# THE ECONOMICS OF CLIMATE CHANGE POLICY IN THE UK

**An analysis of the impact of low-carbon policies on households, businesses and the macro-economy**
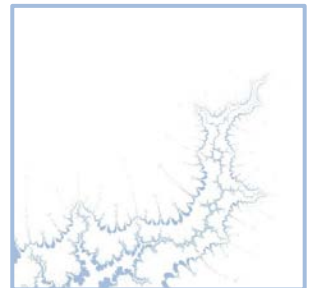
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# Executive Summary

**The purpose and value of this research**

- As part of the Climate Change Act (2008) the UK has committed to reduce greenhouse gas (GHG) emissions by at least 80% by 2050. To meet that goal, the independent Committee on Climate Change (CCC) has set out its recommendations for the first four carbon budgets, collectively spanning the period 2008 to 2027, which have subsequently been accepted into law by the UK government.

- **This study provides a rigorous, model-based assessment of the macroeconomic costs and benefits that could occur as a result of the UK putting in place the measures and changes required to meet the emission reductions proposed by the CCC in the first four carbon budgets.** The analysis was undertaken using the well-established MDM-E3 macro-econometric model of the UK economy, energy system and environment.

- Intuitively, it seems appealing to assume that the additional energy system cost required to meet GHG emissions targets will be similar to a loss in GDP. However, macroeconomics is concerned not only with costs, but also benefits, since any transaction is a cost to the buyer and benefit to the seller. **As discussed throughout this report, changes to the energy system do result in slightly higher costs (reflecting the CCC's analysis) but they also change the structure of the economy, with net benefits for the UK economy.**

- **The evidence in this report suggests that meeting the reduction in greenhouse gas emissions set out in the first four carbon budgets will lead to a net 1.1% increase in GDP by 2030, the creation of an additional 190,000 jobs and higher real disposable incomes (£565 per household per year), relative to a counterfactual scenario where no action is taken to mitigate the effects of climate change.** This does not assume any increase in exports of low-carbon goods and services from the UK.

**Modelling approach**

- We follow a scenario-based approach and model three scenarios:

  (1) A scenario in which climate policy returns to the policies before the adoption of the Low Carbon Transition Plan in 2009. As a result, the second, third and fourth carbon budgets are not met (Low Ambition);

  (2) A scenario in which all four carbon budgets are met (4CB);

  (3) A scenario in which all four carbon budgets are met and, in addition, a higher level of greenhouse gas (GHG) emission abatement is achieved in the transport and building sectors (4CB+)

- We model the impact of the low-carbon transition on households, businesses and the macro-economy in the period up to 2030. The key results from the 4CB scenario are summarised below.

**Meeting the carbon budgets- key results**

- **Households will be better off financially (Section 3):** Our analysis shows that, on average, each household is expected to be £565 better off each year, by 2030, as a result of climate mitigation action. This is because the structural changes required by the low-carbon transition leads to increases in output and subsequent demand for labour, which in turn drives increases in real wages and employment. This effect will not be felt evenly across households, with those households including individuals moving out of unemployment (and underemployment) seeing the largest benefits.

- In addition to a net increase in real household incomes and consumption, there will be a transfer of expenditure. Households will spend less on energy (particularly oil and gas) and will spend more on energy-efficient appliances and vehicles. Overall, they will also have more money available to spend on other goods and services.

- Savings from energy efficiency measures in homes offset the cost of the efficiency measures and are nearly sufficient to also cover the entire increase in electricity prices.

- In transport, cars in particular will be cheaper to own and run over their lifetime, by around £266 per year. Indeed, there is evidence that consumers are already benefitting from EU regulation to improve efficiency standards.

- The modelling does not assess the distribution of impacts across types of households, but it is clear that costs and benefits will not fall evenly. To address any potential inequality, government policies could be targeted to support exposed or vulnerable groups, for example by investing directly in energy efficiency in fuel-poor households.

- Energy efficiency measures do not just result in financial gains for households. It will also allow some households to heat their homes to higher standards of comfort.

- **Positive impacts on UK business (Section 4):** British-based businesses would benefit directly from the measures and changes required by a low-carbon transition, such as the development, manufacture and installation of low-carbon technologies in the power sector; the manufacture of low-carbon vehicles and components; and the manufacture and installation of energy efficiency measures in the home.

- Many businesses that are not directly affected by a transition would benefit indirectly from the additional spending power of households and the knock-on effect this has on the wider economy. Our results suggest that this effect would lead to a 1% increase in gross output in the service sector by 2030. However, there will be reductions in output and employment in the gas supply and petroleum refining industries, due to reduced demand for oil and gas.

- **The impacts on energy-intensive industries will need to be managed by policy (Section 4):** While energy-intensive industries will face important challenges during the transition to a low-carbon economy, these are manageable if addressed by well-designed policy. The analysis in this report assumes the free allocation of EU ETS allowances to energy-intensive industries continues. Furthermore, the existing and proposed compensation

of the indirect carbon costs and Contracts for Difference Levy, respectively, in electricity bills to electro-intensive industries, are in place. This will support industry in remaining competitive and in doing so provide a more stable environment for investment during the transition to a low-carbon economy, as acknowledged in the Chancellor's 2014 Budget Statement[1].

- **It is also worth noting that energy-intensive firms will form part of the supply chains providing the components needed for a low-carbon energy and transport system and the modelling results show that increased demand for low-carbon products will result in a 1.9% increase in gross output in energy-intensive sectors by 2030**. This places even more importance on the design of policy to support industry in remaining competitive while reducing carbon emissions. If industry is not supported, then the additional demand could be met through imports with a higher carbon intensity (carbon leakage), undermining UK efforts to reduce emissions. Higher import penetration would also reduce the benefits of decarbonisation accruing to the UK economy.

- **Higher net levels of employment and GDP (Section 5):** There will be an annual increase in low-carbon investment of around £20bn by 2030 that we assume will be financed by higher electricity and product prices. The increase in investment would lead to net increases in output and employment (the effect of which is slightly diminished due to higher consumer prices). Higher employment and higher household incomes would stimulate the economy further leading to further growth and more jobs, which in turn boost household incomes – the so-called multiplier effect. **By meeting the carbon budgets, our analysis suggests that, by 2030, GDP will be 1.1% higher, and an additional 190,000 net jobs would be created.**

- **An energy system far less dependent on fossil fuels (Section 5):** The energy system, more broadly, is also transformed. **By meeting the fourth carbon budget, decarbonisation across all sectors results in a 30% reduction in the demand for primary oils and petroleum products, and a 55% reduction in the demand for gas by 2030. This leads to an £8.5bn annual reduction in imports of oil and gas to the UK by 2030.**

- **Improved energy security in the UK (Section 5):** In broad terms, energy security would be improved. By reducing demand for fossil fuels, the UK's exposure to the impact of price spikes is reduced, which means more stable energy bills for consumers and businesses.

- **The UK would still benefit economically from meeting the carbon budgets under lower fossil fuel price assumptions.** Future fossil fuel prices are uncertain and in the scenarios, these prices are assumed to be in line with DECC's central projections. The macroeconomic benefits presented in this report would be slightly diminished, but still remain positive (GDP increases by 0.8%) by 2030, if fossil fuel prices turned out to be consistent with DECC's 'Low' projections in which gas and oil prices are more than 40% lower than the 'Central' projections. Equally, the economic

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[1] See: https://www.gov.uk/government/speeches/chancellor-george-osbornes-budget-2014-speech

benefits of decarbonisation would be slightly greater (GDP increase of 1.3% by 2030) if fossil fuel prices were nearer DECC's 'High' projections which are just over 40% higher than the 'Central' projections.

- **Government revenues are improved (Section 5):** Directly, the auctioning of EU ETS allowances and revenue from the carbon price support mechanism will offset around 75% of the reductions in hydrocarbon tax revenue from falling petrol and diesel sales. There is also an increase in revenue from income tax and VAT. **Based on the MDM-E3 results, there is a net increase in annual government revenue of £5.7bn by 2030 due to a stronger economy.**

- **Possible exports could mean greater economic benefits (Section 5):** The benefits to the UK economy could be even greater. This analysis does not quantify the potential for capturing export opportunities in low-carbon technologies such as offshore wind turbines and electric vehicles and their components. With a stable commitment to decarbonisation in the UK, it is possible that low-carbon technology firms would locate in the UK and that export opportunities could arise in the future.

- **Significant reductions in carbon emissions (Section 6):** The principal purpose of the carbon budgets is to reduce domestic greenhouse gas emissions. In the abatement scenarios presented in this report, the power sector will be transformed from a system dominated by coal and gas-fired power generation towards a low-carbon electricity mix with a high renewable content and a carbon intensity of $50gCO_2/kwh$ by 2030, around a 90% reduction in carbon intensity compared to that in 2000. Other sectors of the economy will also realise substantial reductions in GHG emissions, compared to the counterfactual scenario.

- **Improved health and lower healthcare expenditure (Section 6):** Meeting the carbon budgets would improve air quality by reducing local pollutants such as particulates (black smoke) and $NO_x$. **This would create health benefits and the reduction in emissions of particulates from road transport alone could reduce gross healthcare spending by between £96m-£288m annually by 2030.**

- The results presented in this report are dependent on a number of assumptions, here considered to be conservative. Interpreting the results of our analysis crucially depends on understanding and judging the plausibility of the assumptions that are detailed in Appendix A and Appendix B, and are summarised below:

  - The scenarios and abatement potential in each sector are based on the CCC's 'Fourth Carbon Budget Review'. Technology costs are taken from the CCC's analysis and the supporting literature and are presented in Appendix A.

  - Consistent with the varying levels of ambition, the EU ETS carbon price differs between scenarios. In the Low Ambition scenario, a very low carbon price is assumed, which is consistent with DECC central projections, reaching just £6.2/$tCO_2$ in 2030. In the 4CB and 4CB+ scenarios, it is assumed that the carbon price reaches £42.1/$tCO_2$ in

2030 and the additional carbon price faced by the power sector from the carbon price support is assumed to remain fixed at £18/tCO$_2$ over the projection period (see Figure 2.1 in Section 2).

− Fuel costs are taken from DECC central projections and DECC's low and high fuel cost projections are used as sensitivities.

− The study focuses on the UK, and we assume that the level of decarbonisation achieved in the rest of the world is invariant between scenarios. By assuming that no new climate change policies are introduced in the rest of the world, the impact on relative prices is greater than it might otherwise be, which reduces the UK's competitive position. We therefore consider this to be a conservative assumption.

− Assumptions on the UK based content of low-carbon energy technology supply chains are crucial to our analysis, and are reported in Appendix A.

− The damage costs associated with climate change are not assessed in this analysis. Costs to 2030 are largely 'locked in', the costs will accrue as a result of past emissions, and carbon mitigation measures to 2030 will have only a marginal impact by 2030. However, it should be noted that the long-term climate damage costs associated with the Low Ambition scenario (if adopted globally) are estimated to be significant and far-reaching.

− Our modelling approach uses historical data to estimate the behavioural responses of firms and households. This econometric simulation approach differs from the mainstream economic modelling approach (Computable General Equilibrium modelling, CGE) in that it does not assume optimising behaviour or full employment of resources in the long term. The implication of following this approach is that policy intervention could have either a positive or negative impact on the economy depending on the specific nature of the interventions, while the assumption of an optimal starting point in CGE models means that any additional demand side policy can only result in lower GDP.

• The key drivers of the economic results in the low-carbon scenarios include:

− lower final energy demand, a reduction in fossil fuel imports and re-allocation of expenditure to other goods and services

− an increase in low-carbon investment

− an increase in prices to pay for the transition costs

− multiplier and induced effects

**Summary conclusions**

• The objective of this report is to provide model-based evidence to the policy discussion about meeting the UK's carbon budgets.

• **Overall, the modelling evidence suggests that meeting the fourth carbon budget will lead to a higher GDP (1.1% by 2030) supporting more jobs across the economy (190,000) and higher real disposable incomes (£565 per household per year).** There are also environmental co-benefits from reduced air pollution arising from local air pollutants.

- Collectively these are the benefits that go hand-in-hand with the sustainable pathway envisaged through the carbon budgets to meet the UK's legally binding commitment by 2050, largely as a result of reducing imports of fossil fuels. **Meeting the first four carbon budgets would entail a reduction in cumulative GHG emissions of 2,580 MtCO$_2$eq over the period 2014-2030.**

# 1 Introduction

## 1.1 Overview

In 2012, greenhouse gas (GHG) emissions in the UK were estimated[2] at 581 MtCO$_2$eq. Although this represented a small increase on 2011 levels, there has been a general downward trend in emissions over the last decade, with GHG emissions in 2012 around 25% lower than 1990 levels[3].

The objective of the analysis presented in this report is to quantify the likely macroeconomic and sectoral impacts of cutting GHG emissions in the UK further in the period up to 2030. Specifically, we assess the implications for households, industry and the economy as a whole of meeting the first four carbon budgets set by the UK government as part of the 2008 Climate Change Act.

The analysis draws heavily on prior analysis by the Committee on Climate Change, the UK's independent body established to provide guidance to government on the issue of climate change.

This report is not intended to assess the effectiveness of particular policies required to bring about the required transition in the UK energy system to meet the UK's carbon targets, but instead attempts to quantify the economic impact of doing so compared to a counterfactual world in which the UK's legally-binding GHG emissions targets are abandoned.

## 1.2 International context

The Intergovernmental Panel on Climate Change (IPCC) recently launched its Fifth Assessment Report[4] presenting scientific evidence on the consequences of global climate change. The analysis presented across the three main volumes of the report included three notable conclusions:

1.  It is "unequivocal" that the climate system is warming and "extremely likely" that human influence has been the dominant cause.

2.  Global warming will severely impact ecosystems and food production, pushing more people into poverty globally, if emissions are not urgently reduced over the next few decades.

3.  Action to mitigate GHG emissions over the coming decades to avoid warming of 2°C is both necessary and affordable. Assuming global growth in consumption of 1.6%-3% per annum, the IPCC concluded that the cost of mitigation would only reduce consumption growth by 0.06 percentage points per annum throughout the century.

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[2] See DECC (2014), '2012 UK Final Greenhouse Gas Emissions, Final Figures'. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/295961/20140204_2012_UK_Greenhouse_Gas_Emissions_Final_Figures_-_revised_27_March_2014.pdf

[3] According to DECC (2014) GHG emissions in the UK were 581.1 MtCO$_2$eq in 2010 compared to 777.6 MtCO$_2$eq in 1990.

[4] IPCC (2014), 'IPCC Fifth Assessment Report (AR5)' Available online at: http://www.ipcc.ch/report/ar5/

The IPCC advises that each nation state has a role to play in order to prevent the potentially severe impacts of climate change. Whilst it is recognised that the UK has already made progress towards decarbonisation, further action is clearly required to achieve its share of the necessary emissions reductions.

## 1.3 The UK Climate Change Act

In 2008 the UK established a legally binding target to cut GHG emissions. The Climate Change Act requires, by law, a reduction of at least 80% in emissions by 2050 (relative to 1990 levels)[5] and, in order to put the UK on a trajectory to achieve this emissions target, the Committee on Climate Change (CCC), again as required by law, has set out a plan for decarbonisation through a series of carbon budgets. Each of the carbon budgets spans a five year period and specifies progressively stringent emissions reduction targets, with a 50% reduction in GHG emissions (relative to 1990 levels) envisaged during the fourth carbon budget period (see Table 1.1).

The first carbon budget, which ended in 2012, required on average that GHG emissions were reduced by 23% compared to the 1990 level. This target was met comfortably. However, the global economic downturn, which led to recession in the UK, made a substantial contribution to reducing GHG emissions in this period, in addition to the emissions savings achieved by policy action.

**Table 1.1 Carbon budgets in the UK**

|  | Period covered | GHG emissions target over period | Reduction in GHG emissions (relative to 1990 levels) |
|---|---|---|---|
| **First carbon budget** | 2008-2012 | 3,018 MtCO$_2$eq | -23% |
| **Second carbon budget** | 2013-2017 | 2,782 MtCO$_2$eq | -29% |
| **Third carbon budget** | 2018-2022 | 2,544 MtCO$_2$eq | -35% |
| **Fourth carbon budget** | 2023-2027 | 1,950 MtCO$_2$eq | -50% |

Source: DECC (2011) 'The Carbon Plan: Delivering our low-carbon future'[6]

## 1.4 Recent analysis and the basis for this report

Existing literature on the impact of decarbonisation has, in most cases, focused on energy system costs, as opposed to the full macroeconomic consequences of investing in abatement measures.

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[5] Legislation for the 2008 Climate Change Act. Available online:

http://www.legislation.gov.uk/ukpga/2008/27/contents

[6] Available online:

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47613/3702-the-carbon-plan-delivering-our-low-carbon-future.pdf

In December 2013, the CCC published the 'Fourth Carbon Budget Review'[7], which assessed the impending climatic risk and identified the cost-effective path to meeting the fourth carbon budget. The review details the abatement opportunities in the power sector, buildings, industry, transport and agriculture, and assesses the cost of the measures required in order to achieve the required level of emissions abatement.

The results of the CCC's analysis show that the direct cost of meeting the fourth carbon budget would be equivalent to 0.5% of GDP by 2030, relative to a baseline scenario with limited GHG emissions abatement. The analysis shows that abatement measures in transport, industry and agriculture would create a net saving, but this cost saving would be outweighed by the cost of decarbonising the power sector and the ensuing higher electricity prices.

The CCC's analysis is based on estimates of the marginal abatement cost of various technologies and, whilst this measure provides an indication of the direct cost of abatement for consumers and industry, it does not reflect the indirect and induced effects of mitigation measures. For example, the CCC's 'Fourth Carbon Budget Review' does not consider the economic impact of reduced reliance on oil and gas imports; it also does not take into account potential benefits to equipment makers and their associated supply chains.

**Intuitively, it seems appealing to assume that the additional energy system cost (or marginal abatement cost) will be similar to a loss in GDP. However, macroeconomics is concerned not only with costs, but also benefits, since any transaction is a cost to the buyer and benefit to the seller. As discussed throughout this report, changes to the energy system do result in slightly higher costs (reflecting the CCC's analysis) but they also change the structure of the economy with net benefits.**

The analysis presented in this report builds on the work published by the CCC and considers the macroeconomic impacts of meeting the fourth carbon budget, taking into account direct, indirect and induced effects. A modelling approach is applied and we have constructed scenarios consistent with those assessed by the CCC, which include abatement measures in the power sector, buildings, industry, transport and agriculture.

## 1.5    Report structure

The remainder of the report is structured as follows:

- Section 2 provides details of the methodological approach that was adopted and describes the three scenarios that were modelled.

- Section 3 presents our analysis on the impact of abatement on households, specifically focusing on the impact on household energy bills and the cost of buying and running a car under the abatement scenarios.

- In Section 4 the implications for industry are discussed. The model results for industry costs and competitiveness are considered and we explore two

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[7] Committee on Climate Change (2013), 'Fourth Carbon Budget Review – part 2'. Available online:
http://www.theccc.org.uk/publication/fourth-carbon-budget-review/

case study examples to assess the opportunities to develop a UK-based export market in low-carbon technologies.

- The macroeconomic impact of meeting the fourth carbon budget is discussed in Section 5, where we consider the impact of reduced reliance on fossil fuel imports and an increase in domestic investment. We also present results showing the net impact on GDP and employment in this section.

- Section 6 considers the environmental impact of meeting the fourth carbon budget and discusses the potential health benefits due to air quality improvements.

- Section 7 summarises the results and draws conclusions from the analysis.

- Section 8 outlines the key assumptions and limitations in the modelling.

- There are also two appendices. Appendix A outlines the critical assumptions that were applied to this analysis and summarises the key scenario inputs in each of the five sectors considered (the power sector, buildings, industry, transport and agriculture). Appendix B provides a detailed description of the MDM-E3 model.

## 1.6    Report conventions

All monetary values in this report are expressed in pounds sterling (£) and have been converted to real 2013 prices, unless otherwise stated.

Energy consumption figures are quoted in TWh, unless otherwise stated.

# 2 Methodology

## 2.1 The scenarios

Our analytical approach is primarily model-based. The starting point is a set of detailed assessments of the cost and abatement potential of the various technologies identified in the CCC's 'Fourth Carbon Budget Review'. These are used as inputs to the MDM-E3 macro-econometric model of the UK economy and energy system, which gives an estimate of impacts on key industry sectors and the economy as a whole.

Three scenarios were modelled:

- a reference scenario with which the other scenarios are compared (Low Ambition)

- a scenario in which the fourth carbon budget is met (4CB)

- a higher ambition scenario in which the fourth carbon budget is surpassed due to additional efficiency measures in buildings and transport (4CB+)

**Low Ambition scenario** In the Low Ambition scenario energy demand and emissions projections are based solely on policies that existed before the Low Carbon Transition Plan (2009). This scenario is consistent with DECC's 'Baseline Policies' projections, as outlined in its annual publication 'Updated Energy and Emissions Projections'[8], and is aligned with the counterfactual scenario used in the CCC's 'Fourth Carbon Budget Review'. This scenario is therefore representative of a case in which no further action is taken to reduce emissions and the UK diverges from its current climate policy goals and legally-binding framework.

The economic projections in this scenario are aligned to the Office for Budget Responsibility (OBR)'s central forecast in the period up to 2018, and the period to 2030 is extrapolated using Cambridge Econometrics' long-term industrial forecast (published in December 2013).

By presenting results from the 4CB and 4CB+ scenarios relative to this Low Ambition scenario, our headline figures reflect estimates of the full economic impacts of decarbonisation (and therefore incorporate the economic impact of policies that have been in place since the Low Carbon Transition Plan).

**4CB scenario** The 4CB scenario has been aligned with the 'Updated Abatement' scenario from the CCC's 'Fourth Carbon Budget Review' and indicates the level of ambition required in order to meet the fourth carbon budget. The 4CB scenario includes abatement measures across the power sector, buildings, industry, transport and agriculture. The main features of this scenario include:

- a highly decarbonised power sector, with emissions intensity of $50gCO_2/KWh$ by 2030 (around a 90% reduction from the emissions intensity in 2000)

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[8] DECC (2013), 'Updated Energy and Emissions Projections'. Available online at:
https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2013

- investment in low-carbon heat and energy efficiency measures in residential and non-residential buildings

- abatement measures in industry, including investment in low-carbon heat, process improvements and industry CCS

- a highly decarbonised transport sector with plug-in hybrid electric vehicles (PHEVs) and battery-electric vehicles (BEVs) accounting for 60% of vehicle sales by 2030

- a reduction in non-$CO_2$ emissions in agriculture

**4CB+ scenario**  The more ambitious 4CB+ scenario is an extension to the 4CB scenario. While the power sector technology mix and the measures adopted by industry and agriculture are identical to that in the 4CB scenario, further efficiency measures are modelled in the buildings and transport sectors. These include:

- more energy-efficient installations in residential buildings

- a higher uptake of EVs in the vehicles stock

By 2030, the net annual reduction in GHG emissions in this scenario is around 5% lower than that in the 4CB scenario.

**Presentation of results**  It is important to note that in this study the results for the two abatement scenarios are presented relative to the Low Ambition scenario. The Low Ambition scenario only includes policies that existed *before* the Low Carbon Transition Plan (2009). Therefore, by comparing the two abatement scenarios to the Low Ambition scenario, we estimate the macroeconomic impact of the additional measures required to meet the four carbon budgets. This includes the impact of low-carbon policy measures that have been instated since the 2009 Low Carbon Transition Plan.

## 2.2    Modelling approach

All three scenarios are assessed using MDM-E3, a macro-econometric model that applies economic (national) accounting identities and empirically estimated equations to model interactions between the UK economy, energy system and the environment. MDM-E3 incorporates a bottom-up approach to modelling power generation technologies and uses an input-output framework to model the supply chain effects of changes to industrial output and expenditure.

**Macro-econometric structure of MDM-E3**  There are two different analytical approaches that are typically applied to model energy-environment-economy interactions: (1) econometric-based simulation models and (2) Computable General Equilibrium (CGE) models.

MDM-E3 is an example of an econometric-based simulation model. It differs somewhat from CGE models, as it does not make assumptions about optimising behaviour or assume that all resources are employed in an 'equilibrium' state. It instead uses empirical equations to estimate the behaviour of households and industry, drawing on historical time-series data. Although these issues may seem overly technical in nature, they can have an important bearing on the results; if an optimal equilibrium is assumed in the no-policy case, then adding a carbon constraint must, by definition, have a negative impact on economic rates of activity.

Experience has shown that economies usually exhibit involuntary unemployment and that there is therefore spare capacity in the economy, meaning that an increase in demand would lead to an increase in output (and not just an increase in price). The benefit of the econometric approach applied in MDM-E3 is that it does not necessarily assume that the economy is in an optimal position in the long run with no policy. The Low Ambition scenario in MDM-E3 allows for the possibility of spare capacity (for example, the unemployed part of the workforce) that can be brought into service if the right stimulus is applied. A positive outcome is therefore possible (but not guaranteed) under certain conditions.

The main differences between the two modelling approaches are summarised in Table 2.1 below.

**Table 2.1 A summary of the differences between macro-econometric and CGE modelling approaches**

| | Econometric modelling approach | Computable General Equilibrium (CGE) approach |
|---|---|---|
| **Demand and supply** | Industry output is demand-driven i.e. supply adjusts to meet an increase in demand. | Assumes markets are in equilibrium, and that prices adjust until supply and demand are in balance |
| **Behaviour of households and firms** | Behaviour of economic agents is determined by empirically estimated equations. | Agents are assumed to be rational and optimise. |
| **Treatment of investment** | Investment demand creates an economic stimulus, leading (where there is spare capacity) to an increase in output and employment, as well as an empirically estimated increase in prices. | Interest rates (the price of investment) adjust so that additional investment fully crowds out investment that would otherwise take place. |
| **Labour market treatment** | Unemployment exists in the baseline, so policies that drive an increase in economic activity lead to increases in employment and wage rates | There is assumed to be no involuntary unemployment and an economic stimulus would only lead to an increase in wages and, therefore, inflation |

It is worth noting that, almost without exception, modelling analysis undertaken in CGE models has shown GDP loss as the net impact of decarbonisation, while simulation models have often shown more positive results. This is evident in the range of estimates of the impact of mitigation policies on GDP quoted in  the IPCC report, which vary from -1.0% to -3.7% for a stabilisation of global greenhouse gas emissions to 450 ppm $CO_2$-eq[9] in 2030[10]. For the

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[10] See IPCC synthesis report. Available online:
http://report.mitigation2014.org/spm/ipcc_wg3_ar5_summary-for-policymakers_approved.pdf

most part, the models that assess the GDP impacts of climate policy in the IPCC report are CGE models. By assuming that the economy is operating at full capacity in the baseline, CGE models implicitly assume that policy interventions will always lead to negative GDP impacts. Another key difference is that the IPCC analysis considers the global GDP impact (rather than the impact on the UK economy specifically) but recognises that the impacts of climate change mitigation policies could vary considerably between countries and regions.  A more comprehensive discussion of the difference between our results and those presented in the IPCC report is available in Appendix B.3.

In a recent paper[11], Synapse Energy discusses the relative weaknesses of economic modelling in assessing climate policy with a particular focus on the role of the mainstream CGE model (as exemplified by the economic model of Her Majesty's Revenue and Customs, HMRC).

Our analysis does not address all of their criticisms, but goes some way to addressing some of them:

- MDM-E3 does not impose the assumption of full crowding out of investment

- MDM-E3 does not assume optimality and full employment in the long run

- Co-benefits from reductions in other air pollutants, while not quantified in monetary terms in the modelling framework, are outlined and discussed in this report and potential monetary values are put forward based on published estimates.

Further details about the MDM-E3 model are provided in Appendix B. A discussion of some of the limitations to the analysis related to the modelling approach is provided in Section 8.

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[11] Synapse Energy (2014), '(Mis)understanding climate policy'. Available online: http://www.synapse-energy.com/Downloads/SynapseReport.2014-04.0.Misunderstanding-Policy.14-011.pdf

## 2.3 Fossil fuel and carbon price assumptions

The assumptions for fossil fuel and carbon prices are outlined in Table 2.2.

**Table 2.2 Key Assumptions**

| Assumption | Source |
|---|---|
| **Fossil fuel prices** | DECC central (September 2013)[12] |
| **Carbon price in the Low Ambition scenario** | The EU ETS price is taken from DECC's central scenario (September 2013) and reaches £6.2/t$CO_2$ by 2030. As this scenario only includes policies that existed before 2009, we assume no carbon price support in the projection period. |
| **Carbon price in 4CB and 4CB+ scenarios** | The EU ETS price is taken from a Thomson Reuters report (January 2014)[13] and reaches £42.1/t$CO_2$[14] by 2030. Carbon price support is assumed to remain fixed at £18/t$CO_2$ in the period to 2030. To remain consistent with the CCC report, in cases where the carbon price is too low to incentivise industry to reduce emissions, we assume these measures still take place but are financed by supplier obligations that result in higher household electricity bills. |

In the Low Ambition scenario it is assumed that the carbon price remains very low over the period to 2030 at just £6.2/t$CO_2$ and, in addition, we assume that there is no carbon price support in this scenario. This is the least ambitious scenario in terms of climate policy, and even assumes the abandonment of some climate policies that have already been instated. Facing such a low carbon price, the power sector and traded industry sector have no incentive to decarbonise and the result is a very limited reduction in $CO_2$ emissions over the period considered.

The policy environment in the 4CB and 4CB+ scenarios is very different. In these scenarios, we assume a moderate increase in the carbon price over the period and, by 2030, the carbon price reaches £42.1/t$CO_2$. This incentivises industries and the power sector to decarbonise more quickly.

We apply the same fossil fuel price assumptions in each scenario (taken from DECC's central scenario) and run low and high fossil fuel price sensitivities to test the robustness of our results.

The carbon price assumptions in the 4CB and 4CB+ scenarios are shown in Figure 2.1.
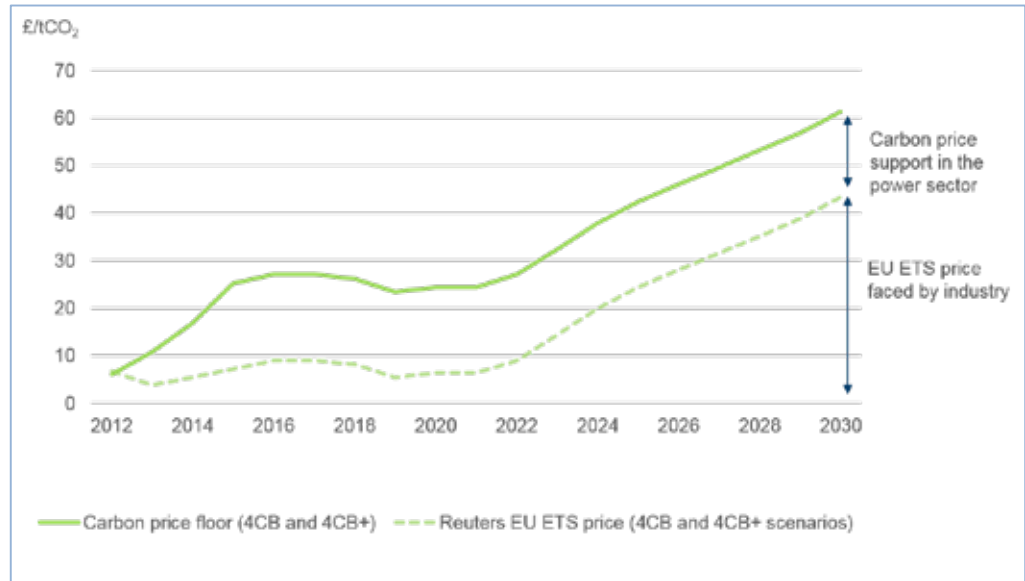
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[12] Available online:

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/212521/130718_decc-fossil-fuel-price-projections.pdf

[13] See: Reference scenario, http://www.ceps.eu/system/files/u153872/Ferdinand.pdf

[14] This figure has been converted to pound sterling (2013 prices).

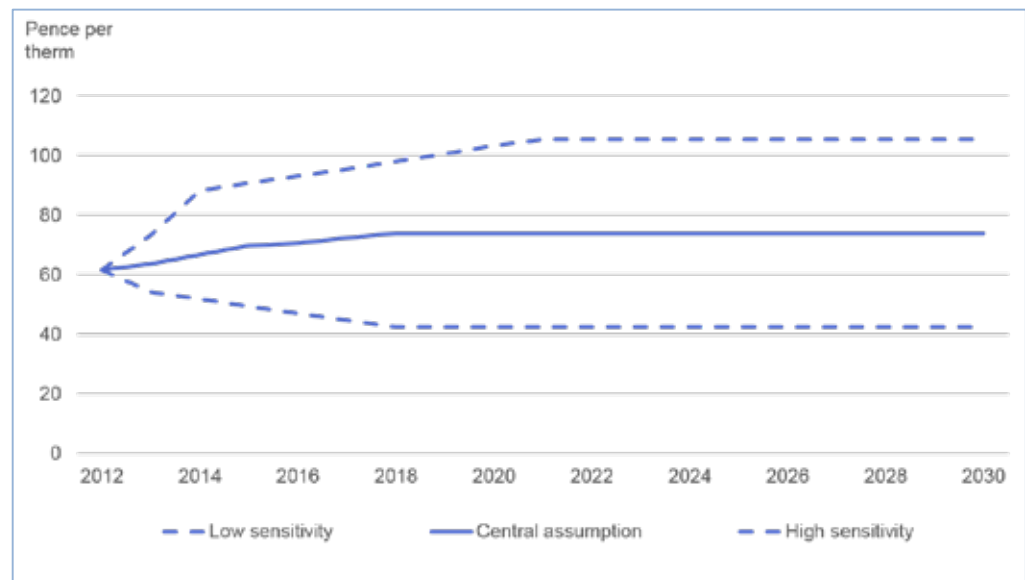**Figure 2.1 Carbon price assumptions in the 4CB and 4CB+ scenarios**



Source: Thomson Reuters Point Carbon (2014), converted to pound sterling (2013 price base)

The gas and coal price assumptions and the high and low price sensitivities that were tested are shown in Figure 2.2 and Figure 2.3.
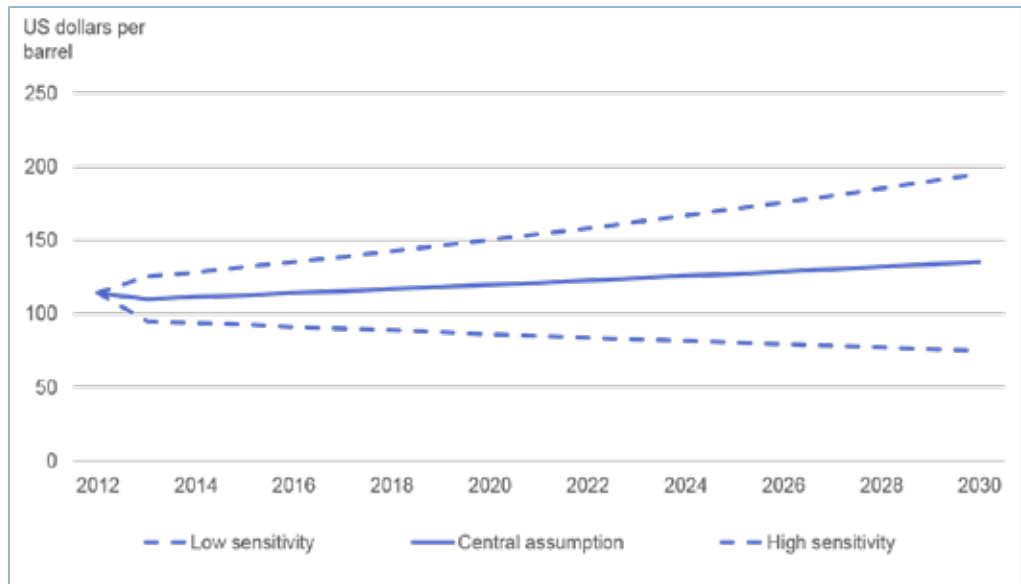
Other key assumptions in our analysis include the achievable level of abatement and costs associated with the various low-carbon technologies modelled. These assumptions are detailed in Appendix A.

**Figure 2.2 Central gas price assumptions and low/high sensitivities**



Source: DECC (2013)

**Figure 2.3 Central oil price assumptions and low/high sensitivities**



Source: DECC (2013)

# 3    Impact on Households

## 3.1    Introduction

This section presents modelling results that show the impact of low-carbon policies on the average household. The distributional effects across households (which are not modelled) will be dependent on how government policies are targeted towards different social groups and these effects are therefore sensitive to specific policy design. The distributional aspects of low-carbon policy design will determine the extent to which the impact on households is progressive, for example, due to the inclusion of targeted support for fuel-poor households.

There are several different ways in which households will be affected in the 4CB and 4CB+ scenarios, including:

- changes to gas and electricity bills, which are the net outcome of savings from the adoption of more energy-efficient technologies and higher electricity prices

- changes to the lifetime cost of vehicle ownership, as the cost of buying cars increases but the cost of running a car falls

- changes to product prices, including reductions in food prices due to efficiency gains in agriculture, and increases in the price of products that require electricity in their manufacturing processes

- changes to real incomes as a result of changes in wages and levels of employment

The different factors affecting households are set out in the sections below. A detailed description of the underlying assumptions for this analysis is presented in Appendix A.2 and Appendix A.4.

## 3.2    Household gas and electricity bills

**Electricity prices**  The price of electricity charged to domestic consumers comprises the wholesale price, supplier costs, network costs, a retail margin, policy costs and VAT.

The wholesale price accounts for around half of the price charged to households, and is principally determined by the cost of generation across the various technologies in the power sector mix[15]. Under the projections of future costs and fossil fuel prices, we estimate that there would be an increase in the wholesale price of electricity in the 4CB and 4CB+ scenarios due to the higher capital cost of renewable technologies in the power sector, the higher transmission costs associated with these technologies and a higher carbon

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[15] In MDM-E3, the electricity price is calculated based on the average annualised cost of electricity generation, including the cost of capital investment, operations and maintenance, distribution, fuel costs, carbon costs and a supplier margin. This ensures that all investment costs are passed on to households, and that utility companies realise the same profits per MWh of electricity generated in each scenario.

price that would push up the cost of gas generation in this scenario. These factors would lead to an increase in annual electricity bills of around £127 per household in the 4CB and 4CB+ scenarios, when considered in isolation and without any improvements to household energy efficiency. This is equivalent to a 15% increase in electricity prices faced by households, relative to the Low Ambition scenario[16].

However, it should be noted that the move towards a low-carbon electricity system would reduce the UK's exposure to volatile fossil fuel prices, which would improve the stability of consumers' electricity bills. It should also be noted that electricity prices are expected to increase in the period to 2030, even if the UK economy does not decarbonise, due to an expected rise in fossil fuel prices[17].

**Energy efficiency measures**

Counteracting the impact of an increase in electricity prices in the 4CB and 4CB+ scenarios is a reduction in demand for electricity, gas and oil due to household energy efficiency improvements (which we assume are not taken up in the Low Ambition comparison scenario).

Analysis undertaken by Element Energy for the Committee on Climate Change[18] shows that the more efficient technologies installed in households in the 4CB and 4CB+ scenarios will be more expensive than the equipment that would be manufactured and sold without incentives and standards in place to decarbonise. However, the cost of energy-efficient products that incorporate newly developed technologies is likely to fall in the short to medium term, due to learning effects and by benefiting from economies of scale as the products begin to be manufactured more widely. In addition, the energy efficiency improvements associated with these measures means that the newer products are often cost-effective over their lifetimes.

There is often a rational case for households to take up energy efficiency measures, as the derived energy savings from the installation of these measures are often greater than the upfront installation cost. However, studies have shown that due to a number of factors, including inadequate information and the relatively high rate at which households discount the future, these measures are rarely taken up by households unless there are significant government incentives encouraging them to do so[19].

Given that energy efficiency is one of the most cost-effective ways to cut carbon emissions, the government is most likely to do this where it has ambitious carbon reduction targets to meet, which is why the effect of

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[16] Under the average cost calculation, wholesale electricity prices in the 4CB scenario are 30% higher by 2030, but as distribution costs, supplier margins and tax together account for around 50% of the domestic electricity price, the percentage increase in domestic electricity prices in the 4CB scenario is around 15%.

[17] See the sensitivity analysis presented in Section 5.5 for the impact on household income and GDP if shale gas, shale oil and/or other factors lead to a reduction in fossil fuel prices over the period to 2030.

[18] Element Energy (2013), 'Review of potential for carbon savings from residential energy efficiency ' http://www.theccc.org.uk/wp-content/uploads/2013/12/Review-of-potential-for-carbon-savings-from-residential-energy-efficiency-Final-report-A-160114.pdf

[19] Allcott and Greenstone (2012), 'Is there an Energy Efficiency Gap', The Journal of Economic Perspectives, Vol. 26, No. 1, pp. 3-28, 2012

efficiency measures is only modelled in the 4CB and 4CB+ scenarios. As outlined in Appendix A.2, the CCC anticipates a series of cost-effective measures that will lead to substantial reductions in household energy demand.

**Net impact on household fuel bills**

Table 3.1 shows that higher costs of electricity generation in the 4CB and 4CB+ scenarios would add around £127 to the average household energy bill in 2030. However, households could offset almost all of this increase in bills through the installation of cost-effective energy-efficient measures. Our analysis shows that in the 4CB scenario, the additional annualised cost of energy-efficient measures for the average household in 2030 (£155) would be more than offset by the associated annual fuel bill savings (-£260), and overall it would be cost-effective for consumers to install these measures.

However, a number of studies have considered the barriers to take-up of efficiency measures[20]. These barriers include: inadequate information, financial constraints, innovation market failures, and short time-preferences when making purchasing decisions. Therefore, despite the fact that these measures are cost-effective over their lifetime, policies that target the removal of these barriers to take-up will be required to incentivise households to install the energy efficiency improvements in the 4CB and 4CB+ scenarios.

**By 2030, the net impact for average household expenditure on gas and electricity (inclusive of the upfront cost of efficiency measures) will be a small increase of £22 and £19 in the 4CB and 4CB+ scenarios, respectively, relative to bills in the Low Ambition scenario.**

**Table 3.1 Impact on households' energy-related expenditure in 2030 (relative to the Low Ambition scenario)**

|  | Effects on energy bills due to a higher electricity price | Effects on energy bills due to efficiency improvements | Additional purchase cost of energy efficiency measures | Net impact on household energy-related expenditure |
|---|---|---|---|---|
| **4CB** | +£127 | -£260 | +£155 | **+£22** |
| **4CB+** | +£127 | -£371 | +£263 | **+£19** |

Source: MDM-E3, Cambridge Econometrics

**Modernisation of homes**

On balance, modernisation of homes through the installation of newer, more energy-efficient products could also improve health, hygiene, warmth and overall building performance[21], as well as improving the ability to cope with increased climatic extremes.

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[20] See, for example, Gillingham et. al (2009), 'Energy Efficiency Economics and Policy'. Available online: http://weathervane.rff.org/rff/Documents/RFF-DP-09-13.pdf

[21] See W. Barker (2001), 'Fuel Poverty and Ill Health'. Available online: http://www.cse.org.uk/pdf/pub11.pdf

## 3.3    Vehicle purchasing and running costs

The emission reductions in the transport sector require a substantial improvement in the efficiency of cars. It is anticipated that this will arise partly from an improvement in the efficiency of the internal combustion engine and partly from hybridisation and the gradual shift towards electric powertrains (see Appendix A). In addition, there is assumed to be a 5% reduction in car use in the 4CB and 4CB+ scenarios due to a modal shift to public transport, walking and cycling.

European legislation that limits new car carbon emissions to $130gCO_2/km$ by 2015 and $95gCO_2/km$ by 2020 is already in place and so far this has already led to benefits to consumers, with the efficiency benefits outweighing the additional technology cost[22] as well as considerable reductions in $CO_2$ emissions (see Table 3.2).

Moreover, the average cost of the car not only reflects the technology cost to improve $CO_2$ efficiency, but also to meet Euro 5 standards on carbon monoxide, nitrous oxides, and particulate matter. In 2012 nearly 90% of cars sold in the UK met this standard, compared to none in 2001 (which predates the standard). Further still, the average car sold in the UK in 2012 was heavier, longer, wider and more powerful than the average 2001 car, partly as a result of improved safety standards.

**Table 3.2 Improvements in vehicle efficiency since 2001[23]**

| Costs | 2001 car | 2012 car | Change |
|---|---|---|---|
| Average new vehicle cost | £19,438 | £21,737 | £2,295 |
| Annual fuel cost | £1,301 | £963 | -£339 |
| Annualised new vehicle cost (10% APR) | £2,736 | £3,059 | £323 |
| **Annual cost of fuel and new vehicle** | **£4,038** | **£4,022** | **-£15** |
| *Features* | | | |
| *Average new vehicle efficiency (gCO₂/km)* | *178* | *134* | *-44* |
| *Length (mm)* | *4170* | *4256* | *+86* |
| *Width (mm)* | *1704* | *1771* | *+67* |
| *Weight (kg)* | *1681* | *1858* | *+177* |
| *Power (BHP)* | *105* | *125* | *+20* |

Source: ICCT and own calculations

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[22] Cambridge Econometrics and Ricardo-AEA (2013), 'Fuelling Europe's Future'. Available online at: http://www.camecon.com/Libraries/Downloadable_Files/Fuelling_Europe_s_Future-_How_auto_innovation_leads_to_EU_jobs.sflb.ashx

[23] Adapted from ICCT (2013) 'European Vehicle Market Statistics 2013 Pocketbook'.

In the 4CB scenario, new car emissions in 2030 will fall to around 38gCO$_2$/km and average emissions for the whole vehicle stock fall to around 89gCO$_2$/km. The additional technology required to meet the emissions targets is expected to add around £321 to the annualised capital cost of owning a car in 2030[24]. However, the average fuel bill savings are expected to be around £610 per annum and, even after accounting for the additional costs required to support the infrastructure for electric vehicles, **the average car owner is expected to save £266 per year on the cost of owning and running a car in the 4CB scenario** (see Table 3.3).

The faster transition to more advanced electric vehicles in the 4CB+ scenario slightly reduces the net benefit as, in the early years, the technologies are still relatively new, and the effects of learning-by-doing on the capital cost of electric vehicles have not been fully realised.

**Table 3.3: Average annualised cost of vehicle ownesrhip in 2030 (relative to the Low Ambition scenario)[25]**

| | Effect on the average vehicle fuel bill[26] | Effect on the annualised cost of vehicles[27] | Annualised cost of EV infrastructure[28] | Net impact on car ownership cost (relative to Low Ambition) |
|---|---|---|---|---|
| **4CB** | -£610 | +£321 | +£23 | **-£266** |
| **4CB+** | -£638 | +£498 | +£44 | **-£97** |

Source: MDM-E3 and own calculations

## 3.4    Food bills

The CCC analysis suggests that there are cost-effective abatement measures in agriculture. If these options are taken up, the result could be slight reductions in agricultural prices and, although the UK imports a substantial share of its food demand, our analysis shows that **food prices are reduced by around 1% in the 4CB and 4CB+ scenarios**.

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[24] The annualised capital cost of a new vehicle is based on the assumption of a 10% interest rate and a lifetime of 13 years. The fuel cost calculation is based on the assumption that EV users pay the same price for electricity as households and do not pay any additional duties. The total cost of ownership for a new vehicle in 2024 is assumed to be representative of the average vehicle in the stock in 2030.

[25] In these results, the average car sold in 2024 is presented as typical of the average car in the 2030 vehicle stock.

[26] EV users are assumed to be charged the same price of electricity as the domestic sector.

[27] Assuming a borrowing rate of 10% APR.

[28] This refers to the annualised cost (over the vehicle lifetime) of EV charging posts installed in households. Public charging infrastructure is assumed to be financed by the additional electricity sector profits from sales to EV users. The average annualised cost of charging posts in the 4CB scenario is much lower than in 4CB+, as there are so many fewer electric vehicles (and therefore fewer charging posts) in the vehicle stock.

Our results also show that as a result of the lower food price, higher real household incomes and the reallocation of expenditure from fuel to other goods and services, households would choose to spend slightly more on food.

## 3.5    Net impact on households

Our analysis shows that, on average, households are slightly better off in the 4CB and 4CB+ scenarios and, by 2030, real household incomes are 1.1% higher in the 4CB scenario, relative to the Low Ambition scenario. There are two key elements of this result: an increase in the level of employment, and an increase in real wages. The contribution of each of these elements to average household incomes is shown in Table 3.4.

**Employment effects**
One of the drivers of the increase in real incomes is due to a net positive impact on employment. In the 4CB scenario, the increase in demand for labour leads to reductions in the level of unemployment and increases in the number of people participating in the labour market. The employment results comprise three effects:

- a direct employment effect, relating to the creation of jobs in the low-carbon sector

- an indirect effect, relating to jobs created in the low-carbon technology supply chain

- an induced effect, as higher incomes will lead to higher induced demand and, in turn, an increase in output and employment

Our analysis shows that the shift in production will create additional jobs in the manufacturing and service sectors, whilst a reduction in output in refining and gas supply would lead to lower levels of employment in these smaller sectors. Overall, there is a net increase in employment of 190,000 and 230,000 in the 4CB and 4CB+ scenarios respectively. Taken in isolation, the employment effect would lead to an increase in average annual household income of £269 in the 4CB scenario by 2030. It is important to note that this effect will not be evenly distributed across households, since the total additional income will accrue entirely to those individuals entering into employment.

**Real wage effects**
Higher levels of economic output, higher employment and productivity improvements will also lead to an increase in real wages. This will be evident in many sectors, but particularly in the high-tech manufacturing and low carbon technology sectors, which are expected to see the highest proportional increases in labour demand. Furthermore, higher company profits will lead to higher incomes for shareholders and higher returns on pension funds. However, it is important to note that the low-carbon technology investment in the 4CB and 4CB+ scenarios is financed by higher product prices. Facing these higher prices, consumers' real purchasing power is diminished and this slightly reduces the net positive impact on real incomes. The real wage effect corresponds to a net increase in average annual incomes of £269 by 2030 in the 4CB scenario.

**Net income effects**
**Overall, the macroeconomic modelling suggests that average real household incomes will be 1.1% (£565) higher by 2030 and average household spending around 1.0% (£474) higher in the 4CB scenario**

**compared to the Low Ambition scenario**. Although we have not modelled the distributional aspects of climate policy, there is likely to be a reduction in fuel poverty due to higher incomes and fuel bill savings.

**Table 3.4 Impact on real household income in 2030**

| | Low Ambition | 4CB | 4CB+ |
|---|---|---|---|
| **Average annual real household income** | **£53,188** | **+£565** | **+£717** |
| - increase in average real incomes due to higher employment | - | £269 | £317 |
| - average increase in real wages and unearned income | - | £296 | £401 |

Source: MDM-E3 and own calculations

The increase in real household incomes in the 4CB and 4CB+ scenarios leads to a net increase in real household expenditure of £474 and £604, respectively by 2030. As discussed in Section 3.2 and Section 3.3, there is also a transfer of consumer spending away from energy towards other goods and services, including vehicles and energy-efficient appliances. Table 3.5 shows the net impact on consumption in the 4CB and 4CB+ scenarios.

**Table 3.5 Impact on real annual household consumption in 2030**

| | Low Ambition | 4CB | 4CB+ |
|---|---|---|---|
| **Real consumption expenditure** | **£49,868** | **+£474** | **+£604** |
| - net expenditure on vehicles and vehicle fuel[29] | £4,027 | -£266 | -£97 |
| - net expenditure on household dual-fuel bills and energy-efficient measures | £1,840 | +£22 | +£19 |
| - net expenditure on other goods and services | £44,000 | +£718 | +£682 |

Source: MDM-E3 and own calculations

**In addition to the monetary benefits and the improved stability of energy bills, our analysis suggests that there could also be health benefits as a result of reduced exposure to particulate matter and NO$_x$ in the 4CB and**

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[29] Based on the assumption that the average household owns one vehicle.

**4CB+ scenarios. Studies have shown that improved air quality can reduce symptoms of asthma and reduce the risk of suffering from heart and lung conditions (see Section 6 for further details).**

# 4    Impact on Businesses

## 4.1    Introduction

The impacts of reducing industry GHG emissions are widespread and vary considerably between different industry sectors. The low-carbon transition will benefit high-tech manufacturing industries due to an increase in demand for energy-efficient products, whilst industry sectors that are electricity-intensive will be more affected by higher electricity prices.

This section of the report focusses on the likely impact of decarbonisation on three broad industry sectors:

- **The energy-intensive sector** - this sector includes iron and steel, paper, glass, cement, non-ferrous metals, ceramics and chemicals.

- **The services sector**- including transport, accommodation, information and communication, real estate, professional, scientific and administrative services, and private provision of health and social care.

- **The low-carbon technology sector** – including manufacturers of energy-efficient products, manufacturers of renewable and low-carbon technologies and the associated supply chains.

The relative size in terms of output and employment of these three broad industry sectors is shown in Table 4.1[30]. The service sector is by far the largest, both in terms of output and employment, whilst the energy-intensive sector is relatively small, accounting for just 2% of total UK Gross Value Added (GVA) and employment. The low-carbon technology sector is also small, but is growing rapidly, achieving 4% growth in output over 2011/12 according to BIS[31].

**Table 4.1 Sector characteristics in 2011 (in absolute terms and percentages of UK totals)**

|  | Turnover | Gross Value Added | Employment |
|---|---|---|---|
| **Energy-intensive sector** | £89bn (3%) | £23bn (2%) | 347,000 (2%) |
| **Services sector** | £1,072bn (32%) | £511bn (54%) | 12,751,000 (59%) |
| **Low-carbon sector and supply chain** | £128bn (4%) | Not available | 939,000 (4%) |

Source: ONS Annual Business Survey (2013) and BIS (2013)

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[30] The figures in this table are taken from different sources (as the low carbon sector is not defined in the Standard Industry Classification). The figures for the low-carbon sector are for the financial year 2011/12. Therefore the figures are not directly comparable, but give an indication of the size of each sector.

[31] BIS (2013) 'Low carbon environmental goods and services report for 2011/2012'. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224068/bis-13-p143-low-carbon-and-environmental-goods-and-services-report-2011-12.pdf

## 4.2    Energy-intensive industry

**Overview**    Our definition of energy-intensive industry includes manufacturers of iron and steel, non-ferrous metals, mineral products (including cement and glass), paper and chemicals. These industries have some specific characteristics that make them particularly vulnerable to changes in energy prices and energy policy:

- they use large quantities of energy (particularly gas and electricity) and energy costs can account for around 5-10% of total production costs[32]

- they are typically included within the EU ETS, and face a carbon price for GHG emissions released into the atmosphere during their production process[33]

- in many cases they operate in competitive markets and changes in the cost of inputs relative to their international competitors could harm their competitive position[34]

**Actions to reduce emissions**    In line with the CCC's analysis, the 4CB and 4CB+ scenarios include the following measures in energy-intensive industry:

- efficiency improvements to manufacturing processes

- low-carbon heat installations

- industry CCS installations (over the period 2025-2030)

In the 4CB and 4CB+ scenarios, the carbon price faced by energy-intensive industries is assumed to reach £42.1/tCO$_2$ in 2030, compared to just £6.2/tCO$_2$ in 2030 in the Low Ambition scenario. The higher carbon price in the 4CB and 4CB+ scenarios is sufficient to incentivise energy-intensive industries to take up cost-effective abatement measures. We assume that traded industry sectors continue to receive free allowances in the period up to 2030, and so, in instances when the marginal abatement cost of a particular installation is lower than the carbon price, industries could profit from investing in the measure and selling excess carbon allowances to other ETS installations in Europe at the EU ETS market price.

However, some of the abatement measures are not cost effective under the modelled carbon price. For example, in some instances, the marginal abatement cost of industrial CCS and low-carbon heat in 2030 is higher than £42.1tCO$_2$. In these cases, we assume that the measures are installed through a supplier obligation and ultimately paid for by an increase in consumer electricity bills. In the 4CB scenario, there is £19bn cumulative industry investment in efficiency improvements, CCS and low-carbon heat over the period 2014-2030. Around 8% of these measures (£1.5bn) are not

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[32] Based on estimated UK input-output coefficients

[33] Energy intensive industries are currently provided with carbon allowances for free to protect their competitive position in international markets. For this analysis, we continue to assume that energy-intensive industries are compensated for the cost of carbon in the period to 2030.

[34] It is to be noted, however, that trade intensities vary considerably between sectors, with the paper and chemicals sectors operating in more internationally competitive markets, whilst foreign competition in the non-metallic minerals sector is much lower.

cost-effective for industries to install without further incentives and this investment must therefore be paid for by electricity consumers on their bills, since there is no incentive for industry to invest directly. In reality, policy design will determine which groups pick up these additional investment costs, whether by tax payers, industry, or energy consumers. The most important factor for any macroeconomic analysis is that all the investment is fully paid for.

**Impact on energy bills**

Energy efficiency improvements in the 4CB scenario lead to a 40% reduction in industrial gas demand and a 3% reduction in electricity demand by energy-intensive industry in 2030 (relative to the Low Ambition scenario). Therefore, despite a 30% increase in industrial electricity prices in this scenario, total energy bills for energy-intensive industries are only expected to increase by around 8% in 2030. Furthermore, it is expected that learning effects will bring down the cost of low-carbon electricity considerably in the longer term, and the CCC estimate that, by 2040, industrial electricity prices in a low-carbon world would be lower compared to a scenario in which the electricity sector is heavily dependent on gas generation[35].

**Carbon leakage and competitiveness**

The higher carbon price and higher electricity prices in the period to 2030 lead to an increase in industry unit costs, of which at least some is passed on to consumers through an increase in the final price of goods[36]. The model results suggest that, by 2030, the price of products from energy-intensive industry will be, on average, 3% higher in the 4CB scenario as a result of the higher energy bills, a higher carbon price and the cost of investing in energy-efficient equipment.

Industry profitability could be eroded where cost increases cannot be passed on in full. In our analysis, we have assumed that other countries are invariant between scenarios, and do not reduce GHG emissions to the same extent as in the UK in the period to 2030. In the longer term, if countries around the world do commit to reducing GHG emissions, then industries everywhere will have to make these investments. As a result, competitiveness may not be affected directly in the long term from investing in emissions reductions. In the transition phase, however, where the EU, and within that context the UK, strongly commits to rapid GHG reduction targets there could be losses to competitiveness and profitability without compensation measures.

To avoid competitiveness losses, there are a number of policies that are currently in place to support the transition of energy-intensive industries:

1) EU ETS allowances for emissions are freely distributed to firms (more accurately, installations) considered to be at risk of carbon leakage (competitive losses) until at least 2020. This allows firms to directly offset carbon costs that cannot be passed on to consumers. Firms remain incentivised to reduce emissions as this would allow them to sell their surplus emission permits.

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[35] See: http://www.theccc.org.uk/wp-content/uploads/2013/04/Competitiveness-report.pdf

[36] Evidence suggests that industries still pass on part of the carbon cost in the final product price, despite the fact that industries are ultimately fully compensated for the carbon costs. See CE Delft (2010), 'Will the energy-intensive industry profit from EU ETS under Phase 3?'

2) Electro-intensive firms are supported by a compensation package of around £250m over the spending review period (2013-15) to offset the 'indirect' costs of the EU ETS and Carbon Price Floor. This remains subject to state aid guidelines. The package also includes an increase in the level of relief from the climate change levy on electricity from 65 to 90% for Climate Change Agreement participants.

3) Eligible firms are expected to receive exemptions from the Contracts for Difference Levy under the Levy Control Framework. This legislation is currently under consideration following a consultation in 2013.

We assume that these policies remain in place in the scenarios. Since many energy-intensive industries cannot pass cost increases on in full, these compensation measures serve to maintain profitability in the medium term and maintain investment in new production capacity.

**Growth opportunities for energy-intensive industry**

The low-carbon transition will provide opportunities for the energy-intensive sector, as low-carbon technologies in the energy sector require capital goods which require iron, steel and cement. This would lead to an increase in demand, and potential growth opportunities for the energy-intensive industry sector, particularly if the low-carbon component manufacturers are located in the UK. For example, it is possible that UK-based iron and steel companies, if compensated for any loss of competitiveness, will supply the planned Siemens wind turbine production facility in Hull (see Case Study 1 below).

Overall, our analysis suggests that, in aggregate, the energy-intensive industries[37] will see an increase in gross output of 1.9% because the investment required for a low-carbon transition increases demand for energy-intensive products (steel for wind turbines, glass for glazing, concrete for foundations, etc). Moreover, as energy-intensive sectors remain compensated by government, there are no losses in competitiveness.

## 4.3    Service sector

Although the service sector is not obliged to buy carbon allowances, reducing emissions in this sector will be important for meeting the carbon budgets. In the 4CB and 4CB+ scenarios it is assumed that there is an increase in energy efficiency measures, leading to 17.5TWh gas savings and 24TWh electricity savings by 2030. Increased uptake of heat pumps and biomass boilers in these sectors leads to a further 33TWh of gas saving and a small increase in demand for electricity and biomass energy.

However, the higher electricity prices outweigh the impact of energy efficiency savings, and energy bills faced by the service sector in the 4CB and 4CB+ scenarios are 5% higher than in the Low Ambition scenario. This increase in bills is likely to have only a small impact on businesses. Assuming that energy accounts for 3.5% of total intermediate costs in services[38], this translates to just a 0.18% increase in unit costs. **Despite this small increase in costs, the**

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[37] Our definition of the energy-intensive industry sector excludes the petroleum refining sector, which would see a reduction in gross output due to a reduction in demand for petrol and diesel.

[38] According to the latest published ONS input-output tables, energy costs account for 3.5% of total intermediate costs in the service sector.

**increase in consumer and investment demand means that gross output in services is 1.0% higher in the 4CB scenario.**

## 4.4    Low-carbon technology sector

**An increase in investment in renewables and energy-efficient technologies, coupled with an increase in household demand for energy-efficient appliances and installations, could provide substantial growth opportunities for equipment manufacturers**. The key question is how much of the value added in their supply chains can be captured within the UK.

By locating manufacturing facilities geographically close to the expected market, companies could expect to save on transportation and storage costs, and this is the primary reason why strong domestic demand for low-carbon products could attract new manufacturing activities to the UK. However, the attractiveness of locating manufacturing sites in the UK will also depend on the UK's corporate tax policy, market conditions abroad, financial conditions and potential supplier risks.  In terms of potential supplier risks, the perceived stability of the UK's climate change policies will be critically important as investors will want evidence that the demand for low-carbon goods in the UK will continue to grow well into the next decade before making significant investments in the UK (such as investing in a new offshore wind factory).

*First mover advantage* If the high domestic demand was sufficient to attract low-carbon manufacturing industries to the UK, then the UK would have the potential to benefit from first mover advantage and additional exports of equipment. This could also be the case in terms of exports of specialised construction, engineering, legal and financial services. For this to happen, there would need to be both new capacity developed in the UK and demand for low-carbon equipment from other countries (particularly in Europe, where a new climate and energy package of legislation is being debated). While the possibility of establishing first mover advantage and a new technology base in the UK favours taking early action to reduce domestic emissions, the outcome is quite uncertain and so has not been included in the macroeconomic modelling.

## Case Study: Siemens wind turbine manufacturing plant in Hull

**Siemens is a multinational electronics and engineering company which has recently developed a sub-division specializing in the design and manufacture of wind turbines. Siemens is now the largest manufacturer of wind turbines in Europe and, in 2013, Siemens wind turbines accounted for a 74%[39] share of total offshore wind capacity installed in Europe that year[40].**

**Siemens has existing turbine and blade production facilities in Denmark, China, Canada and the USA and, in March 2014, announced plans to build two wind turbine manufacturing facilities in the UK. The main manufacturing site will be located in Green Port Hull, whilst another facility located in nearby Paull will specialise in the production of rotary blades.**

**There is already over 3.5GW of offshore wind capacity in the UK and total installed capacity is expected to grow rapidly over the next decades. The decision to locate production facilities in the UK is likely to have been driven by the size and expected growth in the UK market for offshore wind[41]. The close proximity to the Humber Estuary means that it is likely that these two manufacturing facilities will supply the Dogger Bank and Hornsea offshore wind farms.**

**The two manufacturing plants will be part of a £310m investment project that will boost construction jobs in the local area and, when the manufacturing plants are in full operation, is expected to create an additional 1,000 full-time jobs[42]. The potential benefits of this project could be greater if the manufacturing sites attract industry suppliers to the local area, which could become an enterprise zone for offshore wind.**

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[39] European Wind Energy Association (2014), 'The European Offshore Wind Industry – Key Trends and Statistics 2013'. Available online:

http://www.ewea.org/fileadmin/files/library/publications/statistics/European_offshore_statistics_2013.pdf

[40] Of cumulative offshore wind capacity installed up to the end of 2013, 60% of the wind turbines were supplied by Siemens.

[41] Siemens (2013), available online: http://www.siemens.co.uk/en/wind/hull.htm

[42] Siemens (2013), available online: http://www.siemens.co.uk/en/wind/hull.htm

## Case Study: Manufacture of the Nissan Leaf in Sunderland

The UK is Europe's fourth largest producer of vehicles[43] with domestic production reaching 1.6m vehicles in 2012[44] (80% of which were exported). Within the UK, Nissan has been the largest car manufacturer for 15 years. The company manufactured more than 500,000 vehicles at its plant in Sunderland last year, employing over 6,000 people.[45] The Leaf is one of the first fully electric vehicles in Nissan's range and, in March 2013, production of the Nissan Leaf began at their plant in Sunderland. In the first twelve months of production, more than 13,000 Leafs were made at this plant alone, with capacity to manufacture up to 60,000 per year in the future.[46]

Nissan has signed an agreement on zero-emission mobility and commits to the development of a network of charging infrastructure in the North East along with continued production of EVs at their plant in Sunderland. This is expected to maintain over 2,000 jobs at Nissan and in the associated supply chain.[47] Further enlargements of the Sunderland plant could also have a considerable impact on employment. Of the 1,000 jobs due to the latest expansion, 280 were estimated to be created at their plant in Sunderland, with the rest in the supply chain[48]. The plant in Sunderland is not fully dependent on domestic demand as the majority of the cars produced at the plant are exported. However, a commitment to low-carbon transport in the UK could incentivise more EV manufacturers and a higher proportion of the associated supply chain to be located in the UK. This, in particular, is likely to create macroeconomic benefits, as the size of the supply chain for more efficient vehicles, that include a higher content of low-carbon technologies, is expected to be larger than the supply chain for conventional vehicles.

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[43] Based on 2012 data from ACEA. Available online at:

http://www.acea.be/uploads/statistic_documents/POCKET_GUIDE_13_37.pdf

[44] SMMT (2014): Motor Industry Facts, available at http://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT_Facts-Guide_May.pdf

[45] SMMT (2013). Available online at: http://www.smmt.co.uk/2013/06/a-record-year-for-nissan-sunderland-plant/

[46] Nissan (2010). Available online: http://www.nissan.co.uk/GB/en/inside-nissan/news/leaf_news/ev_news.html

[47] Prime minister's office, (2013). Available online: https://www.gov.uk/government/news/prime-minister-visits-nissan-sunderland-car-manufacturing-plant

[48] See: http://www.theguardian.com/business/2012/dec/19/nissan-create-jobs-sunderland-infiniti

# 5 Macroeconomic Impacts

There are four main drivers of the macroeconomic results in the 4CB and 4CB+ scenarios:

- lower final energy demand, a reduction in fossil fuel imports and re-allocation of expenditure to other goods and services

- an increase in low-carbon investment

- an increase in prices to finance the investment costs

- multiplier and induced effects

Some of the key drivers are discussed in the following sections.

## 5.1 Fossil fuel imports and energy security

**The UK's fossil fuel imports** The UK is already heavily reliant on imported fossil fuels, which accounted for around 63% of natural gas, 89% of crude oil and 82% of coal supplied to the UK market in 2013[49]. According to DECC (2014), total spending on imports of crude oil, natural gas and petroleum in 2013 reached £58bn.

Imported supplies of natural gas are dominated by Norwegian supply and LNG, which is predominantly sourced from Qatar. The remaining imports are supplied through pipeline connections with Belgium and the Netherlands.

Storage facilities have been developed to provide improved resilience to supply interruptions (whether they are domestic or import related). At the end of 2013, the UK had stored natural gas reserves equivalent to around 6% of total annual consumption[50].

This diversity of supply, in combination with the available storage facilities suggest that gas supplies would remain secure in the medium term. In the longer term, however, reductions in aggregate annual gas demand, brought about through efficiency improvements would further increase gas security. Moreover, by increasing the range of technologies deployed in the power sector, rather than becoming dependent on a single source, the UK economy would be less vulnerable to technology-specific supply disruptions that could increase the risk of power outages.

**In the 4CB scenario, decarbonisation across all sectors results in a 30% reduction in the demand for primary oils and petroleum products and a 55% reduction in the demand for gas in 2030 compared to the Low Ambition scenario.** This results in a £8.5 bn reduction in imports of oil and gas, relative to the Low Ambition scenario. The economic implication of this is that, instead of spending money on imported fuel, households (and industries) increase their consumption of other goods and services. It is very likely that the supply chain for these goods and services will have a larger domestic

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[49] DECC (2014), 'Digest of UK Energy Statistics'.

[50] DECC (2014), 'Digest of UK Energy Statistics'.

component than the supply chain for fossil fuels and therefore there is likely to be an increase in domestic output and GDP.

*Energy security and exposure to price volatility*

Although energy security is not formally defined in the modelling framework, reduced demand for fossil fuels could improve the UK's energy security, as long as existing storage capacity was maintained (or improved) and energy supplies remained diverse. In recent times, security of fossil fuel supply has been shown to be vulnerable to political unrest, industrial disputes and technical failures in exporting countries. However, disruption to domestic supplies could also cause energy security problems.

Historically for the UK, it has been sudden and unpredictable changes in price, rather than outright interruptions to supply, that have caused damage to the domestic economy. Whilst it is difficult to capture investor confidence and behaviour in response to reduced exposure to unforeseen energy price shocks, we have run the scenarios under higher and lower fossil fuel price assumptions to capture the macroeconomic impacts of changes in international fuel prices. The results of the sensitivity analyses show that by reducing demand for fossil fuels, exposure to price shocks is reduced. In a future world in which fossil fuel prices are closer to DECC's high fossil fuel price scenario, the relative impact on GDP in the 4CB and 4CB+ scenarios is greater.

It is worth noting that exposure to fossil fuel price shocks is not necessarily reduced if imported supplies are replaced by increases in the domestic supply of fossil fuels, for example, due to domestic shale gas extraction. In this case, domestic suppliers would be expected to charge the market (marginal) price, which, in the case of gas and oil, is determined by the price of imports. However, in this example, domestic suppliers would at least retain the value added and provide tax revenues to government that could be used to partially offset the negative social impacts of higher fossil fuel prices. The sensitivity analysis in Section 5.5 presents the macro-economic results if the market price of gas and oil fell to the levels envisaged by DECC's low fossil fuel price scenario[51], which is possibly indicative of increased extraction from unconventional oil and gas.

## 5.2  Investment and prices

The investment required to bring about a low-carbon transition is substantial. Financing such investment will require the government to put in place policies that will give adequate incentives to the private sector to make the bulk of the investments, with the policy credibility that these incentives will be sustained over the long term. **The additional investment in low-carbon measures in buildings, industry and transport (relative to the Low Ambition scenario) exceeds £10bn in the 4CB scenario in 2030. Furthermore, there is an additional £12bn investment in the power sector in the 4CB scenario in 2030 relative to in the Low Ambition scenario.** In the 4CB scenario, additional cumulative low-carbon investment in buildings, industry and transport over the period 2014-30 is around £100bn, and there is an additional £181bn cumulative investment in the power sector. In total, the required

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[51] DECC (2013), 'Updated Energy and Emissions Projections'.

additional low-carbon investment is equivalent to around 0.75% of total GDP over the period.

The increase in investment benefits both the producers of equipment and their associated supply chains. As many of these sectors are relatively labour-intensive, the investment has the potential to increase employment and generate multiplier effects. The result is higher levels of output and GDP.

In the power sector, the anticipated domestic content of the capital investment for each technology varies substantially (see Appendix A; Table A.2). However, the full cost of each technology is not represented by capital costs alone, but also includes fuel costs, operating costs, and carbon costs.

For motor vehicles, the additional expenditure on low-carbon vehicles flows to the manufacturers and upstream to their suppliers. We assume that the UK motor vehicles sector receives a representative portion of this value chain based on the ratio of domestic supply to import supply. In 2012, imports of motor vehicles stood at around £50bn while domestic production was £48bn.

Investment in buildings and industry flows to the construction and mechanical engineering sectors. There is insufficient data to draw detailed assumptions by technology and so we assume that the value flows to these sectors on the basis of projected domestic supply and import shares. In 2030, imports account for around 50% of total supply of mechanical and electric engineering products. In contrast, the construction sector (representing the sector that installs insulation, for example) is almost entirely dominated by domestic suppliers.

**Financing the investment**

In almost all cases, we assume that the investment is financed by an increase in product prices. Power sector investment is paid for by higher electricity prices, industry investment is paid for by higher product prices and households are assumed to pay a higher price for more energy-efficient appliances (at the expense of alternative expenditure). Consistent with the CCC's analysis, the rate at which energy-efficient appliances are taken-up in households is slower than the rate at which they retire from the stock. In the 4CB scenario we do not assume that households replace appliances more frequently than in the Low Ambition scenario, but instead assume that when households do decide to replace existing appliances, they either choose to buy more efficient appliances (due to expected energy savings), or legislation and product standards would be put in place to ensure that the more efficient products are bought.

In addition to energy efficiency investment, this analysis, consistent with the CCC's, suggests that the power sector can be substantially decarbonised. Before accounting for efficiency savings, measures to decarbonise the power sector would lead to an annual average electricity bill increase of £127, relative to the Low Ambition scenario. Taken in isolation, these price increases would slightly reduce real incomes and would lead to an increase in industry costs and, as a result, a small loss of international cost competitiveness. However, the impact on energy bills is almost entirely offset (see Section 3) because of efficiency savings in households, industries and transport. Furthermore, the economy grows because of changes in the economic characteristics of the energy system from fuel costs (with slightly higher import

content) towards capital costs (with slightly higher domestic content). Some energy-intensive industries could also gain from the additional demand for their products stimulated by the investment in low-carbon capital goods.

Whilst industries will pass on a proportion of the investment costs to consumers (in the form of higher prices), part of the investment is also assumed to be funded by the future energy bill savings and trading of unused carbon allowances, which will more than offset the upfront cost of the measures over their lifetime. For these investments, it is important to note that the modelling approach does not assume optimal and efficient use of resources in the Low Ambition scenario and therefore low-carbon investment does not 'crowd-out' investment that would otherwise take place in the Low Ambition scenario. This assumption is described in more detail in Section 7.

We have used a lower carbon price assumption than that used in the CCC's analysis of the fourth carbon budget. In some instances, the measures installed in the traded industry sector are not cost-effective i.e. the marginal abatement cost of some measures are higher than the carbon price. In these instances, it would not be cost-effective for industries to invest in these measures. We assume that the industry investment still takes place, but is financed by supplier obligations that result in higher consumer electricity bills.

## 5.3 Multiplier and induced effects

As well as modelling the direct impact of low-carbon investment, MDM-E3 also takes into account indirect supply chain effects and induced effects, due to higher employment levels.

An increase in low-carbon investment demand leads to an expansion of the supply chain for these measures and technologies and, consequently, a further increase in economic output, referred to as the '(Type I) multiplier effect'. For example, to meet higher demand levels, energy-efficient product manufacturers will require more component parts and component manufactures will require more raw materials. The size of the multiplier, which is an effective outcome of the model, depends upon the size of the supply chain and the proportion of the supply chain that is located domestically.

Increases in production are likely to in turn lead to an increase in the demand for labour. The unemployment rate will fall as vacancies are filled, and more people will be attracted into the labour market. Wages may also rise. The increase in employment and wages will lead to a rise in real incomes and consumption (as well as a slight increase in inflation); this will again drive further increases in output and employment. This is the 'induced effect' and, combined with the indirect effects described above, gives the Type II multiplier effect.

## 5.4 GDP and employment results

**The results of our analysis show that, in net terms, GDP is 1.1% higher in the 4CB scenario and 1.2% higher in the 4CB+ scenario by 2030 (relative to the Low Ambition scenario).** As discussed above, the main drivers of this

result are: an increase in investment demand[52]; a reallocation of expenditure from imported fossil fuels to goods with a higher domestic content; and multiplier and induced effects. These effects more than offset the small negative impact of higher prices and losses to cost competitiveness.

It is important to note that the labour intensity of the sectors that see an increase in output (low-carbon manufacturing sectors and their supply chain) is considerably higher than the labour intensity of the petroleum refining and gas supply sectors. Therefore, the increase in employment is not only driven by a net increase in output demand, but also by the transition of production to more labour-intensive sectors.

The investment stimulus and the multiplier and induced effects also leads to a substantial increase in employment in the two abatement scenarios. **Employment increases in net terms by 190,000 jobs and 230,000 jobs respectively in the 4CB and 4CB+ scenarios, by 2030.** As discussed in Section 4, if the UK government's commitment to a low-carbon future attracted more low-carbon manufacturing industries to the UK than is currently known and anticipated, the impact on GDP and employment could be greater. Notably, this report does not take into account the additional growth in GDP and employment that could be created through export opportunities of low-carbon goods and services that would be likely to arise should the UK commit itself to a rapid move towards a low-carbon economy. However, any such growth would be limited by the spare capacity in the economy, as is the impact on growth from the low-carbon investment modelled in these scenarios.

## 5.5 Sensitivity analysis

Sensitivity analysis was run to test the impact of meeting the fourth carbon budget under both lower and higher fossil fuel price assumptions.[53] The low fossil fuel price assumption is particularly important to test the robustness of our results to uncertain factors, such as the possibility that global investment in shale gas and oil could reduce future gas and oil prices. In our low price sensitivity, we assume that, by 2030, gas and oil prices are around 40% lower than in the DECC 'Central' projections. **Under these low fossil fuel price assumptions, we find that the 4CB scenario would still lead to an increase in GDP (of 0.8% by 2030 relative to the Low Ambition scenario) and the creation of an additional 180,000 jobs.**

**Under DECC's high fossil fuel price assumptions, the benefits of reduced fuel consumption are greater, and the impact of decarbonisation (4CB) on GDP is estimated at 1.3% by 2030, with the creation of an additional 210,000 jobs.**

## 5.6 Tax revenues

The 4CB and 4CB+ scenarios are expected to have a net positive impact on the UK government's total tax take. Assuming auctioning of EU ETS allowances in the power sector only, the higher price of £42.1/tCO$_2$, leads to

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[52] Annual investment in 2030 is around £22bn higher in the 4CB scenario

[53] For this sensitivity the fossil fuel price assumptions are based on DECC's 'Low Price' and 'High Price' scenarios.

an increase in annual revenue of around £5.2bn in the 4CB and 4CB+ scenarios in 2030, relative to the Low Ambition scenario. In addition, the Low Ambition scenario, which only includes low-carbon policies that were instated pre-2009, does not include a carbon price floor. Therefore, despite the relatively lower carbon intensity of the power sector in the 4CB and 4CB+ scenarios, there are additional revenues from the carbon price floor that lead to an estimated £439m increase in annual government revenue by 2030.

There is a reduction in fuel duty revenue, due to reduced expenditure on petrol and diesel as EVs begin to penetrate the market in the 4CB and 4CB+ scenarios. However, there is expected to be an increase in income tax revenue, national insurance revenue and VAT revenue, due to higher employment and higher incomes. We have not assessed the impact on corporation tax revenues, but net profits are higher in the 4CB and 4CB+ scenarios and therefore, it is highly likely that corporation tax revenue would also be higher in the 4CB and 4CB+ scenarios, despite reductions in royalty payments from the oil and gas sector. The net impact on government tax revenues (excl. corporation tax) in the 4CB and 4CB+ scenarios is shown in Table 5.1.

**Table 5.1 Net impact on tax revenue in 2030 (relative to the Low Ambition scenario)**

|  | 4CB | 4CB+ |
|---|---|---|
| **Auctioned EU ETS revenues**[54] | +£5,029 m | +£5,029 m |
| **Carbon price support revenues** | +£439 m | +£439 m |
| **Fuel duty revenue** | -£6,790 m | -£7,297 m |
| **Income tax revenue**[55] | +£3,279 m | +£4,191 m |
| **National insurance revenue** | +£1,708 m | +£2,022 m |
| **VAT revenue** | +£2,068 m | +£3,013 m |
| **Net impact on tax revenue**[56] | +£5,733 m | +£7,399 m |

Source: MDM-E3, Cambridge Econometrics

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[54] It is assumed that the same number of carbon allowances are auctioned by the government in the Low Ambition, 4CB and 4CB+ scenarios. In the 4CB and 4CB+ scenario, power sector emissions are substantially lower, and it is assumed that the remaining allowances are auctioned to other EU countries at a price of £42/tCO$_2$ in 2030.

[55] The income tax revenue estimates are based on average annual incomes and average rates of income tax. For simplicity, we do not model employment or income tax revenues by income decile.

[56] The impact on corporation tax revenue is not modelled but is expected to be higher in the 4CB and 4CB+ scenarios due to higher industry profits in these scenarios.

# 6    Impact on the Environment

## 6.1    Greenhouse gas emissions

The primary purpose of the 2008 Climate Change Act and the resulting carbon budgets was to reduce domestic emissions to a sustainable level in the long term. Figure 6.1 shows total greenhouse gas emissions in the Low Ambition, 4CB and 4CB+ scenarios. Whilst all four carbon budgets are comfortably met in the 4CB and 4CB+ scenarios, emissions in the Low Ambition scenario only fall slightly relative to current levels, and the second, third and fourth carbon budgets are not met.

**Figure 6.1 Greenhouse gas emissions in the Low Ambition, 4CB and 4CB+ scenarios**
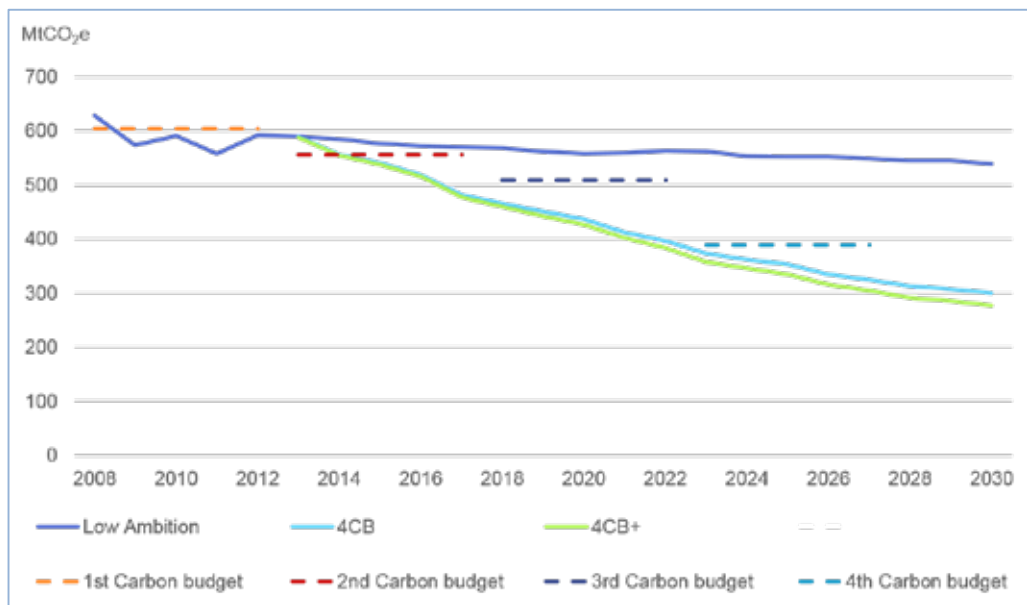


Source: CCC (2013), 'Fourth Carbon Budget Review' and own calculations

In 2030, there is a 239 MtCO$_2$eq and 255 MtCO$_2$eq reduction in GHG emissions in the 4CB and 4CB+ scenarios respectively, when compared to the Low Ambition scenario. Over the period 2014-30, cumulative GHG emissions released into the atmosphere are 2,580 MtCO$_2$eq and 2,795 MtCO$_2$eq lower in 4CB and 4CB+ respectively, compared to in the Low Ambition scenario. Around 40% of this reduction is achieved through decarbonisation of the power sector. The reduction in 2030 emissions by sector is shown in Table 6.1.

**Table 6.1 GHG emissions by sector in 2030**

| | Emissions in Low Ambition scenario (MtCO$_2$eq) | Abatement in 4CB scenario (MtCO$_2$eq) | Abatement in 4CB+ scenario (MtCO$_2$eq) |
|---|---|---|---|
| **Power sector** | 131 | -111 | -111 |
| **Buildings (residential and non-residential)** | 107 | -40 | -52 |
| **Industry** | 122 | -30 | -30 |
| **Transport** | 128 | -47 | -52 |
| **Agriculture and land use change** | 51 | -10 | -10 |
| **Total** | 539 | -239 | -255 |

Source: CCC (2013), 'Fourth Carbon Budget Review' and own calculations

## 6.2    Air quality

Atmospheric particulate matter refers to solid or liquid particles that are suspended in the air. They are categorised by size into PM-10s (particles with a diameter less than 10 micrometers) and fine particulates (PM-2.5, particles with a diameter less than 2.5 micrometers). Most atmospheric particulates originate from anthropogenic sources, particularly from industrial combustion processes and the road transport sector (e.g. from vehicle exhaust fumes, tyre wear and road abrasion)[57].

There is a growing body of evidence to suggest that prolonged exposure to particulate matter can have adverse impacts on human health, in some cases causing respiratory and cardiovascular diseases and aggravating symptoms of asthma[58]. According to a recent report published by Public Health England[59], prolonged exposure to particulates is expected to be responsible for around 2.5% of deaths in rural areas in the UK and over 8% of deaths in some London boroughs (based on 2010 data)[60].

As well as reducing GHG emissions, the 4CB and 4CB+ scenarios will lead to a reduction in atmospheric particulates. In the 4CB and 4CB+ scenarios emissions of PM-10 from road transport exhaust fumes are reduced by 38% and 40% respectively by 2030[61], relative to the Low Ambition scenario.

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[57] DEFRA (2012), 'Fine Particulate Matter (PM-2.5) in the United Kingdom' Available online: http://uk-air.defra.gov.uk/assets/documents/reports/cat11/1212141150_AQEG_Fine_Particulate_Matter_in_the_UK.pdf

[58] DEFRA (2012), 'Fine Particulate Matter (PM-2.5) in the United Kingdom'

[59] Public Health England (2014), 'Estimating Local Mortality Burdens associated with Particulate Air Pollution.' Available online: http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1317141074607

[60] Although it should be noted that in most cases particulates are regarded as a contributory factor and not the cause of death.

[61] Source: MDM-E3 scenario results

**Although we have not attempted to quantify the effects in the modelling, improved air quality and reduced particulate matter in the 4CB and 4CB+ scenarios would be very likely to provide co-benefits including a more productive workforce and reduced healthcare expenditure.**

A recent study by Synapse Energy[62] reviews existing literature on the healthcare costs associated with pollutants in the UK. Based on the literature they sourced, Synapse Energy calculate that the healthcare cost associated with exposure to PM-10s ranges from £20,654-£61,993 per tonne of PM-10s. Our analysis shows that the PM-10s from reduced fuel consumption in the road transport sector alone would be 4,650 tonnes lower in the 4CB scenario and 4,930 tonnes lower in the 4CB+ scenario, compared to the Low Ambition scenario. Using the cost figures quoted in the Synapse Energy report, this translates to **a gross saving on healthcare expenditure of £96m- £288m in the 4CB scenario and savings of £102m-£306m in the 4CB+ scenario, purely as a result of reduced PM-10s from energy consumption in the road transport sector in 2030. If we were to include the health benefits of reduced exposure to NOx in the 4CB and 4CB+ scenarios, the healthcare savings would be even greater over the period.**

## 6.3 Noise pollution from road transport

The impact of low-carbon vehicles on noise pollution is inherently difficult to quantify as it is dependent on a multitude of factors including engine-type, vehicle speed and tyre quality. CE Delft have estimated the impact on noise pollution associated with a higher share of electric vehicles in the stock[63]. Their 'EV breakthrough' scenario is comparable to our 4CB+ scenario, as it includes similar shares of each powertrain type. In this scenario, CE Delft estimate that noise pollution from road transport would be 3.2% lower by 2030 as a result of the transition to a higher share of quieter electric engines, and therefore we could expect to observe similar noise improvements in our 4CB+ scenario. However, since the publication of the CE Delft report, EU legislation has come in to place to increase the sound of EVs and hybrids for safety reasons, and therefore, the noise improvements may be lower than CE Delft's estimate.

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[62] Synapse Energy (2014), '(Mis)understanding climate policy'. Available online: http://www.synapse-energy.com/Downloads/SynapseReport.2014-04.0.Misunderstanding-Policy.14-011.pdf

[63] CE Delft (2011), 'Impacts of Electric Vehicles – Deliverable 5'. Available online: http://www.cedelft.eu/publicatie/impact_of_electric_vehicles/1153

# 7    Conclusions

This study provides a rigorous model-based assessment of the macroeconomic costs and benefits that could occur as a result of the UK putting in place the measures and changes required to meet the emission reductions proposed by the CCC in the first four carbon budgets. The analysis was undertaken using the well-established MDM-E3 macro-econometric model of the UK economy, energy system and environment.

We follow a scenario-based approach and model three scenarios:

(1)  A scenario in which climate policy returns to the policies before the adoption of the Low Carbon Transition Plan in 2009. As a result, the second, third and fourth carbon budgets are not met (Low Ambition);

(2)  A scenario in which all four carbon budgets are met (4CB);

(3)  A scenario in which all four carbon budgets are met and, in addition, a higher level of greenhouse gas (GHG) emission abatement is achieved in the transport and building sectors (4CB+).

Drawing on the CCC's independent technical analysis, the evidence in this report suggests that meeting, or exceeding, the fourth carbon budget will result in net economic benefits for the UK, as well as the stipulated reduction in greenhouse gas emissions.

If the four carbon budgets are met as in the CCC's analysis, our results show that:

- **Households will be better off financially (Section 3):** Our analysis shows that, on average, each household is expected to be £565 better off each year by 2030, due to higher real wages and employment resulting from increases in investment demand and multiplier effects.

- **Households' spending patterns will change (Section 3):** Higher average incomes will result in an overall increase in real household expenditure. Moreover, there will also be a transfer of spending: households will spend less on oil and gas and more on low-carbon technologies. In order to finance the required level of investment households (and industries) will face higher product prices.

- **There will be positive impacts on UK business (Section 4):** British-based businesses would benefit directly from increases in low-carbon investment and induced demand. The development, manufacture and installation of low-carbon technologies in the power sector; the manufacture of low-carbon vehicles and components; and the installation of energy efficiency measures in the home will lead to increases in production in the low-carbon sector and higher up the supply chain. This will lead to increases in employment and income that will lead to further growth in the economy (the multiplier effect).

- **There will be higher net levels of employment and GDP (Section 5):** By meeting the carbon budgets, our analysis suggests that, by 2030, GDP will be 1.1% higher, and an additional 190,000 net jobs would be created.

- **Energy security in the UK will be improved (Section 5):** By reducing demand for fossil fuels, the UK's exposure to the impact of price spikes is reduced, which would mean more stable energy bills for consumers and businesses.

- **Government revenues will be improved (Section 5):** Taking into account the net impact on revenue from auctioned carbon permits, the carbon price floor, fuel duty, income tax, national insurance and VAT, we estimate a net increase in annual government revenue of £5.7bn by 2030.

- **Significant reductions in carbon emissions (Section 6):** Meeting the first four carbon budgets would entail a reduction in cumulative GHG emissions of 2,580 $MtCO_2$eq over the period 2014-2030.

- **Air quality improvements (Section 6):** Our analysis shows that gross reductions in PM-10s from reduced diesel consumption in the road transport sector would create health benefits and reduce NHS costs

The modelling encompasses the full economic costs and benefits of a transition, but does not assess specific policies directly. There are two implications of this; first, that our analysis does not fully consider the distributional impacts of specific measures on different types of household; and second, that if policy fails to incentivise the low-carbon transition in a cost-effective manner, not only might the carbon budgets be missed but there could be negative economic consequences. The role and design of policy is therefore imperative in meeting the budgets.

Overall, the modelling evidence suggests that meeting, or exceeding, the fourth carbon budget will not only lead to net macroeconomic benefits but will also benefit households directly and bring about wider (non-monetary) co-benefits, such as reduced air pollution.

# 8    Limitations to the Analysis

## 8.1    Overview

As with any economic modelling exercise, it is important to be aware of the main assumptions and limitations when interpreting the results. This report is no different and in the following sections we set out the main assumptions relating to the MDM-E3 model and the main assumptions relating to these particular scenarios.

## 8.2    Assumptions relating to the model

All models are, by definition, simplifications of reality and therefore incorporate a set of assumptions to make them manageable in scale. When modelling a system as complex as the UK economy, the scope of these assumptions is necessarily considerable.

The form that these assumptions take differs from model to model and for the main part reflects the macroeconomic theories that the model relies on. There are several prominent schools of thought about how a modern economy operates and the various modelling tools that exist reflect these differing approaches.

As noted in Section 2, the MDM-E3 model differs from traditional CGE macroeconomic models in that it does not make assumptions about efficient optimising behaviour. This approach allows for the existence of inefficiencies in production (e.g. as apparently exist at present in the agricultural sector, see Appendix A.5) and consumption patterns, which provide the opportunity for 'win-win' policies that boost both environmental and economic performance. These features contrast starkly with CGE models that impose conditions of equilibrium and long-term full employment of resources. In our view, these model features make simulation models more suitable for this type of analysis than CGE models.

The MDM-E3 model and some of the more technical modelling assumptions are described in more detail in the appendices.

## 8.3    Assumptions relating to this analysis

Forward-looking analysis is highly uncertain. The analysis in this report does not attempt to forecast the future, but instead compares three possible scenarios for the UK energy system in the period up to 2030. We assess the macroeconomic impact of the scenarios using the MDM-E3 modelling framework.

The analysis is therefore contingent on the assumptions that define the scenarios. In general these are consistent with the CCC's analysis but it was necessary to make some additional assumptions relating to the economy. Some of the main assumptions are outlined below:

- Fossil fuel prices: DECC's central fossil fuel prices were adopted for this analysis. As one would expect, lower fossil fuel prices reduce the economic rationale for a decarbonised economy (but, based on the

sensitivities we tested, would still result in net economic benefits), while higher fossil fuel prices would increase the economic rationale for decarbonisation. In both cases, however, a decarbonised economy is less exposed to the negative and positive impacts of both higher and lower fossil fuel prices.

- Action in the rest of the world: It is assumed that GHG emission reductions in the rest of the world are invariant between scenarios. Although we have assumed a higher ETS price in the 4CB and 4CB+ scenarios, we assume there are no cost increases for overseas producers in these scenarios. This assumption is very conservative, especially given that the EU is currently debating a new set of climate change and energy legislation for 2030 and world leaders are meeting with the objective of agreeing a global deal in 2015 to curb emissions of greenhouse gases[64].

- Technology costs: The progression of technology costs will depend on economies of scale, learning and the cost of borrowing, which is highly dependent on an investor's perception of political risk. Technology cost data are sourced primarily from the CCC's analysis and supporting literature. Technology costs have steadily and incrementally fallen for onshore wind and solar PV over the past decade. CCGT capital costs, which are a small proportion of the overall CCGT generation cost, have remained low. Substantial cost reductions in offshore wind and CCS are anticipated but have not yet been realised. The costs in the modelling exercise reflect those put forward by the CCC and are reported in detail in Appendix A. Equally, costs of other unproven technologies such as vehicles and heat pumps are based on expert analysis by the CCC and/or the wider expert literature. These costs are also stated clearly in Appendix A.

- Export market potential: Some of the technologies considered are not particularly well-developed anywhere in the world, including offshore wind and electric vehicles. This opens up the potential for businesses operating in the UK (several of which have been mentioned previously in this report) to expand UK production capabilities and target future export markets. However, the potential scale of export markets and UK-based firms' ability to capture that market is uncertain and has not, therefore, been included in the economic analysis.

- We have not taken into account in the modelling any health co-benefits in the 4CB and 4CB+ scenarios, that could improve the productive capacity of the workforce. As described in Section 6, the modelling results suggest lower emissions of particulates that would be expected to lead to positive local health benefits. Whilst we have used published literature to estimate the impact of air quality improvements on NHS costs, the co-benefits of a healthier workforce have not formally been included in the modelling.

- The damage costs associated with climate change are not assessed in this analysis. Costs to 2030 are largely 'locked in', the costs will accrue as a result of past emissions, and carbon mitigation measures to 2030 will

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[64] http://ec.europa.eu/clima/policies/international/negotiations/future/index_en.htm

have negligible impact. However, it should be noted that the long-term climate damage costs associated with a low ambition scenario (if adopted globally) are estimated to be significant and far-reaching. By 2030, if no action was taken to reduce GHG emissions globally, the government would likely need to invest more in adaptation, because projected impacts at that point would be significantly more serious

## 8.4    Other limitations of the analysis

Two important areas are left open for further analysis:

- Social impacts: The implications of the scenarios on income distribution, and social impacts more generally, have not been considered in this report. It is likely that measures to reduce food and fuel bills would benefit some of the most vulnerable groups in society but this is quite dependent on how the energy efficiency investment is targeted. More efficient vehicles are likely to benefit mainly higher-income groups. However, there are several other socially relevant uncertain factors, such as the types of jobs created and how labour market responses might affect lower-paid workers. This aspect of the scenarios therefore needs to be assessed in further research.

- Path dependency and long-term outcomes: Although the analysis focuses on the period to 2030, the scenarios have implications in the longer term (and the legally binding commitment to reduce GHG emissions by at least 80% by 2050) because of the long lifetimes of the plants involved. For example, the Low Ambition scenario would lock in a large amount of CCGT capacity that would need to be retired early for the legally binding target to be met, increasing overall system costs.

The modelling analysis to 2030 cannot consider, by definition, the impacts post 2030 of delayed action rather than following the CCC's proposed pathway to the legally-binding 2050 target. However, a few qualitative insights can be drawn out:

- The use and efficiency of an economy's capital stock (its power stations, factories, vehicles and homes) defines an economy's emissions. Over time the capital stock is renewed and without additional technological investment, this locks in the emissions of an economy, since capital investments can last far into the future. By not investing in capital goods that reduce carbon emissions, the UK economy could become locked into either a higher emissions pathway, or one that requires capital to be replaced before the end of its cost-effective lifetime. Alternatively, breakthrough technologies to retrofit carbon capture and storage could be developed and deployed.

- By not providing a stable clear policy environment for decarbonisation, growth in low-carbon industry is unlikely to be fostered within the UK thereby limiting the economic benefits to the UK that could arise from a wider transition in major economies around the world.

- The transition to reduce emissions by at least 80% by 2050 is challenging; by not taking sufficient action today, future generations will face even greater costs and challenges.

- The pathway (in itself) matters; targets are expressed in annual emissions (a flow) but the climate is effected by the stock of emissions in the atmosphere and so in terms of the impact on the climate, reducing annual emissions by 2030 has a greater impact on the climate than meeting the same annual reduction by 2040 since the stock of emissions accumulating over the period is reduced.

# Appendices

# Appendix A   Model inputs and assumptions

## A.1   The power sector

**Generation and capacity**

The power sector mix in the 4CB and 4CB+ scenarios is broadly consistent with the 'Ambitious Renewables' scenario from the CCC's analysis on Electricity Market Reform[65]. Total generation in the 4CB and 4CB+ scenarios, however, has been adjusted downwards slightly compared to the CCC's 'Ambitious Renewables' scenario due to net electricity savings as a result of energy efficiency measures.

By 2030, the 4CB scenario includes 34GW of offshore wind, 27GW of onshore wind and 18GW of solar PV capacity. This scenario also includes 12GW of interconnection capacity, 14GW of nuclear, 20GW of gas CCS and 21GW of gas CCGT back-up capacity, which is required to deal with the variability of solar and wind power.

In these two abatement scenarios (4CB and 4CB+) over 56% of the electricity generated in 2030 is from renewable sources[66] and, in the same year, the carbon intensity of electricity reaches 50gCO$_2$/kwh.

In contrast, the bulk of electricity supplied in the Low Ambition scenario is generated by unabated gas. Coal generation is gradually phased out over the projection period but at a slower rate than in the 4CB and 4CB+ scenarios. There is also a gradual reduction in electricity generated from nuclear sources and growth in renewable technologies is limited. This is consistent with the DECC Baseline Policies scenario[67]. Generation by technology in the Low Ambition and 4CB scenarios is shown in Figure A.1 and Figure A.2 respectively. Power sector capacity in the Low Ambition and 4CB scenarios is shown in Figure A.3 and Figure A.4.

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[65] Committee on Climate Change (2013), 'Next steps on Electricity Market Reform – securing the benefits of low-carbon investment'. Available online:

http://www.theccc.org.uk/wp-content/uploads/2013/05/1720_EMR_report_web.pdf

[66] Total electricity generated in the 4CB+ scenario is marginally higher than in the 4CB scenario, as higher demand for electricity in the 4CB+ scenario (due to increased deployment of electric vehicles) is not quite offset by the reduction in demand for electricity in this scenario (due to household efficiency improvements). However, despite slightly higher total generation and capacity in the 4CB+ scenario, we assume that the share of each technology in the generating mix is the same as in that 4CB.

[67] DECC (2013), 'Updated Energy and Emissions projections'. Available online:
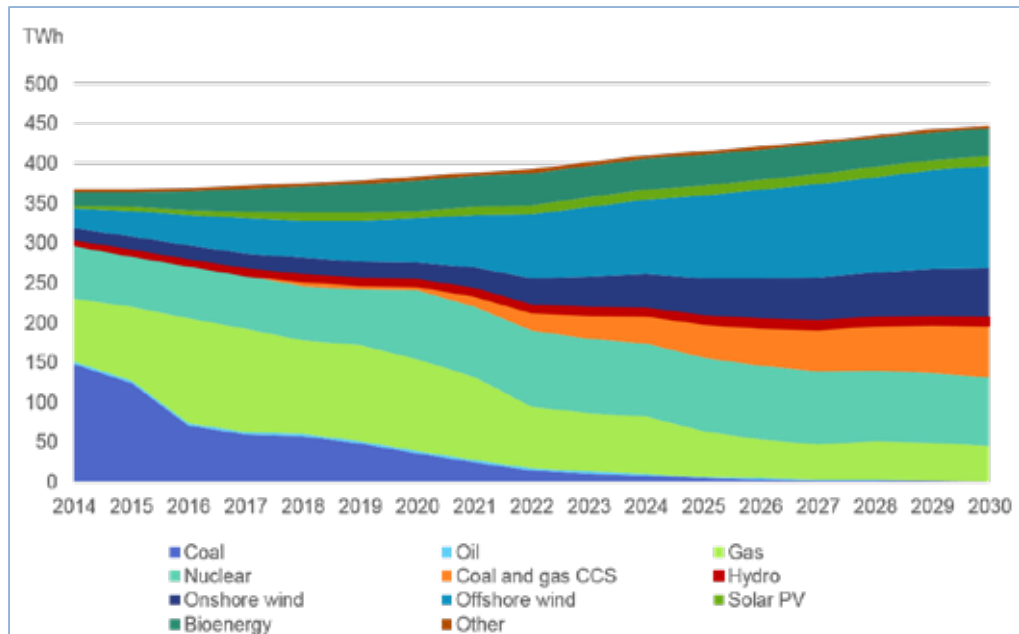
https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2013

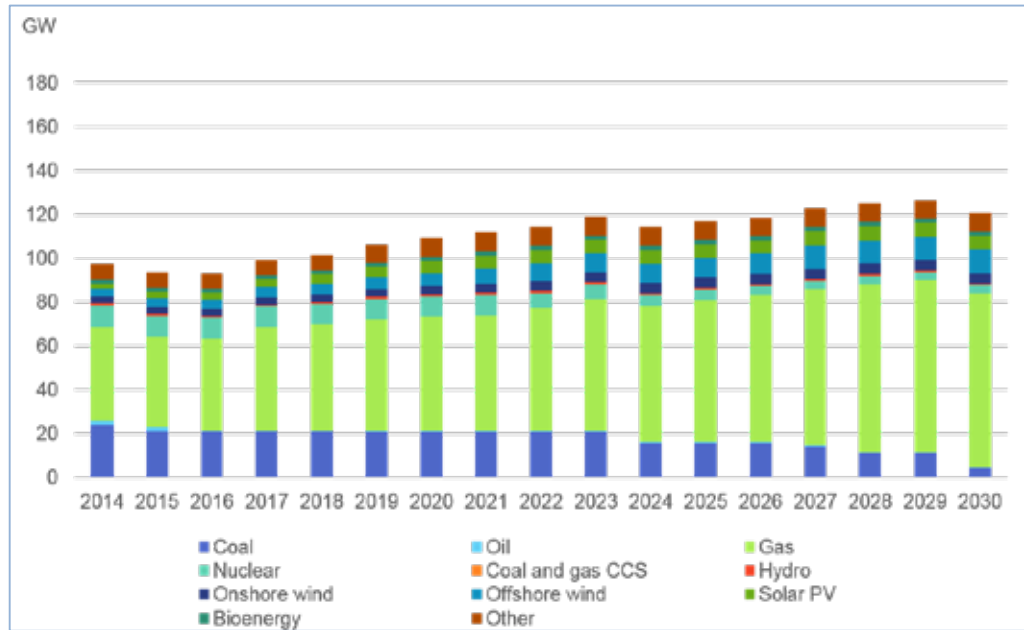**Figure A.1 Electricity generation in the Low Ambition scenario**
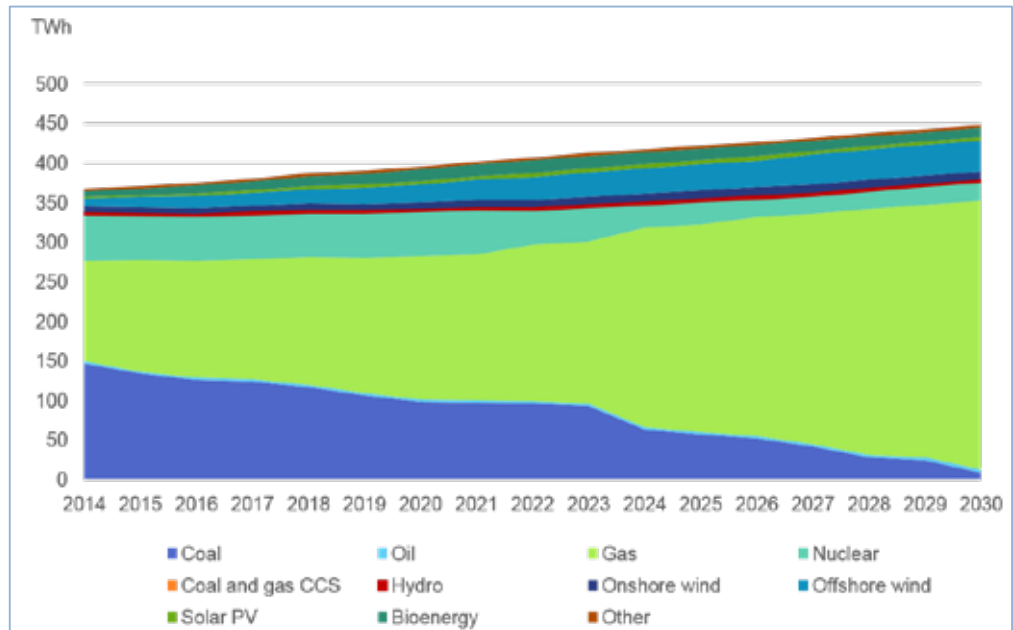


Source: Baseline Policies scenario, DECC (2013), 'Updated Energy and Emissions Projections'

**Figure A.2 Electricity generation in the 4CB scenario**
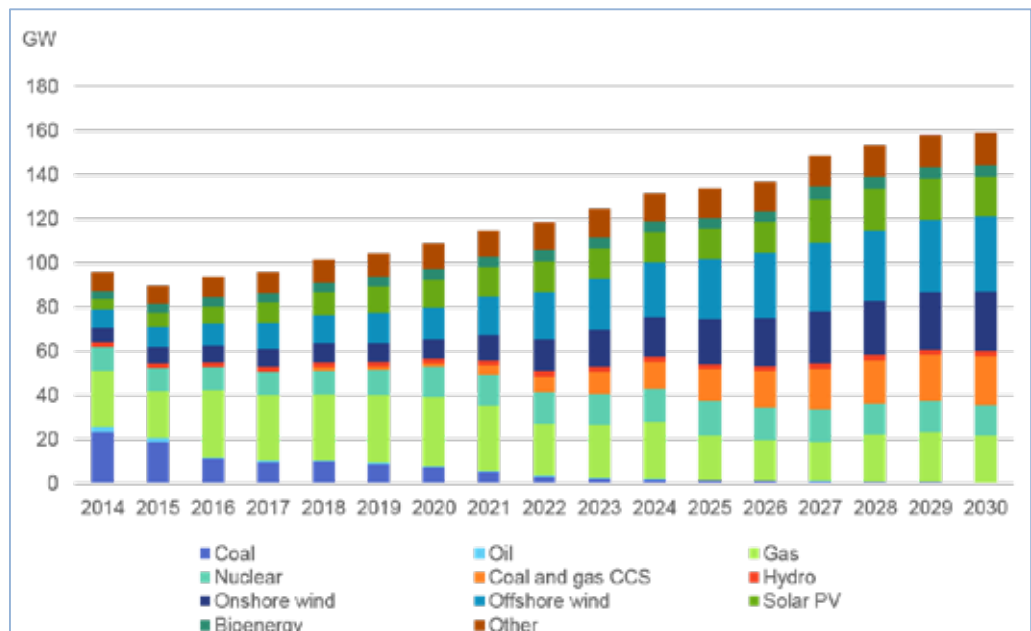


Source: Based on Ambitious Renewables scenario from CCC (2013), 'Next steps on Electricity Market Reform' and own calculations

**Figure A.3 Power sector capacity in the Low Ambition scenario**



Source: Baseline Policies scenario, DECC (2013), 'Updated Energy and Emissions Projections'

**Figure A.4 Power sector capacity in the 4CB scenario**



Source: Based on Ambitious Renewables scenario from CCC (2013), 'Next steps on Electricity Market Reform' and own calculations

**Power sector costs**

Power sector capital costs and operating costs for each technology are taken from Mott MacDonald[68][69]. Where available, these assumptions have been updated with more recent cost estimates from Parsons Brinkerhoff[70] and Pöyry[71]. The capital and operating cost assumptions are summarised in Table A.1.

**Table A.1 Power sector technology cost assumptions in 2030**

| Technology | Total capital cost excl. borrowing (£/KW) | Fixed operating cost (£/KW/year) | Fuel cost (£/MWh electricity) | Borrowing rate (%) |
|---|---|---|---|---|
| **Coal** | 1,900 | 59 | 27 | 7.0% |
| **Gas CCGT** | 638 | 24 | 49 | 7.0% |
| **Coal CCS** | 2,385 | 69 | 31 | 10.0% |
| **Gas CCS** | 1,235 | 29 | 57 | 10.0% |
| **Nuclear** | 4,100 | 82 | 5 | 8.4% |
| **Onshore wind** | 1,418 | 44 | - | 8.5% |
| **Offshore wind** | 2,282 | 135 | - | 9.1% |
| **Solar PV** | 630 | 11 | - | 7.5% |
| **Hydro-electric** | 2,105 | 47 | - | 7.2% |
| **Biomass** | 2,393 | 142 | 37 | 10.5% |

Source: Mott MacDonald (2010, 2011), Parsons Brinkerhoff (2013), Pöyry (2013)

Although the technology cost projections include a learning effect, we have not modelled this endogenously (i.e. we do not assume that the costs of renewable technologies are lower in the 4CB scenario where there is greater uptake). This is intended to be a conservative assumption, as it is likely that the learning rate associated with the more recently developed renewable technologies will be higher in the 4CB and 4CB+ scenarios.

For most renewable technologies an 8-10% financing rate is assumed in the calculation of generation costs in 2030[72]. This is marginally higher than the borrowing rate assumptions for coal and gas CCGT. However, as renewable technologies develop it is likely that the perceived risk of investing in these technologies will fall, leading to reductions in the cost of borrowing and therefore a reduction in the cost of renewable generation[73].

Transmission costs are taken from the Element Energy (2014)[74] 'Core Decarbonisation' scenario which includes a similar amount of offshore and onshore wind capacity as in 4CB. Element Energy calculate the additional

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[68] Mott MacDonald (2011) 'Costs of Low Carbon Generation Technologies'

[69] Mott MacDonald (2010) 'UK Electricity Generation Costs Update'

[70] Parsons Brinkerhoff (2013) 'Electricity Generation Costs Model – 2013 Update'

[71] Pöyry (2013) 'Technology Supply Curves for Low Carbon Power Generation'

[72] Pöyry (2013) 'Technology Supply Curves for Low Carbon Power Generation'

[73] Crown Estate (2012) ' Offshore Wind Cost Reduction Pathways Study' see:

http://www.thecrownestate.co.uk/media/305094/offshore-wind-cost-reduction-pathways-study.pdf
[74] Element Energy (2014), 'Infrastructure in a low-carbon energy system to 2030: Transmission and distribution'. Available online: http://www.theccc.org.uk/wp-content/uploads/2013/12/CCC-Infrastructure_TD-Report_22-04-2014.pdf

transmission costs (relative to a 'No Climate Action' scenario) to be £4.08bn over the period 2013-2020 and £2.19bn over the period 2020-2030. This equates to an increase of £12 on the average electricity bill over the period to 2030, in addition to the investment cost of the renewable technologies themselves, which add £115 to the average electricity bill in 2030.

Distribution costs for the various low-carbon technologies (including EV charging posts and low-carbon heat) are assumed to be covered by the technology costs and installation costs summarised in the following sections.

**Domestic content in the power sector**  The domestic content of capital expenditures in the power sector also has an important bearing on the results, as it determines the extent to which UK-based industries could benefit from the increase in capital investment in the power sector. The domestic content of the supply chain for power sector technologies in this analysis are laid out in Table A.2.

**Table A.2 Power sector domestic content assumptions in 2030**

| Technology | Domestic content |
|---|---|
| Coal | 76% |
| Gas CCGT | 76% |
| Coal CCS | 38% |
| Gas CCS | 38% |
| Nuclear | 44% |
| Onshore wind | 49% |
| Offshore wind | 45% |
| Solar PV | 39% |
| Hydro-electric | 100% |
| Biomass | 76% |

## A.2   Buildings

**Energy efficiency measures**  The CCC report includes a wide range of different energy efficiency measures that could be applied in residential buildings. Some examples include:

- fabric insulation – loft, cavity wall, and solid wall insulation

- better heating controls and hot-water generation – room thermostats, efficient boilers, or hot-water cylinder jackets

- greater uptake of more efficient electrical appliances and lighting

- behavioural changes – e.g. turning down the thermostat or turning off lights

Uptake of these measures could be driven by product standards, efficiency regulations and policy incentives. It is important to note that, in some cases, the energy savings associated with each technology may be lower than anticipated due to:

- In-use factors, which relate to the underperformance of a given technology, and represent the discrepancy between the predicted savings and actual attainable savings.

- The direct rebound effect, where residents increase energy demand because of efficiency savings and higher real incomes.

- The heat displacement effect, which, in some cases, leads to increases in direct $CO_2$ emissions, as more efficient lighting and electrical appliances produce less heat, and therefore lead to an increase in demand for heating fuel to compensate.

The figures presented in Table A.3 show the direct and indirect $CO_2$ savings associated with energy efficiency measures in residential buildings in the 4CB scenario, after taking account of in-use factors, rebound effects and the heat displacement effect.

**Table A.3 Overview of the direct and indirect emission savings associated with measures installed in residential buildings in the 4CB scenario**

|  | Direct $CO_2$ savings (MtCO$_2$) | Indirect $CO_2$ savings (MtCO$_2$) |
|---|---|---|
| **Solid wall insulation** | 2.5 | 0.3 |
| **Cavity wall and loft insulation** | 2.7 | 0.2 |
| **Other fabric measures** | 0.7 | 0.1 |
| **Heating controls** | 1.4 | 0.0 |
| **Heating 1 degree centigrade decrease** | 2.0 | 0.1 |
| **Lighting** | -1.2 | 2.6 |
| **Cold and wet appliances** | -0.7 | 2.7 |
| **Electric products** | -3.2 | 3.4 |
| **Other measures** | 3.0 | 1.6 |
| **Total** | 7.2 | 11.0 |

Source: CCC (2013), 'Fourth Carbon Budget Review'

Note(s): Negative direct $CO_2$ savings for some measures are a result of the heat displacement effect, where more heating is required to compensate for the loss of heat from inefficient electrical appliances.

**Figure A.5 Marginal abatement cost of efficiency measures in households**
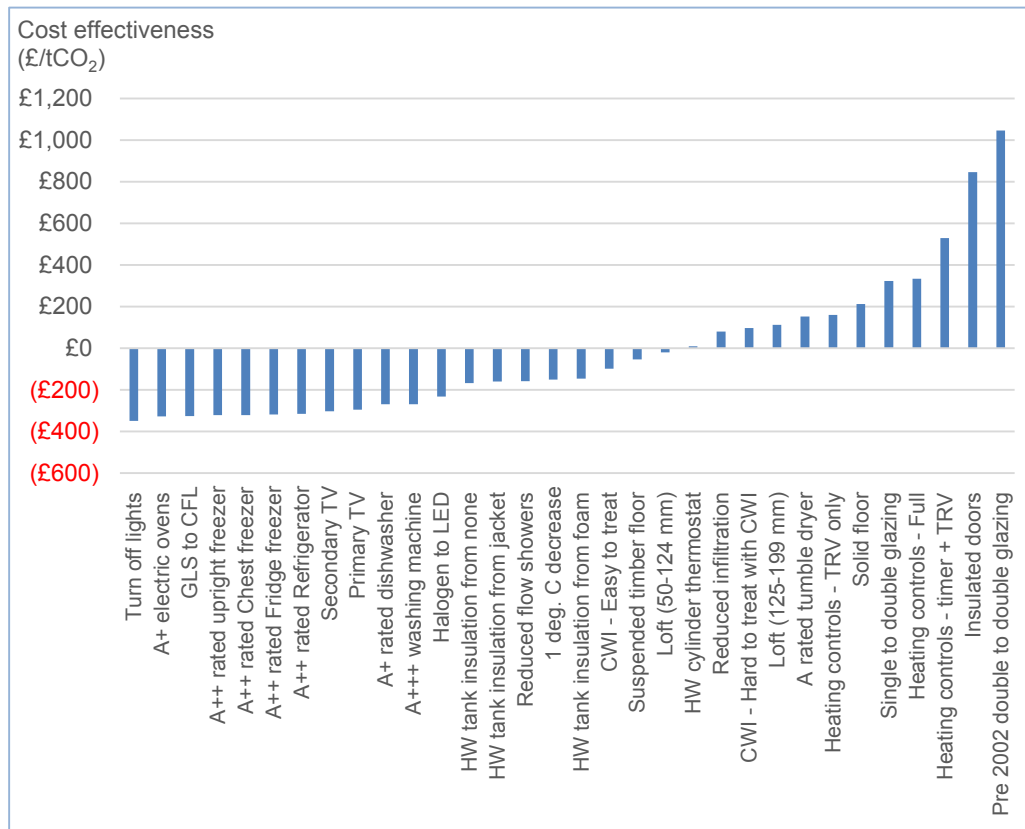


Source: CCC (2013), 'Fourth Carbon Budget Review' and Element Energy (2013), 'Review of potential for carbon savings from residential energy efficiency'

Figure A.5 shows the marginal abatement cost associated with the various household efficiency measures installed in the 4CB and 4CB+ scenarios. Whilst most measures create a net saving for households, we also assume that some measures, which are not always cost effective, are installed in hard-to-treat households. This could be the case, for example, if policy is targeted towards reducing fuel poverty, which in some cases could require large investments in the most energy-inefficient fuel-poor households. The measures include cavity wall, solid floor and loft insulation in hard-to-treat households and upgrading double glazing.

The 4CB and 4CB+ scenarios also include energy efficiency measures in non-residential buildings in the public and commercial sectors. These measures differ slightly from those installed in households as the buildings in question differ in use and size. As well as efficiency improvements for appliances, lighting and heating, there are energy savings in commercial and government offices due to more energy-efficient use of computers, printers and photocopiers. Total direct and indirect abatement from non-residential efficiency improvements reaches 12MtCO$_2$ in the 4CB and 4CB+ scenarios in 2030, relative to the Low Ambition scenario (as shown in Table A.4). The marginal abatement cost associated with the efficiency measures in Public Admin and Commerce are shown in Figure A.6.

**Table A.4 Overview of the direct and indirect emission savings associated with measures installed in non-residential buildings in the 4CB scenario**

| | Direct CO$_2$ savings in Public Admin (MtCO$_2$) | Direct CO$_2$ savings in Commerce (MtCO$_2$) | Indirect CO$_2$ savings in Public Admin (MtCO$_2$) | Indirect CO$_2$ savings in Commerce (MtCO$_2$) |
|---|---|---|---|---|
| **Cavity wall and roof insulation** | 0.03 | 0.08 | 0.04 | 0.11 |
| **Heating/air-conditioning** | 0.87 | 2.35 | 0.33 | 1.47 |
| **Lighting** | 0.00 | 0.00 | 0.20 | 1.25 |
| **Energy management of office equipment** | 0.00 | 0.00 | 0.17 | 0.45 |
| **Energy-efficient appliances and monitors** | -0.02 | -0.10 | 0.90 | 3.59 |
| **Other** | 0.00 | 0.00 | 0.06 | 0.38 |
| **Total** | 0.88 | 2.33 | 1.70 | 7.25 |

Source: CCC (2013), 'Fourth Carbon Budget Review' and own calculations

Note(s): Negative direct CO$_2$ savings for some measures are a result of the heat displacement effect, where more heating is required to compensate for the loss of heat from inefficient electrical appliances.

**Figure A.6 Marginal abatement cost of efficiency measures in non-residential buildings**
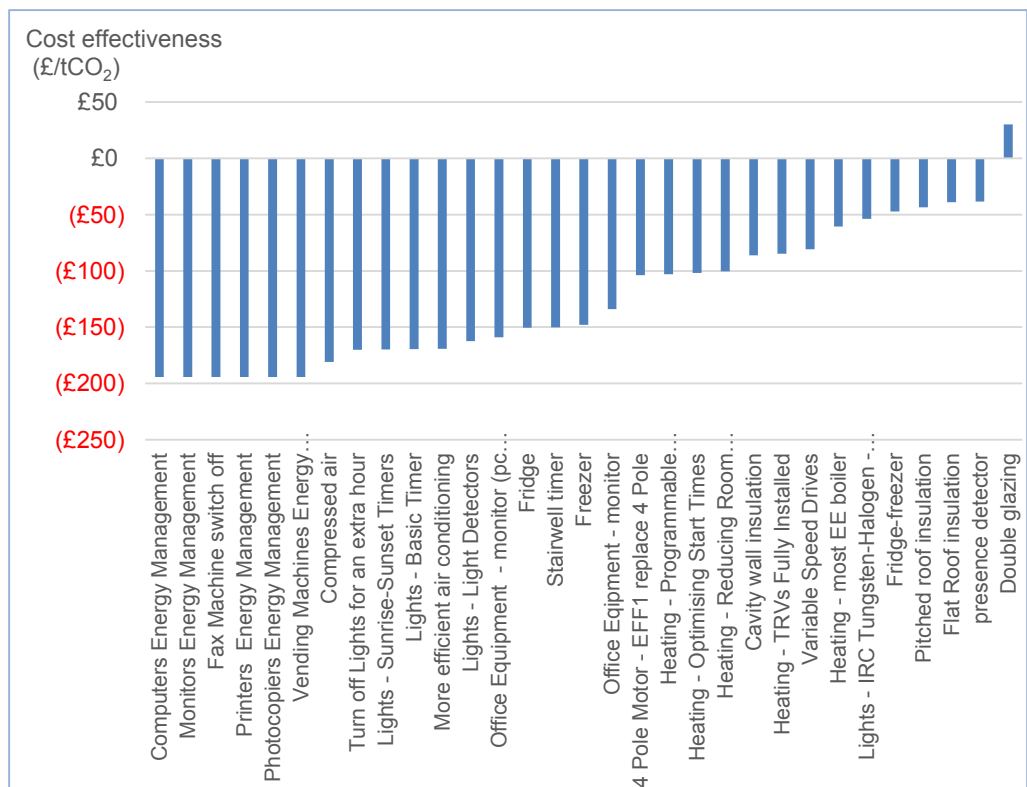


Source: CCC (2013), 'Fourth Carbon Budget Review' and own calculations.

**Low-carbon heat** In addition to energy-efficient appliances and installations, there is an increase in uptake of low-carbon heat in the residential and non-residential sectors in the two abatement scenarios (4CB and 4CB+). This mainly involves replacement of existing gas and oil-fired boilers with heat pumps, biomass boilers and district heating. The direct emissions savings related to low-carbon heat in residential and non-residential buildings is shown in Table A.5, and the change in energy demand due to increased uptake of low-carbon heat is shown in Figure A.7.

The level of abatement from the various forms of low-carbon heat is consistent with the CCC's updated abatement scenario. Whilst there is a small net increase in electricity demand in the 4CB scenario due to increases in installation of heat pumps, the lower carbon intensity of the power sector in the 4CB scenario means that the net impact in terms of extra power sector emissions is negligible. The increase in uptake of biomass boilers is consistent with the CCC's analysis, which draws on evidence from the CCC's 2011 Bioenergy Review,[75] and the cost associated with the various heat installations was taken from Element Energy (2012)[76]. Table A.5 and Figure A.7 show the energy and emissions savings associated with low-carbon heat installations in the 4CB scenario in 2030.

**Table A.5 Overview of the direct emission savings associated with low-carbon heat in residential and non-residential buildings in the 4CB scenario by 2030**

|  | Direct $CO_2$ savings - Residential sector (MtCO$_2$) | Direct $CO_2$ savings - Non-residential sector (MtCO$_2$) |
|---|---|---|
| **Air source heat pump (air-to-air)** | 0.00 | 2.37 |
| **Air source heat pump (air-to-water)** | 6.82 | 0.08 |
| **Biomass** | 1.42 | 1.14 |
| **GSHP** | 2.57 | 2.42 |
| **District heating** | 3.61 | 3.61 |
| **Biogas** | 5.22 | 0.63 |
| **Total** | 19.63 | 10.25 |

Source: CCC (2013), 'Fourth Carbon Budget Review' and own calculations

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[75] CCC (2011), 'Bioenergy Review: Is bioenergy low-carbon?'

[76] Element Energy (2012), '2050 options for decarbonising heat in buildings'. Available online:
http://archive.theccc.org.uk/aws/IA&S/Element%20Energy%20-%20Decarbonising%20heat%20to%202050%20-%20Annex.pdf

**Figure A.7 Change in energy demand in 2030 due to replacement of oil/gas boilers and electric heating with low-carbon heat installations**
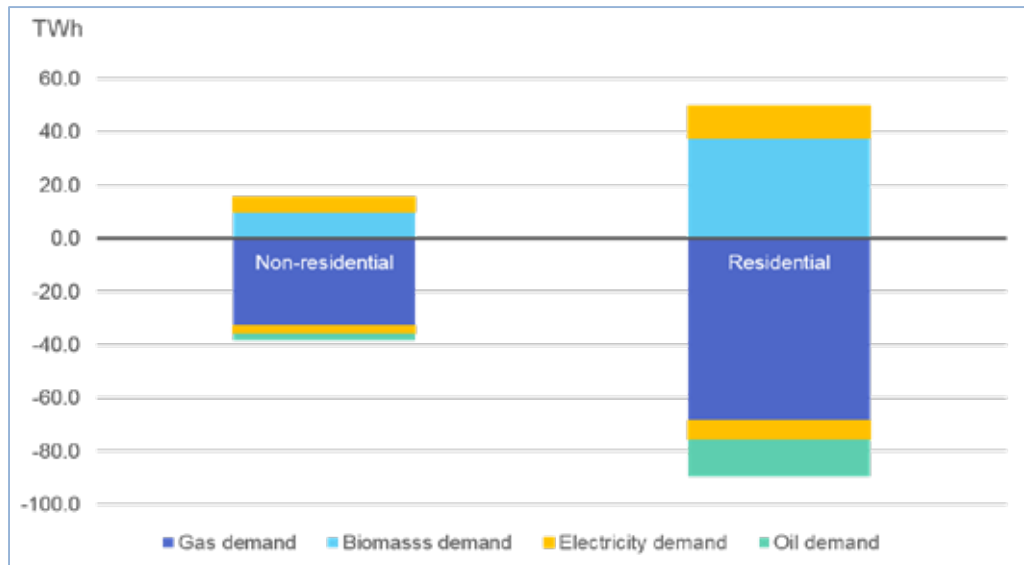


Source: CCC (2013), 'Fourth Carbon Budget Review' and own calculations

Note(s): The reduction in electricity demand is associated with an increase in uptake of more energy-efficient heat pumps and biomass boilers in buildings that were previously electrically heated.

## A.3    Industry

Emissions abatement in industry includes installation of energy efficiency measures and process improvements, replacement of fossil-fuel boilers with low-carbon heat and, in the period 2025-30, industry CCS installations in some energy-intensive industries.

Efficiency improvements to the manufacturing process are modelled for iron and steel, chemicals, food and drink, glass, cement, paper and refineries. In the 4CB scenario, these efficiency improvements lead to a direct emissions reduction of 10MtCO$_2$ in 2030 relative to the Low Ambition scenario (see Table A.6).

It is also assumed that low-carbon heat installations in industry will lead to direct emissions savings of 13.5 MtCO$_2$ in the 4CB scenario in 2030 (see Table A.7).

**Table A.6 Overview of the direct and indirect emission savings associated with efficiency improvements to industrial processes in the 4CB scenario in 2030**

| | Direct CO2 savings (MtCO$_2$) | Indirect CO2 savings (MtCO$_2$) |
|---|---|---|
| **Cement**- clinker substitution; belite aluminate clinker system | 1.14 | 0.00 |
| **Glass**- pre-heating of cullet; oscillating combustion; submerged combustion; batch reformulation; batch consolidation; waste heat recovery | 0.13 | 0.02 |
| **Chemicals**- improved distillation; chlor alkali; bioprocessing | 0.58 | 0.74 |
| **Food and Drink**- heat recovery; membrane Technology | 0.24 | -0.01 |
| **Iron and Steel**- incremental imp; EAF increased recycling | 3.33 | -0.11 |
| **Refineries**- whole refinery optimisation; Reduced fouling; Separation technologies | 3.80 | 0.33 |
| **Other efficiency measures** | 1.22 | 2.88 |
| **Total** | 10.43 | 3.84 |

Source: CCC (2013), 'Fourth Carbon Budget Review' and own calculations

**Table A.7 Overview of the direct emission savings associated with industry low-carbon heat in the 4CB scenario in 2030**

| | Direct CO2 savings (MtCO$_2$) | Indirect CO2 savings (MtCO$_2$) |
|---|---|---|
| **CHP** | 0.48 | 0.00 |
| **Biomass boilers** | 9.58 | 0.14 |
| **Air source heat pump (air-to-air)** | 0.89 | -0.08 |
| **Air source heat pump (air-to-water)** | 0.24 | -0.03 |
| **Ground source heat pump** | 1.29 | 0.00 |
| **Biogas** | 1.04 | 0.00 |
| **Total** | 13.52 | 0.04 |

Source: CCC (2013), 'Fourth Carbon Budget Review' and own calculations

The 4CB and 4CB+ scenarios also include £1.2bn cumulative investment in industry CCS over the period 2025-2030, which finances 11 CCS installations in energy-intensive industry and leads to a cumulative CO$_2$ saving of

15MtCO$_2$. These cost assumptions are based on CCS cost analysis by Element Energy (2013)[77], as summarised in Table A.8.

**Table A.8 Overview of the direct emission savings associated with industry CCS in the 4CB scenario in 2030**

|  | Annualised CAPEX (£m/yr) | O+M (£m/yr) | CO$_2$ avoided (MtCO$_2$/yr) | £/tCO$_2$ avoided |
|---|---|---|---|---|
| **Large Iron and Steel** | 35.9 | 12.3 | 1.8 | 26.2 |
| **Small Iron and Steel** | 4.1 | 1.0 | 0.1 | 73.3 |
| **Large cement** | 15.4 | 5.1 | 0.5 | 39.5 |
| **Small cement** | 13.3 | 5.1 | 0.2 | 80.3 |
| **Lime** | 11.3 | 4.1 | 0.2 | 90.6 |
| **Ammonia** | 4.1 | 1.0 | 0.4 | 13.2 |
| **Hydrogen** | 4.1 | 1.0 | 0.2 | 23.3 |

Source: Element Energy (2013) and own calculations (converted to 2013 prices)

## A.4    Transport

For the transport sector, consistent with the CCC's 'Fourth Carbon Budget Review', we only consider abatement measures for road transport in the 4CB and 4CB+ scenarios. Emissions in aviation and shipping are not currently included in the carbon budgets (despite recent recommendations for their inclusion[78]) and therefore are not modelled in the abatement scenarios. Our analysis considers the impact of decarbonising cars and vans but, for simplifying reasons, does not include potential efficiency improvements for HGVs and buses.

**Modelling the vehicle stock** A bottom-up model of the UK vehicle stock was used to model passenger cars. Drawing on historical sales, current stock, longevity of vehicles and scenario-specific assumptions for the future sales mix, we modelled the future stock of vehicles and were able to estimate the impacts on energy demand, emissions and vehicle price levels. For vans, fuel demand and the purchase cost of vans in the 4CB and 4CB+ scenarios was based on similar shares of the various powertrain technologies as assumed for the passenger car stock.

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[77] Element Energy (2013), 'The costs of Carbon Capture and Storage (CCS) for UK industry'. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/181161/bis-13-745-the-costs-of-carbon-capture-and-storage-for-uk-industry-a-high-level-review.pdf

[78] http://www.theccc.org.uk/publication/international-aviation-shipping-review/

The stock of cars in the Low Ambition scenario remains largely unchanged, with only diesel cars becoming more prevalent, reflecting the current sales mix. In contrast there is a higher number of battery-electric, fuel cell and hybrid-electric vehicles in the 4CB and 4CB+ scenarios in both 2020 and 2030. To simplify the modelling approach, and because fuel cell electric vehicles are emerging technologies that are only expected to become prevalent in the 2030-2050 period, we do not include fuel cell electric vehicles in our analysis.

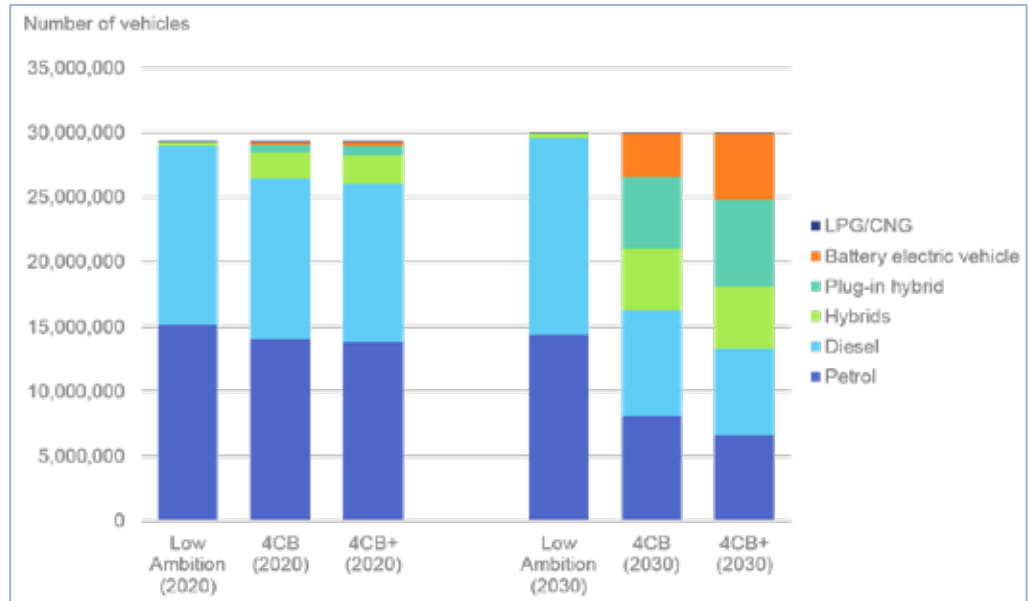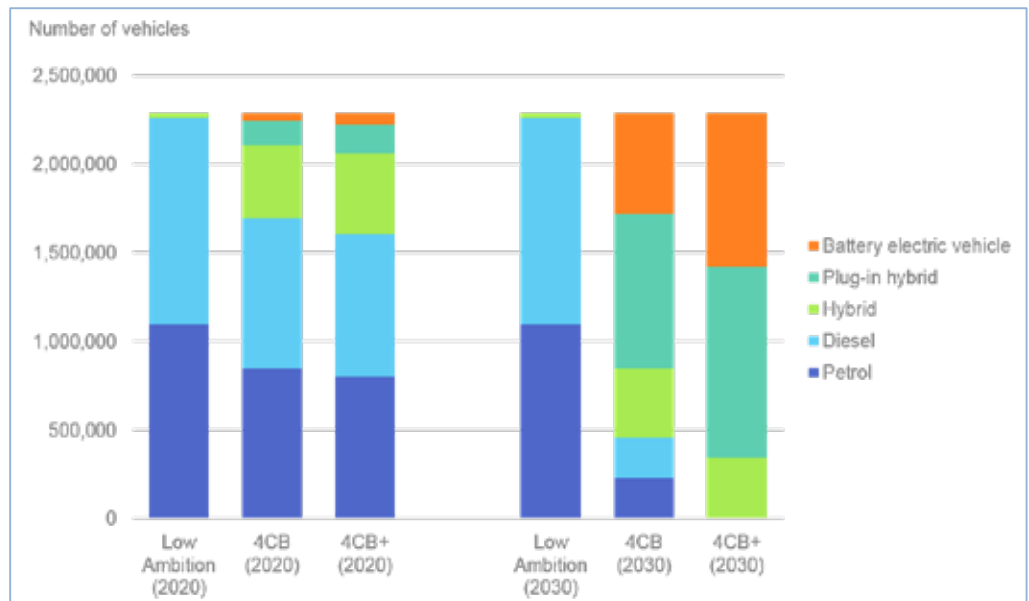**Figure A.8 Stock of cars by engine type in 2020 and 2030**



**Figure A.9 Sales of new cars by engine type in 2020 and 2030**

We have made several assumptions to model efficiency improvements to the vehicle stock:

- Changing sales mix – The move away from conventional Internal Combustion Engines (ICEs) is modelled in both the 4CB and 4CB+ scenarios. Conventional ICEs are primarily replaced by hybrid vehicles- both HEVs (hybrids) and PHEVs (plug-in hybrids). BEVs (battery-electric vehicles) make up 25% of total sales and 11% of the vehicle stock by 2030 in the 4CB scenario and in the 4CB+ scenario, they account for 38% of sales and 17% of the stock by 2030. Uptake becomes more prevalent in the 2020-2030 period once public charging infrastructure is built and overall technology costs decline.

- Efficiency improvements – Vehicle efficiency is set to match the improvements in 'Fuelling Europe's Future' report,[79] which includes a set of technical improvements for conventional ICEs. Measures such as weight reduction, changes of friction and start-stop technology are included and affect average emissions as well as prices of new vehicles.

- Use of biofuels – Consistent with the CCC's analysis, we assume that the use of biofuels, as a share of total vehicle liquid fuel consumption, increases from current levels of 2-3% to 8% over the period 2020-2030

- Distance travelled and eco-driving – The scenarios include a range of measures aimed at voluntarily decreasing the distance travelled through reduction in trips, as well as modal shift to other forms of transportation. Eco-driving refers to techniques that help reduce fuel consumption, such as more careful acceleration and breaking.

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[79] Cambridge Econometrics and Ricardo-AEA (2013), 'Fuelling Europe's Future', available online at: http://www.camecon.com/Libraries/Downloadable_Files/Fuelling_Europe_s_Future-_How_auto_innovation_leads_to_EU_jobs.sflb.ashx

**Table A.9 Modelling assumptions for passenger cars**

| | Low Ambition | 4CB | 4CB+ |
|---|---|---|---|
| **Average lifetime of vehicles** | 13.5 years | | |
| **Distance travelled** | 8,400 miles per year | 8,000 miles per year over the period 2020-2030 due to Smarter Choices measures[80]. | |
| **Sales mix** | Unchanged beyond 2013, no increase in uptake of PHEVs or EVs. | Sales of ICEs and hybrids fall to 20% and 17% respectively by 2030. Plug-in hybrids make up 38% of new vehicles, and battery-electric vehicles make up 25% of the sales mix in 2030. | No sales of conventional ICEs in 2030. Plug-in hybrids make up 47% of new vehicle sales and battery-electric vehicles account for 38% of new vehicle sales. |
| **Use of biofuels** | The share of biofuels in liquid fuel demand remains at current levels of around 3.5%. | Consistent with the CCC assumptions[81], we assume biofuels account for 8% of liquid fuel consumption over the period 2020-30. | |
| **Efficiency improvements[82]** | None beyond 2013. | Average new vehicle efficiency reaches 38gCO$_2$/km[83] in 2030 due to ICE improvements[84] and a higher share of EVs in the mix. | Average new vehicle efficiency reaches 21gCO$_2$/km in 2030 due to ICE improvements and a higher share of EVs in the mix. |
| **Behavioural changes** | None. | Eco-driving and a reduction in annual miles travelled by 5%. | |

Source: CCC (2013), 'Fourth Carbon Budget Review' and own calculations

[80] Smarter Choices measures include a modal shift from use of passenger cars to public transport, walking and cycling, as well as a reduction in trips due to schemes to promote car sharing and working from home.
[81] CCC (2013), 'Fourth Carbon Budget Review'. Available online at:
http://www.theccc.org.uk/publication/fourth-carbon-budget-review/
[82] The new vehicle efficiency figures, refer to tailpipe emissions, and therefore do not include embodied emissions in the production of electricity used by EVs.
[83] Although ambitious, this is in-line with recent Electric Vehicle scenarios that have been modelled at the EU level. For example, the efficiency of cars in the 'Fuelling Europe's Future' Tech 3 scenario reaches 23gCO2/km in 2030, and the 'EV Breakthrough' scenario form CE Delft (2011) is even more ambitious and broadly in line with the 4CB+ scenario.
[84] ICE improvements (including low-rolling resistance tyres, light-weighting and other efficiency measures) lead to the average efficiency of a conventional ICE reaching 80gCO$_2$/km by 2030, which is in line with the CCC's 'Fourth Carbon Budget Review'.

*Fuel demand*  Given these assumptions, demand for transport fuels was estimated over the projection period in all three scenarios. There is a decrease in liquid fuel demand in the two abatement scenarios, due to the phasing out of ICEs and improvements to the efficiency of ICEs that are sold. Electricity demand rises as battery-electric vehicles and plug-in hybrids are adopted but the increase is much smaller due to the relative efficiency of electric motors.

**Figure A.10 Passenger car fuel use in 2030 across scenarios**
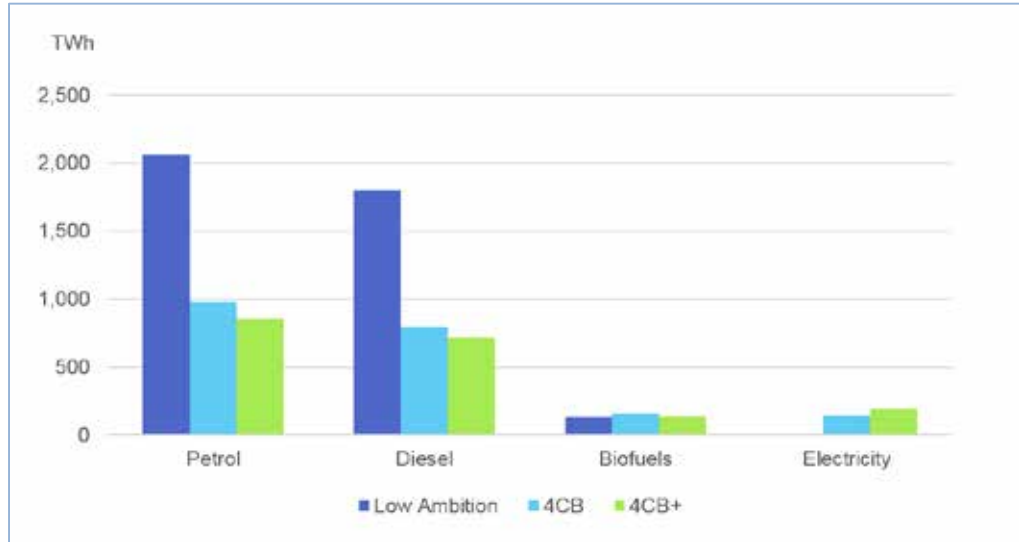


Source: Cambridge Econometrics' Vehicle Stock Model

*Vehicle costs*  Figure A.11 shows the average price of vehicles in the three scenarios modelled. There are two main factors affecting the average cost of vehicles in the scenarios modelled: (1) the proportion of more expensive battery-electric vehicles and plug-in hybrids in the sales mix; (2) the cost of efficiency improvements to conventional ICEs.

**Figure A.11 Average price of vehicles**
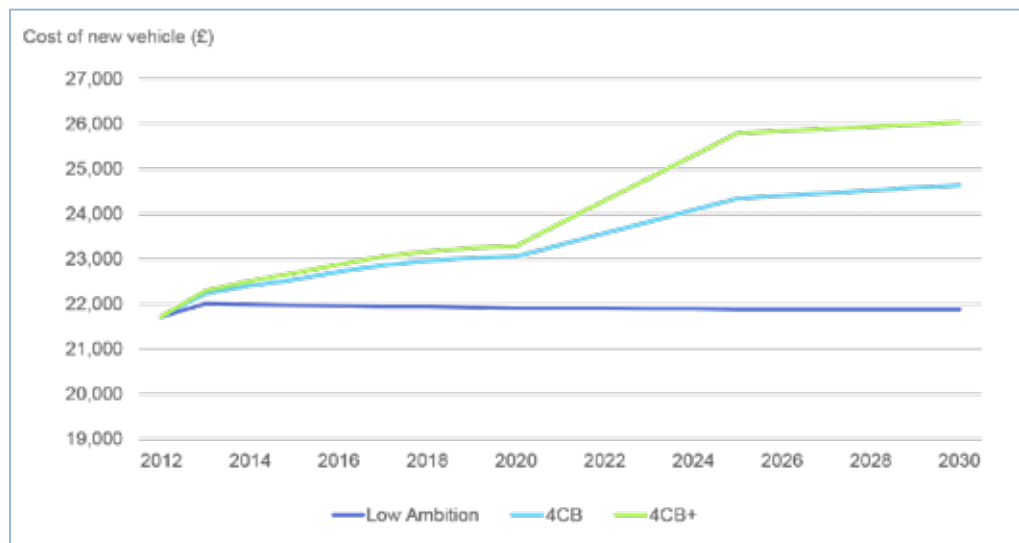


Source: Average vehicle cost in 2010 is taken from ICCT (2014). Vehicle costs in each scenario are taken from Cambridge Econometrics' Vehicle Stock Model

Average vehicle prices are higher in the two abatement scenarios, as they have a higher share of EVs and PHEVs in the sales mix, and, in the 4CB scenario, prices continue to increase over the period up to 2030 as the share of EVs in the sales mix increases[85].

**Electric vehicle charging infrastructure**

There are four important factors to consider when estimating the cost of widespread installation of EV charging infrastructure.

- The density of charging posts

- The cost of charging posts (including production and installation costs)

- The method of financing the infrastructure investment

- Upgrades to electricity distribution infrastructure

The cost and density assumptions are summarised in Table A.10 and the method of financing differs for public and private infrastructure. The assumptions are based on the idea that EV users are 'grazing', topping up their vehicles frequently for short distance journeys. There is a lot of initial investment in fast-charging until a critical mass is reached. The cost of home and work charging posts is assumed to be borne by consumers at the time of vehicle purchase, whilst public charging infrastructure (installed in shopping centre car parks and by motorways) is financed by higher prices in retail sectors.

**Table A.10 Costs of EV charging stations**

|  | Production cost per charging post[86] | Installation cost per charging post | Density (charging posts per EV) |
|---|---|---|---|
| **Home charging** | £340 | £850 | 0.8 |
| **Work-place charging** | £680 | £850 | 0.2 |
| **Public charging** | £5,100 | £2,550 | 0.4 |
| **Fast charging (motorways)** | £18,695 | £21,245 | 0.006 |

Source: Cambridge Econometrics and Ricardo AEA (2013), 'Fuelling Europe's Future', infrastructure scenario 2 (converted to pound sterling, 2013 prices)

## A.5    Agriculture

Measures to reduce GHG emissions in the agriculture sector are based on analysis carried out by the Scottish Agricultural College as part of the supporting literature for the CCC's 'Fourth Carbon Budget Review'. The

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[85] Learning effects are modelled exogenously and, in the 4CB scenario, lead to the average cost of a new battery-electric vehicle to fall by £5,000 by 2030. However, this learning effect is not sufficient to offset the impact on average new vehicle costs of the rapid transition to the more expensive powertrains.

[86] A 10% learning rate per doubling of production is assumed for the charging infrastructure. Variations in the production cost and installation costs are due to the features of the various type of charging infrastructure e.g. public charging and fast charging points are ground-mounted and high resilience with different access options and have two plug sockets or more.

abatement measures in this sector mainly relate to a more efficient use of resources and productivity improvements in arable farming, rearing livestock and through land use change[87]. Most of the GHG emissions savings in the agriculture sector are assumed to come from non-$CO_2$ sources and mainly relate to a reduction in nitrous oxide ($N_2O$) and methane ($CH_4$) emissions.

The total emissions abatement and the marginal abatement cost associated with the measures in the 4CB and 4CB+ scenarios are summarised in Table A.11. In 2030, the efficiency measures in the agriculture sector give rise to an emissions saving of 10.1 $MtCO_2e$ in the 4CB and 4CB+ scenarios, relative to the Low Ambition comparison scenario. This equates to a net carbon saving of 93.5 $MtCO_2e$ over the period 2014-30.

Most of the abatement measures identified in agriculture relate to efficiency and productivity improvements and, in many cases, they create a cost saving for the agriculture sector. This is most apparent in the measures that reduce emissions associated with keeping livestock, where substantial cost savings of over £300/$tCO_2$ could be realised.

The negative figure raises the question of why these options are not taken up already, which is likely to be a key challenge for policy makers. Some studies have suggested that this could be due to risk aversion, capital constraints, ease of compliance and imperfect information[88]. In the 4CB and 4CB+ scenarios we assume that these measures are adopted due to enforced regulation.

**Table A.11 Measures to reduce emissions in agriculture (2030)**

| Abatement Measure | Level of Emissions Abatement in 2030 (MtCO2eq) | Weighted Average Marginal Abatement Cost (£/$tCO_2$ avoided) |
|---|---|---|
| **Nutrient Management** | 2.60 | -110 |
| **Use of more nitrogen efficient plants** | 2.80 | 27 |
| **Livestock breeding** | 1.40 | -405 |
| **Livestock feeding** | 2.25 | -341 |
| **Anaerobic digestion** | 0.63 | 5 |
| **Manure management** | 0.20 | 47 |
| **Land use change** | 0.20 | 41 |
| **Total** | **10.1** | **-150.9** |

Source: based on analysis for the CCC's Fourth Carbon Budget Review (2010) and Scottish Agricultural College (2008)[89] and own calculations

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[87] $CO_2$ reductions from land-use change primarily relates to the conversion of land to forestry and grassland

[88] http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter8.pdf

[89] http://www.research.ed.ac.uk/portal/files/10846133/ReportToCommitteeOnClimateChangeAndDefra.pdf

# Appendix B   The MDM-E3 Model

## B.1    A brief description of the model

**Energy-Environment-Economy (E3) modelling**

MDM-E3 is an econometric input-output model of the UK economy, energy system and environment. It is maintained and developed by Cambridge Econometrics (CE), and is frequently applied to assess the macroeconomic impact of energy policies and technologies, as well as other energy-environment-economy (E3) interactions. In the context of this study, it is applied as a tool to assess the economic impact of whole energy system scenarios on the wider economy. The model uses a combination of accounting identities and empirically estimated econometric equations to assess the impact of these different energy system pathways on consumers, industries and the economy as a whole.

**Determination of final output**

MDM-E3 retains an essentially Keynesian logic for determining final expenditure, output and employment. The model is demand-driven with total demand defined as the sum of industry consumption, household final consumption, investment, government expenditure and exports. The model assumes that supply will adjust to meet demand either by means of a change in domestic production, or through imports.

**The input-output structure of MDM-E3**

MDM-E3 incorporates a full top-down macro and sectoral simulation analysis of the economy, allowing industrial factors to influence the macroeconomic picture. The structure of MDM-E3 disaggregates industries, commodities, and household and government expenditures, as well as foreign trade and investment, and incorporates a detailed input-output framework to identify the inter-relationships between industry sectors. There is detailed treatment of changes in the input-output structure of the economy over the forecast period to incorporate the effects of technological change, relative price movements and changes in the composition of each industry's output. The first part of this treatment uses results from the energy module to change the relationships between energy-consuming sectors and energy-producing sectors. The second part of this treatment requires projecting trends of input-output coefficients forward so that they reflect long-term trends in the structure of the economy, for example, the tendency for businesses to purchase more services from one another. The high level of disaggregation and the complete specification of the accounting relationships required to model output by disaggregated industry are the main features that distinguish MDM-E3 from purely macroeconomic models.

**Modelling the energy system**

In addition to modelling the UK macro-economy, MDM-E3 also includes an energy module with two-way feedback to the economy to assess the causal relationships between energy prices, energy demand, and economic outcomes. For this study, the energy system (demand, supply, costs, etc.) is set exogenously to be consistent with the CCC's 'Fourth Carbon Budget Review'. Consumption of energy (disaggregated by final user and fuel type) feeds back to the economy through household expenditure on energy,

industry consumption of energy, and the implications for domestic supply and imports of fuel.

The power sector is modelled by a range of defined archetypal technologies. Power sector technology costs and capacity and generation projections are used to derive the cost of electricity generation by technology. The electricity price is then calculated according to the generation mix of power sector technologies and the cost of transmission. Margins (which cover distribution costs and profits) and taxes (as relevant) are then added to the electricity prices faced by electricity consumers. In turn this impacts on real disposable incomes.

**Econometric approach**

MDM-E3 combines the detail and structure of input-output models, with the features of an annual short and medium-term sectoral model estimated by formal econometric methods, in this case providing analysis of outcomes for key E3 indicators in response to different energy system scenarios.

The behavioural parameters in MDM-E3 are estimated at an aggregate and sector level using annual time series data dating back to 1970. The equations are typically of Engle Granger cointegrating form with an error correction term. By applying this type of econometric specification, the economy is represented as being in a continual state of dynamic adjustment, and the speed of adjustment to changes (in, for example, electricity prices or energy technology investment) is based on empirical evidence. There is therefore no assumption that the economy is in equilibrium in any given year, or that there is any automatic tendency for the economy to return to full employment of resources. The parameters estimated are bounded within the limits suggested by theory, but are not imposed from theory.

## B.2    Limitations of the modelling approach

**Overview**

All models are defined by their underlying assumptions and MDM-E3 is no different. The key issue is how these assumptions influence the final results and conclusions drawn from the study. In this section we focus on some of the most important ones.

**Model parameterisation**

The parameters (or 'elasticities') in MDM-E3 are estimated using econometric techniques. This gives the model a strong empirical grounding and replaces the need for the assumptions relating to optimal behaviour described above. However, it should be recognised that there is uncertainty about the model parameters in future projections.

One well-known criticism of econometric models is the 'Lucas Critique' which states that behaviour under one set of policy conditions should not be expected to stay the same under a different set of conditions. In the scenarios assessed in this report, the policy conditions change quite substantially so the critique could be applied.

However, in our view, while changes to behavioural parameters could change slightly the magnitude of results (in either direction), they are unlikely to change the qualitative conclusions. The sensitivity analysis that has been carried out has suggested that the results are quite robust in nature.

**Rest of the world**  MDM-E3 is a model of the UK economy and we assume that the rest of the world does not make any changes to policy or production patterns between the scenarios. This is likely to mean that results are slightly understated.

**Treatment of the labour market**  MDM-E3 includes equations for employment demand, labour supply and wage rates. Adjustments in wage rates are assumed to follow historical patterns and do not automatically ensure that supply and demand balance. This means that voluntary and involuntary unemployment are a feature of the model.

In the 4CB and 4CB+ scenarios, there are net increases in employment and reductions in unemployment. There are also shifts between sectors, for example from energy sectors to equipment producers. It is assumed in the modelling that the available workforce has the necessary skills to allow for these shifts between sectors. If this was not possible then not only would unemployment be higher but there could be bottlenecks in production supply chains.

Given the relatively minor scale of the shift, the assumption seems reasonable for these scenarios. It is important to be aware that the labour market is in a state of constant fluctuation and shifts between sectors in the Low Ambition scenario are likely to far outweigh the additional movement in the low-carbon scenarios.

**Treatment of capital markets**  In most macroeconomic models, capital markets, like all other markets, are assumed to operate efficiently, with a single price (here the interest rate) adjusting so that there is a balance between supply (savings) and demand (investment). Since resources are assumed to be fully employed, it is not possible to increase investment in one sector without either reducing investment elsewhere or increasing savings (at the expense of current consumption). If an increase in investment in one product leads to a reduction in investment elsewhere, this is referred to as 'crowding out'.

As MDM-E3 does not assume full efficiency in capital markets, it is possible for businesses to make investment without there being a reduction in investment elsewhere. While the model still respects the accounting identity that savings must equal investment, there are two reasons for assuming that energy system investment does not 'crowd out' investment that would otherwise take place in the domestic economy:

- Firstly, many of the energy investment projects are financed by international corporations and, if these companies do not invest in the UK, it is likely that they will invest overseas instead.

- Secondly, there is a possibility of spare domestic financing capacity or credit creation, which could become available to fund investment projects. For example, firms may be currently investing in existing financial or property assets, which would push up prices of these assets but may not increase activity in the real economy.

In fact, firms pass on a large share of their investment costs through higher product prices (effectively enforcing higher savings by their customers) and so the difference due to crowding out assumptions is not as big as sometimes made out. However, the result of higher investment is typically an overall increase in economic output in the model results.

## B.3    Comparison with results from the IPCC Report (AR5 WG3)

There are two key differences between the analysis presented in this report and the economic assessment of mitigation costs in the IPCC report (AR5 WG3)[90]:

1) The results presented in the IPCC report are predominantly based on analysis by CGE models, whereas the analysis presented in this report uses an econometric simulation approach.

2) The IPCC report focuses on the global economic impact of climate change mitigation, whereas this report focuses on the impact of mitigation measures in the UK.

It is noted that many of the models used to assess the GDP impact of climate change mitigation measures in the IPCC report are CGE models[91]. The models crucially rely on the assumption that the economy is in an optimal position in the baseline, and, as a result, increases in demand only lead to price effects, and no real increase in economic output. Low-carbon investment is assumed to 'crowd-out' investment with higher returns that would otherwise take place in the baseline. There is assumed to be no involuntary unemployment, and exchange rates are typically assumed to fully adjust following changes to the trade balance arising, for example, from a reduction in oil and gas imports. These assumptions mean that low-carbon policy intervention will always result in GDP losses: the baseline assumes an optimal outcome, so any departure from this baseline will incur a net cost.

As described in Section 2, the key difference of our approach is that we do not assume an optimal baseline. This approach means that well-designed climate change policy could stimulate output and economic growth, lead to reductions in the level of unemployment, and lead to structural change, with a transfer of expenditure away from oil and gas imports, to domestically produced goods in the low-carbon sector and its supply chain. This transition means that UK businesses will benefit from increases in demand, at the expense of countries that export oil and gas to the UK. When assessed at the global level, the economic impact of changes in trade balances will cancel out to some extent. However, we would still expect to see a marginal net positive impact in an econometric simulation model due to the low-carbon investment stimulus.

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[90] As summarised in IPCC (2014) WGIII AR5, 'Summary for Policy Makers'. Available online at: http://report.mitigation2014.org/spm/ipcc_wg3_ar5_summary-for-policymakers_approved.pdf

[91] The models used to assess the GDP impact of climate mitigation policies in the IPCC report are listed in WG III, Chapter 5, Annex II. Available online at: http://report.mitigation2014.org/drafts/final-draft-postplenary/ipcc_wg3_ar5_final-draft_postplenary_annex-ii.pdf. The models include: BET, EC-IAM 2012, ENV-Linkages (WEO2012), FARM, GEM-E3-ICCS, GRAPE, GTEM REF32, IGSM, IMACLIM, iPETS, MARIA23_org, MERGE, MERGE-ETL, Phoenix, REMIND, SGM, WITCH and WorldScan 2.