agriculture, land-use, forestry, waste, F-gases and combustion and processes are projected to decrease relatively slowly over time: In 2020 these emissions are projected to be around 60-95 MtCO_2e (51-69% below 1990 levels), and in 2050 around 54-79 MtCO_2e (60-73% below 1990 levels). At these levels non-energy non-CO_2 GHG emission would account for 34-50% of emission under the 2050 target (excluding international aviation and shipping).

Non-CO_2 GHG emissions are dominated by those from the agriculture and waste sectors. Methane (CH_4) and Nitrous Oxide (N_2O), which have a Global Warming Potential (GWP) 21 and 310 times respectively of CO_2, are the main non-CO_2 GHG gases.

Agriculture: Non-CO_2 GHG emissions from agriculture are composed mainly of methane from enteric fermentation in ruminant livestock and from the management of manures, and nitrous oxide predominantly from synthetic fertiliser application. Defra has produced[157] high and a low emission scenarios. The high emissions scenario assumes agricultural activities increase to meet higher UK and global demand, forecasting emissions to increase to 49 MtCO_2e by 2050. The low scenario assumes abatement estimated to cost less than £100 per tonne of CO_2[158] is implemented by 2040, livestock activity declines marginally, but that there is some intensification of fertiliser application, and forecasts emissions at 36 MtCO_2e. These scenarios reflect a 13% increase and 36% reduction compared to the 1990 emissions inventory, though the projections do not reflect all types of uncertainties in particular scientific uncertainties.

Waste: The main source of non-CO_2 GHG waste emission is methane, generated by the degradation of biodegradable waste in landfills. Emissions from wastewater treatment and non-energy incineration will become relatively more important as landfill emissions decrease. Defra provides one scenario for waste emissions, representing business as usual, in which landfill methane emissions are expected to decline to 11 MtCO_2e and then further decrease to 6.2 MtCO_2e by 2050, 88% lower than 1990 emissions inventory. There are a number of uncertainties associated with these projections. Firstly, estimates are affected by the scientific uncertainty that arises from the lack of tools to measure actual emissions. Secondly, they are based on important assumptions about the amount and composition of waste at any point in time. Thirdly, they are obviously linked with the uncertainty arising from the future of the sector. Finally, these projections are very sensitive to the assumption on the capture rate of methane in landfill, presently assumed to be 75%.

Fluorinated gases: F-Gases include HFCs (Hydrofluorocarbons), SF6 (Sulphur Hexafluoride) and PFCs (Perfluorocarbons). HFCs are by far the most prevalent type and are generated in a number of sectors, notably stationary refrigeration in supermarkets. The scenario models the impact of the regulatory measures in place and also assesses the further adoption of technologies with a low global warming potential (GWP) and how these are likely to affect the ongoing consumption of HFCs in the UK over the next years. Total F-gases are forecast to be around 10 MtCO_2e in 2020, falling to around 5 MtCO_2e by 2050.

LULUCF projections are estimated by the Centre for Ecology and Hydrology under contract to DECC, using methods consistent with the UK greenhouse gas emission inventory, coupled with projections of future land use and land-use change, based on what has happened historically and possible future scenarios. Uncertainties are estimated using Monte-Carlo Analysis, projected forward where necessary.

Other non-CO_2 GHG emissions are linearly extrapolated forward to 2050 based on existing forecasts to 2030.

[157] At the moment based on work from AEA, which in turn is based on the BAU III (Business as Usual) scenario developed by ADAS in 2007.
[158] As identified by the SAC II analysis.