A report for the Committee on Climate Change

How the UK met its carbon budgets

Covering carbon budgets 1 and 2

cambridge econometrics
clarity from complexity

Final Report

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Contents

Executive Summary

Key findings

1 The second carbon budget was met by 384 $MtCO_2e$ (14%) but most of this (296 $MtCO_2e$) can be attributed to accounting revisions in the UK's share of the EU Emissions Trading System (ETS) cap.

2 Had the global financial crisis not occurred, and had economic growth turned out as expected when the carbon budgets were set, the second carbon budget would have been missed by 66 $MtCO_2e$.

3 Policy has fallen short of bringing about the measures required to put the UK on course to meet its original long-term ambition of an 80% reduction, let alone the recently agreed net zero ambition.

Background

This report presents the results of a study for the Committee on Climate Change (CCC) investigating how the second carbon budget was met. The research considers the contribution of economic conditions in the UK over the period of the first two carbon budgets and how these compared to the assumptions made when these carbon budgets were proposed (in 2007) and legislated (in 2009).

As part of the Climate Change Act, carbon budgets were set to put UK emissions on a pathway to meet the legally binding long-term ambition of reducing emissions by at least 80% by 2050. The pathway requires that measures are incrementally added to decouple economic activity from the production of greenhouse gas emissions.

Since the Climate Change Act came into force, UK greenhouse gas emissions have been falling and the first two carbon budgets legislated by the government were met comfortably. The first and second carbon budgets were overachieved by 36 $MtCO_2e$ (1%) and 384 $MtCO_2e$ (14%), respectively. At-a-glance this might suggest that UK greenhouse gas emissions are falling on the trajectory required to meet future carbon budgets, but a fuller analysis is required to understand how this has happened.

The UK has comfortably met its first two carbon budgets, the research presented in this report quantifies some of the reasons and the implications for future budgets

The research presented in this report investigates some of the reasons the carbon budgets were outperformed, specifically by applying econometric and statistical techniques to estimate the impact of:

- ***External conditions***; external factors that policymakers have no (or little) control over, including:
  - economic activity; the impact of UK GDP (and its composition across sectors) as a driver of energy demand and subsequent emissions
  - fossil fuel prices; how consumer and industrial fuel prices influence their demand for energy
  - air temperatures; lower temperatures increase heating demand
- Changes to the EU ETS cap; the EU ETS cap and the UK's share of the cap had not been finalised when the carbon budgets were set in 2009. Changes to the traded sector cap correspond directly to performance against carbon budgets because they become the *de facto* limit for traded

sector emissions and, because they are legislative instruments, carbon budgets are not updated to reflect changes in the cap.

- Uncertainty from data revisions; the National Atmospheric Emissions Inventory (NAEI) of greenhouse gas emissions is regularly updated to reflect improvements in measuring and validating emissions data. However, carbon budgets are not updated to reflect changes in the data and so large data revisions can have a significant impact on performance against the carbon budget. We investigate the potential scale of these revisions relative to the outturn performance against the carbon budget

Separately, the CCC has considered the impact of ***policy measures*** on meeting the second carbon budget.

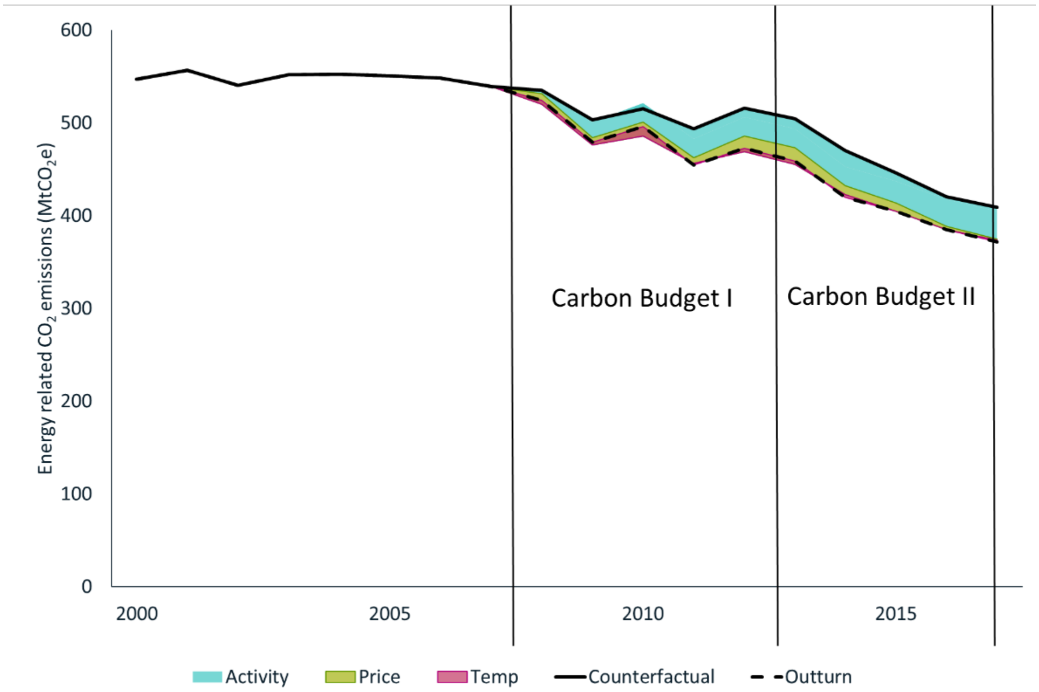
There were significant differences between outturn conditions and counterfactual conditions (i.e. those assumed when the first and second carbon budgets, 2008-2012 and 2013-2017 respectively, were set in 2009):

- **Economic activity** was much lower than expected as a result of the global financial crisis, subsequent recession and slow recovery which significantly lowered energy-related CO_2 emissions. UK GDP was 14.5% lower by 2017 than the government expected when the carbon budgets were set in 2009. Manufacturing output was 22% lower. During the first and second carbon budget, we estimate the impact of lower economic activity was to reduce CO_2 emissions by around 281 $MtCO_2e$ (the blue area in Figure ES.1) compared to a counterfactual scenario where the recession did not take place and growth was in line with the government's assumptions.
- **Fossil fuel prices** were generally higher than assumed when the carbon budgets were set, leading to reduced emissions from lower-than-expected energy consumption. Overall, the effect of higher gas and oil prices was to reduce energy related CO_2 emissions by 81 $MtCO_2e$ over the ten years (the green area in Figure ES.1). Our analysis does not account for fuel switching in the power sector from relative changes in fuel prices and the impact of the carbon price[1].
- Air temperatures were broadly as expected in the second carbon budget, reflecting the recent average (2000-2007) which was 0.6 ^{O}C above the longer-term mean (1970-2000). However, cold snaps in 2010 and 2012 meant that outturn carbon emissions were 18 $MtCO_2e$ higher over the period (the magenta area in Figure ES.1).

In total, the combined net impact of the conditions over the ten-year period is 347 $MtCO_2e$ (6% of UK greenhouse gas emissions in the period 2008-2017). In the second carbon budget period the effect of external conditions being different to those expected when the budget was set amounted to 210 $MtCO_2e$ (57 $MtCO_2e$ in the traded sector and 153 $MtCO_2e$ in the non-traded sector). Of this, economic activity alone contributed 166 $MtCO_2e$ (54 $MtCO_2e$ in the traded sector and 112 $MtCO_2e$ in the non-traded sector).

[1] See Chapter 2 for a discussion on methodology.

Figure ES.1: The impact of conditions on carbon emissions



The large surplus in the second carbon budget was achieved as a result of revisions to the EU ETS and weak economic conditions. After accounting for these factors, we conclude that policy measures have been insufficient

As shown in Figure ES.2, an accounting change to the UK's share of the ETS cap was the most significant contribution to the overachievement of the second carbon budget, at 296 $MtCO_2e$. When the carbon budgets were set, the UK government expected the traded sector cap to be 1,078 $MtCO_2e$ over the second carbon budget. However, the UK traded sector cap was revised downwards to 782 $MtCO_2e$ as a result of changes to the design of the EU ETS and the outturn share to the UK. This accounting change was not reflected by an equal change in the total carbon budget and therefore created some headroom (or "hot air" as the CCC refers to it) in the non-traded sector budget. In turn, this means that the second carbon budget was easily met, purely as a result of changes in accounting and not measures to lower carbon emissions.

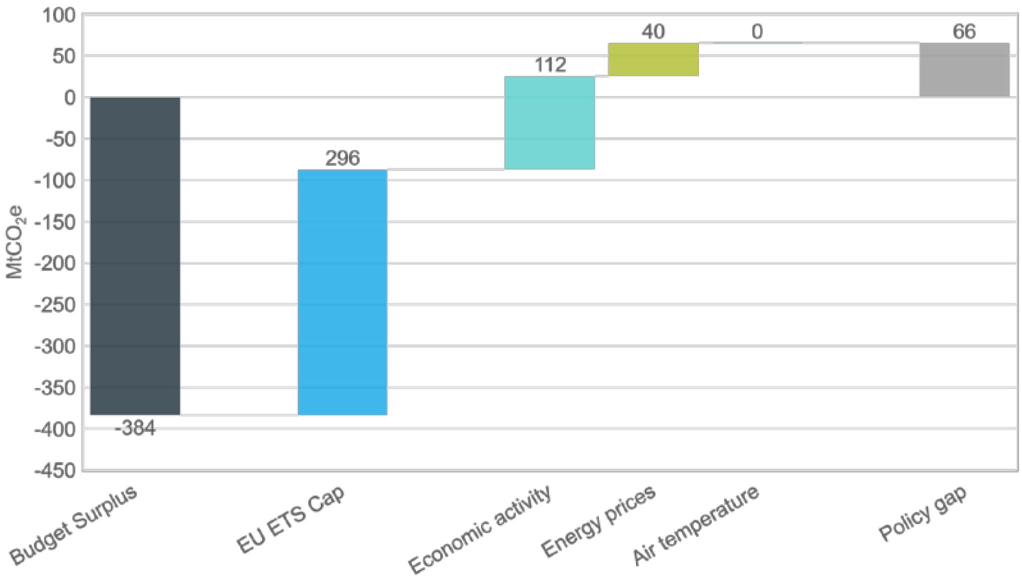
After allowing for the revision to the traded sector cap, our analysis shows that had the global financial crisis not occurred, and economic growth and fossil fuel prices had been as expected, the second carbon budget would have been missed by 66 $MtCO_2e$, suggesting that there is a substantial policy gap for carbon emission reductions measures.

Data revisions to UK greenhouse gas emissions have been large since the introduction of the carbon budgets. By extrapolating different data vintages over the outturn emissions data, we observe that data revisions over the past twelve vintages of NAEI emissions data imply an uncertainty range of 154 $MtCO_2e$ in the second carbon budget. This uncertainty range is larger than our estimated policy gap and it is also larger than the amount the government has decided to carry over.

Only by implementing measures that have long-lived impacts on reducing carbon emissions will we meet future budgets

That the carbon budget has been met only because of the wider economic conditions and traded sector accounting changes, rather than through effective policy measures, is significant. The long-term (2050) emission reduction target of at least an 80% reduction in emissions that was in place when the budgets were set required that energy-related CO_2 emissions be largely decoupled from economic growth. The government's acceptance of the CCC recommendation to aim for a net zero carbon target for the UK in 2050 requires that economic growth must become completely decoupled from producing greenhouse gas emissions. That can only be achieved by implementing measures that remove carbon entirely from our daily economic activities and not, as we find for the first two carbon budgets, by a reduction in economic activity.

Figure ES.2: The impact of data revisions and conditions on the second carbon budget



Policy considerations

1 Under the Climate Change Act, carbon budgets were set to establish a long-term pathway to at least an 80% reduction in GHG emissions by 2050. The CCC has recently recommended that the 2050 target is further tightened to net zero and that future carbon budgets are set to reflect this ambition. The long-term pathway is designed to bring about measures to incrementally reduce GHG emissions. However, we find that success in meeting the first two carbon budgets is not the result of measures but of changes in accounting for the EU ETS and the traded sector cap; and the impact of the global economic downturn in 2009. We find that rather than an emissions surplus there is, in fact, a policy measures gap.

2 In our view, therefore, the UK government should not carry any perceived budget surplus from the second carbon budget forward to future budget periods. Carrying over any surplus risks further papering over the cracks of not implementing satisfactory measures to put the UK on course to achieve its long-term and ambitious target of net zero by 2050.

3 The NAEI data on greenhouse gas emissions data is regularly revised as a result of improvements in data collection and processing methods. By extrapolating each of the last twelve vintages of data over the outturn period, we estimate that outturn greenhouse gas emissions could have been between 99 MtCO_2e lower and 55 MtCO_2e higher over the second carbon budget compared to the latest vintage of data. However, carbon budgets are not revised for data revisions and neither are the government's assessment of performance against the carbon budget. Future data revisions might well show that the carbon budget was met by much more or much less.

4 Carbon budgets are set by quantifying 'baseline' (limited policy) emissions projections using econometric techniques and then subtracting plausible (but stretching) policy measures that are needed to set a pathway to the long-term ambition. However, as the transition is underway, it becomes increasingly difficult to quantify baseline emissions separately from measures especially using top-down econometric techniques where measures are not explicitly identified. We recommend that top-down econometric methods are not further employed in revising or setting carbon budgets after the third carbon budget.

5 The government's assessment of performance against the second carbon budget is limited to an accounting exercise. However, the implementation of measures is critical to setting a pathway for reducing domestic greenhouse gas emissions. As part of assessing progress, the government should formally adopt a series of Key Performance Indicators (KPIs) to assess progress towards achieving long-term decarbonisation. Performance against such KPIs should be reported alongside the government's own assessment of progress.

1 Background and context

1.1 Background

The Committee on Climate Change (the CCC) was set up as part of the 2008 UK Climate Change Act and is an independent body tasked with providing advice to government and Parliament on climate change issues. The CCC's mission is particularly focused on the setting of carbon budgets for the UK and monitoring progress against these carbon budgets.

In the second carbon budget period (2013-17), UK greenhouse gas emissions were 384 $MtCO_2e$ below the carbon budget. The surplus, some 14% of budgeted emissions, compares to a smaller surplus from the first carbon budget of 36 $MtCO_2e$. As the second budget has come to an end, the Committee now has a statutory duty to make a detailed assessment of the UK's performance over the second budget period to inform its 2019 Progress Report to Parliament.

Following its own assessment of performance against the second carbon budget by the Department for Business, Energy and Industrial Strategy (BEIS), the government has decided that 88 $MtCO_2e$ is carried forward to future carbon budgets. This raises a second issue for consideration in this research; whether it is reasonable to carry forward the emissions surplus.

The CCC set out their initial advice on this matter in a letter to the Minister of State for Energy and Clean Growth dated 15th February 2019, stating "*The Committee's unequivocal advice is that surplus emissions from the second carbon budget should not be carried forward*".[2] This advice was based on an assessment of climate science, the broader national and international policy context and the CCC's assessment that the surplus was not a result of effective policy (***measures***) but rather of changes in accounting and the lasting effects of the recession (***conditions***).

The assertion that slow economic growth was a significant contributor to the surplus is based on a comparison of GDP growth and manufacturing GVA outturn against the assumptions used when setting the carbon budgets and the CE (2013) report "Identifying the impact of economic and other conditions on UK GHG emissions during the first carbon budget period". The latter showed that emissions were some 52 $MtCO_2e$ lower during the first carbon budget than assumed by government when carbon budgets were set, as a result of lower economic outturn.

Setting future budgets will continue to rely on quantitative modelling. It matters therefore whether the approach taken, and the data used are robust. In particular, the CCC needs to understand how the modelling can be improved to better take account of factors that are ***permanent*** (or, at least, long-lived factors affecting the energy using capital stock, e.g. factories, cars and buildings) as opposed to those that are ***transitory*** (variable factors that affect the use of the stock, such as the rate and composition of economic production and consumption which drives the demand for energy to produce goods and services that, in doing, so generates carbon emissions from the capital stock).

[2] *Letter from Lord Deben to Claire Perry*, Committee on Climate Change. February 2019. https://www.theccc.org.uk/wp-content/uploads/2019/02/Letter-from-Lord-Deben-to-Claire-Perry.pdf

In the 2018 Progress Report to Parliament, the CCC showed that the cost-effective pathway to long term emissions reductions implies that the third, fourth, and fifth carbon budgets are all set too high and need to be outperformed. The CCC will need to consider if the next three carbon budgets should be revised and will need, next year, to make recommendations on the sixth carbon budget covering the period from 2033-2037. If data revisions, revisions to the EU ETS, and the lasting effects of the recession are the main drivers of the outperformance to date, then the CCC needs to understand to what extent these issues are *permanent* or *transitory* to inform future budget setting.

1.2 Study objectives and report layout

Given the context, the research objectives were to:

- quantify the impact of **external conditions** on UK domestic GHG emissions, specifically energy-based carbon emissions, including the following:
    - economic activity
    - fossil fuel prices
    - weather conditions (external air temperatures)
- quantify the factors affecting the carbon budget performance, including the impact of:
    - conditions
    - changes to the EU ETS cap
- understand and/or quantify issues of uncertainty around:
    - data
    - the approach used to model the impact of conditions
- consider the implications of the findings for future carbon budgets:
    - what do the findings mean for future carbon budgets setting and whether there's a rationale to carry over the surplus to future budgets?
    - what do the findings imply for the approach to setting carbon budgets?

The rest of this report is structured to reflect these broad objectives.

Section	Content
2. Impact of conditions on emissions	Quantification of the effect of conditions on energy-based CO_2 emissions by energy-using sector and condition. A discussion of the approach, the data used and the strengths and limitations to the approach is also provided.
3. How the second carbon budget was met	Quantification of the factors, including conditions, contributing to the over performance of the second carbon budget on a net carbon accounting basis.
4. Uncertainties	An assessment of the uncertainty in the data and in the approach used.
5. Lessons learnt	Our reflection on the meaning of the findings for future carbon budgets and the approach used to set carbon budgets in the future.

2 Impact of conditions on emissions

2.1 Summary

Isolating the effects of economic activity, energy prices, and air temperature on energy demand and carbon emissions

To assess the impact of various conditions on emissions, three major conditions that impact energy demand, and in turn carbon emissions, were identified:

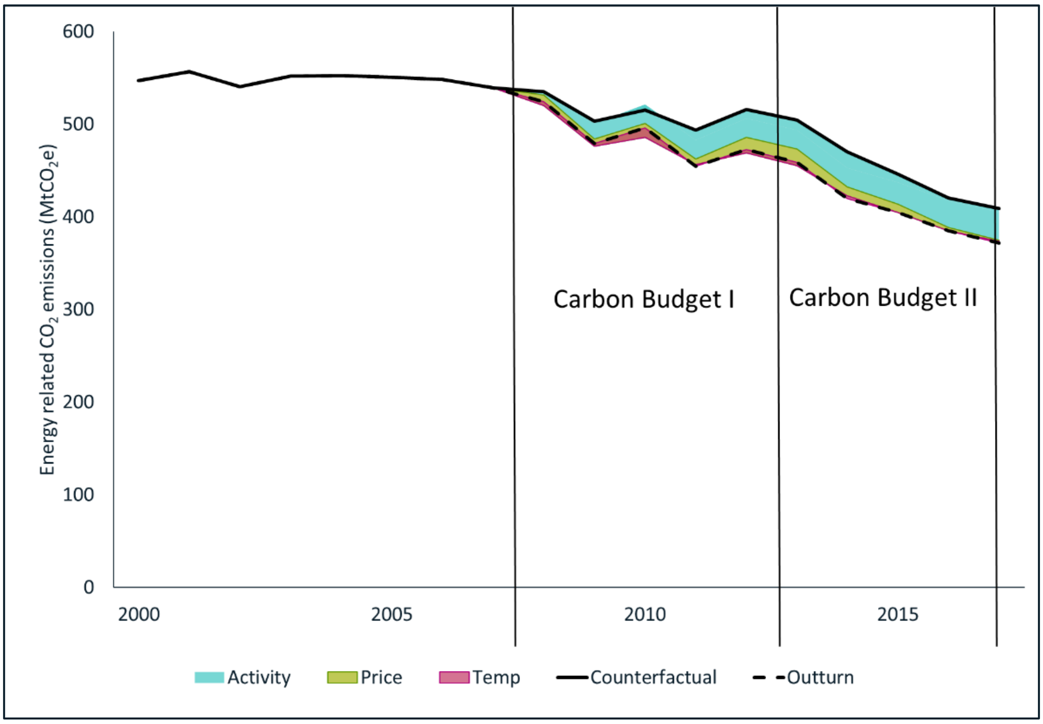
- Economic Activity
- Fossil Fuel Prices
- Air Temperature

Conditions are defined here as external factors that policy makers typically have no, or very little, control over. To assess the impact of these identified conditions on emissions we have estimated a counterfactual scenario of how emissions *would have* developed if these conditions were as expected when the carbon budgets were originally developed in 2008.

According to our econometric modelling, we estimate that the difference between outturn conditions (what actually happened) and the counterfactual conditions assumed when the first and second carbon budgets were legislated in 2009, meant that energy-based CO_2 emissions were 347 $MtCO_2e$ lower than expected over the two carbon budget periods (136 $MtCO_2e$ in Carbon Budget 1 and 210 $MtCO_2e$ in Carbon Budget 2).

As shown in Figure 2.1, the reduction in emissions over both carbon budget periods was mostly explained by slower than anticipated economic growth. Economic activity was much lower than expected as a result of the global financial crisis. The recession and slow recovery led to lower than anticipated energy-related CO_2 emissions.

Figure 2.1 The impact of conditions on energy-based carbon emissions



Over the second carbon budget, we estimate the impact of lower economic activity was to reduce CO_2 emissions by around 166 $MtCO_2e$ (the blue area in Figure 2.1) compared to a counterfactual scenario where the recession did not take place and growth was in line with the government's assumption when setting the carbon budgets.

Changes in fossil fuel prices and air temperature also had an impact on emissions over both carbon budget periods – though less of a driving force than the drop in economic activity.

Fossil fuel prices were higher during the first carbon budget than assumed when the carbon budgets were set. During the second carbon budget, outturn prices started higher and then fell below the counterfactual assumption. The price spikes in the early period lead to reduced emissions throughout the period due to lower-than-expected energy consumption in our econometric analysis. We attribute this to the take up of more energy efficient products, which persistently reduce the demand for energy. Overall, the estimated effect of higher gas and oil prices was to reduce energy-related CO_2 emissions by 81 $MtCO_2e$ over the two carbon budgets[3].

For air temperature, cold snaps over the first carbon budget period (in 2008 and 2010) meant that carbon emissions were 18 $MtCO_2e$ higher over the period. Over the second carbon budget, air temperature was roughly the same as the recent average and so energy demand for heating was broadly unchanged and so too were emissions.

Overall, we find that the combined impact of these conditions over carbon budget I and II is nearly equivalent to one year's energy-related carbon emissions at 347 $MtCO_2e$ (Chapter 3 explains how this impacted on the second carbon budget specifically).

The rest of this chapter focuses on the modelling approach used to examine the impacts of these conditions on the UK's ability to meet the first and second carbon budgets and examines in more detail the effects of these conditions on energy-related emissions across different sectors of the UK economy.

[3] Our analysis does not account for fuel switching in the power sector from relative changes in fuel prices and the impact of the carbon price.

2.2 Approach

We assess the impact of conditions on the outturn of energy-related emissions with an econometric approach, estimating the counterfactual of how emissions *would have* developed if important drivers of energy demand (economic activity, energy prices, and air temperature) were as expected when the carbon budgets were originally set.

Modelling

The econometric specification used captures long run relationship between energy demand, economic activity, energy prices, and air temperature

To develop the counterfactual scenario, we first estimate the relationship between energy-related emissions and conditions. We use an econometric specification to estimate the long run relationship between energy demand, economic activity, energy prices, and air temperature, such that for each end use energy sector and energy type, we set out an equation with the following general form:

$$y_{i,j,t} = \alpha_{i,j} + \beta_{i,j}^{1,n} x_{i,j,t}^{1,n} + \varepsilon_{i,j,t}$$

Where:

$$y_{i,j,t} \text{ is energy consumption}$$
$$\text{by end use sector } (\boldsymbol{i}), \text{energy type } (\boldsymbol{j}) \text{ and in each time period } (\boldsymbol{t})$$

$$\alpha_{i,j} \text{ is the intercept term for each equation,}$$
$$\text{by end use sector } (\boldsymbol{i}) \text{ and energy type } (\boldsymbol{j})$$

$$\beta_{i,j}^{1,n} \text{ are the parameter estimates for variables } 1 \text{ to } n,$$
$$\text{by end user sector } (\boldsymbol{i}) \text{ and energy type } (\boldsymbol{j})$$

$$x_{i,j,t}^{1,n} \text{ are the explanatory variables } (\textbf{conditions}) 1 \text{ to } n,$$
$$\text{by end user sector } (\boldsymbol{i}) \text{ and energy type } (\boldsymbol{j}) \text{ and in time period } (\boldsymbol{t})$$

$$\varepsilon_{i,j,t} \text{ is the error term for each equation,}$$
$$\text{by end user sector } (\boldsymbol{i}), \text{energy type } (\boldsymbol{j}) \text{ and in each time period } (\boldsymbol{t})$$

We then apply the equations to counterfactual projections for economic activity, energy prices and air temperature to derive a counterfactual projection of energy demand.

From energy demand, we calculate the emissions generated by energy use. This is relatively simple for end-use fuels (gas burned in homes, or petrol in cars), where CO_2 emissions from energy consumption can be calculated by applying emissions coefficients per unit of fuel burned. These are derived from emissions data from the National Atmospheric Emissions Inventory (NAEI) and are constant over time. A different approach is needed for implied emissions from electricity consumed, where of the carbon emissions from electricity generation changes over time as the generation mix changes. We include the average emissions intensity from the power sector per unit of electricity consumed to reflect this.

Strengths and limitations of the approach

A counterfactual approach is useful because it allows us to not only isolate the specific impact of different conditions, but also to remove any other factors that could explain the outperformance such as data revisions and, to some extent, model methodology.

There are some limitations associated with econometric approach

However, there are some limitations to the approach, first of which is omitted variable bias, whereby the parameters estimated capture effects that should be attributed to variables that are not included in the model specification. Our general econometric specification covers what we consider to be the main drivers across all end users and fuel types but there will be additional factors influencing energy demand beyond these. In most cases, this gets accounted for in the residual term of unexplained variance between estimated energy demand and actual energy demand and therefore doesn't affect the difference between scenarios. However, there are some factors that are correlated with the main conditions which, if unaccounted for, may lead to an over estimation of the impact of a condition.

In our review of the estimation we identified a few cases where this was significant. One such case is road transport, where over the last decade or so there has been a persistent shift from petrol to diesel fuel. To account for this, we included a time dummy over the period of the shift to capture this transition and improve the fit of the equation.

A second case is in energy consumptions from domestic buildings, where we observe a change in the trend for energy consumption from 2005 onwards. In our model this is strongly attributed to the increase in prices but might instead be attributed to policy measures at the time. However, we were not able to account for this by applying a dummy variable.

Our view is that there is no risk in incorrectly estimating the direction of the impacts and only a small risk in over-estimating the scale of the impacts, since the parameters used are broadly consistent with those used in other studies and by the government itself in its top-down econometric projections for the Updated Energy and Emissions Projections (EEP).

Finally, it is important to be precise in defining what the analysis seeks to explain, and what it cannot adequately capture given the nature of the modelling approach and available data. The approach is aimed to explain all ***energy use related CO_2 emissions***. Moreover, we do not attempt to explain detailed changes within the power sector, only the impact on power sector emissions of changes in demand for electricity from other sectors.

Other greenhouse gases associated with energy use are not modelled, nor are the process emissions associated with a range of industrial processes. The approach also does not attempt to explain possible changes in emissions due to changes in land use or forestry. The econometric analysis focuses exclusively on CO_2 emissions due to energy used by end-users. However, we include all greenhouse gas emissions in our net carbon accounting so that we can assess performance against carbon budgets. The non-energy and non-CO_2 emissions are the same in both the outturn and the counterfactual scenarios over both carbon budgets.

Data

The conditions that are represented in our econometric approach are those that have been identified as the largest drivers of change in energy demand across various sectors of the economy, with some conditions more impactful than others depending on the characteristics of the sector (e.g. air temperature affects the demand for energy for heating, but not industrial energy demand).

This section shows the counterfactual conditions compared to the outturn data for air temperature, economic activity, and fossil fuel prices in turn.

Persistent effects of the economic crisis have led to lower levels of economic activity and energy demand over the first and second carbon budgets

Over the first carbon budget period, there were a series of cold snaps that we expect would lead to increases in energy demand and emissions compared to the counterfactual. Over the second carbon budget, temperatures in the outturn data were closer to the assumption for the counterfactual scenario, with some instances of warmer than average temperatures and some colder (Figure 2.2).

Figure 2.2 Change in mean air temperature in counterfactual scenario and outturn data

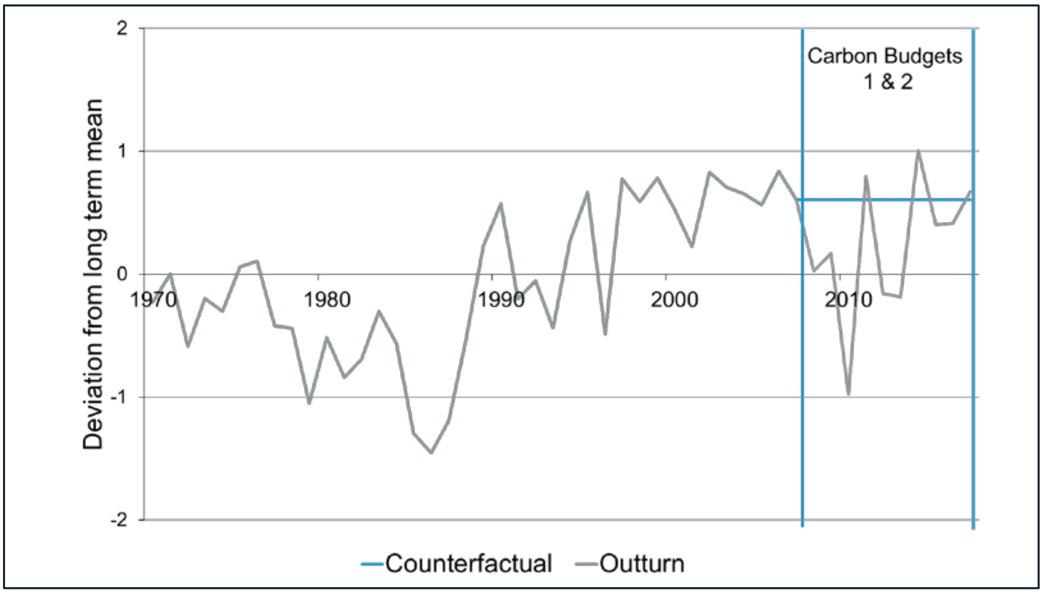


Figure 2.3 shows UK GDP in the outturn and counterfactual scenario and captures the persistent effects of the economic crisis. GDP has not recovered to the levels anticipated at the time carbon budgets were set. By 2017, UK GDP was 14.5% lower than expected by the government when the carbon budgets were being set.

Moreover, manufacturing output is yet to recover to even pre-crisis levels (Figure 2.4). By 2017, outturn manufacturing value added was 22% lower than anticipated when setting the first three carbon budgets.

Figure 2.3 GDP (£bn) in counterfactual scenario and outturn data

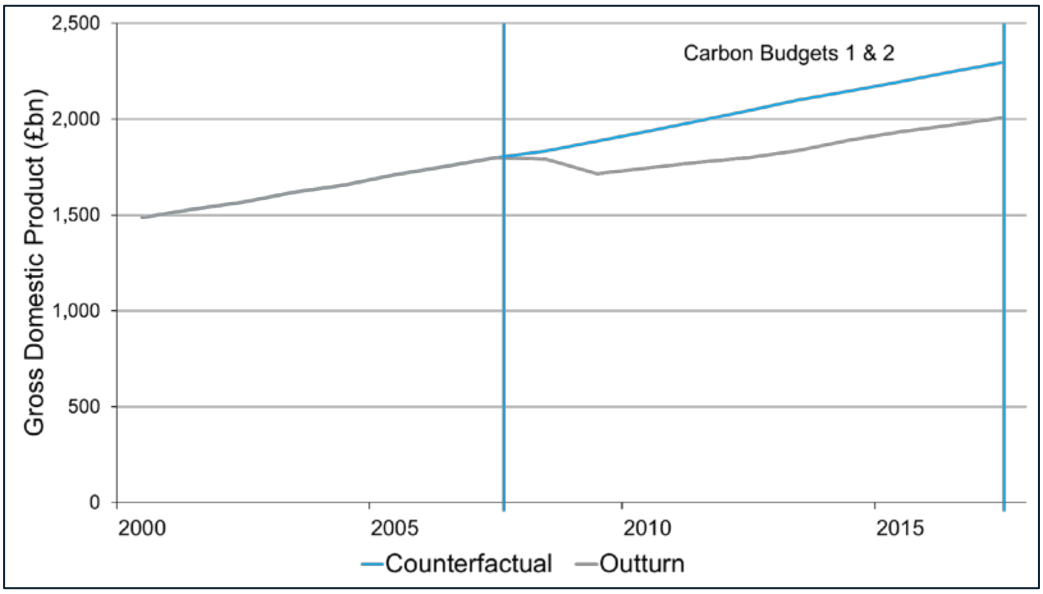
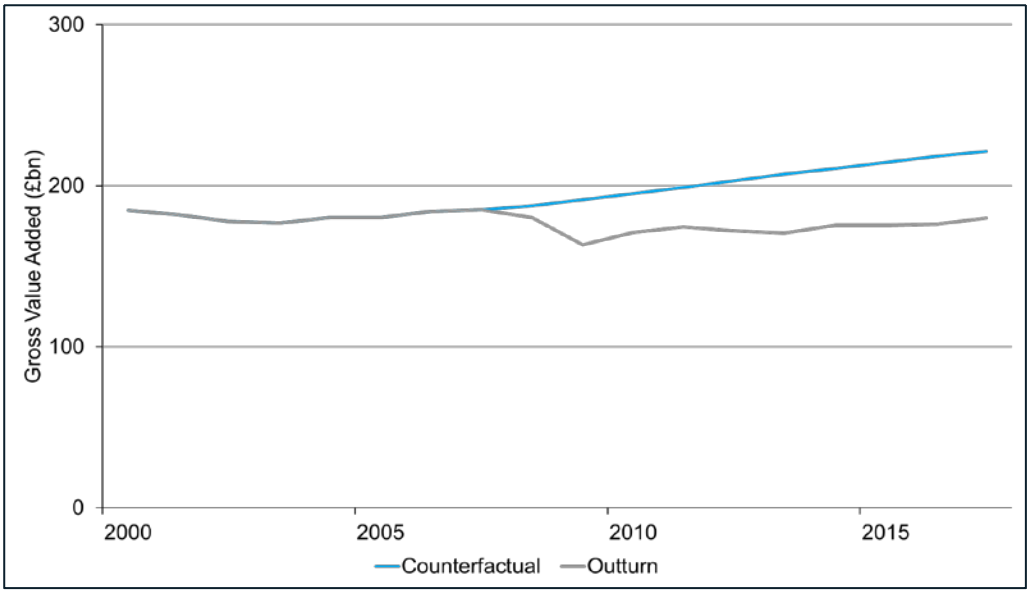
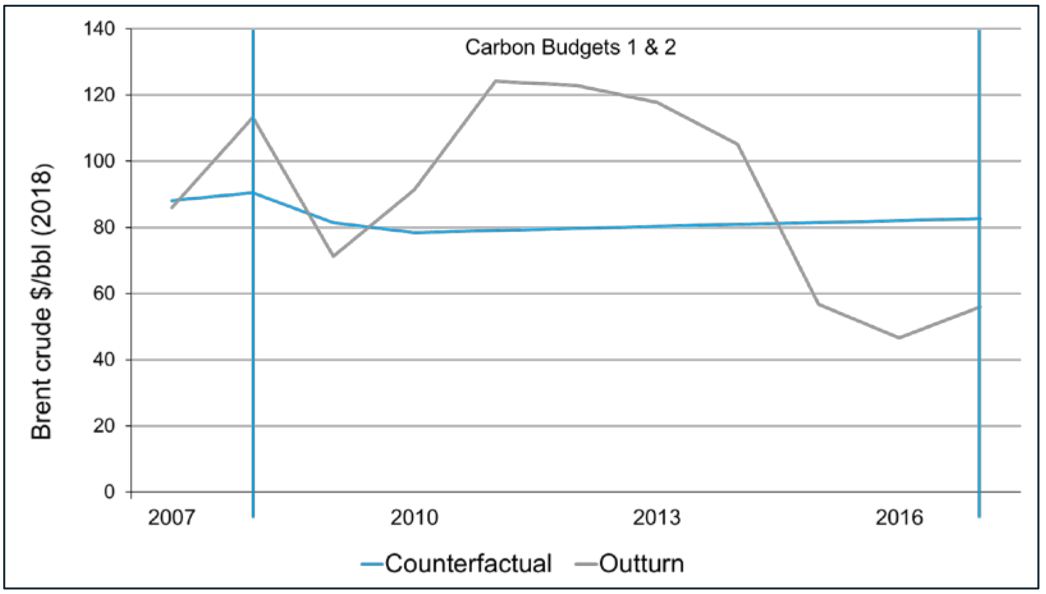


Figure 2.4 Manufacturing GVA (£bn) in counterfactual scenaio and outturn data



Over the first carbon budget, energy prices were much higher than expected (Figure 2.5). The oil price was much higher than expected by the end of the first carbon budget. In the second carbon budget period, the gap between actual, and expected prices closes as fossil fuel prices dropped sharply around 2015 and dipped below the expected (counterfactual) price by the end of the second carbon budget period.

Figure 2.5 Oil Price



The econometric specification is estimated using data from 1970-2017. We estimate across 21 end-use sectors based on the data classifications in the Digest for UK Energy Statistics (DUKES)[4]. The estimation is then further disaggregated across 8 fuel types covering both the large fuel types (Coal, Gas, Electricity) but also splitting out oil use into the specific oils to better model specific fuel users such as petrol and diesel use by road transport.

Only a few sectors account for the majority of UK energy related emissions

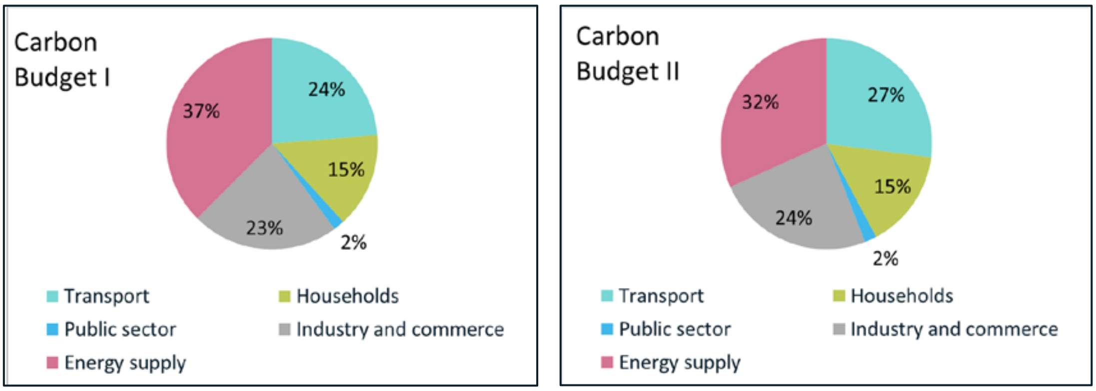
Across the 21 broad end-use sectors modelled, a relatively small number of energy users account for most UK energy-related CO_2 emissions[5]. Across the first and second carbon budgets, the contributions of each broad end-use sector to total UK energy-related CO_2 emissions remains mostly unchanged.

Over the second carbon budget, transport and industry energy use emissions each account for almost a quarter of total UK energy-related CO_2 emissions (27% and 24% respectively). The energy supply sector (electricity supply, refining and oil and gas extraction) remains the largest single contributor (32%) and households accounted for 15% of total UK energy-related CO_2 emissions over the second carbon budget period.

[4] See Appendix A for full list of fuels and fuel users included in CCC spreadsheet model

[5] And energy-related CO_2 emissions account for most UK GHG emissions

Figure 2.6 Contribution of each sector towards total energy-related CO_2 emissions



NB: Shares represent share of total UK energy-related CO_2 emissions

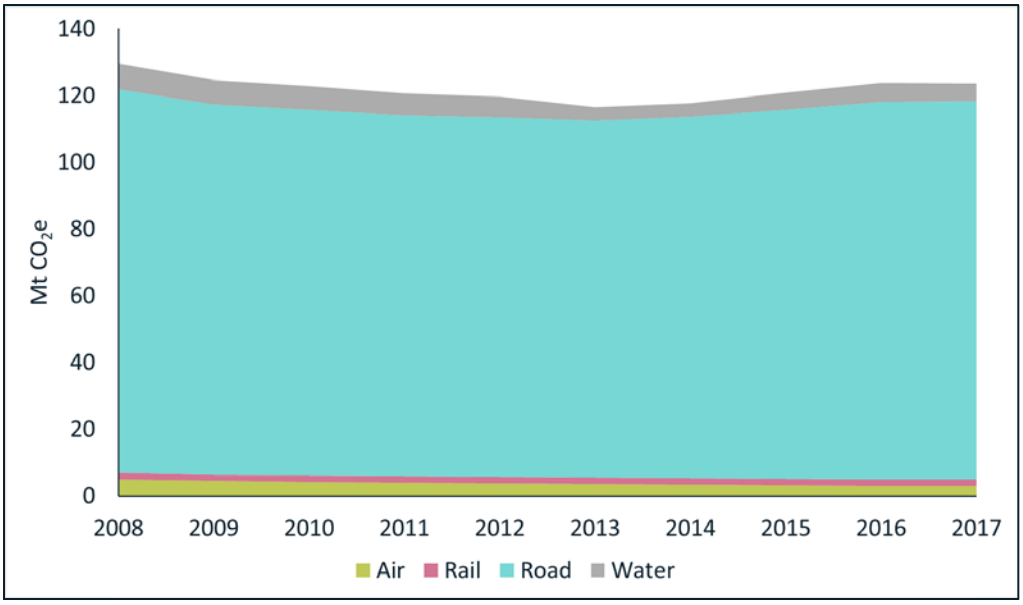
2.3 Transport Emissions

Significant emissions from road transport

Transport emissions are a large share of total UK energy use emissions. The combustion of petrol and diesel in motor vehicles in the road transport sector leads to significant CO_2 emissions. As of 2017, over a quarter of all UK energy-use related emissions arise from the road transport sector.

Domestic aviation[6], inland waterways, and rail transportation contribute a relatively smaller share of emissions. Combined, they contribute to less than 10% of total transport emissions by 2017. The road transport sector accounts for by far the most transport-related emissions. Figure 2.7 summarises total transport emissions, and the large contribution from road transport to this total for the sector.

Figure 2.7 Transport sector energy use emissions (2008-2017)



[6] International aviation and shipping are not included in the carbon budgets.

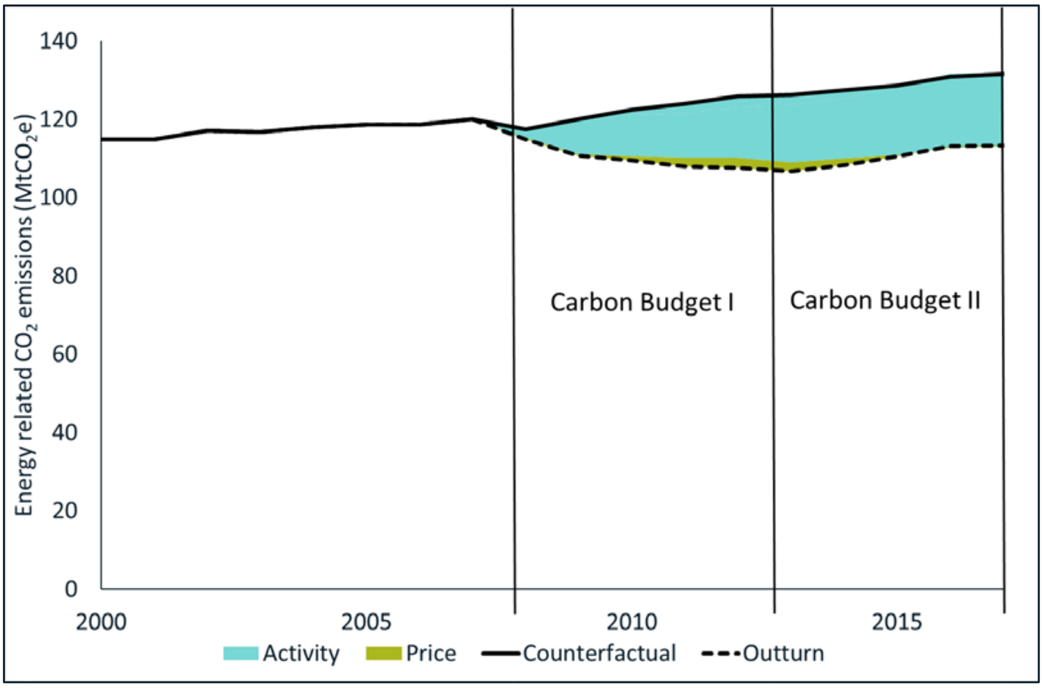
Figure 2.8 shows energy-based emissions in the counterfactual scenario and outturn data for the road transport sector, identifying the effects of each condition that contributed to the estimated difference between counterfactual and outturn emissions.

Road transport fuel prices in the counterfactual scenario are lower than were realised in the outturn data, but the responsiveness of road transport to oil prices is low. This partly reflects the high proportion of the final price made up by fixed fuel duty which does not change between the two scenarios.

Most of the difference in road transport emissions is driven by effects of the economic crisis

The overwhelming difference in energy-based emissions between the two scenarios is driven by the effects of the economic crisis. Expectations for economic activity in the road transport sector were 15% higher than the outturn data by the end of the first and second carbon budgets. Had economic activity been consistent with expectations at the time the carbon budgets were set, energy-based transport emissions would have been 16% higher by 2017.

Figure 2.8 Impact of external conditions on road transport CO_2 emissions



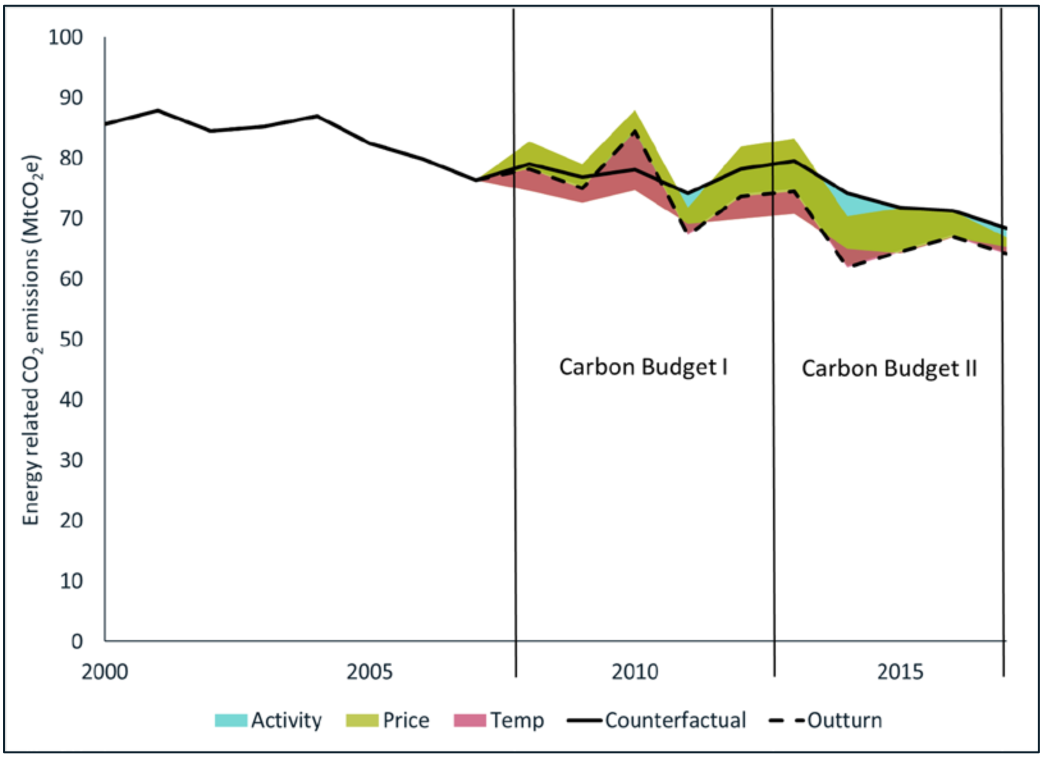
2.4 Households

Household emissions are a significant component of energy-based emissions, comprising approximately 15% of total UK energy-based emissions in 2017 (64 $MtCO_2e$) and are primarily driven by natural gas consumption for heating.

Household emissions have been on a generally downward trajectory since 2004

Figure 2.9 presents total energy-related household emissions in the outturn data and counterfactual scenario and highlights the contribution of various conditions towards the estimated difference between outturn and counterfactual emissions. Household emissions have been on a generally downward trajectory since 2004, increasing in some years where temperatures were on average cooler.

Figure 2.9 Impact of external conditions on households CO_2 emissions



Household emissions are driven largely by heating demand and are particularly sensitive to changes in temperature conditions

Since household energy-use emissions are driven largely by heating demand, household emissions are particularly sensitive to changes in temperature conditions. In years where mean temperature drops lower than average, (as in 2010, 2012, and 2013), there is an increase for heating demand from households and so emissions increase too. If temperatures had followed the counterfactual assumptions in those years, emissions from households would have been much lower (the bottom of the magenta area in Figure 2.9).

Over the second carbon budget period, average air temperatures were similar to the recent mean temperature (the temperature assumption for the counterfactual) and household emissions were therefore not greatly affected.

Economic activity has little impact on heating demand (income elasticity of energy demand is low), but households are responsive to prices. As a result, had the gas prices been lower (as expected in the counterfactual scenario for Carbon Budget 1), we would have expected more gas demand from households leading to higher CO_2 emissions.

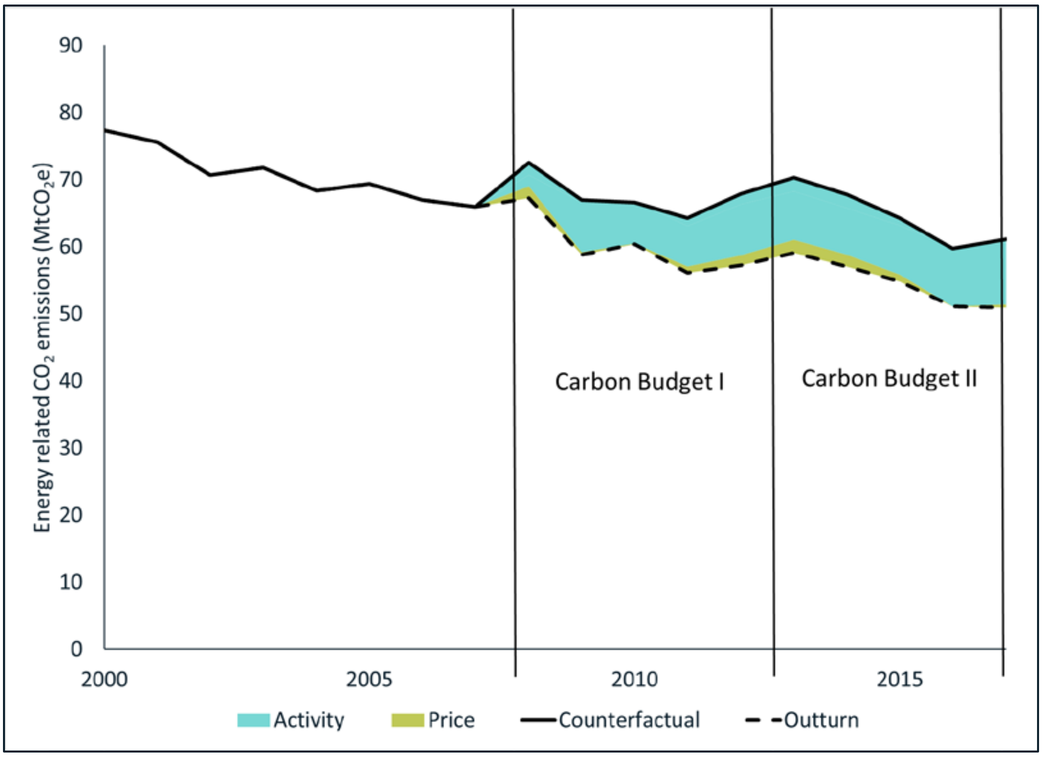
2.5 Industry and Commerce

Energy related CO_2 emissions from industry and commerce arise from various energy-intensive industrial processes, and as a result of heating demand in commercial buildings.

Economic conditions were the most important driver of the difference between outturn and counterfactual emissions

Figure 2.10 summarises energy-based CO_2 emissions in the counterfactual scenario and outturn data, and the impact of conditions towards the estimated difference in emissions. Economic conditions were the most important driver of the difference between outturn and counterfactual emissions for industry: manufacturing output was 22% lower by 2017 than the government's assumption for manufacturing output when the carbon budgets were set. Had assumptions about economic conditions been consistent with expectations when the carbon budgets were set, energy-based industrial and commercial emissions would have been 11% higher over the first carbon budget, and 16% higher over the second carbon budget.

Figure 2.10 Impact of external conditions on industrial and commercial CO_2 emissions



Prices are estimated to have a small impact on the difference between estimated counterfactual energy-related emissions and observed outturn emissions. Observed industrial and commercial energy prices were estimated to be around 6% higher than the counterfactual assumptions over the first carbon budget and were broadly the same as in the counterfactual over second carbon budget. The effect of the higher prices in the early period was to slightly lower energy demand and emissions. This effect starts to be reversed by the end of the second carbon budget.

Industrial and commercial heating and cooling is not sensitive to changes in temperature, and the results are dominated by emissions from energy-intensive industrial processes.

Emissions from industry and commerce fell sharply because of the global recession

Table 2.1 summarises disaggregated industrial and commercial energy-related emissions over the two carbon budget periods for the outturn data and counterfactual scenario. Cumulative emissions for many heavy-industry sectors decrease significantly between the first and second carbon budget periods in the outturn data – energy-based emissions from the iron and steel sector decrease by 27% and emissions from the chemicals by 18%.

Energy-based CO_2 emissions from industry would have been much higher in nearly every sub-sector had the recession not occurred and manufacturing output had tracked the assumptions made when the carbon budgets were set. Food, Drink and Tobacco goes against the trend, as output in this sector was better than expected despite the financial crisis.

Table 2.1 Energy-based emissions for each carbon budget period for disaggregated industrial and commercial sectors ($MtCO_2e$)

	Carbon Budget I: 2008 - 2012		Carbon Budget II: 2013 - 2017	
	Outturn	Counterfactual	Outturn	Counterfactual
Iron and steel	23.4	27.9	16.9	20.1
Non-ferrous metals	4.9	7.1	5.8	7.4
Mineral products	46.9	51.3	38.8	45.4
Chemicals	54.1	71.6	44.4	69.0
Mechanical engineering	12.9	15.5	19.0	22.6
Electrical engineering	5.9	7.9	6.4	9.2
Vehicles	16.7	16.7	18.8	18.6
Food, drink, and tobacco	47.3	45.0	46.0	44.9
Textiles, clothing, and leather	11.7	11.8	8.6	8.7
Paper, print, and publishing	25.5	27.7	16.3	17.8
Other industry	21.4	25.9	20.2	23.7
Construction	8.5	8.9	10.4	10.5
Total	279.2	317.3	251.6	297.9

Power Generation

Policy measures have led to rapid decarbonisation of the UK power sector

The UK has pursued a variety of policy measures that have led to significant decarbonisation of the power generating sector. These efforts are important given the large contribution of the power generation sector to total UK emissions, approximately a third of total energy-related UK emissions as of 2017. Overall, the significant reduction in emissions from the power sector has come from lowering the carbon intensity of electricity generation, as renewables have increased, and coal has decreased (displaced by gas and renewables). There has also been a decrease in total electricity demand of around 15% between 2008 and 2017, which has also contributed to the reduction in emissions from the power sector over the period.

Figure 2.11 Emissions intensity of power generation

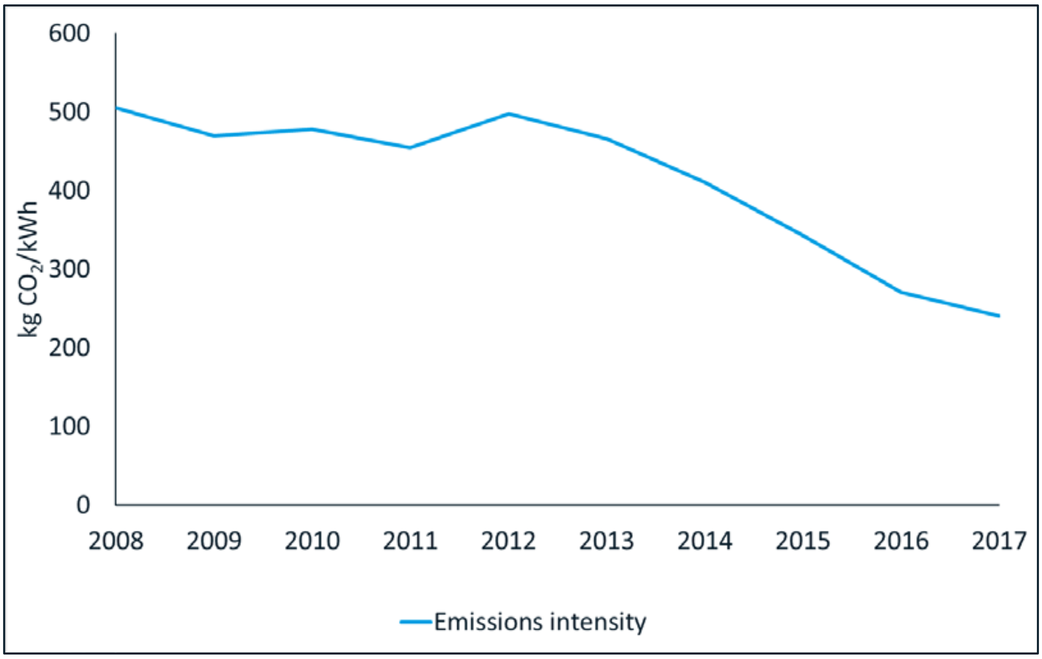
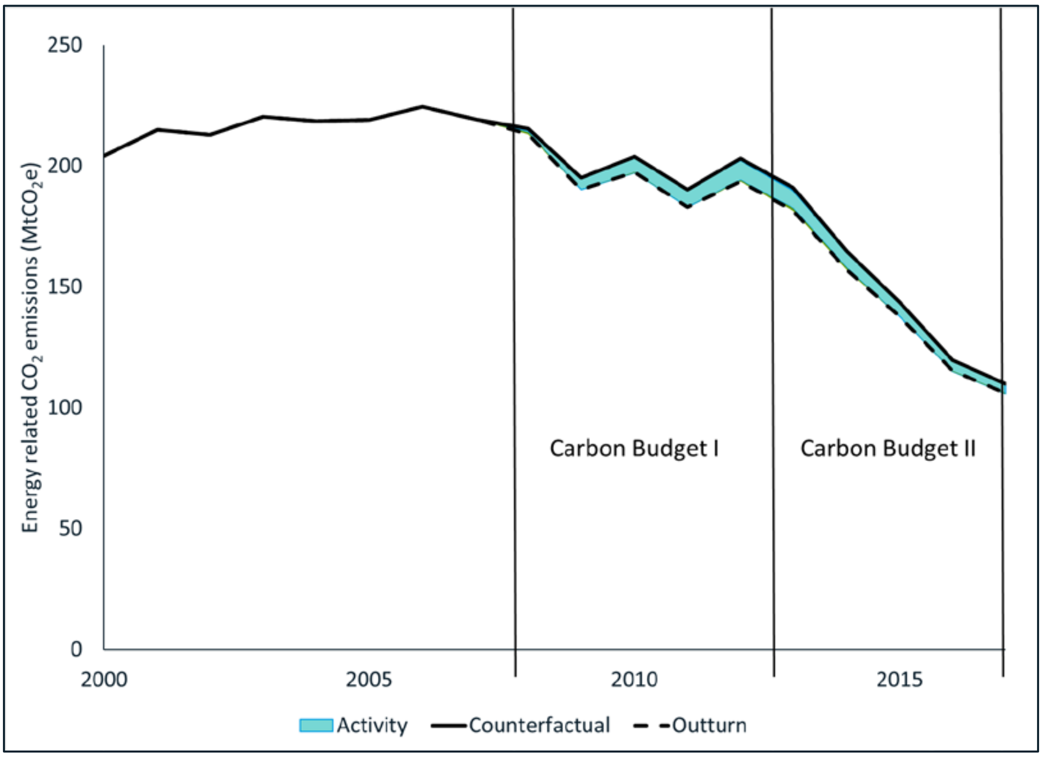


Figure 2.12 shows energy-related emissions in the counterfactual scenario and outturn data for the power sector, identifying the effects of each condition that contributed to the estimated difference between counterfactual and outturn emissions.

We estimate a weak, but positive, relationship between the demand for electricity and economic growth. The difference in emissions between the counterfactual scenario and outturn data mostly captures the difference in electricity demand, as a result of lower economic activity than expected when the carbon budgets were set (Figure 2.12). As with other sectors we are only isolating the impact of conditions; successful measures to lower emissions from the power sector are present in both scenarios.

Prices are estimated to have had a very small impact on the demand for electricity (our estimates imply that most sectors are relatively unresponsive to changes in electricity prices). We do not attempt to capture fuel switching in the power sector as a result of different prices as this analysis only looks at the demand for energy.

Figure 2.12 Impact of external conditions on power sector CO_2 emissions



2.6 Concluding remarks

Emissions reductions explained by deviations from expected conditions - mainly economic conditions

The analysis suggests that external conditions made a significant impact on energy related CO_2 emissions (and therefore total UK domestic greenhouse gas emissions) throughout the period covering the first two carbon budgets.

Table 2.2: Impact of external conditions on greenhouse gas emissions

	Carbon Budget 1 ($MtCO_2e$)	Carbon Budget 2 ($MtCO_2e$)
Counterfactual greenhouse gas emissions estimate	3,081	2,713
Net effect of economic activity	-116	-166
Net effect of fossil fuel prices	-38	-43
Net effect of temperature	18	-1
Outturn greenhouse gas emissions	2,945	2,503

The global financial crisis that was triggered by the collapse of Lehman Brothers in May 2008 led to a recession that was not anticipated when the first three carbon budgets were being set. As a result, carbon budgets were set using a projection for economic activity (GDP) that was 14.5% higher than outturn GDP by 2017. In manufacturing the gap between projection and outturn was even greater, 22% by 2017. We estimate that this difference contributed to outturn greenhouse gas emissions being 116 $MtCO_2e$ lower in the first carbon budget period and 166 $MtCO_2e$ lower in the second carbon budget period.

Fossil fuel prices have been generally higher than predicted by the government when the carbon budgets were set leading to lower energy demand and emissions. In 2008 there was a spike in fossil fuel prices. The global recession in 2009 brought these prices crashing back down, but only temporarily. For most of the period 2008 to 2017, fossil fuel prices were higher than expected when the carbon budgets were set. Only in the last few years have outturn fossil fuel prices been slightly lower than expected. We observe long lasting effects to the price spikes in the early period, such that we estimate outturn emissions 38 $MtCO_2e$ and 43 $MtCO_2e$ lower in carbon budgets 1 and 2, respectively.

As with any econometric approach, there are limitations to consider. One common limitation is omitted variable bias. Although the econometric specification covers the principal drivers of energy demand (economic activity, energy prices, outside temperatures), this is a necessary simplification. It is possible therefore, that we have over and/or under attributed the impact of each condition in different sectors. However, the estimated parameters used are broadly in line with the literature and, in our view, this simplification does not affect the broad messages of this report.

The next chapter puts this into the context of the net carbon account and specifically focusses on how the second carbon budget was met.

3 How the second carbon budget was met

3.1 Summary

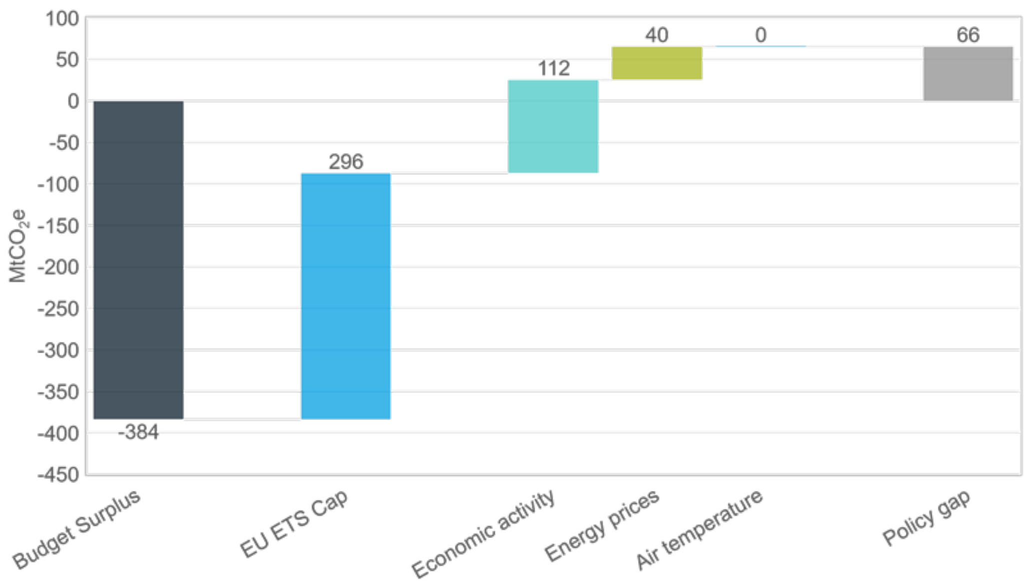
Our research finds that the carbon budgets were only met because of accounting changes to the EU Emissions Trading System (ETS) and economic conditions turning out very differently from the government's assumptions when setting the first three carbon budgets.

The large surplus in the second carbon budget was achieved as a result of revisions to the EU ETS and weak economic conditions. After accounting for these factors, we conclude that sufficient policy measures have not been put in place during the first two carbon budgets

As shown in Figure 3.1, an accounting change to the UK's share of the ETS cap (section 3.2) was the most significant contribution to the overachievement of the second carbon budget, at 296 $MtCO_2e$. When the carbon budgets were set, the UK government expected the traded sector cap to be 1,078 $MtCO_2e$ over the second carbon budget but this was before the rules for Phase III of the EU ETS had been finalised. Following the legislation of the EU ETS, the outturn cap ended up at 782 $MtCO_2e$. This accounting change was not reflected by an equal change in the carbon budget and effectively meant that there was an additional 296 $MtCO_2e$ of headroom in the non-traded sector (the CCC refer to this as 'hot air'). This meant that the second carbon budget was easily met as a result of changes in accounting and not by measures to lower carbon emissions.

After allowing for accounting revisions to the EU ETS, our analysis shows that had the global financial crisis not occurred, and economic growth and fossil fuel prices had been as expected, the second carbon budget would have been missed by 66 $MtCO_2e$, suggesting that there is a substantial policy gap for carbon emission reductions measures.

Figure 3.1: The impact of EU ETS revision and conditions on the second carbon budget



3.2 EU ETS Cap changes

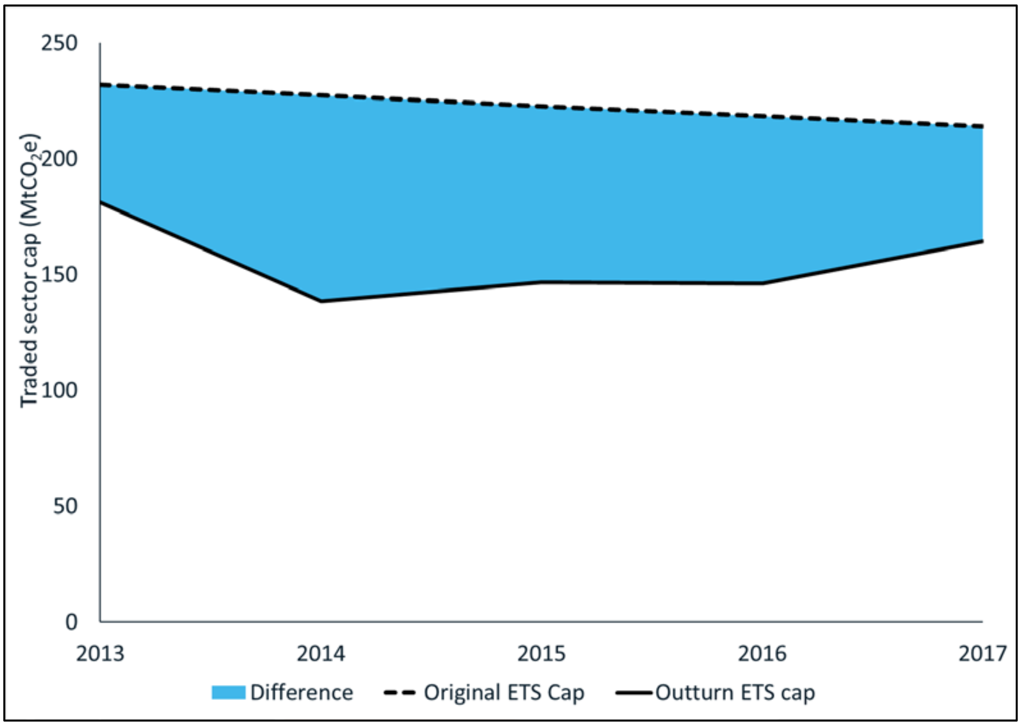
The Carbon Budgets include a traded sector and a non-traded sector component. The traded sector component is intended to be consistent with the EU Emissions Trading System (ETS) and allows for the sale and purchase of emissions permits over the border. The traded sector includes emissions from the power sector, other energy sectors such as oil and gas extraction and refining, some carbon intensive manufacturing (such as the manufacture of iron and steel), and intra-EU flights. By definition, the traded sector cap cannot be missed because there must be purchases of EU ETS permits to offset.

At the time of setting the first carbon budget, the UK's EU ETS cap was known and the period, 2008-12, was exactly aligned with the second phase of the EU ETS.

However, the second carbon budget was also legislated at this time but the cap for the EU ETS and the UK's share of the cap for the period, 2013-2017, had not been finalised at that time, only indicatively proposed. The third phase of the EU ETS runs from 2013 to 2020, and therefore covers the second and part of the third carbon budget. In the interim period the EU ETS rules were finalised leading to a tighter overall cap and the UK's share was reduced. This was not reflected in the carbon budget. For the second carbon budget (2013-2017) the UK's traded sector cap was expected to be 1,078 $MtCO_2e$, but the outturn was around 782 $MtCO_2e$, a difference of 296 $MtCO_2e$ (the blue area in Figure 3.2). This revision represents nearly a 30% reduction in traded sector emissions under the EU ETS cap.

The reduction in the cap directly translates to a reduction in the outturn against the carbon budget. Since the carbon budget has not been revised to take account of the difference between the expected traded sector cap and the

Figure 3.2 Revisions to UK traded sector cap



outturn cap, there is effectively an additional 296 $MtCO_2e$ of headroom ('hot air') in the non-traded part of the second carbon budget.

Looking ahead to Carbon Budget 3 covering the period 2018-2022, at 985 $MtCO_2e$, the traded sector cap proposed is much higher than traded emissions from the second carbon budget. From a legislative perspective, then, without any change to the third carbon budget it is highly likely that carbon budget will be comfortably met again if only because of this accounting change.

3.3 Impact of external conditions on Carbon Budget 2

Chapter 2 set out the impact of three external conditions on domestic greenhouse gas emissions:

- economic activity
- fossil fuel prices
- external temperature conditions

This section assesses the impact of each of these on ***the net carbon account*** to assess the contribution of each condition to performance against the second carbon budget. There are differences in the figures because some of the extra emissions observed in the counterfactual scenario came from the traded sector and therefore did not contribute to the net carbon account but instead led to an increase in purchases of emissions permits.

Table 3.1 shows the net carbon account across the second carbon budget period. The net carbon accounts for the outturn are presented alongside the counterfactual scenario and the isolated effect arising from each condition included in the counterfactual scenario: economic activity, energy prices, and air temperature. For the second carbon budget, the outturn traded sector cap is used in the outturn scenario but the initial budget figure is used in the counterfactual.

Changes in economic activity were largest driver of difference between outturn and counterfactual emissions

Of the three conditions assessed, changes in economic activity had the largest impact on the difference between outturn and counterfactual emissions. This is clear from analysing the effects of conditions on emissions by broad sector level (see section 2.3 through 2.6) and when considering the net carbon accounts.

Had economic activity been consistent with expectations at the time the first and second carbon budgets were set (and all other conditions were consistent with the outturn data), the net carbon account (rather than total GHG emissions) in the second carbon budget period would have been 112 $MtCO_2e$ higher. This would have meant that the carbon budget was missed.

Prices and temperature do not have as large an effect on performance against the second carbon budget. By isolating the effect of changes in prices, we find that emissions (on a net carbon account basis) would have been 40 $MtCO_2e$ greater in the second carbon budget, had prices been consistent with expectations when the budgets were set. This happens despite assumed fossil fuel prices in the counterfactual averaging similar levels to the outturn prices, instead the change in energy demand and emissions is driven by changes brought about from price spikes in the earlier period which had long lasting effects.

Prices and temperature do not have as large an impact on performance against the first and second carbon budgets

Temperature has a relatively small impact on total emissions. Over the second carbon budget period, outturn temperatures were similar to the recent average (the assumption for our counterfactual scenario is the average between 2000 and 2008) and so differences in air temperatures in this period had no discernible impact.

Table 3.1 Carbon budget II: net carbon account

	Outturn data and counterfactual scenario		*Effects of each condition compared to outturn (absolute difference $MtCO_2e$)*			
	Outturn	**Counterfactual**	**Economic activity**	**Fossil fuel prices**	**Air temperature**	**EU ETS (changing the traded sector cap)**
Traded Sector CO_2	887	944	*53*	*3*	*0*	*0*
Traded Sector Cap	782	1,078	*0*	*0*	*0*	*296*
Net Purchases (-) / Sales	-105	134	*-53*	*-3*	*0*	*296*
Non-Traded Sector CO_2	1,153	1,307	*112*	*40*	*0*	*0*
Non-Energy CO_2	16	16	*0*	*0*	*0*	*0*
Non-CO_2 GHGs	447	447	*0*	*0*	*0*	*0*
Total GHGs	2,503	2,713	*165*	*43*	*0*	*0*
Net Carbon Account	2,398	2,848	*112*	*40*	*0*	*296*
Carbon Budget	2,782	2,782	*0*	*0*	*0*	*0*
Performance	-384	+66	*+112*	*+40*	*0*	*+296*

3.4 Concluding remarks

Only by implementing measures that have long-lived impacts on reducing carbon emissions will we meet future budgets

That the second carbon budget has been met only because of the wider economic conditions rather than through effective policy measures is significant. By 2050, the CCC has recommended a net zero carbon target for the UK. To meet that target, economic growth must become completely decoupled from producing greenhouse gas emissions. That can only be achieved by implementing measures that remove carbon entirely from our daily economic activities and not, as it has largely been to date in the non-traded sectors, by a reduction in that activity.

The second carbon budget was not met by putting in place sufficient policy measures. Instead, we find that after accounting for changes to the EU ETS and the impact of external conditions, there is actually a policy measures gap of 66 $MtCO_2e$.

4 Uncertainties affecting carbon budgets

4.1 Summary

The assessment of carbon budgets relies on robust data, most pertinently data on greenhouse gas emissions from the National Atmospheric Emissions Inventory (NAEI). The data in the inventory is continually being improved and so we can have increasing confidence that the data is providing insight. However, as the data is improved, the historical levels of greenhouse gas emissions are revised upwards and downwards while the carbon budgets are not revised to take account of this. The major revisions are relatively largest in the non-CO_2 greenhouse gas emissions and, specifically, the conversion of these gases to CO_2 equivalence.

By extrapolating each previous vintage (release) of data forward in line with the growth rates in the most recent vintage, at a summary level, we estimated the range of changes in the levels of greenhouse gas emissions data on the second carbon budget.

Data revisions have been significant and the range of data revisions over the past eleven revisions (at 154 $MtCO_2e$) is larger than our estimated policy gap (66 $MtCO_2e$) and the government's estimated surplus for carry-over (88 $MtCO_2e$). Depending on which vintage of data had been used, the policy gap might have been 55 $MtCO_2e$ higher (i.e. 119 $MtCO_2e$) or 99 $MtCO_2e$ lower (the budget would have been met by 35 $MtCO_2e$ even if the conditions had turned out as the government expected at the time of setting the budgets).

Uncertainty also arises from the analytical approaches used. Cambridge Econometrics assessed this in a previous report for the CCC in 2015 "Quantifying Uncertainty in Baseline Emissions Projections", which attempted to quantify some of the uncertainty in the type of modelling approach used to inform carbon budgets.

The range of uncertainty quantified in the 2015 report is consistent with our findings in this research, that the government effectively overestimated baseline emissions in the second carbon budget period by 8% as a result of external conditions not turning out as anticipated.

Overall this presents an intractable problem for setting future carbon budgets because the uncertainty is inherent (in the data and the approach) and there is a requirement to set a single figure into the legislation between ten and twenty years ahead of time (the next budget legislated will be the 6th for the period 2033-37).

Instead of trying to solve the problem, it's worth considering some of the options available to the government to support better outcomes:

- extend the scenario planning methods[7] used to inform carbon budgets
- develop more flexible legislation that allows carbon budgets to be revised
- compiling a range of additional indicators that inform progress

[7] As part of developing the Updated Energy and Emissions Projections (EEP) which are used as the baseline for developing carbon budgets, the government undertakes a simple scenario analysis for different economic growth and fossil fuel price scenarios.

4.2 Data revisions

The greenhouse gas emissions data used to set and assess carbon budgets are revised regularly. The first three carbon budgets were set on the basis of the 2008 vintage of the National Atmospheric Emissions Inventory (NAEI), which had 2006 as the last year of data. Since then there have been eleven updates and each time, as well as adding an extra year of data, the historical data set was revised to reflect improvements in measuring and collecting the data. The assessment of the second carbon budget makes use of the 2019 vintage of the NAEI data in which 2017 is the last year of data.

Revisions to NAEI data affect the assessment of performance against carbon budgets

Changes to the NAEI data are important to consider in assessing performance against the carbon budgets because revisions to the data are not reflected in revisions to the legislated carbon budget levels. A downward revision to the data would contribute to meeting (and outperforming the budget) whereas an upward revision to the data would contribute to missing the budget. Effectively the assessment of the carbon budget is done using a different data set to the one it was set on.

Revisions to the data have moved upwards and downwards between revisions and not persistently in one direction. The revisions have also been significant, especially in non-CO_2 GHG emissions, contributing directly to the carbon budget performance as they do not fall within the traded sector. Non-CO_2 GHGs have been revised more than CO_2 partly because of changes in climate science to measure the global warming potential of these gases in CO_2 *equivalence*. In the 2011 vintage, non-CO_2 GHGs were measured at 94 $MtCO_2e$ in 2007. This was revised to 130 $MtCO_2e$ in the 2015 vintage, but by the 2019 vintage the 2007 non-CO_2 data had been revised back to 117 $MtCO_2e$.

Figure 4.1 Extrapolated emissions for 2019 and 2008 data releases

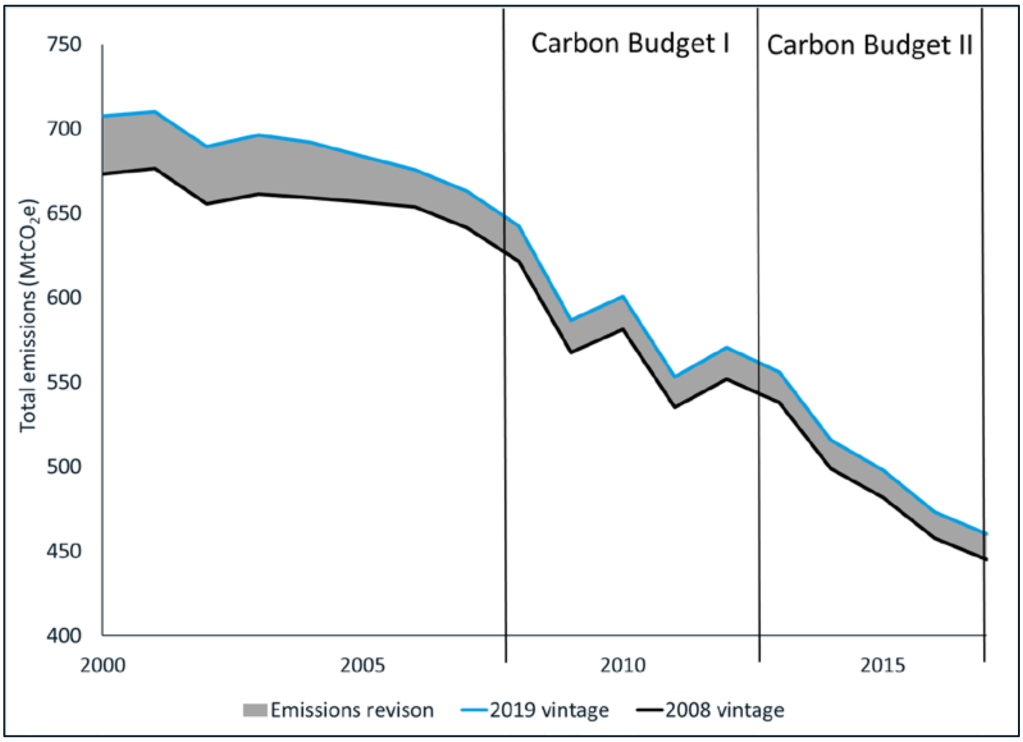


Table 4.1 shows the estimated impact of revisions to the GHG data inventory. We extrapolated each vintage of data over the recent historical period using the growth rates in the most recent (2019) vintage of data. For each vintage of data, we then estimate the total greenhouse gas emissions in the second carbon budget period and compare this to the 2019 vintage.

Performance against the carbon budgets is sensitive to revisions of NAEI data

Table 4.1 Data Revisions

Data vintage	Estimated greenhouse gas emissions in Carbon Budget 2 (excluding trading) ($MtCO_2e$)	Absolute difference in emissions compared to 2019 vintage ($MtCO_2e$)	Relative difference in emissions compared to 2019 vintage (%)
2008	2,422	-81	-3.3
2009	2,410	-93	-3.7
2010	2,430	-73	-2.9
2011	2,405	-99	-3.9
2012	2,449	-54	-2.2
2013	2,492	-11	-0.5
2014	2,525	22	0.9
2015	2,558	55	2.2
2016	2,500	-3	-0.1
2017	2,498	-5	-0.2
2018	2,479	-24	-1.0
2019	2,503	-	-

By extrapolating the data, we estimate a range of uncertainty from the previous eleven vintages compared to the most recent data vintage of between -3.9% and +2.2% (a range of 6.1%). Had improvements to the data collection not happened, we might have estimated emissions to be either 3.9% (99 $MtCO_2e$) lower based on the 2011 vintage or 2.2% higher (55 $MtCO_2e$) based on the 2015 vintage. Future revisions to the data might mean the budget was exceeded by even more than originally estimated or, conversely, that it was missed.

This uncertainty range (154 $MtCO_2e$) is larger than the outperformance against the second carbon budget after accounting for revisions to the EU ETS (88 $MtCO_2e$) and our estimate of the policy gap (66 $MtCO_2e$).

4.3 Modelling Uncertainty

Uncertainty also arises from the analytical approaches used. Cambridge Econometrics assessed this in a report for the CCC in 2015 "Quantifying Uncertainty in Baseline Emissions Projections", which attempted to quantify some of the uncertainty in the type of modelling approach used to inform the government's "Updated Energy and Emissions Projections" (EEP), which provide baseline for setting carbon budget, specifically:

- the omission of recent trends in each sector that, in our view, would not be captured in the parameters
- the statistical error in the parameter estimates used in the econometric model
- the range of plausible assumptions used in developing baseline emissions projections including the three external conditions discussed in this report (economic activity, fossil fuel prices and external temperatures)

Overall, the study found that the range of modelling uncertainty in projections 20 years ahead was expected to be around 34% of the central estimate (at a 95% confidence interval). The approach was slightly more likely to overestimate than underestimate emissions as the range around the central estimate was +15% and -19%.

Beyond the quantifiable uncertainty considered in the 2015 study, we noted that there is clearly also an inexhaustible list of unpredictable and unquantifiable uncertainty that would have an unknown impact. This could include:

- disruptive technological breakthrough
- societal-scale behavioural change
- geo-political shocks with long-lived consequences
- economic crises

The quantified uncertainty is broadly consistent with our findings in this research: the government overestimated baseline greenhouse gas emissions in the second carbon budget period (five to ten years ahead) by 8% as a result of data revisions, external conditions and particularly economic growth not turning out as anticipated.

This matters for policy and carbon budgets. The government's baseline emissions projections are, we would argue, reasonable predictions considering the difficulty and inherent uncertainty in making quantified and detailed predictions five, ten and twenty years into the future. However, the result has led to carbon budgets set too high and, as a result comfortably met without the required policy effort. Given that the economy is not going to suddenly catch up with the pre-recession assumptions, this is also likely to persist into at least the third carbon budget.

Overall this presents an intractable problem for setting future carbon budgets because the uncertainty is inherent and there is a requirement to set a single figure into the legislation between ten and twenty years ahead of time (the next budget legislated will be the 6th for the period 2033-37).

Instead of trying to solve the problem, it's worth considering options available to the government to support better outcomes:

- extend the scenario planning methods to look at a broader range of plausible futures (including negative outcomes e.g. a recession) and, depending on the outcomes, consider setting conditional carbon budgets
- develop more flexible legislation that allows carbon budgets to be set with a long lead time but revised nearer the time, perhaps by;
  - determining upper limits for carbon budgets based on climate science, scenarios for effective transition pathways, and the UK's role within the wider international policy context
  - revise these ***downwards*** depending on progress against budgets, economic and other external conditions, and revisions to the data
- compile a range of other indicators that inform progress towards emissions reduction and regularly evaluate progress against these to support assessments of whether (and how) carbon budgets are met

There is a relevant quote about making predictions from Nils Bohr "Prediction is very difficult, especially if it's about the future". In practice this means applying some caution about any projections and the extent to which they can be relied upon for setting legislation ten to twenty years into the future.

4.4 Changes in parameters over time

As part of this research, we also assessed the impact of whether the parameters changed over time by undertaking the analysis using two sets of explanatory parameters:

- parameters estimated from 1970-2017: our best estimate of the impact that conditions had on emissions (these are the basis for the results presented in the report)
- parameters estimated from 1970-2007: an estimate of what would have been attributed to the conditions at the time the carbon budgets were set

Table 4.2: Comparing results across two sets of parameters

	Carbon Budget 2 ($MtCO_2e$) 1970-2017 parameters	Carbon Budget 2 ($MtCO_2e$) 1970-2007 parameters
Counterfactual greenhouse gas emissions estimate	2,713	2,738
Net effect of economic activity	-166	-168
Net effect of fossil fuel prices	-43	-61
Net effect of temperature	-1	-4
Outturn greenhouse gas emissions	2,503	2,503

The impact of excluding the years 2007 onwards is to increase the impact of the counterfactual scenario relative to the outturn, suggesting that over the first and second carbon budget period, there is a reduction in the responsiveness to all external factors. This reduction, as illustrated in Table 4.2 is quite small, which suggests robustness in the parameters. However, it does also weakly indicate that the responsiveness to external conditions (and price in particular) is smaller if we account for the last ten years of data, which, in turn, might indicate limited progress in lowering the aggregate carbon intensity of the economy.

5 Lessons learnt

This research provides robust evidence that the UK's first and second carbon budgets were met not by policy but predominantly because of the substantial reduction in economic activity as a result of the global financial crisis. After accounting for changes to the traded sector cap, we estimate that in aggregate external conditions contributed to a reduction in emissions of 154 $MtCO_2e$ over the second carbon budget, and that without the global financial crisis the second carbon budget would not have been met. Moreover, we have also shown that there is considerable uncertainty in the data to the extent that while we can be reasonably sure the carbon budget was met, we cannot rule out that subsequent data revisions might significantly reduce (or increase) the overachievement. At present, such revisions to the data would not lead to revisions in the carry-over amount.

In our view these findings have implications for the use of the budget surplus to offset against future carbon budgets and the methodology for setting carbon budgets. These implications are discussed in the next two sections and summarised as policy recommendations at the end of the chapter.

5.1 Carrying over the surplus

One of the flexibilities in the carbon budgets is that surpluses can be carried over from one budget period to the next to help support a low-cost transition to a low, and now zero, carbon economy by 2050. This is a useful design feature and is based on climate science and the political context at the time of setting carbon budgets. From a scientific perspective, it is the accumulation of long-lived greenhouse gases in the atmosphere over time that matters (the stock of emissions) and so if the UK's domestic emissions are within the combined budgets it is largely (but not entirely) irrelevant whether they were emitted, for instance, in 2015 or 2020. From a political context, if the UK's emissions are within the combined budgets then the government could consider the transition a success and that the UK has met its international and legal obligations.

However, there are several strong reasons to not carry-forward the surplus. The first two are direct outcomes from this analysis and the third one links our findings to the wider observation about the change in the international policy context. This does not present a fully comprehensive set of arguments to not carry forward the surplus but rather arguments based on the findings from this report.[8]

- The second carbon budget was not met because of measures but rather by external conditions. Had these conditions been known with perfect foresight at the time the budgets were set, the budgets would have been set tighter. Moreover, the weak economic activity that has been observed is now thought to be a permanent loss to GDP rather than temporary, as part of the business cycle

[8] The CCC's full advice on this was published in February 2019, taking into account the whole range of factors required under the Climate Change Act.

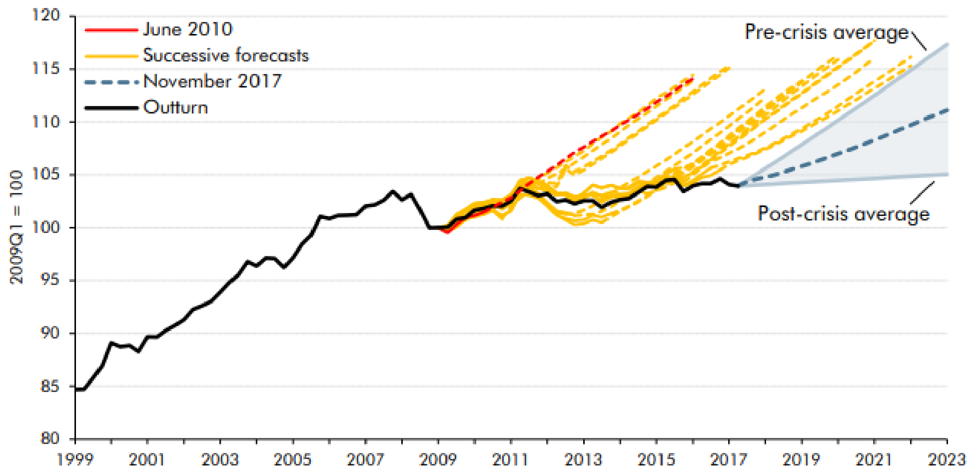
- There is considerable uncertainty in the data that means we cannot be certain of the size of the proposed carry over (currently estimated at 88 $MtCO_2e$, the surplus after allowing for the outturn traded sector cap)
- The domestic and international policy context has changed in light of the Paris agreement and global commitment to limiting global warming to 1.5^{O}C. In response, the UK has tightened the legally binding target of 80% reduction in emissions by 2050 to a net zero target. The fourth and fifth carbon budgets were set based on an at least 80% reduction and so any action to make the budgets looser (by carrying forward the surplus) could compromise the trajectory needed to get to net zero

The loss to GDP is expected to be permanent and even widening from the long-term trajectory before the global financial crisis, irrespective of the Brexit outcome

The argument to carry-forward the surplus partly hinges on whether the loss in UK GDP is considered temporary or permanent. By 2017, UK GDP was 14.5% lower than expected by the government at the time the carbon budgets were set. This was, of course, the result of the global financial crisis, but also the subsequent weak recovery that has become the new normal over the past ten years. On the one hand, if we now expect a sudden strong recovery, then the argument for carrying over the surplus emissions would be stronger: the reduction in emissions can be attributed to a temporary dip and the surplus will therefore be needed to offset the emissions arising from a stronger economy. On the other hand, if we now expect continued slow growth, or even growth rates similar (but not higher) than those previously expected by government of around 2-2.5% pa, then the output gap will not close, the loss of GDP will be permanent and the rationale for carrying forward the budget surplus is diminished.

The latest evidence suggests that UK GDP growth will remain weak. The government's independent Office for Budget Responsibility (OBR) has persistently over-estimated productivity growth since the financial crisis and in November 2017 downgraded its forecast (see Figure 5.1). Accompanying the downgrade in productivity the OBR stated, "We now expect real GDP to grow by 5.7% between 2017/18 and 2021/22." This is equivalent to a growth rate of 1.4% pa over most of the third carbon budget period compared to between 2% and 2.2% pa assumed when the carbon budgets were set. To summarise, the gap between expected GDP (at the time of setting the first three carbon budgets) and outturn GDP is now expected to widen. Throughout the third carbon budget, economic output is now expected to be between 14.5% and 17.5% lower than expected when the third carbon budget was set.

Figure 5.1: OBR productivity projections, November 2017



As the economic growth outlook is so much weaker than expected when the first three carbon budgets were set, it seems unnecessary to carry over surplus emissions because we can already expect the third carbon budget to be met with significantly less policy effort than first anticipated.

The scale of uncertainty in the data means we should be cautious about the true scale of the surplus on which the proposed carry-over is based

Uncertainty in the data lends itself to taking a conservative approach to carrying over surplus emissions. As discussed in Chapter 4, when data revisions are extrapolated over the second carbon budget period, the implied difference in emissions each vintage dating back to 2008 (twelve vintages) ranges between +99 $MtCO_2e$ and -55 $MtCO_2e$ compared to the most recent vintage (2019). The budget surplus has been calculated on the latest vintage of the data, but as this could be revised in the future (upwards or downwards) it would be imprudent to carry it over. This is especially true since the range of uncertainty (some 154 $MtCO_2e$ over the five-year budget period) is larger than the surplus of 88 $MtCO_2e$ in the non-traded sectors (i.e. the proposed carry over).[9] If the uncertainty were smaller than this surplus, it might be reasonable to carry over a smaller amount by subtracting some amount from the initial surplus to reflect the observed uncertainty range in the data.

Since the carbon budgets were set, both the international and domestic policy context has changed and that has implications for the decision to carry-forward a surplus. Internationally, the Paris Agreement committed the signatories to limit global warming to well below 2.0ºC and pursue efforts to limit the rise to 1.5 ^{O}C. This has led to a disconnect between the global ambition and nationally stated actions. The UN estimates that globally, the gap between the committed action (Nationally Determined Contributions, NDCs) and the required pathway to limit global warming to 1.5 ^{O}C is estimated to be 32 $GtCO_2e$ by 2030[10]. In this context, it seems incongruous to carry forward any emissions surplus that has already been achieved in the UK especially as it is only a result of weak economic conditions rather than government policy.

There is one argument that might be made from our analysis to consider rolling over the surplus. We estimate that the policy measures gap in the non-traded sectors (road transport and buildings particularly) is relatively large (66 $MtCO_2e$ in carbon budget 2) and there is only limited evidence that the UK is on track in rolling out measures that will have permanent (long-lived) impacts by lowering the carbon intensity of the energy-using capital stock. As such, it is possible that the surplus will be needed to offset the lack of policy progress in future carbon budgetary periods. However, while a carry-over might help the government meet its fourth (and fifth) carbon budgets in accounting terms, it does nothing to support the implementation of the permanent measures in these periods that will be required to meet subsequent budgets and because of this puts at risk meeting the long-term targets.

5.2 Approach to setting future carbon budgets

The approach to setting future carbon budgets separates economic activity (and other conditions) from measures. Ahead of any significant action to tackle climate change when the first carbon budgets were set, the approach was to set a baseline scenario which included only limited amounts of earlier policy

[9] This equals the overall surplus of 384 $MtCO_2$ net of accounting changes in the EU ETS of 296 $MtCO_2$.

[10] https://wedocs.unep.org/bitstream/handle/20.500.11822/26879/EGR2018_ESEN.pdf?sequence=10

measures and was effectively a continuation of economic and other conditions. A separate second step is then to determine the extent to which greenhouse gas emissions could be reasonably reduced by implementing (policy) measures.

The baseline scenario is typically taken from the government's Updated Energy and Emissions Projections (EEP). This approach makes use of econometric techniques (and other models) to project forward energy demand and emissions. Recent policy measures will therefore be ***implicit*** in the parameters that are estimated from the recent data, but it becomes extremely difficult to ***explicitly*** quantify the policy impacts that are wrapped up in the baseline. Putting aside the issue of determining future economic conditions, a separate risk here is that the baseline is set too low (and carbon budgets that are set too tight because there is an implicit double counting of policy measures). An alternative could be to estimate parameters excluding the recent data, but that risks setting a baseline that is too high. Our analysis in Chapter 4 shows that parameters estimated over a period not including the first two carbon budgets implied a more carbon intensive economy than parameters estimated over a period including the first two carbon budgets.

Ten years into the transition, we think setting future budgets will require a more nuanced approach as measures and conditions are linked. Going forward, an approach is required in all carbon emitting sectors that explicitly identifies the energy-using (carbon-emitting) capital stock and links it to economic activity. Road transport is an illustrative example of a sector where this can already be done. As observed in the final emissions data there has been little (no) progress to reduce emissions in road transport, but from that data alone it's not possible to observe whether emissions are flat because:

1. travel demand (passenger km) has increased greatly but this has been offset by tremendous gains in vehicle efficiency, or because;
2. travel demand is flat and there have been no gains in vehicle efficiency

Depending on which of these has happened and the dynamics between the two drivers (throughput and carbon intensity), should have a bearing on the level of future carbon budgets and the type of policies pursued. Across all carbon emitting sectors therefore, we recommend developing 'hybrid' approaches where throughput (economic activity, e.g. passenger km) and the carbon intensity of the capital stock can be explicitly tracked, linked together and projected forwards, as the CCC does in its regular progress reports.

Future external conditions are unknown, and it is difficult to project forecasts forward even a few years ahead with reasonable accuracy. The approaches used here should make use of scenario planning techniques and simulate forward alternative scenarios of conditions and policy. Within such proposed modelling frameworks, where the capital stock is explicitly linked to throughput, it should be possible to identify (a minimum set of) measures that must be in place to meet the carbon budgets, regardless of the range of outturn conditions.

Economic activity will matter less as the carbon budgets are set lower, while the carbon intensity of the economy will matter more. In the longer term, the stated ambition is to become a net zero-carbon economy by 2050. Implicitly, the expectation is that this will be done by reducing the carbon intensity of the economy to zero and not by reducing economic activity to zero. As such, it is important to measure progress not only in terms of emissions reductions but also in terms of the carbon intensity of the carbon emitting capital stock such as buildings (thermal efficiency, carbon intensity of heating technologies), cars and other road vehicles (new vehicle efficiency and the efficiency of the vehicle fleet) and manufacturing processes (carbon intensity of production methods).

Currently, the government's own assessment of carbon budgets is an accounting exercise[11] which doesn't explain ***how*** progress has been achieved. Only the *outcome* of policy measures, in the form of greenhouse gas emissions, are measured and reported. Instead the government needs to set a stronger framework for measuring progress in the carbon intensity of the capital stock separately from its use and the resultant emissions. Key Performance Indicators (KPIs) should be developed from the modelling and analysis in setting the carbon budgets that track the required progress in reducing the carbon intensity of the energy-using capital stock. These should be set and measured alongside the respective carbon budget setting and evaluation processes and reported on alongside the formal reporting that the government submits to parliament. The message from such an assessment would be entirely different from the messages that arise from the accounting exercise that is currently undertaken.

Better information is crucial to setting and assessing carbon budgets

In both setting and assessing future carbon budgets, much more data is required to identify and separate the energy-using (carbon emitting) capital stock from its throughput. This is well understood in some sectors (power generation, passenger cars and to a lesser extent buildings) but is not as well understood for industrial production, non-domestic buildings, refining, aviation, shipping and agriculture.

11 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/803404/Final_Statement_for_2n__Carbon_Budget.pdf

5.3 Policy considerations

Policy considerations

1 Under the Climate Change Act, carbon budgets were set to establish a long-term pathway to an 80% reduction in GHG emissions by 2050. The CCC has recently recommended that the 2050 target is further tightened to net zero and that future carbon budgets are set to reflect this ambition. The long-term pathway is designed to bring about measures to incrementally reduce GHG emissions. However, we find that success in meeting the first two carbon budgets is not the result of measures but of changes in accounting for the EU ETS cap; and the impact of the global economic downturn in 2009. We find that rather than an emissions surplus there is, in fact, a policy measures gap.

2 In our view, therefore, the UK government should not carry any perceived budget surplus from the second carbon budget forward to future budget periods. Carrying over any surplus risks further papering over the cracks and not implementing satisfactory measures to put the UK on course to achieve its long-term target of net zero by 2050.

3 The NAEI data on greenhouse gas emissions data is regularly revised as a result of improvements in data collection and processing methods. By extrapolating each of the last twelve vintages of data over the outturn period, we estimate that outturn greenhouse gas emissions could have been between 99 $MtCO_2e$ lower and 55 $MtCO_2e$ higher over the second carbon budget compared to the latest vintage of data. However, carbon budgets are not revised for data revisions and neither are the government’s assessment of performance against the carbon budget. Future data revisions might well show that the carbon budget was met by much more or much less.

4 Carbon budgets are set by quantifying ‘baseline’ (limited policy) emissions projections using econometric techniques and then subtracting plausible (but stretching) policy measures that are needed to set a pathway to the long-term ambition. However, as the transition is underway, it becomes increasingly difficult to quantify baseline emissions separately from measures especially using top-down econometric techniques where measures are not explicitly identified. We recommend that top-down econometric methods are not employed in revising or setting carbon budgets after the third carbon budget.

5 The government’s assessment of performance against the second carbon budget is limited to an accounting exercise. However, the implementation of measures is critical to setting a pathway for reducing domestic greenhouse gas emissions. As part of assessing progress, the government should formally adopt a series of Key Performance Indicators (KPIs) to assess progress towards achieving long-term decarbonisation. Performance against such KPIs should be reported alongside the government’s own assessment of progress.