Quantifying Greenhouse Gas Emissions

Committee on Climate Change
April 2017

Acknowledgements

The Committee would like to thank:

The team that prepared the analysis for this report: Ellie Davies, Ewa Kmietowicz, Indra Thillainathan and James Thorniley-Walker.

Other members of the Secretariat who contributed to this report: Jo Barrett, Matthew Bell, Adrian Gault, Aaron Goater, Mike Hemsley, Jenny Hill, David Joffe, Stephen Smith, Mike Thompson, Helen Tsang, Emma Vause and Steve Westlake.

A number of organisations and individuals for their support: including Peter Brown at Ricardo AEA; the National Physical Laboratory particularly David Butterfield, Marieke Beckmann, Heather Powell and Jane Burston; Stephen Forden, Julia Sussams and Georgina Eaton at BEIS; Alistair Manning at the Met Office; Dan Say at the University of Bristol; and Tom Misselbrook at Rothamstead Research.

Contents

The Committee

The Rt. Hon John Gummer, Lord Deben, Chairman

The Rt. Hon John Gummer, Lord Deben, was the Minister for Agriculture, Fisheries and Food between 1989 and 1993 and the longest serving Secretary of State for the Environment the UK has ever had. His sixteen years of top-level ministerial experience also include Minister for London, Employment Minister and Paymaster General in HM Treasury. He has consistently championed an identity between environmental concerns and business sense. To that end, he set up and now runs Sancroft, a Corporate Responsibility consultancy working with blue-chip companies around the world on environmental, social and ethical issues. Lord Deben is Chairman of the Committee on Climate Change, Valpak Limited, and the Association of Professional Financial Advisors.

Professor Nick Chater

Professor Nick Chater FBA is Professor of Behavioural Science at Warwick Business School, having previously held chairs in Psychology at Warwick and University College London (UCL). He is particularly interested in the cognitive and social foundations of rationality, and in applying behavioural insights to public policy and business. He has served as Associate Editor for the journals Cognitive Science, Psychological Review, Psychological Science and Management Science. He co-founded and is a Director of the research consultancy Decision Technology Ltd.

Professor Sir Brian Hoskins

Professor Sir Brian Hoskins CBE FRS is the Chair of the Grantham Institute for Climate Change and the Environment at Imperial College London and Professor of Meteorology at the University of Reading. His research expertise is in weather and climate processes. He is a member of the scientific academies of the UK, USA, and China. He has received the top awards of the American and UK Meteorological Societies, the inaugural Gold Medal of the International Union of Geodesy and Geophysics, and the Buys Ballot Medal of the Royal Netherlands Academy of Sciences and Arts which is awarded every 10 years.

Paul Johnson
Paul is the Director of the Institute for Fiscal Studies and is a visiting professor at UCL. He is widely published on the economics of public policy including tax, welfare, inequality and poverty, pensions, education, climate change and public finances. He is also one of the authors of the “Mirrlees review” of tax system design. Paul has previously worked at the Financial Services Authority and has been Chief Economist at the Department for Education and Director of Public Spending in HM Treasury, as well as Deputy Head of the UK Government Economic Service. He is a member of the council and executive committee of the Royal Economic Society and a member of the banking standards board. Paul has previously served on the council of the Economic and Social Research Council. He was a founder council member of the Pensions Policy Institute and in 2010 he led a review of the policy of auto-enrolment into pensions for the new Government.

Baroness Brown of Cambridge
Baroness Brown of Cambridge DBE FREng (Julia King) is an engineer, a crossbench member of the House of Lords, and Chair of the CCC’s Adaptation Sub-Committee. Energy and climate-related interests include being the UK’s Low Carbon Business Ambassador; membership of the World Economic Forum Global Agenda Council on Decarbonizing Energy; a non-executive director of the Green Investment Bank, and of the Offshore Renewable Energy Catapult. She is Chair of the Henry Royce Institute for Advanced Materials and of STEM Learning Ltd, a non-for-profit company providing continuing professional development for science teachers in UK schools. She is a former Vice Chancellor of Aston University, with an academic and industrial career at Cambridge University, Imperial College, London and Rolls-Royce plc where she held senior engineering and manufacturing posts.

Professor Corinne Le Quéré
Professor Corinne Le Quéré FRS is Director of the Tyndall Centre for Climate Change Research and Professor of Climate Change Science and Policy at the University of East Anglia (UEA). She conducts research on the interactions between climate change and the carbon cycle. She has authored multiple assessment reports by the Intergovernmental Panel on Climate Change (IPCC), and is a member of the Scientific Committee of the Future Earth research platform for global sustainability.

Professor Jim Skea

Professor Jim Skea has research interests in energy, climate change and technological innovation. He has been RCUK Energy Strategy Fellow since April 2012 and a Professor of Sustainable Energy at Imperial College since 2009. He was Research Director of the UK Energy Research Centre 2004-12 and Director of the Policy Studies Institute 1998-2004. He has operated at the interface between research, policy-making and business throughout his career. He is President of the Energy Institute and was elected co-Chair of IPCC Working Group III in 2015. He was awarded a CBE for services to sustainable energy in 2013 and an OBE for services to sustainable transport in 2004.

Executive Summary

UK carbon budgets are based on estimates of greenhouse gas (GHG) emissions produced by the National Atmospheric Emissions Inventory (NAEI). These estimates underpin the basis of advice from the Committee on Climate Change ("Committee") in setting carbon budgets and monitoring progress against targets.

The NAEI emissions estimates reflect the current understanding of the science and latest data sources used to quantify the activities that lead to GHG emissions. It is important that the Committee understands uncertainties in these in making its recommendations.

In this report we take a detailed look at how the GHG inventory is constructed, sources of current uncertainty, how these could change over time, and priorities for future improvements. Our focus is on what these imply for setting carbon budgets and monitoring progress.

The Committee concludes that the UK's existing carbon budgets have been set at the right level and provide a reliable guide to the required reduction in emissions despite the uncertainty in emissions estimates.

We concentrate on 'production' emissions (i.e. emissions from sources based in the UK), which is the basis for the inventory, but we also consider other types of estimates (e.g. emissions from UK consumption of goods and services, even if these are produced elsewhere).

Our key messages are:

- **The methodology for constructing the GHG inventory is rigorous but the process for identifying improvements could be strengthened.** Each year the GHG inventory is compiled according to Intergovernmental Panel on Climate Change (IPCC) guidelines. It makes use of a wide range of data sources and expertise, and is validated through a number of quality assurance (QA) and checking procedures. The approach to identifying improvements in the inventory also follows the internationally agreed guidelines but there should be a stronger focus on sectors that contribute a large proportion of uncertainty and a consideration of priorities relevant to the development of policy. The process to prioritise improvements should be more open and transparent, for example through consultation with stakeholders.
- **A small number of sectors contribute most to uncertainty. Research efforts should be directed at improving these estimates.** Statistical uncertainty in the inventory reflects the properties of the underlying data and the state of knowledge of sources and emissions factors. For the sources of gases currently captured by the inventory, uncertainty in total UK GHG estimates for 2014 was ±3% with 95% confidence, which is low by international standards.

  There is a high level of confidence over large parts of the inventory, for example the power, transport, and industry sectors each have a level of uncertainty of less than 3%, due to reliable data on activity and emissions factors. These sectors comprise nearly 70%of all UK emissions. Uncertainty is concentrated in particular sectors and on particular gases. In general, sectors with complex biological processes or diffuse sources such as waste, agriculture and Land USE, Land Use Change and Forestry (LULUCF) have higher uncertainty levels. Further work should be prioritised in areas where uncertainty is greatest (e.g. completion of the Smart Inventory for Agriculture, completion of the work to assess emissions from peat, and examination of methane leakage from a range of sources including landfill and the gas transmission and distribution system).

- **Revisions since the original 2050 UK target for emissions was set in 2008 have led to an increase in estimated emissions, but these have been within uncertainty margins.** The cost-effective path set out in current carbon budgets remains consistent with the path to deliver the long-term target. Each year the inventory is updated to include the latest data and methodology, with revisions backdated to 1990. As the 2050 target is expressed relative to the 1990 level of emissions, large revisions to this could potentially affect the cost-effective path. In practice, this has not been the case. Since the target was set in 2008, the estimate of 1990 emissions has risen by 23 $MtCO_2e$ or 3%. This revision is within estimated uncertainty in both the 2008 inventory[1] (14%) and the 2016 inventory (3%). Based on current inventory methodology, the cost-effective path and associated abatement measures remain valid, but the variation in GHG estimation to date means that ongoing monitoring is required. Carbon budgets are on track to deliver the emissions reduction to around 2 tCO_2e per capita by 2050, the original target.
- **Statistical uncertainty in the current GHG inventory is low, but could rise in percentage terms in the future.** This is manageable in the context of other uncertainties in budgets. If there is no further improvement in the inventory, overall uncertainty is likely to rise as some sectors (e.g. power and transport) decarbonise faster than others. This is because the sectors with the largest uncertainty are also the ones that will de-carbonise last. We estimate that, without further improvements, uncertainty in the inventory could rise to 3.5% by 2030 and to 7.5% by 2050 excluding International Aviation and Shipping (IAS) or to around 17% including IAS. Although uncertainty is expected to rise in percentage terms, in absolute terms it is expected to reduce[2] from 17 $MtCO_2e$ currently to 11 $MtCO_2e$ in 2030 as the overall level of emissions reduces. For currently legislated budgets this is manageable given other uncertainties in budgets. Ongoing improvements in the inventory can also be expected to reduce future statistical uncertainty in estimates.
- **Uncertainty also arises from sources of emissions not currently included in the inventory and from potential changes to IPCC guidelines.** We will monitor the impact of these on historical and future GHG emissions and assess whether this requires a change in approach as new evidence emerges. There are sources of emissions that are not included in the current inventory methodology. These could change both future GHG estimates and associated uncertainty.

  The current inventory is based on 2006 IPCC guidelines, based on the 4th Assessment Report (AR4). The 5th Assessment Report includes different Global Warming Potentials (GWPs) for methane and nitrous oxide that, if adopted in the inventory, would lead to changes in estimated emissions from these gases.

  In addition, the inclusion of other sources of emissions, such as all peatlands, could add up to 21 $MtCO_2e$ (4%) to the UK inventory. This is potentially a significant increase. We will advise on whether this affects emissions targets when evidence is available on their precise impact on emissions estimates and the potential to abate these.

[1] The latest year in the 2008 inventory is for 2006 emissions estimates.
[2] If measured on a consistent basis – i.e. the comparison is made with or without IAS in both 2014 and 2050.

- **Independent external validation of GHG emissions is important and new monitoring techniques should be encouraged.** The National Inventory uses a bottom-up approach to estimate GHGs. Emissions can also be estimated by measuring concentrations of GHGs in the atmosphere and using modelling techniques to identify their geographic sources. New observation towers and modelling improvements have led to a convergence in estimates from the two methodologies. We welcome the work of the GHG Emissions and Feedback Programme in validating GHG emissions and the use of novel techniques and modelling in this area. It is important that government and researchers work together to ensure results of this project feed through to inventory improvements.
- **Government should continue to monitor consumption-based GHG estimates and support continued research to improve methodology and reduce uncertainty in these estimates.** Unlike production emissions estimates, consumption-based estimates take account of emissions embedded in the goods and services the UK imports or exports. Consumption emissions are more uncertain than production estimates, but are important to monitor to ensure that measures to reduce territorial emissions do not lead to increased global emissions. The current internationally agreed guidance from the IPCC based on production accounting methods should continue to be the basis for carbon budgets.

We will continue to keep these issues and uncertainties under review.

The rest of the report is set out as follows:

1. Inventory compilation and methodology
2. Sources of uncertainty
3. Revisions over time
4. Other Greenhouse Gas emissions estimates

An Annex sets out specific issues for each sector.

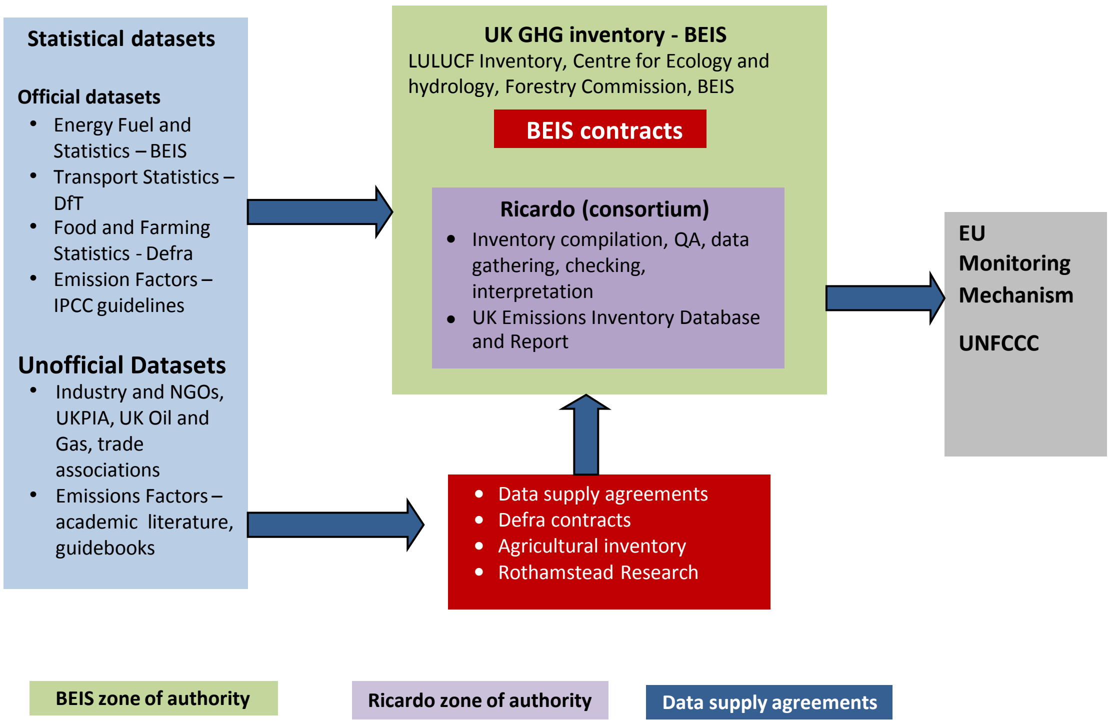
Chapter 1
Inventory compilation and methodology

Institutional arrangements for compilation of the GHG inventory

Each year the UK Government compiles a National Atmospheric Emissions Inventory (NAEI), containing an assessment of GHG emissions from 1990 to the latest available year. These are compiled according to the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines and submitted to the United Nations Framework Convention on Climate Change (UNFCCC) as part of a process agreed through the Kyoto Protocol.

The Department for Business, Energy and Industrial Strategy (BEIS) is responsible for submitting the UK NAEI through the EU monitoring mechanism to the UNFCCC. Ricardo Energy & Environment compiles the inventory on behalf of BEIS, and produces disaggregated estimates for the Devolved Administrations within the UK. There are also designated Key Data Providers that contribute to the inventory compilation covering government and industry bodies. Figure 1.1 presents a simplified diagram of the institutional arrangements.

Figure 1.1. Institutional arrangements for compilation of the GHG inventory



Source: CCC adapted from the NAEI website.

The three bodies responsible for compilation of the inventory – BEIS, Ricardo Energy and Environment and the Key Data Providers– each have separate roles and responsibilities:

- BEIS has overall control of the management and function of the National Inventory System (NIS) which applies to the GHG inventory. It manages the contracts and delivery of the GHG inventory and chairs the Improvement Steering Committee which manages the improvement programme (Box 1.1).
- Ricardo Energy and Environment are responsible for co-ordinating delivery of the GHG inventory with BEIS, reviewing source data and identifying improvements, managing the QA process and acquiring, processing and delivering the National Inventory Report (NIR).
- Key Data Providers are responsible for delivery of source data, management of data acquisition, and communication with BEIS and Ricardo Energy and Environment to help disseminate information and knowledge. There are over 20 Key Data Providers to the GHG inventory, covering:
  - Government departments BEIS, Department for Transport (DfT), Department of Environment Food and Rural Affairs (Defra), Office for National Statistics (ONS));
  - Trade Bodies (e.g. UK Petroleum Industry Association, Mineral Products Association) as well as individual companies (e.g. Shell);
  - Non-Departmental Public Bodies such as the Environment Agency for England and Wales (EA), the Northern Ireland Environment Agency and the Scottish Environment Protection Agency (SEPA); and
  - Research institutes such as the Centre for Ecology and Hydrology and academic researchers.

Box 1.1. The role of the National Inventory Steering Committee and recent inventory revisions

The National Inventory Steering Committee (NISC) was established in 2006 to provide official consideration and cross-Government approval of the GHG inventory prior to its submission to the UNFCCC. The NISC aims to progress research to improve the inventory data quality and help prioritise improvements across the inventory.

Inventory improvements are designed to increase the transparency, accuracy, consistency, comparability, and completeness of the inventory. They are prioritised through: qualitative analysis from Inventory Agency experts; key category analysis; uncertainty analysis; and recommendations from inventory reviews.

Changes implemented in the 2014 inventory led to a 9 $MtCO_2e$ or 1.6% reduction in overall estimated GHGs. Some of the key changes were:

- As part of the ongoing Smart Inventory work, Defra identified new country-specific emissions factors for direct nitrous oxide emissions from urine and dung deposited by grazing animals. This decreased estimated emissions by around 4 $MtCO_2e$ in 1990 and by around 3 $MtCO_2e$ in 2013.
- Changes to estimates of emissions from grasslands, with revised emission factors and a change in relative emissions from shrubby and non-shrubby grasslands.
- New country-specific emissions factors applied to the atmospheric deposition of nitrogen in agriculture and to indirect emissions from leaching and run-off which have replaced default values.

Source: NAEI, BEIS https://www.gov.uk/government/publications/planned-methodology-changes-for-uk-greenhouse-gas-emissions#history

Methodology

The approach to estimate production-based GHG emissions is to combine information on the extent of the activity being assessed with an emissions factor that reflects the emissions per unit of the activity. Following IPCC 2006 guidelines, the basic equation is:

Emissions = activity data * emissions factor

Emissions estimated using this method are classified according to Tiers which reflect the methodological complexity applied. Three Tiers are commonly used:

- Tier 1 is the basic method and is designed to use readily available national or international statistics in combination with default emission factors and other parameters provided by IPCC.
- Tier 2 is intermediate in complexity and can combine country-specific activity data and/or emissions factors with IPCC default values.
- Tier 3 is the most complex in terms of data requirements and uses more advanced modelling techniques and country-specific activity data and can involve extensive monitoring.

Higher Tier methods are generally considered to be more accurate as they use country-specific data that are more likely to be representative of local conditions. However it is possible that higher Tiers can also have a higher degree of uncertainty reflecting the wider range of variables and greater complexity of the methodology.

For some activities, alternative approaches can be more appropriate. For example where there are time lags involved in release of emissions, first order decay models can be used (e.g. for material decomposing in landfill). The 2006 guidelines also contain mass balance methods, for example, stock change methods used in the forestry sector which estimate CO_2 emissions from changes over time in carbon content of living biomass and dead organic matter.

Further detail of the methodologies applied to different sources of emissions are set out in the Annex.

Data Sources

A number of data sources are used to compile the inventory, of which the key ones are summarised in Table 1.1. These cover large-scale surveys tracking activity that produces GHG emissions, National Statistics covering economy-wide indicators such as Gross Value Added and Industrial output, data collected to comply with regulations such as the EU Emissions Trading System (ETS) and more specialised sources of emissions from industrial processes.

Table 1.1. Summary of key data sources to estimate GHG emissions

Source	Activity covered
Digest of UK Energy Statistics	Energy statistics for UK liquid, solid and gaseous fuels and calorific values and conversion factors
Emissions Trading System (EU ETS)	Emissions from installations covered by the EU ETS Carbon emissions factors for major fuels in energy intensive sectors
Transport Statistics GB Northern Ireland Statistics: Transport data Office of Rail Regulation and other rail data	Vehicle km according to vehicle type and road type Vehicle licensing statistics Rail data
UK Petroleum Industry Association (UK PIA)	Refinery emissions
Environmental Emissions Monitoring System (EEMS)	Oil and gas emissions
UK Iron and Steel Industry Annual Statistics	Energy production and consumption in the Iron and Steel sectors
UK Minerals Yearbook	Statistical data on minerals production, consumption and trade
Annual Abstract of Statistics (ONS)	Population data
The June Survey of Agriculture and Horticulture Farm Practices Survey British Survey of Fertiliser Practice UK Forestry Commission data Countryside Survey data	Farming practices and activity data Forestry and land use data

Source: UK Greenhouse Gas Inventory, 1990 to 2014: Annual Report for submission under the Framework Convention on Climate Change http://naei.defra.gov.uk/reports/reports?report_id=902 BEIS, Defra, DfT.

Data collection is a key part of compiling and updating the inventory. In line with IPCC guidelines, data collection activities should be reviewed on a regular basis to enable progressive and efficient inventory improvement.

Key Categories

Key categories are defined as the sources of emissions that have a significant influence on the inventory as a whole, in terms of the absolute level of the emissions, the uncertainty or the trend. Key categories of emissions are identified in the inventory so that resources can be prioritised and ensure best possible estimates of these can be produced. The National Inventory Steering Committee (NISC) helps to prioritise improvements across the inventory based on the Key Category Analysis (KCA).

IPCC guidelines set out both quantitative and qualitative methods to identify Key Categories. The UK uses both methods:

- Quantitative analysis identifies a source as Key if it makes a significant contribution to either the level or trend in emissions.
- Qualitative criteria are also used to ensure that other key sources, not captured by the above, are covered.

The methodology and criteria used to identify key categories are set out in Box 1.2. In the 2014 inventory, nearly 90% of emissions are covered by the KCA, making it difficult to use in practice to prioritise inventory improvements (Figure 1.2). In order to direct research efforts more effectively, there should be a stronger focus on sectors that contribute a large proportion of uncertainty and to take account of priorities relevant to the development of policy.

Box 1.2. Methods used in identifying sources of emissions as Key Categories

Sources of emissions are identified as key categories if they make a high contribution to the level of emissions (in either the base year (1990) or most recent year) or to the trend. There are two quantitative approaches in determining these:

- Approach 1. A source is included as a key category if it is in the top 95% of the level/trend of emissions when the sources are sorted in order (from highest to lowest).
- Approach 2. The uncertainties in the level/trend for each source are calculated and ordered from highest to lowest. The sources in the top 90% of the total uncertainty are included as key categories.

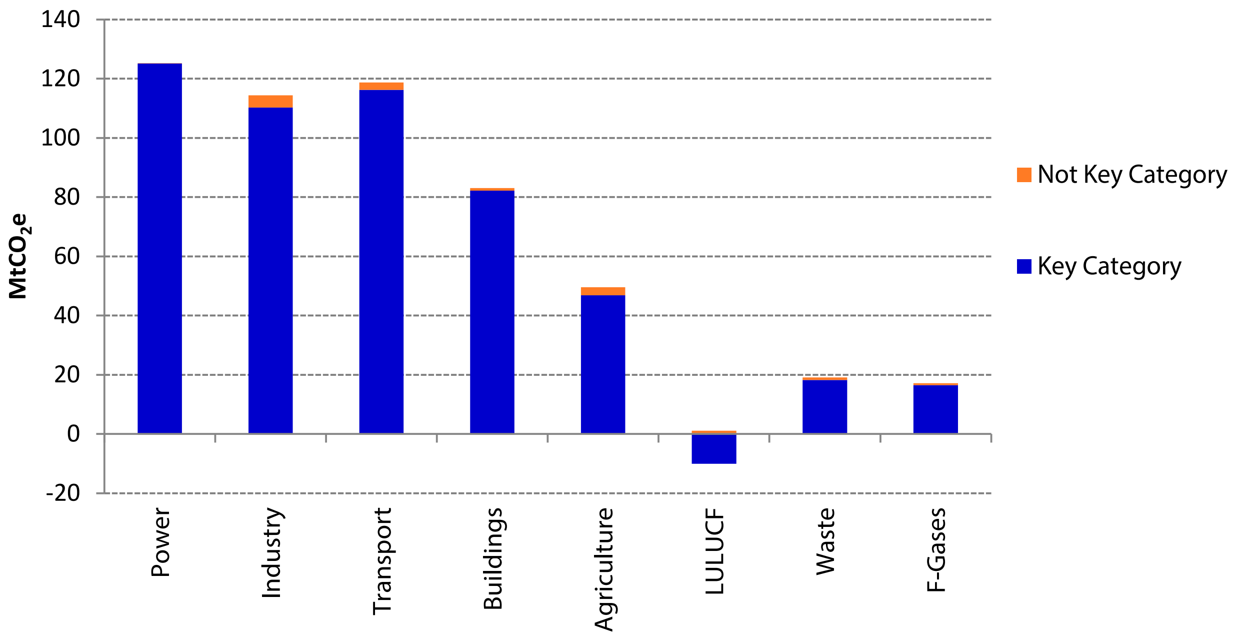
A qualitative analysis of key categories is also performed. The criteria used in the qualitative analysis include:

- Use of mitigation techniques and technologies
- Emissions growth (increase or decrease)
- No quantitative assessment of uncertainties performed
- Completeness (examine qualitatively potential key categories that are not yet estimated quantitatively).

Other criteria can also be used, for example high uncertainty in emissions was taken into account in the 2014 inventory. In this inventory there were no additional sources of emissions that were identified as key from the qualitative analysis that were not already captured by the quantitative assessment.

Source: UK Greenhouse Gas Inventory, 1990 to 2014: Annual Report for submission under the Framework Convention on Climate Change http://naei.defra.gov.uk/reports/reports?report_id=902

Figure 1.2. Emissions by Key Category (2014)



Source: NAEI, CCC calculations.

The methodology for constructing the GHG inventory is rigorous and follows internationally agreed guidelines. Our assessment does, however, suggest that the process for prioritising improvements should be more transparent for example, by publishing areas of improvement in advance and with consultation with stakeholders, and should have a stronger focus on sources that contribute a large proportion of uncertainty and priorities needed for policy development.

Chapter 2
Sources of uncertainty

The GHG inventory is inherently uncertain as it reflects the properties of data underpinning emissions estimates and the current state of knowledge of emissions factors and sources. The monitoring of activities leading to emissions reported in various data sets and understanding of the science may not accurately reflect the full range of conditions under which greenhouse gases are emitted. In addition the understanding of the extent to which different gases lead to climate change has evolved over time.

We have considered three sources of uncertainty which are important for both monitoring and setting carbon budgets:

- **Uncertainty in the current GHG inventory:** this comprises the statistical uncertainty in emission factors and activity data used in estimating emissions. It is internal to the inventory, is well quantified and it is possible to formally assess the probability of errors through methods set out in IPCC guidelines.
- **Uncertainty in Global Warming Potential (GWP):**[3] there have been multiple changes to the GWP estimates used for methane, N_2O and F-gases since the inception of the inventory. Any future changes in GWPs could significantly affect emissions as measured in $MtCO_2e$.
- **Uncertainty from other activities:** some sources of emissions and activities (e.g. peatlands) are not currently included in the inventory but could be included in the future, thus adding to overall GHG estimates.

We conclude this section with a summary of the main areas for improvement in the current inventory in individual sectors. More details on these are in the Annex.

1. Uncertainty in the current GHG inventory

Uncertainty around GHG estimates in the current inventory can be characterised by a probability distribution around the true value of the estimated variable, from which it is possible to construct confidence intervals. The range of uncertainty can be measured in two ways:

- **Error propagation** uses statistical methods to calculate the uncertainty of the final estimate from the uncertainty in the activity data and emission factors. This approach produces estimates of uncertainty by gas and by sector.
- **Monte Carlo** is a method which calculates the uncertainty of a final variable by repeatedly varying the values of underlying inputs according to their statistical properties – usually in the form of distributions around the uncertain input parameters. It is also used to estimate uncertainty in the change in emissions between 1990 and the latest reporting year by gas, as well as by sector.

Uncertainty by sector

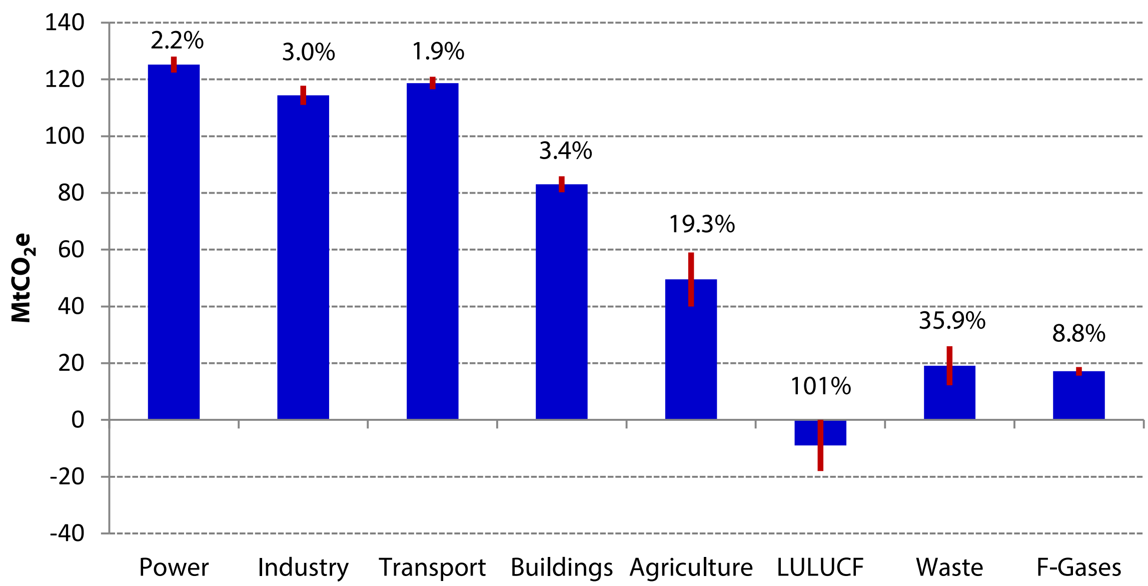
The level of statistical uncertainty in the current GHG inventory is estimated at 3%[4] in 2014, i.e. the estimated level of all GHG emissions is within ± 3% of the true value with 95% confidence. Uncertainty varies across sectors and gases. In general, sectors with complex biological processes or diffuse sources such as waste, agriculture and Land Use, Land Use Change and

[3] Global warming potential is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a given mass of the GHG to the amount of heat trapped by a similar mass of carbon dioxide. The GWPs in the IPCC guidelines are on a 100 year time horizon.
[4] All uncertainty estimates quoted in this report are at the 95% confidence level

Forestry (LULUCF) have higher levels of uncertainty than the energy use sectors (such as power and transport) for which there are good data on activities and emission factors (Figure 2.1):

- Agriculture has the largest absolute level of uncertainty at ± 9.5 $MtCO_2e$, representing 19% of emissions. This predominantly arises from uncertainty in the measurement of N_2O emissions from agricultural soils and methane emissions from enteric fermentation from cattle.
- The LULUCF sector has the highest relative uncertainty at ± 101% or over ± 9 MtCO2e. This is largely due to uncertainty arising from CO_2 emissions from forests and cropland.
- The transport sector has the lowest relative uncertainty as a proportion of emissions in that sector, ± 1.9%, or ± 2.2 $MtCO_2e$.[5] This reflects that there are good data on sales of road fuels and well established emissions factors.

Figure 2.1. Uncertainty by sector (2014)



Source: NAEI and CCC calculations.

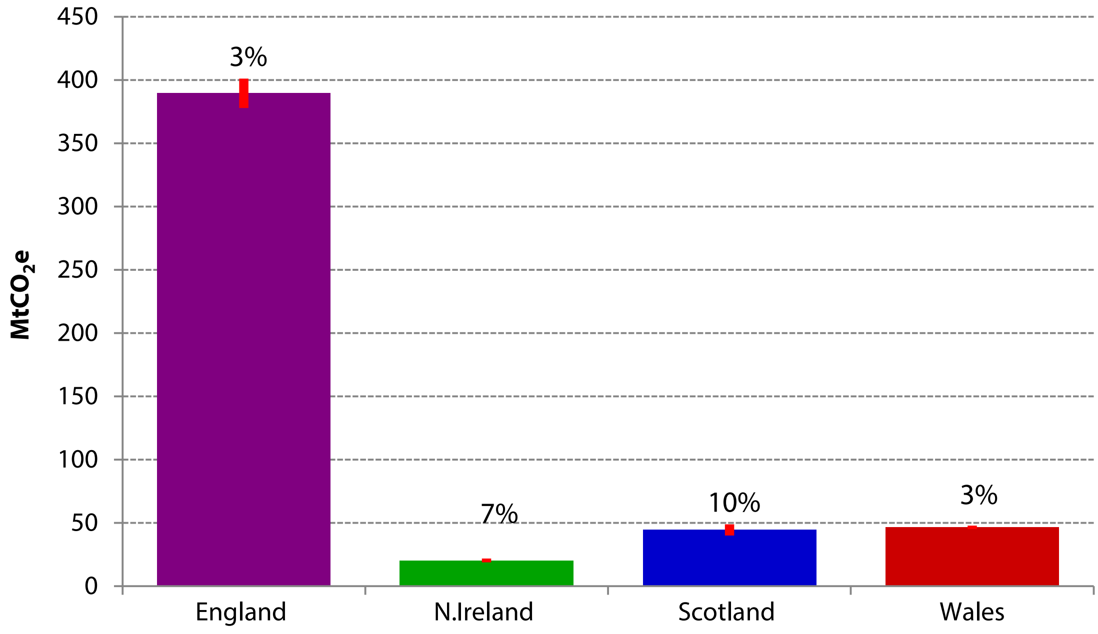
There are considerable differences in uncertainty by Devolved Administration (DA). Scotland and Northern Ireland have the highest uncertainty in overall emissions, mainly driven by the higher share of emissions from sectors with most uncertainty – agriculture and LULUCF (Figure 2.2):

- At 10% in Scotland and 7% in Northern Ireland, uncertainty is 2–3 times higher than in England and Wales (3%).
- Agriculture and LULUCF represent 33% of emissions in Scotland and 31% in Northern Ireland compared with 11% in the UK as a whole. As these are the sectors with the highest uncertainty, the higher shares in Scotland and Northern Ireland contribute to the higher overall uncertainty in these DAs.

[5] Uncertainty for sub-sectors within transport are higher.

- A higher proportion of emissions come from the Industry sector in Wales than the rest of the UK, 33% compared to a national average of 22%, largely due to the steel works at Port Talbot. However, because blast furnace processes are well understood, uncertainty in the Welsh inventory is the same as that for the UK estimates as a whole.

Figure 2.2. Uncertainty in the Devolved Administrations (2014)



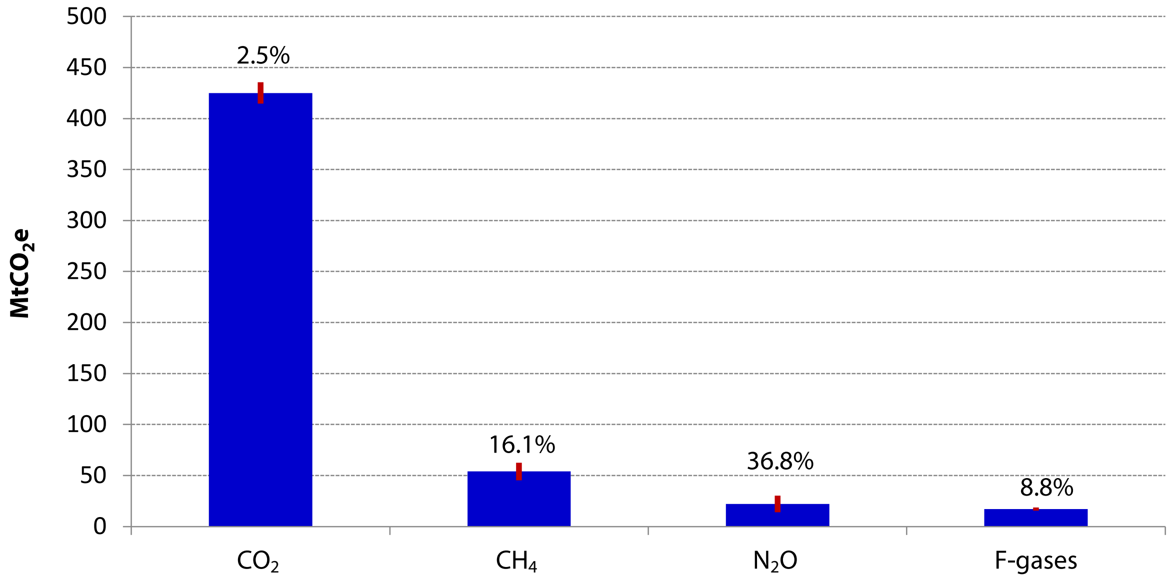
Source: NAEI and CCC calculations.

Uncertainty by greenhouse gas

Uncertainty estimates vary by greenhouse gas. N_2O has the highest percentage uncertainty, given these emissions are predominantly from agriculture. CO_2 gases have the lowest percentage uncertainty as these are mostly from energy use sectors with well-established evidence on sources and emissions factors. However as CO_2 emissions are 19 times higher than N_2O emissions and 8 time higher than methane, the absolute uncertainty is higher for CO_2 (Figure 2.3):

- Uncertainty in N_2O emissions is ± 37%, or ± 8 $MtCO_2e$ with agriculture comprising 74% of emissions of this gas.
- Uncertainty in methane and F-gases is ± 16% (8.5 $MtCO_2e$) and ± 9% respectively, Methane emissions are largely from agriculture and waste, both of which have high relative uncertainty.
- Uncertainty in CO_2 emissions is± 2.5% (10.5 $MtCO_2e$), with uncertainty from the forestry sector contributing a large proportion of this.

Figure 2.3. Uncertainty by greenhouse gas (2014)



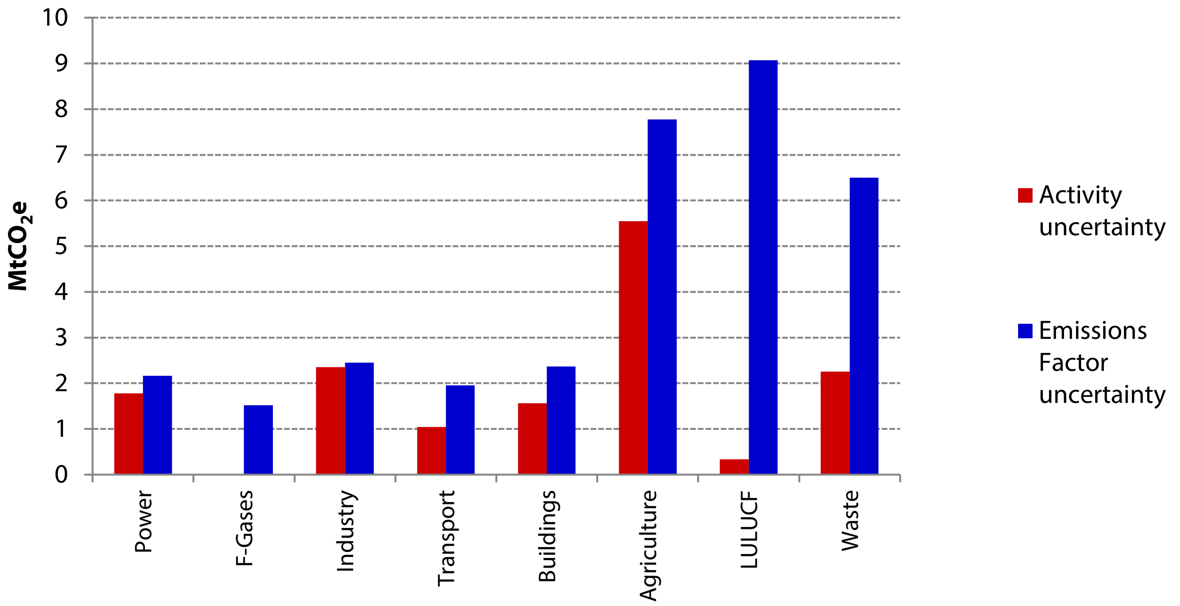
Source: NAEI and CCC calculations.

Uncertainty in activity data and emissions factors

The uncertainty in emissions sources can be split into two factors: the level of uncertainty in the amount of activity in that source and the level of uncertainty in the emission factor used to calculate emissions. In general, emissions factor uncertainty is higher than activity level uncertainty, but there is considerable variation in activity level uncertainty across sectors (Figure 2.4):

- For some smaller sectors, where activity is less well known, uncertainty in activity data is higher than for emissions factors, e.g. use of oil petroleum gas/gas oil in industry and the amount of different types of waste going to landfill.
- For land use the level of activity is well defined (having the lowest uncertainty arising from activity data in all of the sectors). However, uncertainty in the emission factors is the largest of all sectors, primarily relating to CO_2 emissions from forest land and cropland.
- For some non-CO_2 gases, the level of uncertainty in activity data and emissions factors is not well-defined. For example, the same uncertainty in emission factors is used across many different fuels for N_2O in the power sector (e.g. coal, burning oil, natural gas, poultry litter and sewage gas). This is because default IPCC emission factors are used due to the lack of UK data.
- For some sources (e.g. parts of agriculture) it is not possible to estimate separate uncertainties from activity data and emissions factors, therefore only one estimate is produced covering both elements.

Figure 2.4. Activity and emissions factor uncertainty by sector (2014)



Source: NAEI and CCC calculations.
Notes: Uncertainty cannot be split for agriculture, therefore total uncertainty is shown.

As well as generating estimates of uncertainty for the level of emissions, Monte Carlo analysis is used to estimate uncertainty for the trend or change in emissions between 1990 and the latest inventory year. Between 1990 and 2014 the estimated decrease in emissions was 35.2%. The uncertainty in this trend is estimated at ±3.8% at the 95% confidence interval. This means that there is 95% probability that the true decrease is between 39% and 31.5%. The estimation procedure assumes that emissions factors are correlated across time, but activity data are not. This should generally, but not always, lead to lower uncertainty for the trend than for the level of emissions in a given year:

- In 2014, the uncertainty in the trend in emissions from 1990 (-3.8%) was higher than the estimated uncertainty for the level of emissions in 2014 (3%), but lower than the latest uncertainty estimate for 1990 emissions (4.9%).

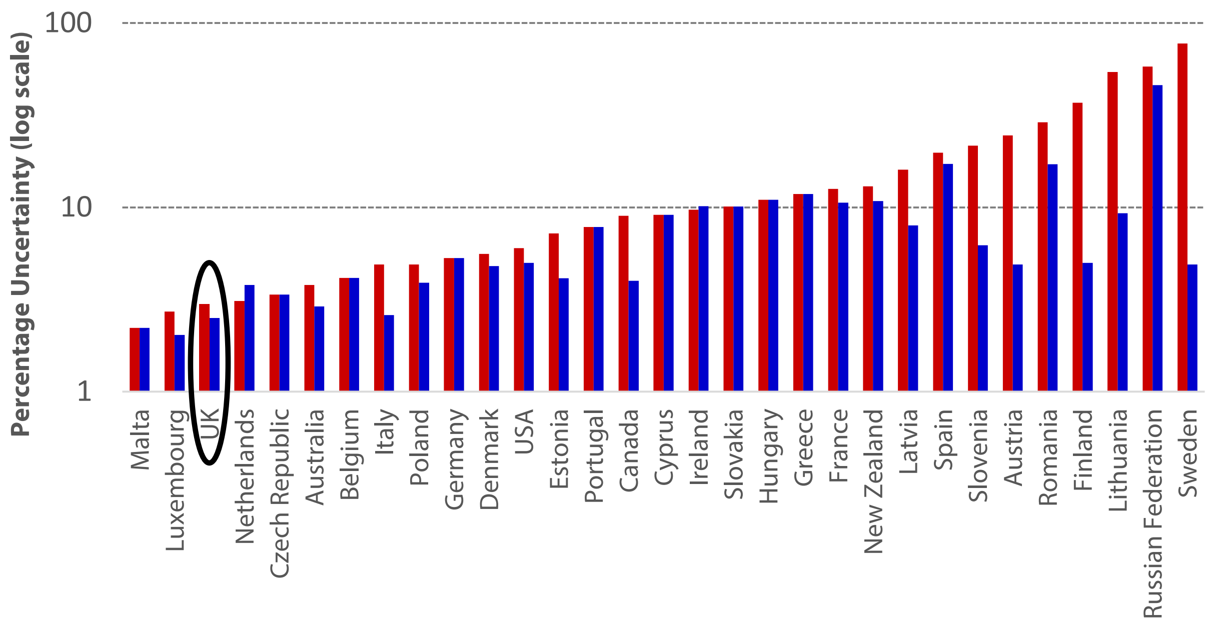
- Where emissions factors are well understood and uncertainty around them is lower than for activity data, the trend uncertainty is dominated by activity data, so could lead to higher uncertainty estimates for the trend.

- Uncertainty in the trend is relatively unchanged over time, ranging between ± 2.5 to ±3.5% over the last five years.

Our analysis shows there is a high level of confidence over large parts of the inventory and uncertainty is concentrated in particular sectors and gases.

Comparing the UK GHG inventory to those of other countries, the uncertainty in the UK GHG inventory is relatively low (Figure 2.5). Of the countries used in our comparison, only Malta and Luxembourg had a lower level of percentage uncertainty in their inventory. The highest level of percentage uncertainty among the countries used in our comparison was in Sweden with 77.5%. This is due to the very large LULUCF sinks in Sweden (when this is removed uncertainty falls to 4.9%). Russia has the largest uncertainty when excluding LULUCF at 46%.

Figure 2.5. International comparison of uncertainty in GHG inventories (2014)



Source: National Physical Laboratory based on UNFCCC data.

Our analysis shows that overall uncertainty in total GHG estimates for 2014 was ±3% with 95% confidence, which is low by international standards. There is a high level of confidence over large parts of the inventory, for example power, transport, and industry each have a level of uncertainty of less than 3%, due to reliable data on activity and emissions factors. These sectors comprise nearly 70% of all emissions. Uncertainty is concentrated in particular sectors and on particular gases.

Uncertainty in the 5th carbon budget and 2050 targets

The legislated carbon budgets set out a path of falling emissions on a trajectory to meet the 2050 target of at least an 80% reduction in GHGs on 1990 levels. As emissions reduce along the cost-effective path, it is possible to estimate uncertainty in future carbon budgets, based on current uncertainty estimates by sector. Since levels of uncertainty differ across sectors and because different sectors are expected to de-carbonise at different rates, overall uncertainty in remaining emissions will change over time.

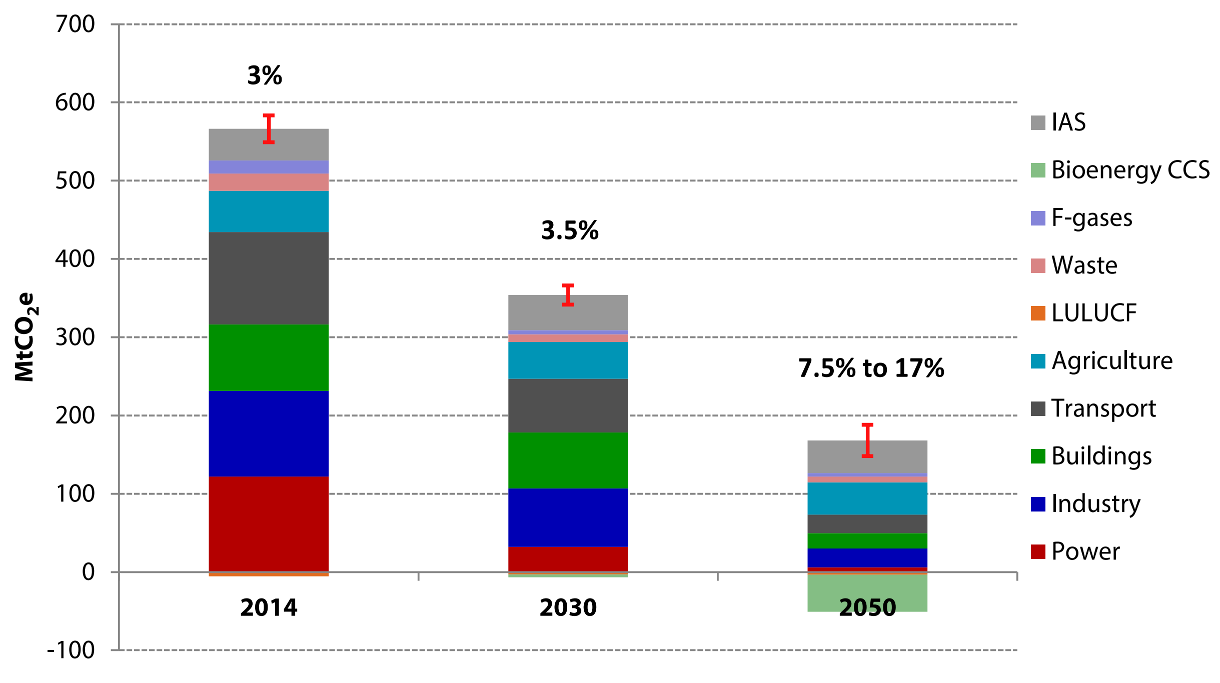
If there is no further improvement in the GHG inventory, our analysis suggests that, based on the cost-effective path set out in the 5th carbon budget, uncertainty in remaining emissions is estimated to increase from 3% in 2014, to 3.5% in 2030 and 7.5% in 2050 (excluding the impact of International Aviation and Shipping (IAS)). Uncertainty in 2050 increases to around 17% if IAS is included (Figure 2.6). Nevertheless, in absolute terms, uncertainty is expected to reduce as the overall level of emissions decreases.

- Significant reductions in emissions from the power and transport sectors are expected by 2030 and 2050. These sectors also have relatively low uncertainty, and contribute little to the overall uncertainty in the level of emissions.

- By 2030, we expect industry and agriculture to form a higher share of remaining emissions. Estimated overall uncertainty increases to ±3.5%, absent further improvements to the current methodology.
- By 2050, nearly full decarbonisation of power, transport and buildings mean the most uncertain sectors – waste, industrial processes, agriculture and IAS – become more dominant. Additional uncertainty also arises through the potential use of bioenergy with capture and storage (BECCS). The range of uncertainty in 2050 is estimated at ±7.5% to ±17%.
- The lower bound excludes estimates for BECCS and IAS, for which there are currently no direct uncertainty estimates.
- The upper estimate includes proxies for these,[6] though these are likely to be on the low side as there are no uncertainty estimates for combustion through CCS.
- Although the percentage uncertainty increases to 2050, the absolute level of uncertainty falls from ±17 $MtCO_2e$ in 2014 to ± 9 $MtCO_2e$ in 2050 (in the lower bound case) as overall emissions reduce along the cost-effective path.

This level of uncertainty is manageable given other uncertainties in budgets. Ongoing improvements in the inventory can also be expected to reduce future statistical uncertainty in estimates.

Figure 2.6. Emissions and uncertainty in the 5th carbon budget central scenario



Source: NAEI and CCC calculations.
Notes: Range in 2050 reflects difficulty in estimating uncertainty for bio-CCS and International Aviation and Shipping. Lower bound excludes these, upper bound includes them. Chart shows upper uncertainty range.

[6] For IAS we assume domestic aviation and shipping uncertainty estimates. For BECCS, we use biomass uncertainty estimates.

2. Uncertainty from Global Warming Potentials assigned to GHGs

The IPCC produces assessment reports (ARs) every 5-7 years about the state of scientific, technical and socio-economic knowledge on climate change, including estimates of global warming potentials (GWPs). The IPCC also produces a set of guidelines on producing national GHG inventories. However, these guidelines and GWPs must be adopted by the Conference of Parties (COP), the governing body of the UNFCCC before countries implement them. This can take some years to take effect. The IPCC AR5 in 2013 included a revision to estimated GWPs, but these have not yet been adopted by the UNFCCC.

Revisions can be up or down. The global warming potential for methane has been revised upwards in AR4 (which has been adopted in 2006 IPCC guidelines) and AR5 (not yet adopted), whereas the global warming potential for N_2O has been revised downwards (Table 2.1). The changes implemented under the AR4 guidelines led to an increase in emissions, but further changes could be higher, especially if climate feedback effects are incorporated:

- The 2006 guidelines (AR4) led to an increase of 20 $MtCO_2e$ and 8 $MtCO_2e$ in estimates of 1990 and 2014 emissions respectively.
- Under the proposals set out in AR5, which suggest a higher GWP for methane, the changes could be an additional 11 $MtCO_2e$ to the UK inventory estimates for 1990 or +44 $MtCO_2e$ if climate feedback effects are included.

Table 2.1. IPCC Guidelines for GWPs for 100-year time horizon

Gas	1996 guidelines	2006 guidelines (AR4)	AR5	AR5 with climate feedback
Carbon dioxide	1	1	1	1
Methane	21	25	28	34
Nitrous oxide	310	298	265	265

Source: IPCC.

3. Uncertainty from other activities

The UK inventory covers all GHG emissions sources required by the current IPCC guidelines. For some categories, the UK is not required to report, due to limited activity in the UK in this area or limited data (and likely negligible emissions). For example, the UK does not report in the rice cultivation category (due to limited activity) or in the accidental fires in building category (due to limited data).

Periodically, the IPCC publishes additional guidance on inventories to reflect scientific advances. This was the case with the 2013 wetlands supplement which covers inland organic soils and various types of wetlands. The coverage of the guidelines was restricted to peatlands drained and managed for peat extraction.

Currently only some emissions from drainage of lowland peat and other small sources are included in the GHG inventory, accounting for around 1.5 $MtCO_2e$ in 2014. The Government is undertaking research to estimate the GHG emissions from all peatlands in the UK, for possible inclusion in the 2018 inventory, which will affect estimates of historical and future emissions. Current estimates suggest this is a significant source of emissions and could have large implications for the DAs:

- The inclusion of all sources of peatland emissions could bring total emissions from this source to 21 $MtCO_2e$[7] of emissions, increasing total emissions by 4% in 2014.
- If peatland emissions are incorporated in the inventory in future years, the emissions from the devolved administrations will be significantly affected. Peatlands cover 20% of the land area in Scotland, 25% of the land area in Wales and 13% of the land area in Northern Ireland.

We will advise on how this affects emissions targets when evidence is available on their impacts and the potential to abate these.

While GHGemissions are the primary cause of current global climate change, other factors from human activity also contribute. For instance, global changes in land use have had a cooling effect by increasing the reflectivity (albedo) of Earth's surface, while contrails and associated cirrus clouds induced by aircraft have had a net warming effect.[8] While these are important in considering all processes leading to Earth's warming, they are outside the scope of this report because the inventory methodology covers emissions only.

Priorities for improving future GHG estimates

In the Annex, we set out our detailed analysis of the methodology and uncertainty underpinning emissions estimates for each sector. This identified several areas for future improvements in the inventory, which are set out below.

Land use land use change and forestry (LULUCF)

The LULUCF sector is one with the highest uncertainty, ± 101% with 95% confidence. Recent revisions in this sector such as the introduction of the new woodland carbon accounting model (Carbine) in the 2014 inventory and the error correction for the emissions factor for the drainage of organic soils on grassland in last year's inventory have produced large changes in the estimates of emissions in the sector. This makes it difficult to monitor progress. There are several things that can be done to address this:

- The high uncertainty is partly due to using a land-use matrix based on old survey data that is not spatially explicit, so that extrapolations and assumptions about current land use need to be made. Work is being undertaken to improve this. BEIS is currently assessing the feasibility of using Earth Observation (remote sensing data in combination with reference data) to track land use change in the UK over time. The aim is to develop a more accurate and repeatable way to track land use change in a spatially-explicit manner for the inventory. The work is due to be completed later this year, and we recommend that a decision on the suitability of this method be made as soon as practicable.

---

[7] Government response to the Environmental Audit Committee report on Soil Health https://www.publications.parliament.uk/pa/cm201617/cmselect/cmenvaud/650/650.pdf

[8] IPCC WG1 AR5 Technical Summary.

- Research is being undertaken by Forest Research to review the CARBINE model to assess soil carbon losses on forestry planted on organic soil, and by Ricardo AEA to assess the impact of land management practices on soil carbon stocks. The impact of these on the level of emissions or on uncertainty is not yet known.
- Further areas of improvement in this sector should be considered if emissions estimates continue to be revised significantly and/or uncertainty remains high.

Peatlands

Peatlands could increase emissions to up to 21 $MtCO_2e$, with the range of uncertainty currently unknown. BEIS is in the process of incorporating the IPCC's Wetland supplements into the UK's 2018 Inventory, which will cover both upland and lowland peat. This work will provide annual estimates of UK peatland emissions losses and removals from 1990, and estimates of the sequestration potential from the restoration of degraded peat.

Peatlands are an important store of carbon. It is important that this work is completed later this year to enable a full assessment of options to avoid further degradation and GHG losses, and to increase carbon sequestration from restoration practices.

Agriculture

Our previous reports have documented the high uncertainty associated with agricultural emissions and the need to incorporate the Smart inventory in the methodology. This should be included without further delay to enable effective monitoring of this sector.

It would be helpful if uncertainty estimates for enteric fermentation and soils could be broken down by activity data and emissions factor uncertainty, if data from the new Smart Inventory enable this.

Waste

Emissions from landfill were 14 $MtCO_2e$ in 2014, consisting entirely of methane and have high relative uncertainty of ±42% at the 95% confidence interval. Landfill emissions are modelled based on information about the quantity and composition of waste going to landfill and respective emissions factors. Work to measure fugitive emissions from landfill and to develop site-specific landfill emissions data should be prioritised:

- A small pilot study was carried out by Defra and the environmental regulatory agencies in the UK to measure fugitive methane emissions from select landfill sites and a programme of research on closed landfills is now complete.
- Related to this, the Environment Agency is currently undertaking work to ascertain whether the use of drones can accurately quantify a known release of methane emissions from landfill.[9]
- This work should be used to develop additional site-specific data on landfill methane emissions.

[9] 'SC160006: Validation of landfill methane measurements from an unmanned aerial system', (2017) Environment Agency.

Industry

Gas transmission and distribution

The level of fugitive emissions from the gas transmission and distribution network in 2014 is estimated as 4 $MtCO_2e$ (equivalent to 0.3% of UK gas consumption), based on a model developed by National Grid (see Annex for further details). Uncertainty in these emissions is relatively high at 22% with 95% confidence. The estimate of 0.3% appears to be towards the lower end of international estimates of fugitive emissions. The Sustainable Gas Institute found that international estimates of fugitive emissions of gas range from 0.1-1.1% of gas produced under best practice technological operations. We intend to study emissions from gas transmission, distribution and processing further as part of our future work programme.

Unconventional petroleum

In future, depending on the scale of unconventional petroleum production in the UK, the associated emissions footprint could become substantial and more uncertain. In the Committee's advice on unconventional petroleum under the Infrastructure Act,[10] we concluded that emissions from well development, production and decommissioning must be strictly limited if shale gas is to be exploited at a significant scale in the UK. Uncertainty about emissions will also be reduced by requiring a range of technologies and techniques to limit methane emissions.

F-gases

F-gases from refrigeration and air conditioning, aerosols and metered dose inhalers (MDIs) form 91% of all F-gas emissions. The F-gas sector has an uncertainty of ±9% at the 95% confidence level.

HFC-134a emissions from refrigeration, air conditioning, aerosols and metered dose inhalers extrapolated from atmospheric measurements have risen at half the rate of inventory estimates. The Refrigeration and air conditioning model has been revised as a result, but inventory emissions are still significantly higher.

To reconcile the inventory and the atmospheric measurements solely by changing the modelling of mobile air conditioning (the largest source of HFC-134a), would require that emissions from mobile air conditioning are calculated to be zero. This is highly unlikely, implying that revisions are also required to the method of calculating aerosol emissions (which accounts for approximately 30% of the UK's HFC-134a inventory), as well as additional improvements to the Refrigeration and Air Conditioning model.

Further research is required to understand this discrepancy and should involve revisions to both the Refrigeration and Air Conditioning Model and the method of calculating emissions from aerosols.

[10] Onshore Petroleum, CCC, March 2016.

Chapter 3
Revisions over time

Each year the inventory is updated to include the latest data and evidence. Any methodological improvements are backdated to 1990 to produce a consistent series across all years and to ensure that estimates are at the lowest level of uncertainty. Revisions to GHG estimates take account of:

- Reporting guidelines under which the submission is made (e.g. 1996 or 2006 IPCC guidelines).
- Emissions estimation methodology, including revisions to assumptions or conversion factors. This could be based on new evidence from external reviews, literature studies or additional measurements.
- Emission factors which are generally derived from measurements made on a number of sources representative of a particular emission sector. Reference sources for emission factors for many industries are researched by environmental institutions around the world and are updated in line with latest evidence.
- Latest data on activities and estimates of sources of emissions. These can be updated with latest survey or other evidence, the inclusion of new sources of emissions or the revision of inaccurate data.

Revisions to estimated 1990 emissions could affect the 2050 climate change target of at least an 80% reduction in emissions on 1990 levels, and also the cost-effective path as set out in carbon budgets. It is therefore important that the Commitee monitors and takes account of such changes.

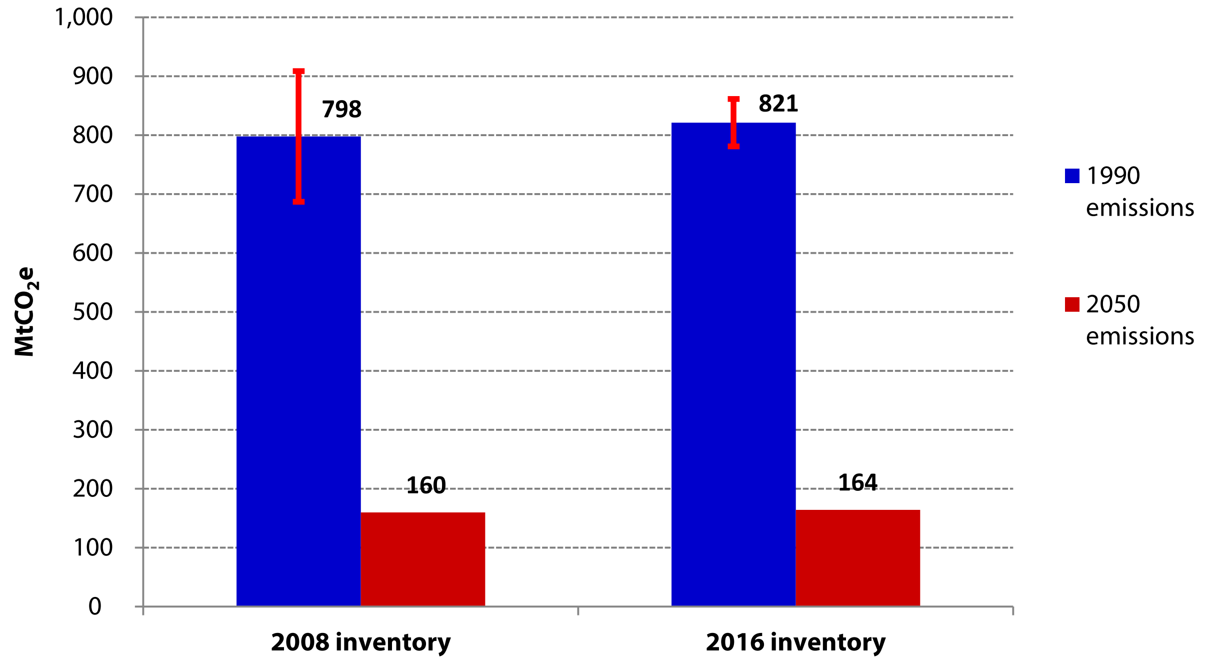
The Climate Change Act was legislated in 2008, and the 2050 target at that time was based on the 2008 inventory, covering estimates to 2006. The estimate of 1990 emissions has risen by 23 $MtCO_2e$ since then, implying a greater level of absolute abatement needed to meet the 2050 target than previously expected (Figure 3.1). However, this revision is within the uncertainty range for GHG emissions estimates as a whole:

- Estimated GHG emissions for 1990 were 798 $MtCO_2e$[11] in the 2008 inventory and have since been revised to 821 $MtCO_2e$.
- This change, +23 $MtCO_2e$ or 3%, is within the estimated level of uncertainty in the 2008 inventory which was 14%, or ± 111 $MtCO_2e$, and is also within the ±3% uncertainty in the 2016 inventory.[12]
- Higher emissions estimates in industrial processes, the agriculture and waste sectors have contributed most to the upward revision to 1990 greenhouse gas estimates since 2008.

[11] Including IAS.

[12] Uncertainty is not estimated for International Aviation and Shipping, therefore uncertainty ranges quoted exclude additional uncertainty from these sources.

Figure 3.1. Revisions in baseline emissions: 2008 and 2016 inventories



Source: NAEI and CCC calculations.

Our analysis shows that revisions since the original 2050 UK target for emissions was set in 2008 have led to an increase in estimated emissions but these have been within uncertainty margins. The cost-effective path set out in current carbon budgets remains consistent with the path to deliver the longer-term target.

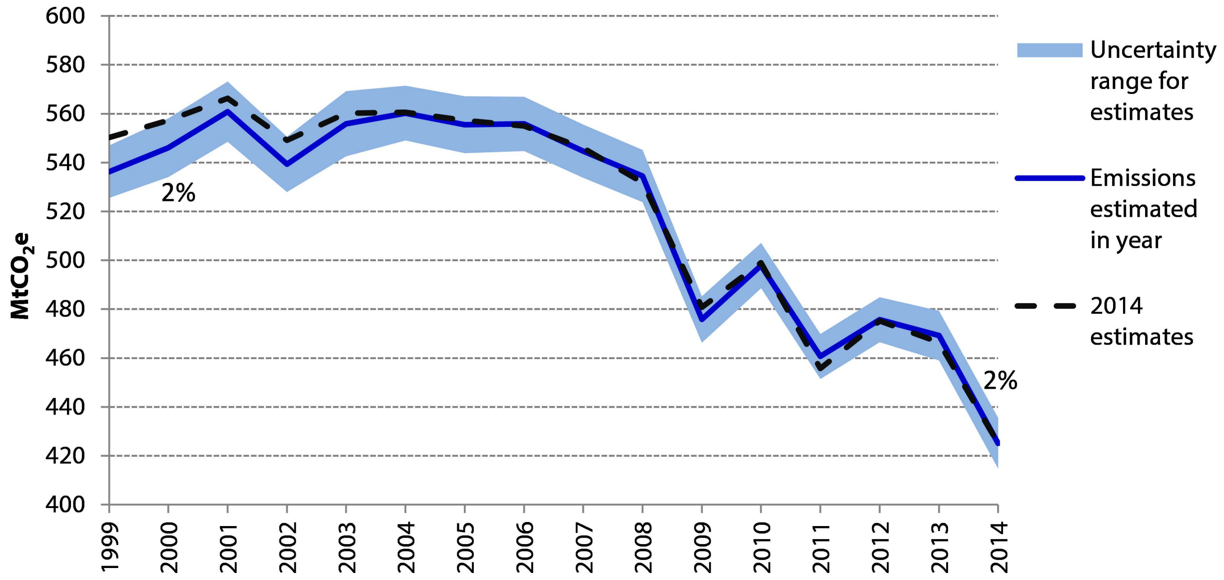
In the next section we analyse the reasons behind key revisions in estimates over time and set out changes by gas.

CO_2

The main source of CO_2 emissions is the burning of fossil fuels in power, transport, industry and buildings. Estimates of CO_2 emissions in the year they were first made have not changed significantly as compared with the 2016 inventory (Figure 3.2):

- The largest changes between initial and current estimates are, as would be expected, in the early inventories (1999-2002) which diverge by around 2% compared with the latest estimates. Revisions since then have been less than 1%.
- Uncertainty in CO_2 estimates has remained fairly constant since 1999, at around 2%, although in the 2016 inventory it increased to 2.4%. This is largely attributable to the energy supply sector where uncertainty has risen from 2% in 2012 to 2.8% in 2014.
- The main revisions over this period were in the 2007 submission, when there was a separation of sinks and sources for CO_2 in the LULUCF sector and in 2016 inventory where the methodology for estimating emissions from grasslands was updated leading to a reduction of nearly 4 $MtCO_2$ in this sector.

Figure 3.2. Recalculation of CO_2 emissions over time



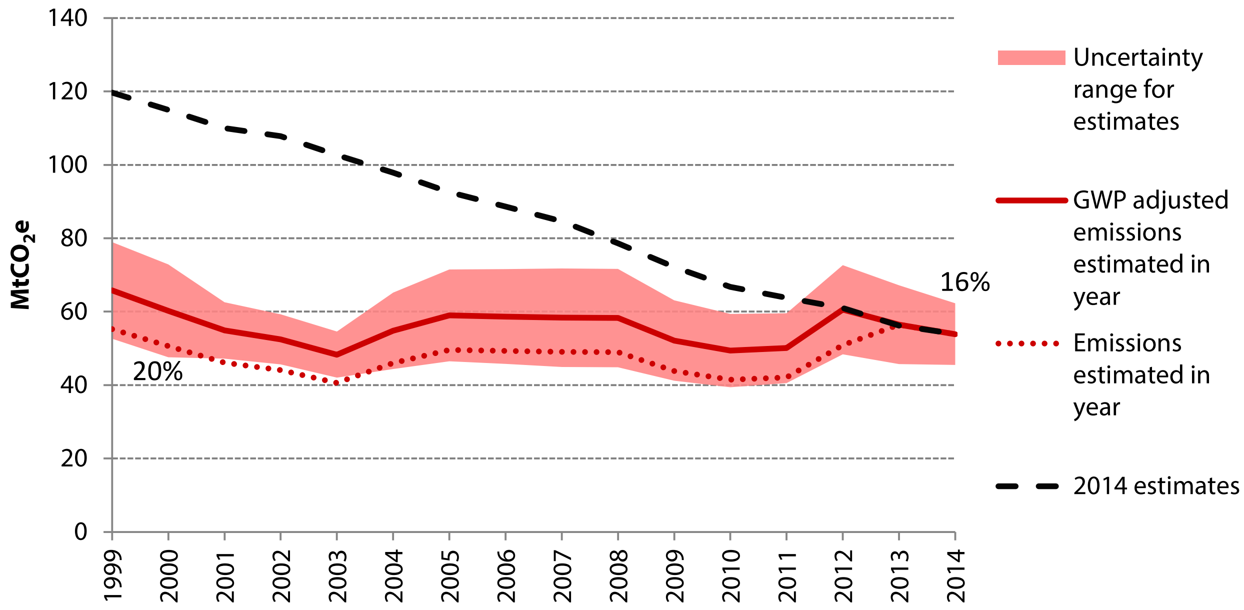
Source: BEIS https://www.gov.uk/government/collections/final-uk-greenhouse-gas-emissions-national-statistics#2016 and CCC calculations.

Methane (CH_4)

The main sources of methane emissions are in agriculture (representing around 50% of emissions), and landfill (around a third). Methane emissions have been revised significantly compared with early inventories, largely reflecting the change in the GWP of methane and improvements to the landfill and agriculture methodologies (Figure 3.3):

- Revision to the GWP potential of methane from 21 to 25, first introduced in the 2015 inventory following the 4th IPCC Assessment Report, led to a 19% increase in methane emissions across the series.
- There have been a series of changes to the way landfill emissions are modelled, which led to a downward revision in the whole series from 2011 onwards. Landfill emissions depend on several factors such as the amount of waste going to landfill, the proportion that is biodegradable and decay rates, all of which are uncertain and unlikely to be replicated across all sites. Further details are in the Annex.
- A number of improvements in agriculture methane emissions estimates introduced as part of the Smart Inventory in 2016 led to some minor revisions.
- Since 1999 uncertainty in methane emissions has reduced by 4 percentage points, although at 16% it is still considerably above economy-wide uncertainty.
- These revisions mean that the current estimate of methane emissions in 1999 falls far outside the previous uncertainty range, and have changed the profile of methane emissions from being relatively flat since 1999 to declining at over 5% per year. We return to the issue of methane emissions in Chapter 4.

Figure 3.3. Recalculation of methane emissions over time



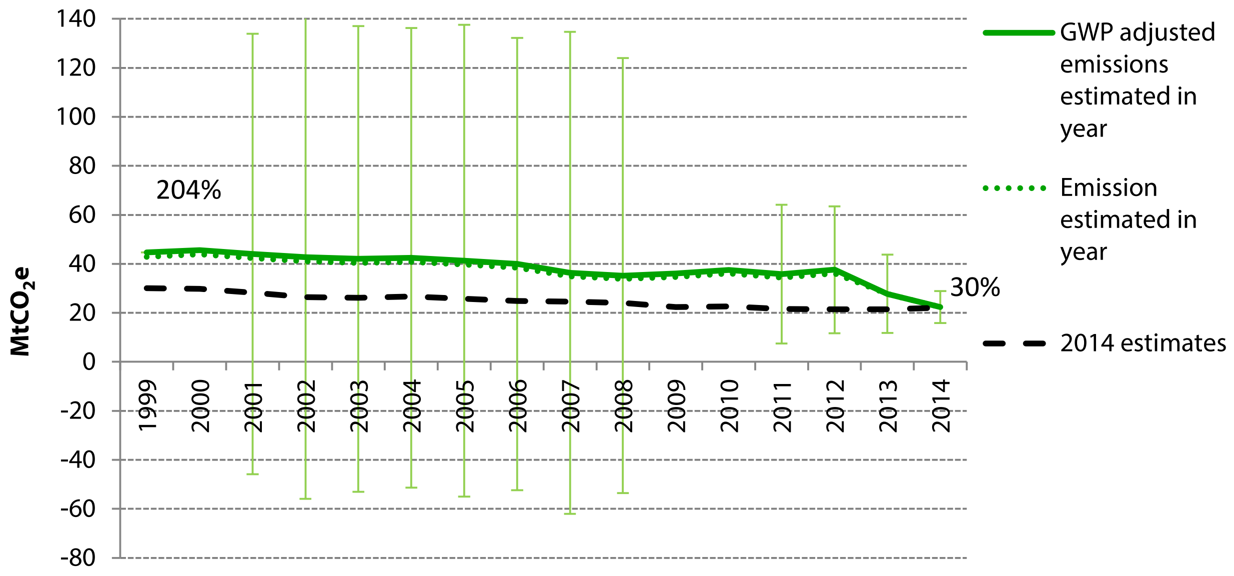
Source: BEIS https://www.gov.uk/government/collections/final-uk-greenhouse-gas-emissions-national-statistics#2016 and CCC calculations.

Nitrous Oxide (N_2O)

Nearly three-quarters of N_2O emissions are from agriculture, with the remainder spread across the other sectors. A reduction in the GWP of N_2O and better evidence from the Agriculture Smart inventory has led to a reduction in estimates across the series. Error ranges have also narrowed but uncertainties remain around fugitive emissions from onshore gas (Figure 3.4):

- The GWP of N_2O emissions was reduced in 2015 from 310 to 298. This led to a 4% fall across the series.
- Country-specific emissions factors for N_2O emissions from manure management and agricultural soils resulted in a reduction of more than 20% in 2014 estimates.
- Uncertainty around N_2O emissions was over 200% in the 2000s but has since reduced to 29%. This is because of the limited state of knowledge and data sources in the 2000s across the diverse sources of emissions. The state of knowledge, monitoring and data sources have improved since that time.

Figure 3.4. Recalculation of N_2O emissions over time



Source: BEIS https://www.gov.uk/government/collections/final-uk-greenhouse-gas-emissions-national-statistics#2016 and CCC calculations.

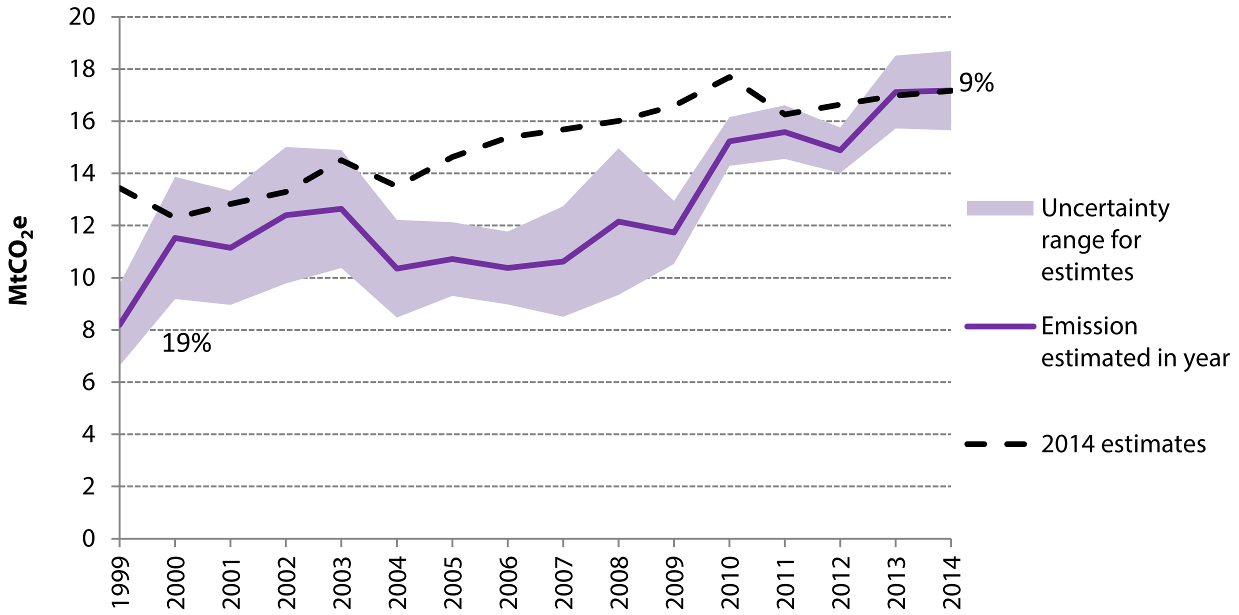
F-gases

Emissions from air-conditioning and refrigeration contribute almost 80% of F-gases, largely from HFCs. Emissions are modelled mainly in the business and industry sectors. Uncertainty is relatively large with revisions over time being outside estimated confidence intervals (Figure 3.5):

- A Tier 3 methodology is used to estimate emissions from cooling in 13 different categories. The model has been revised over time, in consultation with industry and other evidence.
- Improvements in methodology, largely due to a better understanding of emissions factors, have led to a reduction in uncertainty from 19% in 1999 to 9% in 2014.

Although the revisions to F-gas estimates have been outside previous error ranges, F-gases are only 3% of economy-wide GHG emissions, and their contribution to overall uncertainty is relatively low at 4%.

Figure 3.5. Recalculation of F-gas emissions over time



Source: BEIS https://www.gov.uk/government/collections/final-uk-greenhouse-gas-emissions-national-statistics#2016 and CCC calculations.

Our analysis shows that, for certain greenhouse gases (methane and F-gases), revisions since 1999 have been outside estimated uncertainty ranges. These gases are generally more difficult to estimate as they often involve complex relationships, diffuse sources or cover a diverse range of activities and emission factors. As levels of emissions of these gases are relatively low, around 10% of all GHGs, the impact on economy-wide emissions uncertainty is small, and overall revisions to emissions have been within 95% confidence intervals.

Preliminary vs. final emissions estimates

Provisional UK greenhouse gas emissions estimates are published in March each year. These provide an early indication of the emissions from the previous year until final estimates are published the following February.

The provisional emissions figures are not estimated using the greenhouse gas inventory methodology set out above. Instead, estimates are based on the change in energy use between the previous year and the year covered by the preliminary estimate. Therefore, only CO_2 emissions estimates, based on energy use, are updated, with non-CO_2 emissions assumed to be unchanged from the previous year.

The preliminary estimates methodology assumes that the percentage change in CO_2 emissions in the latest two years is the same as the percentage change in energy use for a particular activity and fuel. This means that, unlike final emission statistics, provisional emissions statistics do not use other data sources such as the Digest of UK Energy Statistics (DUKES), EU ETS data and DfT statistics, but instead only rely on Energy Trends data, which are also published in March.

This means that the basis of preliminary estimates is significantly different to final estimates:

- Energy Trends exclude data for some sectors. CO_2 emissions for the agriculture, waste management and LULUCF sectors are assumed to remain the same as the previous year.
- Data are only available for CO_2 emissions. The provisional estimates published in 2016 assume than non-CO_2 remain the same as the previous year. This is a change from previous provisional estimates where non-CO_2 emissions were estimated on an assumption that the trend for these gases was half way between 'no change' on the latest year and a repeat of the trend over recent years.
- Estimates do not take account of any methodological improvements that may have been made to the inventory.

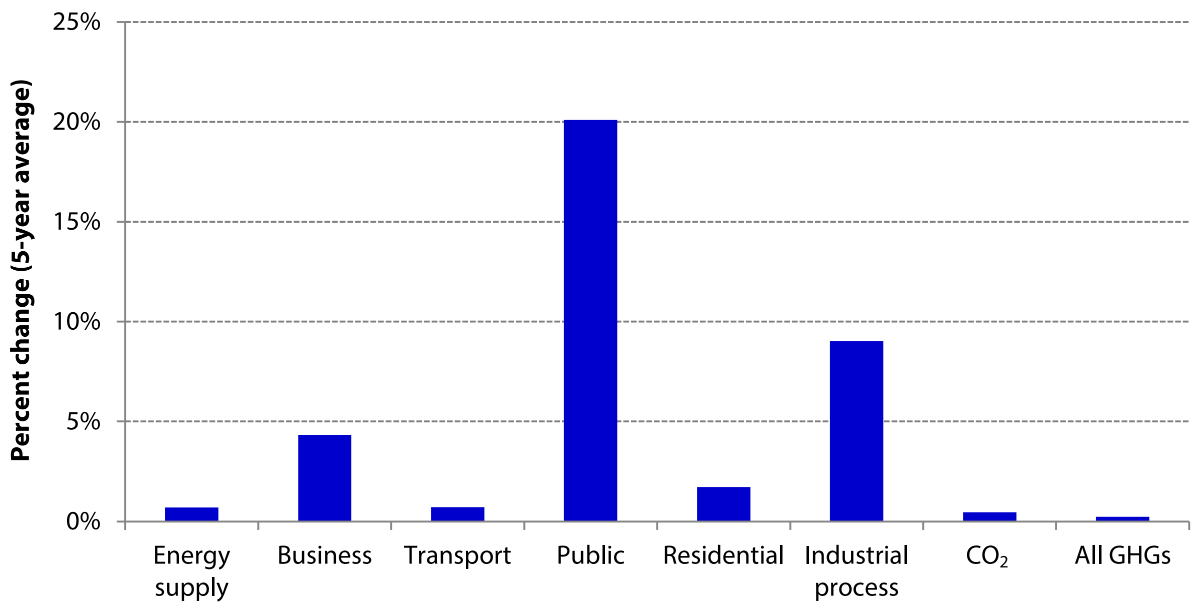
The Energy Trends data used in the provisional emission estimates are themselves subject to revision, and are finalised in July. They are then used to compile the DUKES statistics, used in the final emission statistics in the following February.

Comparing provisional and final emissions estimates for the same time period show that overall CO_2 provisional estimates are close to final estimates, but that there are larger differences across sectors (Figure 3.6):

- Since 2012, the average change between provisional and final total GHG emissions estimates was just 0.5%. There is no apparent trend to over- or under-report emissions.
- The Public and Industrial Process sectors were the ones with the largest revisions, with average changes of 20% and 9% respectively over the past five inventories.

The analysis suggests that provisional emission estimates for sectors covered by energy use in Energy Trends are a good indicator of total emissions, particularly when looking at the trend. This is particularly true for the larger sectors, energy supply, transport and business.

Figure 3.6. Difference between provisional and final emissions estimates



Source: BEIS and CCC calculations.
Note: Percentages are in absolute terms expressed as a 5-year average.

Chapter 4
Other Greenhouse Gas Emissions estimates

This section considers other ways to estimate emissions. In section 4.1 we summarise the approach used to measure emissions through atmospheric readings across observation stations in and around the UK. Section 4.2 considers the latest developments in consumption-based emissions accounting, which estimate the UK's carbon footprint and allows for emissions embedded in goods and services imported by the UK. This is in contrast with the National Inventory estimates, and on which carbon budgets are based, which are defined on the basis of territorial emissions, or those occurring only within the UK's borders.

4.1 Atmospheric emissions estimates

The methodology to estimate emissions through the National Inventory is a bottom-up approach based on calculating the impact of activities that lead to emissions. These can be validated by measuring atmospheric concentrations of emissions and modelling the implied geographic source of these.

To produce atmospheric emissions estimates, BEIS has established and maintained observation stations in the UK and Ireland, which report high-frequency[13] concentrations of the key greenhouse gases. Atmospheric measurements of the concentrations of methane, N_2O and F-gases have been made since 1990, but the methodology is currently too uncertain to be used to measure CO_2 as this has a strong diurnal and seasonal variation which makes understanding the atmospheric observations very challenging.

The Met Office uses these data in its NAME (Numerical Atmospheric dispersion Modelling Environment) model (Box 4.1) to interpret the observations and determine the history of the air travelling across the observation points. By estimating and removing the baseline atmospheric concentrations from the observations from the towers and by modelling where the air came from, it is possible to estimate UK emissions.

[13] Many observations over time.

Box 4.1. Atmospheric emissions measurement methodology for methane, N_2O and F-gases

Atmospheric measurements allow for an independent assessment of the UK GHG inventory. Verification of the inventory is considered best practice by the UNFCCC and atmospheric measurements is one of their suggested approaches.

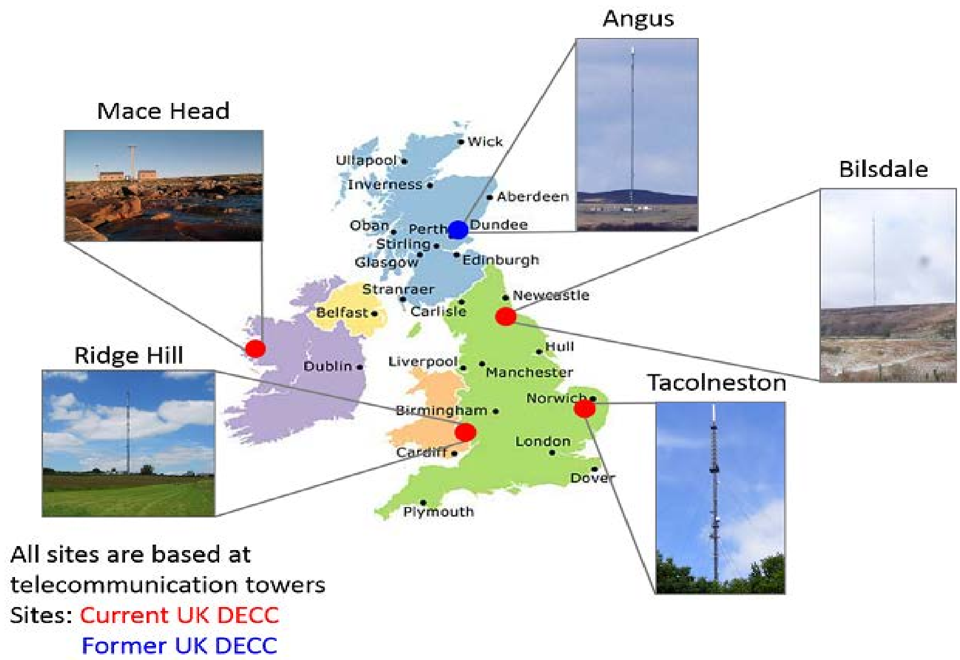
The UK DECC (Deriving Emissions linked to Climate Change) network measures atmospheric trends and UK emissions of GHGs from four telecommunications towers: Mace Head, Ireland; Tacolneston, near Norwich; Ridge Hill, near Hereford and Bilsdale in North Yorkshire. Before 2013 there was only one tower located on the west coast of Ireland at Mace Head, but the network has since been expanded.

The UK DECC network is run by the University of Bristol, funded by BEIS. Atmospheric concentrations of methane, carbon dioxide, nitrous oxide, HFCs, PFCs and sulphur hexafluoride are measured (Figure B4.1a).

The Met office uses a model known as NAME (Numerical Atmospheric dispersion Modelling Environment) to create air history maps for the air arriving at each detector, by generating trajectories using observed mean wind speeds and adding random turbulence. This model has been run every 2-hour period since 1989 to simulate the trajectory of each parcel of air arriving at the towers.

The tower at Mace Head in Ireland can measure the background atmospheric concentrations of each gas from air flowing across the Atlantic to establish a baseline (Figure B4.1b).

Figure B4.1a. A map of the UK DECC network



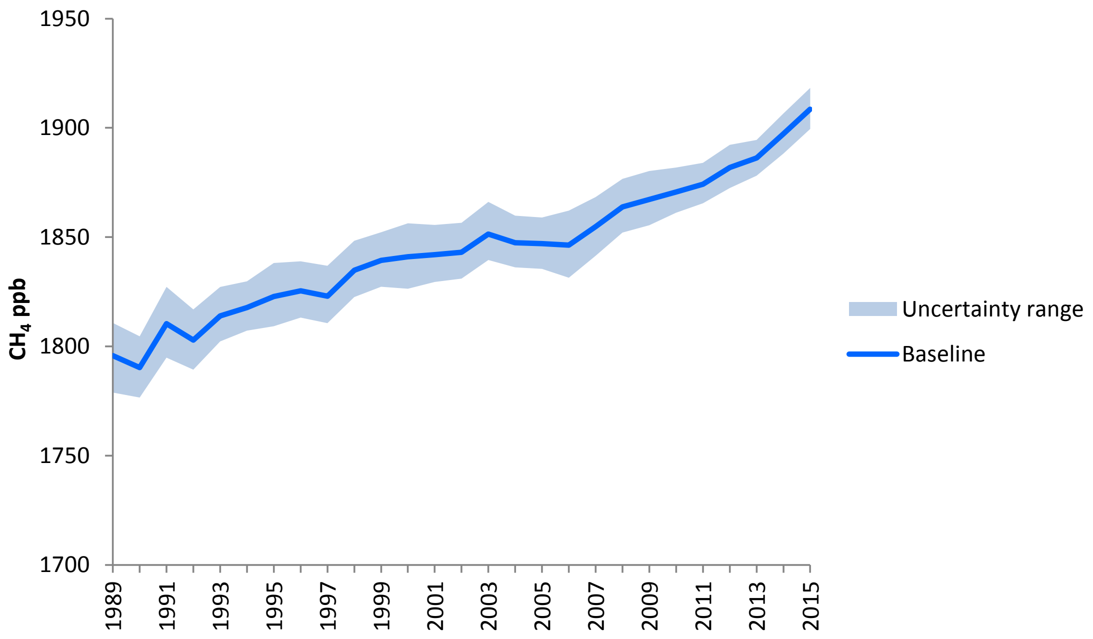
Source: Met Office.

Mace Head and the other towers also measure atmospheric concentrations, making it possible to determine the source of emissions at a higher spatial resolution. By subtracting the baseline data, the increase in the atmospheric concentration of greenhouse gases from UK emissions (both natural and anthropogenic) is calculated.

Box 4.1. Atmospheric emissions measurement methodology for methane, N_2O and F-gases

A technique referred to as InTEM (Inversion Technique for Emission Modelling) is used to convert this to an emission distribution that is comparable to the inventory. A set of random emission maps are generated and improved upon iteratively, searching for the emission map that most closely matches the atmospheric observations. The emission distribution generated for each gas by InTEM can be compared to the Inventory, although CO_2 emissions have a strong diurnal and seasonal variation which makes understanding the CO_2 observations very challenging.

Figure B4.1b. Monthly northern hemisphere concentration of methane at Mace Head



Source: Met Office.
Notes: ppb 'parts per billion'.

Source: Met Office and University of Bristol publication, Annex 6 of National Inventory Report, 2016.

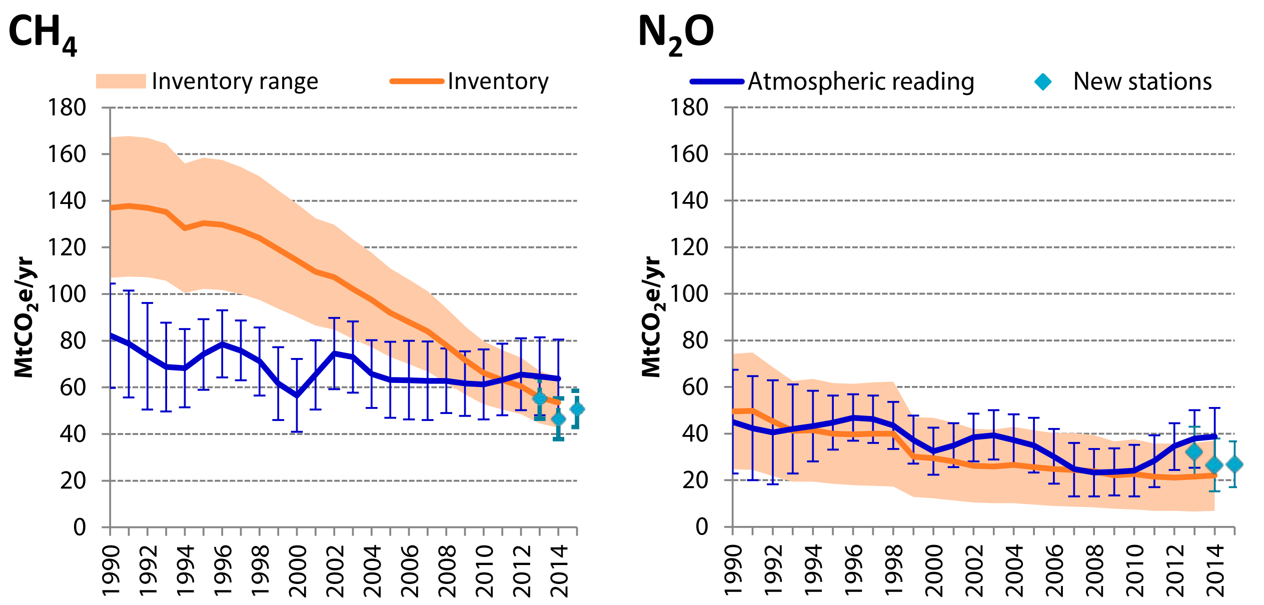
Estimates based on atmospheric modelling have been closer to inventory estimates for N_2O than for methane, but both have converged with the introduction of more observation towers in 2012. Both methodologies produce the same trend in N_2O emissions, but not for methane (Figure 4.1):

- The key sources of methane emissions are landfill, enteric fermentation, coalmining and energy use. Atmospheric measurements of methane emissions agreed poorly with inventory estimates from the 1990s but estimates converged in the late 2000s and more recently with the introduction of additional observation towers.
- The trend in methane emissions is different in the two methodologies. Whilst there have been improvements in inventory modelling of landfill and agriculture emissions, this discrepancy in the trend is pronounced:
  - Inventory estimates suggest that methane emissions fell by 61% between 1990 and 2014, largely a result of reducing waste to landfill and the decrease in livestock.

– Atmospheric measurements suggest these were broadly flat.

- Uncertainty ranges for nitrous oxide are higher than for methane under both methodologies, but estimates under both methodologies have been quite close, particularly from 2012 onwards.

Figure 4.1. External validation of methane and N2O emissions



Source: Met Office.

The work by the Met Office, in conjunction with universities, in modelling atmospheric GHG emissions is important in verifying inventory estimates. The discrepancy in methane emissions has important implications for assessing progress reducing emissions and the effectiveness of policy measures, particularly for landfill and enteric fermentation from livestock, the two largest sources of methane emissions. Further work needs to be done to reconcile these estimates to provide confidence over the trend in emissions, particularly in light of the recent revisions to the National Inventory estimates of this gas.

The Greenhouse Gas Emissions and Feedback Programme, currently underway, could help in this regard. This is a research programme being funded by the Natural Environment Research Council (NERC) to develop a programme of comprehensive measurements, data analysis and modelling activities, focusing on the key GHGs (Box 4.2). The aim of this is for the UK to play a leading role in a coherent measurement programme to improve understanding, reduce uncertainties and underpin policy decisions, and to allow for the independent verification of emissions estimates. It is important that government and researchers work together to ensure results of this project feed through to inventory improvements.

Box 4.2. Greenhouse Gas Emissions and Feedback Programme (2013-17)

The Greenhouse Gas Emissions and Feedback Programme is a comprehensive research programme focusing on nationwide GHG measurement, data analysis and modelling, funded by the Natural Environment Research Council (NERC). A key objective is to improve the understanding and quantification of UK GHGs, which could feed through to improvements in the national inventory. It is being delivered across three inter-linked UK research consortia, of which only two are relevant for the UK national inventory:[14]

- **GAUGE** measures emissions in the air, and is GHG-specific. It works by integrating inter-calibrated information from ground-based, airborne, ferry-borne, balloon-borne, and space-borne sensors, including new sensor technology.
- **GREENHOUSE** uses existing field data to construct regional GHG inventories and improve the capabilities of land-surface models. For example, it is looking at carbon in forests at 1 km scale across the UK, using Forestry Commissions data, satellite data on green cover, and data on soil and climate. As it is region- specific, it could be used to verify the emissions estimates from the non-spatially-explicit Carbine model, which is currently used to estimate the emissions and removals from UK forestry for the LULUCF inventory.

The programme is scheduled to be completed this year. In the first instance, BEIS intend to use the data from GREENHOUSE and GAUGE as independent verification tools for emission estimates in the inventory, for example, highlighting areas of the inventory where the new data suggests either an overestimation or underestimation of emissions. This, in turn, could assist on where efforts of improvement should be directed. As GREENHOUSE is more region- and source-specific, evidence may lead to the development of emission factors for specific sources.

Source: http://www.greenhouse-gases.org.uk/

[14] The third (RAGNARoCC) is an oceanographic project that measures air-sea fluxes of emissions in the North Atlantic region.

4.2 Consumption emissions estimates

The methodology to estimate emissions as set out in the IPCC guidelines and used to produce the UK's GHG inventory covers emissions from production activities in the UK or its associated territories. They also cover international aviation and shipping emissions as a memo item, which may be included in carbon budgets in the future.

This approach does not include emissions embedded in the goods and services the UK imports, nor exclude those in exports; therefore it is not a good indicator of emissions related to final consumption in the UK. Consumption-based emissions estimates are calculated by taking production estimates, adding emissions associated with imports and subtracting emissions due to exports.

Whilst the methodology for estimating inventory estimates is relatively straightforward, this is not the case for consumption emissions. They require estimates of emissions occurring along international supply chains, and there are no agreed international reporting standards. They can be estimated through high-level analysis of trade flows which add net imports of emissions to existing production emissions figures or through more sophisticated input-output analysis (e.g. multi-regional input-output approaches 'MRIO') which track emissions associated with monetary flows across sectors and regions (Box 4.3).

Box 4.3. Consumption based emissions based on input-output models

Consumption emissions based on input-output models use detailed data within input-output tables, which are compiled and published by countries in order to track monetary flows across sectors and regions.

Multi-regional input-output (MRIO) analysis enables tracking of UK purchases to emissions arising from interconnected supply chains across the world. This requires three steps:

- Determining the total monetary demand in each sector of the economy (including all intermediate demand);
- Multiplying by emission estimates of the sector;
- Separating emissions estimates into domestic and foreign demand to remove exported emissions.

To produce estimates based on the MRIO methodology requires detailed information on a range of variables:

- Final demand for goods and services for each sector in the economy and how they trade with each other;
- The carbon intensity of the output from each sector;
- Information on trade flows between the UK and other countries, and the carbon intensity of that trade.

MRIO analysis depicts inter-industry relationships across the world economy, showing how the final demand of a good comprises of dependent consumption throughout the production process. For example, an imported German car will include: steel from China, iron and coal from Australia used to make the steel, rubber from Indonesia, electrics from South Korea etc. The data are compiled into global databases, the two main ones being the Global Trade Analysis Project (GTAP), and Eora.

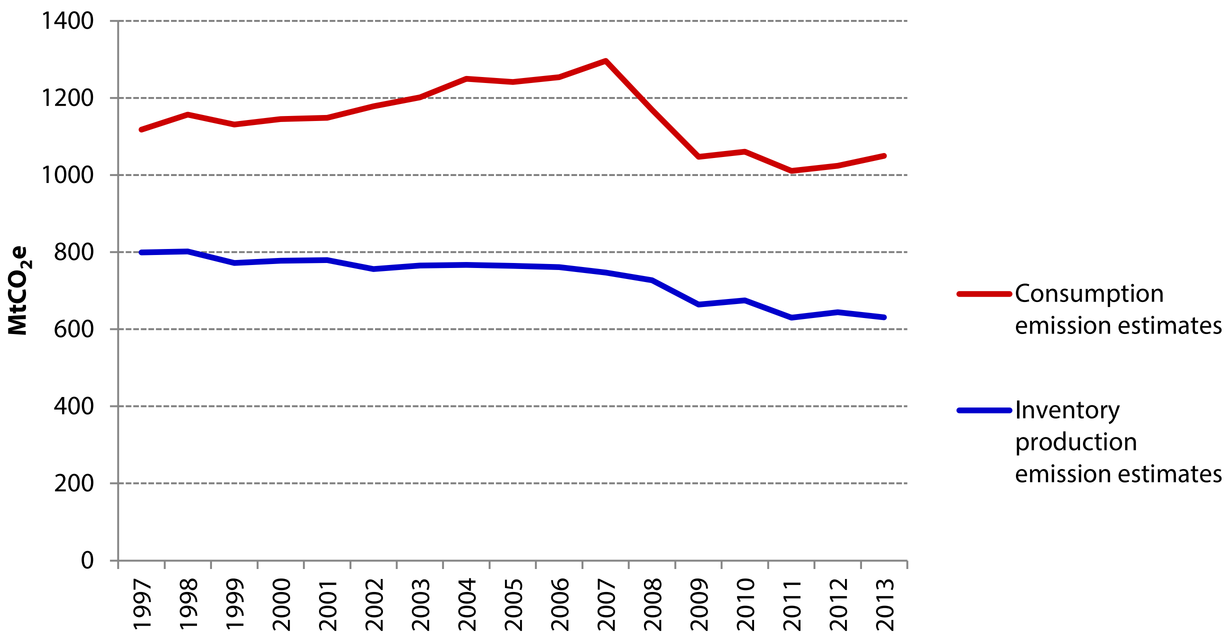
Source: Lenzen, M., Moran, D., Kanemoto, K., & Geschke, A. (2013). Building Eora: a global multi-region input–output database at high country and sector resolution. *Economic Systems Research*, *25*(1), 20-49. Wiedmann, T., Lenzen, M. and Wood, R. (2008) *Uncertainty Analysis of the UK-MRIO Model – Results from a Monte-Carlo Analysis of the UK Multi-Region Input-Output Model (Embedded Emissions Indicator);* Met Office and University of Bristol publication, Annex 6 of National Inventory Report, 2016.

Estimates of the UK carbon footprint

The UK Government has reported on UK consumption emissions based on work undertaken by the University of Leeds. This is based on the MRIO methodology and has been recently improved reflecting modelling undertaken by the University of Sydney. This headline indicator shows that UK carbon footprint emissions are 1.75 times higher than production emissions estimates, and peaked in 2007 before falling back with the financial crisis, then increased in 2012 and 2013 (Figure 4.2):

- The UK's GHG consumption emissions were 1050 MtCO_2e in 2013, compared with 631 MtCO_2e[15] for equivalent production emissions.
- The carbon footprint peaked in 2007 at 1,296 MtCO_2e but has since fallen back and in 2013 was 19% lower than this.
- Between 2012 and 2013, the UK's carbon footprint rose by 3%, mainly reflecting a rise in imported emissions.

Figure 4.2. Consumption and Production GHG emissions (1997-2013)



Source: Defra and NAEI.

Uncertainty in consumption emissions estimates

The complex data requirements and different methodologies used to produce consumption emissions estimates leads to large uncertainties. The estimates are currently classified as experimental by Defra. There are two types of uncertainty: that relating to the statistical data

[15] Includes International Aviation and Shipping emissions

used in a particular study; and uncertainty arising through variation in estimates derived from using different methodologies.

Statistical uncertainty in a single approach

Consumption-based estimates tend to have larger uncertainty than production-based estimates due to the incorporation of a larger set of inputs, each with their own uncertainty. The data sets are information heavy (e.g. the MRIO data set has 2 million data points), require complex data from a wide range of sources, have different country classifications and levels of disaggregation, relate to different time periods and currencies all of which need to be calibrated and harmonised. Key sources of uncertainty are:

- **Data complexity and timing**. Estimates require the modelling of the entire global economy and there are no agreed international standards of data collection. Data are not always available for the same time periods or updated regularly, so there are often gaps in data.
- **Harmonisation**. As there are no international standards, economic and emissions data differ across countries in terms of quality, completeness and methodology. Different countries have different aggregation techniques.
- **Homogeneity**. Estimates assume that products and services traded across sectors and countries are homogeneous with an average emissions factor for relatively large sectors. Trade flows are converted into monetary transactions based on purchasing power parities or other conversion rates, which are representative of the economy as a whole and not individual sectors, and are often not available for all countries.

It is possible to account for some of these uncertainties using error propagation methods and Monte-Carlo simulation techniques. However, this requires information on the distribution of key variables used to compile the estimates, and these are not available systematically across all countries and data sources. Defra published research suggest that uncertainty of consumptions based estimates for the UK is in the range 3.3-5.5%. However, studies[16] suggest such estimates may not be reliable because errors can cancel out with aggregation and that errors may be correlated between different data sources. This makes comparison with uncertainty in production emissions misleading.

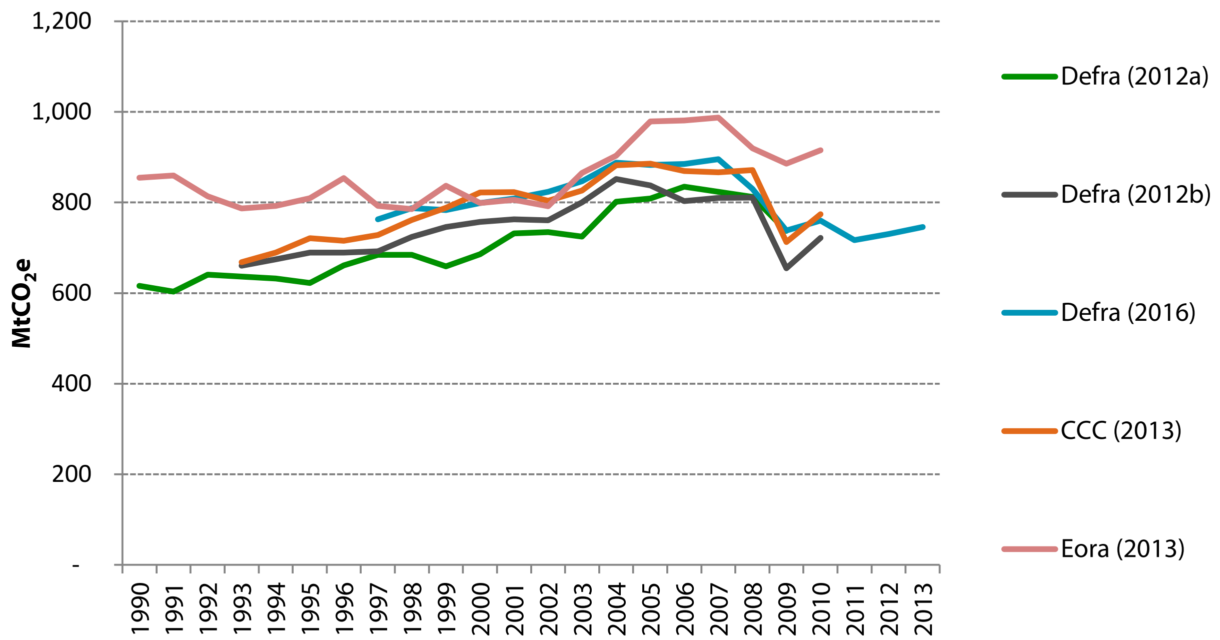
Uncertainty arising from different estimation methodologies

The different methodologies and datasets used for consumption-based emissions estimates can produce very different estimates, although most show a consistent trend (Figure 4.3);

- In a range of recent studies, the UK's CO_2 footprint was estimated in the range 722 to 915 $MtCO_2e$ in 2010. Moran & Wood (2013) have found results for most major economies disagree by less than10% between MRIOs even after harmonising data.
- Most studies show that estimates increased between 1990 and 2007, fell following the financial crisis, and are currently around the level of the mid-1990s.
- The average difference between the highest and lowest estimates was 190 $MtCO_2e$ over the period shown.

[16] (Peters, Glen P., Andrew, Robbie M., Karstensen, Jonas, 2016). Moran and Wood (2013)

Figure 4.3. Range of estimates for CO_2 consumption emissions



Source: University of Leeds and Centre for Sustainability Accounting. https://www.gov.uk/government/publications/uks-carbon-footprint

Notes: Data are for CO_2 only. This figure provides a representative but not exhaustive summary of UK consumption emission estimates in the literature. All studies use multi-regional input output analysis. All studies, with the exception of Defra (2012b) rely on GTAP data for trade, emissions, and economic output data. Defra 2012b is the latest official Defra estimate published in December 2012.

It is important that government continues to monitor consumption-based estimates and ongoing research to improve methodologies and reduce uncertainty, to ensure that measures to reduce UK territorial emissions do not lead to increased global emissions. They are also useful in providing additional information in the development of climate policy, carbon-intensive supply chains and trade flows. However, the current internationally agreed IPCC guidance based on production accounting methods should continue to be the basis for carbon budgets.

Annex
Sector summaries

This annex sets out our detailed analysis of the sources of greenhouse gas emissions, methodologies used in constructing estimates of these, data sources and uncertainty estimates across all sectors. This has informed the analysis in the main report.

The focus of this annex is to identify key messages and improvements that could be made at the individual sector level.

The uncertainty estimates used in constructing this annex have been provided by Ricardo Energy and Environment, based on the 2016 GHG inventory. These may not precisely match other uncertainty estimates published by BEIS and as reported in the National Inventory Reports because separate Monte Carlo runs were generated by Ricardo for the CCC. This was to enable us to produce uncertainty estimates for the classification of sectors and sources of emissions used by the CCC as opposed to the National Communication (NC) definition provided to the IPCC, or the classification used by BEIS.

The uncertainty estimates used throughout this annex relate to the 95% confidence interval. This means that estimates are in the range shown with 95% confidence.

Key messages

- Power sector emissions estimates have relatively low uncertainty at 2.2% in 2014.
- Emissions estimates of the largest emitting fuels, coal and natural gas have low uncertainty.
- Biofuels and waste have the largest uncertainty, at 14.4%, but account for only 2% of emissions.
- There is little scope for future improvements in measurement for this sector due to the reliable data on activity and emissions factors in this sector.

Power emissions

- Power emissions in the UK in 2014 were 125 $MtCO_2e$, which represented 20% of UK emissions.
- It is the sector with the biggest reduction in emissions, with a 49% fall since 1990.
- Coal is the largest source of emissions, comprising 69% of emissions in 2014. Natural gas makes up most of the rest at 28%.
- CO_2 is the dominant GHG emitted by the power sector representing 99% of emissions. Methane and N_2O collectively make up less than 1% of power sector emissions.

Methodology for estimating GHG emissions

- Most emissions data comes from BEIS energy statistics or the EU ETS.
- Emissions associated with fuel combustion are estimated by using fuel consumption data and appropriate emission factors.
- General fuel consumption data are taken from DUKES.

Figure A1: Power sector emissions by fuel, 2014

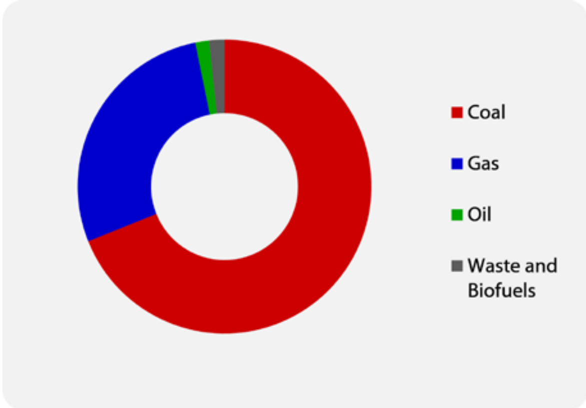
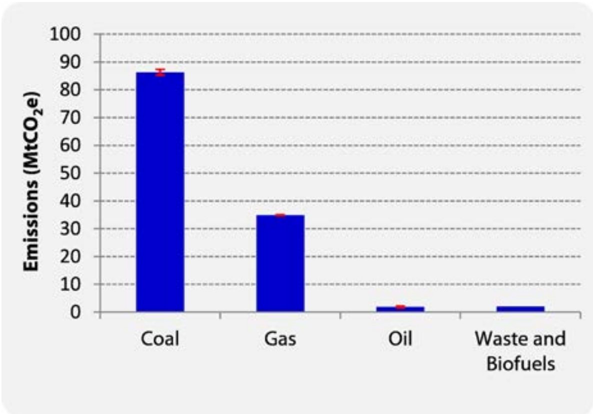


Figure A2: Power sector emissions and uncertainty, 2014



- Emission factors are taken from a variety of sources including the EU ETS, data provided by industry groups and literature based sources.
- For some power stations, and all coal-fired stations, site specific data are available from the EU ETS.
- CO_2 emissions, comprising 124 $MtCO_2e$, (99.4%) of power emissions, are based on Tier 2 methodology. The remaining 0.8 $MtCO_2e$ (0.6%) of power emissions from methane and N_2O are based on Tier 1 methodology.

Uncertainty

- Overall uncertainty for emissions in this sector is estimated at ± 2.2% in 2014.
- The energy supply sector is dominated by emissions from combustion in power stations and refineries. Since the carbon content of the fuels and the fuel consumption is well known, the CO_2 emissions from this source are relatively certain (2.1%).
- Emissions of N_2O (137%) and methane (62%) are more uncertain due to the number of factors that affect emissions of these gases. However due to their very low emission levels, their effect on overall sector uncertainty is small.
- Coal and natural gas represent 97% of emissions, and have low uncertainty (3%), while biofuels and waste have higher uncertainty (14.4%), but only contribute 2% of emissions.

Improvements and revisions

- Phase III EU ETS data has been incorporated which includes new installations and an increased scope for other installations which were already reported.
- Other revisions included reconciliation of offshore EU ETS data leading to clarification of the EU ETS scope, additional emission estimates for the use of process offgases and waste residues at chemical and petrochemical sites and improvements to the completeness of upstream oil and gas emissions data.

Forward look

- The power sector has low uncertainty and emission and activity factors are well understood. There is no reason to believe that this will change in the near future.

Key messages

- Uncertainty in buildings emissions was 3.4% in 2014. It is slightly higher than economy-wide CO_2 uncertainty.
- There are difficulties in measuring the impact of boiler, walls and energy efficiency measures rather than in measuring emissions themselves. This results in a 'Performance gap' between modelled impacts and measured results.
- Better statistics on the low-carbon heat network deployment, fuel use and boiler fleet efficiency would facilitate better monitoring and policy development.

Figure A3: Buildings emissions by sector, 2014

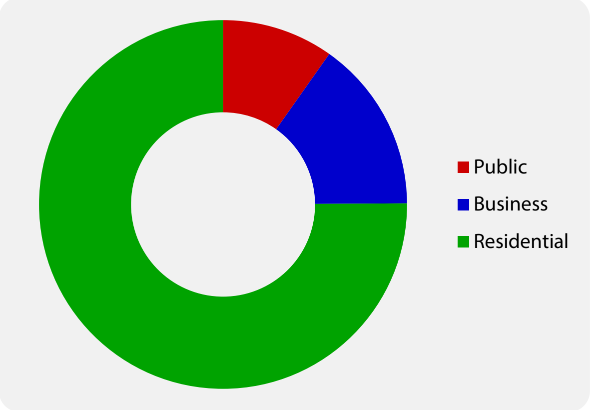
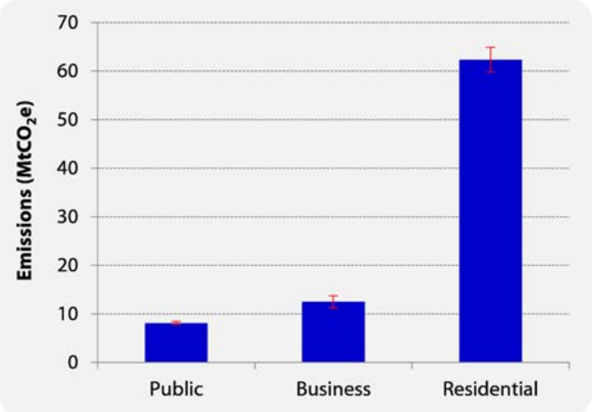


Figure A4: Buildings sector emissions and uncertainty, 2014



Buildings emissions

- Fossil fuel emissions from buildings comprise 16% of all UK GHG emissions in 2014.
- CO_2 emissions are mainly from burning gas for space heating and are split between homes (75%), commercial buildings (15%) and public sector (10%).
- Buildings emissions reduced by 1% on average between 2009 and 2014.[1] Progress has been particularly poor for commercial and public sector buildings.

Methodology and data sets

- Fuel combustion emissions are estimated from fuel use estimates in DUKES, a well-established data source.
- Tier 2 emission factors are used for estimating CO_2 from combustion emissions, while mainly Tier 1 factors are used for methane and N_2O.
- While it is straightforward to calculate emissions from buildings, it is difficult to measure the impact of individual measures.
- Standard Assessment Procedure (SAP), used to generate Emission Performance Certificates (EPC), is a tool to assess impact of measures, but systematic biases have been an issue (e.g. underestimating thickness of solid walls and overestimating impact of insulating solid walls).
- It is difficult to calculate heat produced by energy usage as this is dependent on boiler efficiency, itself dependent on age, type, temperature and maintenance of boiler. Hence, it is difficult to estimate the impact of boiler efficiency regulations.

[1] Temperature-adjusted.

- Inventory estimates can be influenced by weather which affects heating demand. For assessing trends, we typically adjust for variations in temperature.
- A 'performance gap' exists between modelled savings potential and that observed in practice, due to differences in how occupants may behave compared to their behaviour assumed in the modelling (e.g. in setting internal temperatures). Also, there may be installation issues associated with poor workmanship, where upskilling the supply chain and providing quality accreditation would help.
- There is scope for more effective enforcement of building regulations (e.g. many cavity wall properties built in the 1980s and 1990s do not comply with 1985 building regulations).

Uncertainty

- Uncertainty in overall buildings emissions is low at 3.4%, comparable with 3% for the economy as a whole.
- Both the carbon content and level of fuel consumption is well known in the vast majority (98%) of emissions.
- Uncertainty is higher for emissions factors of non-CO_2 gases, which are a function of boiler size and efficiency.
- Uncertainty has reduced over time due to improvements in inventory methodology. The main reductions in uncertainty are a result of using UK-specific emission factors for liquid and solid fuels.

Forward look

- The gap between modelled impacts of energy efficiency measures in this sector and actual emissions continues to make it difficult to effectively monitor progress. Better statistics in this area would facilitate this.

Key messages

- Uncertainty in the sector was 3% in 2014, the same as economy-wide emissions.
- Sectors with the largest uncertainties are: mobile combustion (20%), refineries (15%), chemicals (9%), upstream oil (9%). Smaller sectors are also more uncertain.
- The industry sector includes 4 $MtCO_2e$ from fugitive emissions from the gas transmission and distribution network, based on a model developed by National Grid. Uncertainty in these emissions is relatively high at 22%. We intend to study these emissions further as part of our future work programme along with emissions from conventional petroleum.
- Future unconventional onshore petroleum exploitation should include a monitoring regime to catch potentially significant methane leaks early.

Figure A5: Industry emissions by sector

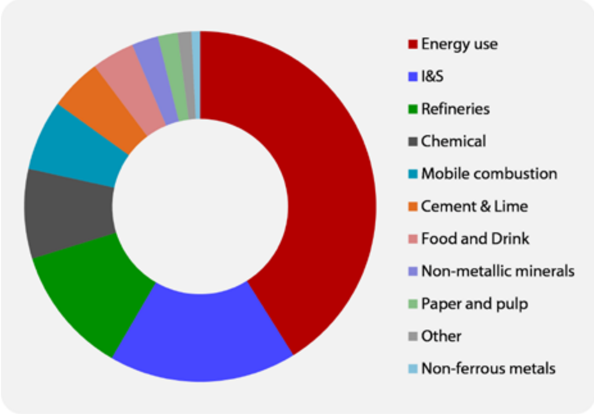
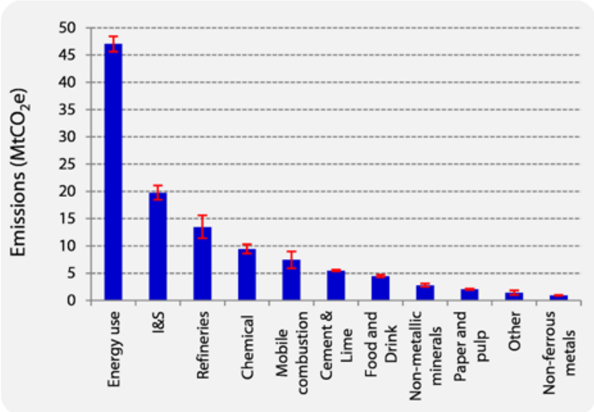


Figure A6: Industry emissions and uncertainty, 2014



Industry emissions

- Emissions in this sector were 114 $MtCO_2e$ in 2014, over 90% of which were CO_2.
- The CCC classification of this sector differs from that used by BEIS and the NAEI. The key differences are the CCC classification includes refineries and industry manufacturing of fuels which are classified in energy supply in the National Inventory and combustion emissions from industry which are classified in the Business sector by BEIS. It also covers industry process emissions, as in the BEIS classification.
- Manufacturing makes up two-thirds of GHG emissions, with refineries and energy supply the remainder.
- The sector covers a diverse range of industrial combustion and process emissions, largely from energy-intensive sectors. Four sub-sectors: iron and steel, refineries, fuel manufacture and chemicals account for half of industrial emissions.

Methodology and data sets

- Table A1 below summarises the data sources and methodology used to estimate emissions for the key parts of this sector. Combustion emissions estimates are relatively straightforward and based on DUKES data. Process emissions are more subsector-specific and use a mix of Tier1-3 methodologies.

Uncertainty

- Overall uncertainty in the industry sector is similar to that of economy-wide emissions: 3% in 2014. Around 40% of emissions in this sector are from energy sub-sectors – direct combustion, fuel manufacture and upstream oil. Uncertainty in these sub-sectors is lower (3%) than in all other sub-sectors (4.6%).
- Sub-sectors with the largest uncertainties are: mobile combustion (20%), refineries (15%), chemicals (9%) and upstream oil (9%). Smaller sub-sectors such as aluminium process emissions (17%) and petrochemicals (30%) are also more uncertain.
- Iron and Steel and Cement are large emitters in this sector. Uncertainties for both of these are low as the processes involved are well understood and data are complete.
- Emissions from off-road machinery account for 7% of this sector's emissions and, at 21%, uncertainty is relatively high. These are estimated through a Tier 3 approach where the population, usage and lifetime of different types of off-road machinery are derived from a study carried out in 2004. Although this is updated based on key drivers, there is no annual data on population and usage of off-road machinery.
- Fugitive emissions from the gas transmission and distribution systems are associated with 22% uncertainty. Emissions are estimated by the gas network operators, as outlined in Box A1. As these emissions can arise from a large number of small release points they are difficult to control and measure.

Forward look

- This sector includes a range of emission factors for specialised industry applications, some of which are under review at both the country level and through the IPPC.
- We note the high uncertainty associated with off-road machinery in this sector and consideration should be given if the model underpinning these estimates could be updated to use more up to date data for types and performance of machinery.
- We intend to study fugitive emissions from the gas transmission and distribution systems and conventional petroleum production further as part of our future work programme.
- In future, depending on the scale of unconventional petroleum production in the UK, the emissions footprint from unconventional petroleum production could become substantial and more uncertain.[1]
  - A monitoring regime that catches the main sources of emissions (known as super-emitters) quickly and significantly limits the quantity of methane released to the atmosphere is essential in both mitigating emissions and reducing uncertainty.
  - Technical solutions to reduce emissions from unconventional petroleum production would also reduce uncertainty.

[1] Figure 2, Onshore Petroleum, CCC, March 2016

Forward look *(continued)*

- In the Committee's advice on unconventional petroleum under the Infrastructure Act[2], we concluded that emissions from well development, production and decommissioning must be strictly limited if shale gas is to be exploited at a significant scale in the UK.
- It is important that top-down studies are integrated further with the bottom-up approach in order to reduce the gap in estimates from the two techniques.
- It is also important to measure a baseline for atmospheric emissions so that any changes induced by future shale gas exploration activity can be compared quantitatively. The British Geological Survey (BGS) and the universities of Manchester and York are measuring methane concentrations at two shale gas exploration sites in Lancashire and Yorkshire before any shale gas development begins.[3]

---

[2] Onshore Petroleum, CCC, March 2016.
[3] British Geological Survey website.

Box A1. Fugitive emissions from the gas distribution and transmission network

The National Inventory Report estimates gas network leakage for three parts of the network:

1. The high-pressure transmission mains.
2. The low-pressure distribution network, medium pressure mains and above ground installations.
3. Losses at the point of use.

95% of the losses come from the low-pressure distribution network. Uncertainty across all three sites was 22% in 2014, with most uncertainty associated with emission factors. The following three sections outline the methods used by the National Inventory Report to estimate fugitive emissions for each part of the network.

1. High pressure transmission

Methane losses from the high-pressure transmission system are estimated by National Grid (NG) based on periodic fugitive emission surveys for the NTS compressor stations and LNG terminals and NG records of intentional venting actions on the network.

These data have not been available for every year across the time series, but are interpolated where no data are available. The last survey was in 2012 and estimates for 2013 and 2014 are extrapolated from that point.

2. Distribution network estimates

The UK GHG inventory estimates for distribution leakage are provided by the gas network operators annually. They are based on the aggregate of mass of gas leaked across all networks (low pressure mains and other losses), with the methane content of the natural gas based on compositional analysis.

The UK gas network operators use a common industry leakage model (the UK Gas Network Leakage Model) to derive their annual estimates of gas leakage. This was developed by British Gas and uses factors and assumptions on leakage rates for different types of gas mains and installations, based on measurements and surveys conducted in 1992 and 2002, with annual updates to maintain the representation of the UK gas network infrastructure (such as length and type of pipelines and other units) and reflect the rolling programme of network replacement.

Data on the methane and NMVOC content of natural gas are obtained from automated samples from the network operators. The weighted average for the UK is estimated from data across all the regional gas networks.

3. Losses at point of use

Losses from industrial heating are assumed to be 'not occurring' as larger boilers typically operate almost permanently once ignited and releases of un-burnt natural gas are strictly controlled for safety reasons.

Methane emissions from pre-ignition losses of gas appliances in the domestic and commercial sectors are based on activity data from Energy Consumption in the UK and assumptions about the types of appliances operated in the sectors.

Source: National Inventory Report, 2014.

Table A1. Data sources and methodology used for key industry sub-sectors

	Data sources	Methodology
Combustion emissions for all sectors	DUKES for all fuels used for direct combustion of fuel.	Country specific activity data from DUKES. EFs either UK specific, from IPCC or from the EU Monitoring and Evaluation Programme-European Environment Agency.
Mobile combustion	Covers fuel use from industrial road machinery. Estimates based on a detailed study in 2004 on the total UK population of this equipment and updated annually based on known drivers.	Tier 3 modelled activity data and emissions factor. Default machinery or engine-specific fuel consumption and emission factors (g/kWh) from EMEP-EEA Guidebook.
Process emissions		
Cement and Lime	Industry, ETS	Tier 1 for EF Activity data from industry
Glass	Survey of raw material usage in glass production used to measure raw materials used in the sector and the estimated emissions intensity. Volume of production based on production data from industry and ETS.	EFs from survey data. Activity data from industry and ETS.
Refineries	Covers wide range of products and processes. Industry and UKPIA data, DUKES are key data sources.	EFs largely UK specific from ETS data and academic research. Non-CO_2 EFs largely IPCC defaults.
Iron and Steel	Operator's data on supply and use of fuels matched against DUKES data. Model recently reviewed by Ricardo-AEA.[4] Processes are well understood and data complete.	Tier 3 carbon balance model of inputs, processes and outputs. Carbon content of fuels from ETS data and are country-specific. Activity data are country-specific.

[4] GHG Inventory Research: Use of EU ETS Data, Ricardo Energy and Environment, April 2014.

Table A1. Data sources and methodology used for key industry sub-sectors

	Data sources	Methodology
Food and Drink – largely from distillation and fermentation processes (beer, spirits and bread)	Activity data and EFs from government or industry sources.	CO_2 emissions use Tier 2 country specific EFs from Baggott et al 2004. Methane and N_2O use Tier 1 IPCC default factors.
Chemicals **Covers CO_2, N_2O from chemical and petrochemicals but not F-gases.**	Chemicals Industry Association, EU ETS, CCA agreement data and pollution inventory data.	Mix of Tier 2 for key gases and IPCC default for minor processes and gases.
Pulp and paper	Emissions are largely NMVOCs from the production of chipboard and related products and CO_2 from combustion processes. Other emissions are not reported.	EFs based on US EPA data Production data from ONS.

Key messages

- Transport emissions uncertainty was 1.6% in 2014. It is lower than economy-wide CO_2 uncertainty and the underlying data sources are well-established.
- The methodology for attributing emissions to different modes should continue to be monitored as this is important for quantifying the gap between real-world and test-cycle emissions.
- Consideration should be given to data needed to effectively monitor progress in IAS, in particular the ICAO agreement, once arrangements have been developed and agreed.

Transport emissions

- Transport was the largest emitting sector in 2014, with 22% of UK GHG emissions.
- Emissions have decreased by 3% since 1990, but rose 1.4% in 2014.
- Road transport is the largest source of emissions (92%). Rail, aviation and shipping are other sources.
- 99% of emissions are CO_2 from fossil fuel combustion.

Methodology and data sets

- **Road Transport**: Fuel consumption is based on DUKES energy data, which is a well-established source for both fuel consumed and carbon content.
- The split of emissions by mode is more difficult to estimate. These are based on the COPERT model, which contains speed emission curves by vehicle type and age for different roads and associated real world emission factors.

Figure A7: Transport emissions by mode, 2014

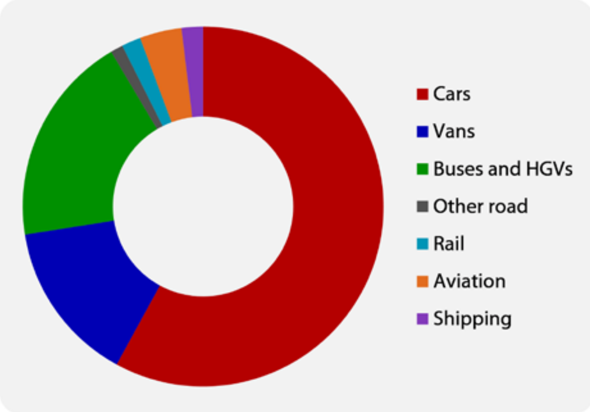
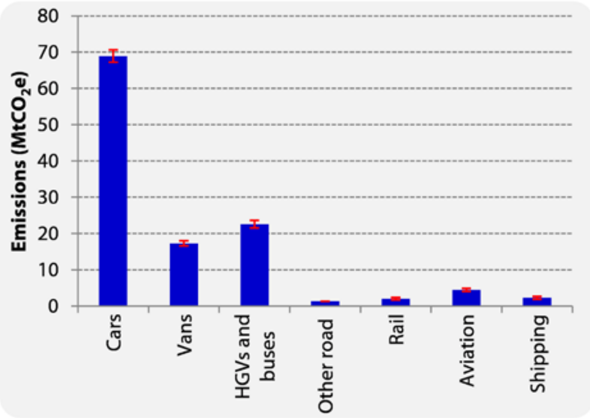


Figure A8: Transport emissions and uncertainty, 2014



- Estimates from the COPERT model are reconciled with DUKES data. The methodology for this was revised in the 2014 inventory, based on evidence on the gap between real-world and test-cycle emissions.
- Overall road transport emissions were unchanged by this methodology revision, but the split between modes was revised. Car and van emissions revised up and HGV emissions down.
- This was important as it shows car and van efficiency did not improve as fast as previously thought, and there was a larger gap between test-cycle and real-world emissions.
- Methane and N_2O emissions are also modelled taking account of vehicle age, fuel type, speed and distance travelled.

- **Rail:** Emissions estimates are based on Kms travelled multiplied by an emissions factor per passenger/freight.
- **Aviation:** Domestic aviation emissions are based on Tier 3 methodology and take the number of aircraft movements multiplied by emissions factors. These are reconciled with DUKES data. International aviation emissions are reported as a memo item.
- **Domestic shipping:** Emissions are calculated using a bottom-up methodology based on shipping movement data for different vessels, fuels and journeys.
- **International shipping:** Estimates are derived using the difference between total fuel consumption statistics from DUKES for marine fuels and fuels used for domestic shipping above. These are included as a memo item.

Uncertainty

- Overall transport CO_2 uncertainty was 1.6% in 2014, lower than economy as a whole.
- Uncertainty for methane (60%) and N_2O (100%) are much larger. N_2O contributes just 1% of emissions.
- Uncertainties for van and HGV emissions are nearly double that for cars, largely due to higher uncertainty associated with diesel emissions.
- Uncertainty in rail (17%) domestic aviation (20%) and domestic shipping (18%) are higher than for surface transport due higher uncertainty associated with data for these activities.
- No uncertainty estimates are published for International Aviation and Shipping as these included as a memo item and not part of the main inventory.

Forward look

- It is important to continue to monitor the gap between real-world and test-cycle emissions for cars and vans as this affects the effectiveness of regulations.
- The ICAO agreement reached in 2016 effectively sets limits to growth in airline emissions post 2020. It is important that data to monitor compliance with the agreement are available when the approach has been agreed.

Key messages

- Agricultural emissions are subject to higher uncertainty (19%) compared to the economy-wide level of 3%.
- On-going improvements to the methodology for calculating agricultural emissions have significantly reduced the level of uncertainty.
- The roll-out of the Smart Inventory in 2018 will further improve our understanding of how UK farming practices and conditions impact emissions and abatement. Government should ensure this work is completed, while continuing to address keys gaps and uncertainties.

Agriculture emissions

- Agriculture emissions were 49 $MtCO_2e$ in 2014. Since 1990 they have declined by 16%, but increased by 2% in 2014 compared to the previous year.
- The sector now accounts for a larger share of UK economy-wide emissions (9.5%) than at any time since 1990.
- By gas, methane accounts for 56% of emissions, N_2O 33% and CO_2 the remaining 11%.
- By source, enteric fermentation – due to the digestive process of ruminant animals such as cattle and sheep – accounts for 49% of emissions. Soils (29%) are the next largest source, followed by the management of livestock waste and manure (11%) and mobile and stationary machinery (10%).

Figure A9: Agriculture emissions by source, 2014

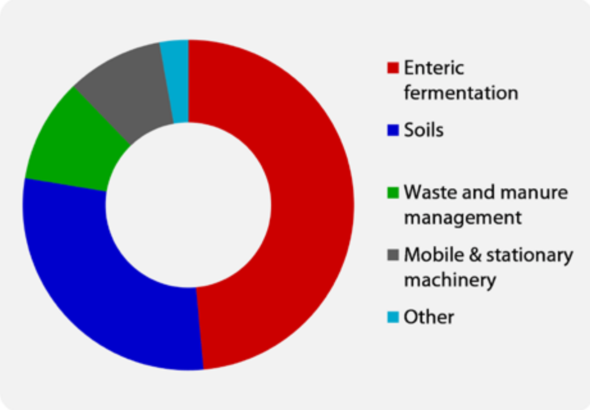
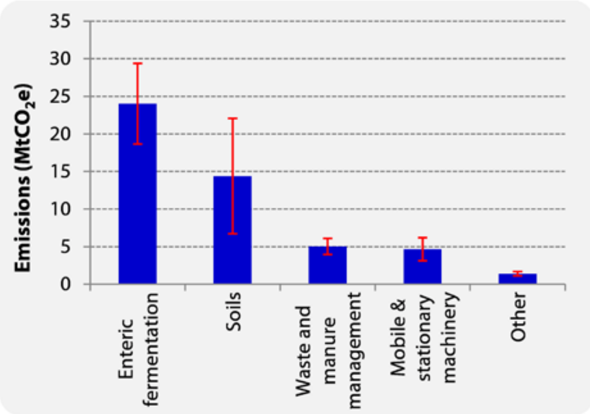


Figure A10: Agriculture sector emissions and uncertainty, 2014



Methodology and data sets

- Estimates of non-CO_2 emissions are calculated using mainly a mixture of Tier 1 and Tier 2 methodologies, while CO_2 estimates are calculated mainly using the Tier 3 approach due to energy combustion being the dominant source of CO_2.
- **Enteric fermentation:** emissions are estimated by multiplying livestock numbers with the relevant emissions factor. Beef and dairy cattle use UK specific factors, which accounts for 41% of enteric emissions. Country specific data such as live weight, milk yield, feed digestibility and carcase weight for beef cattle are used to generate the Tier 2 emissions factors. All other livestock types are derived using default IPCC

(2006) Tier 1 factors, and this accounts for 59% of enteric emissions.

- **Agricultural soils:** country specific emissions factors for soil emissions were adopted in the 2016 inventory for certain sources such as fertiliser use and urine and dung deposition by grazing livestock. This Tier 2 methodology accounts for 62% of UK soil emissions. The remaining 38% of emissions arise from sources that still use default factors such as the incorporation of crop residues into soils.
- **Waste and manure management:** non-CO_2 emissions are calculated using Tier 2 country specific emissions factors, which differ depending on livestock type and manure management system (e.g. liquid system and daily spread).
- **Data sources:** data from Defra's June Survey of Agriculture and Horticulture are used to derive estimates of emissions from the large sources, such as enteric fermentation, animal wastes and manure management, and soil emissions. In addition, the British Survey of Fertiliser Practice is used to derive soil emissions from the use of fertilisers.
- Other data sources include the annual June Agricultural Census published by each country of the UK to derive activity data on livestock numbers and crop area.
- Estimated CO_2 emissions from the combustion of fuels for stationary and mobile machinery are derived from energy use data in the Digest of UK Energy Statistics (DUKES).

Uncertainty

- Uncertainty in the agriculture sector is estimated at 19%, ranging between 40-59 $MtCO_2e$. This compares with 3% for the economy as a whole.
- The largest uncertainty attributed to agricultural soils (53%) due to the variability in the many factors that can impact emissions such as differences in soil type, moisture, temperature, season, crop type, fertiliser, and other agricultural practices.
- Uncertainty in estimating methane emissions is generally lower because the default emissions factors are already based on models that are regional and animal specific.
- The implementation of the 2006 IPCC Guidelines in 2015, which adopted revised Global Warming Potential (GWP) values for methane and N_2O; and the replacement of default emissions factors with UK specific ones developed under Defra's Agricultural GHG Research Platform have reduced the level of uncertainty in recent years.
- Further improvements largely covering methane emissions will be incorporated as part of the planned roll-out of the new UK Smart Inventory next year.

Forward look

- If GWPs in the IPCC's Fifth assessment Report are adopted in the agriculture inventory, estimated methane emissions would increase, while N_2O would decline.
- We note the discrepancy in methane emissions estimates from the inventory and those estimated through atmospheric measurement (also applies to Waste). This has important implications for assessing progress reducing emissions and the effectiveness of policy measures. Further work needs to be done to reconcile these estimates to provide confidence over the trend in emissions.
- The roll out of the Smart Inventory should enable better monitoring of progress reducing emissions in this sector. It is important to monitor, and if needed address, continuing gaps and uncertainties.

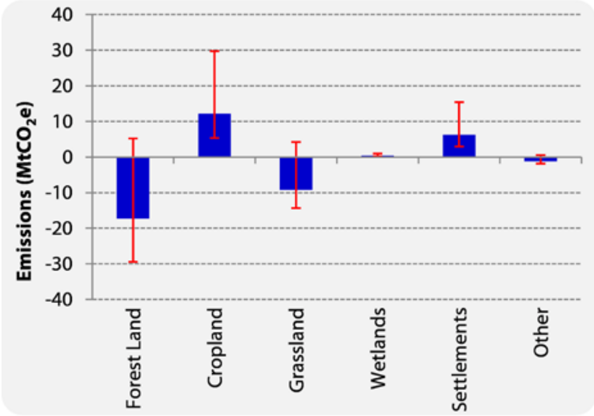
Key messages

- Land use, land-use change and forestry (LULUCF) is the only sector in the national inventory that removes emissions in addition to being a source. Overall, it is a net carbon sink.
- Estimated emissions in this sector are the most uncertain of all the sectors in the inventory, with uncertainty of -101% in 2014. This is due to the natural variability in biomass, soil and underlying processes impacting sinks/sources as well as incomplete knowledge on activity data.
- Government should complete the programme of works to reduce uncertainties, including the inclusion of peatland emissions in the inventory and the development of a more accurate method to track land use change in a spatially explicit way.

LULUCF emissions

- The sector was a net sequester (-9 $MtCO_2e$) in 2014, which is equivalent to abating 2% of all UK GHG emissions.
- The net carbon sink has increased year-on-year since 1990, and strengthened by 4% in 2014 compared to the previous year.
- By land type, cropland is the largest source of emissions (60%). Forests and grassland account for 62% and 34% respectively of emissions sequestered in the sector.
- CO_2 is the dominant GHG accounting for all of the sequestration, and 96% of emissions in 2014.

Figure A11: LULUCF sector emissions and uncertainty, 2014



Methodology and data sets

- **Land use change:** activity data on the area of land use change by land type are estimated from two surveys, the National Forest Inventory and the 2007 Countryside Survey (CS) for agriculture and other land.
- **Forests:** Carbine replaced C-Flow as the new forestry carbon accounting model in 2014. It calculates gains/losses in carbon pools in standing trees, litter and soil in conifers and broadleaves, and in harvested wood products. The new assumptions and improved data sets in Carbine increased forestry sequestration estimates.
- **Cropland:** Land area data covering carbon stock changes, fertiliser use and main crop types are taken from several sources such as habitat/landscape survey, the June Agricultural Census for each UK administration, and the British Survey of Fertiliser Practice.
- **Grassland:** A large revision was made in the 2016 inventory for a correction in the emissions factor for the drainage of organic soils on grassland. While grassland accounted for almost 4 $MtCO_2e$ of emissions released in 2013 based on the 2015 inventory, the revised estimate for the same year is closer to 0.4 $MtCO_2e$.

- **Wetlands:** Includes emissions from extracted peat for energy and horticultural use, and for areas converted to permanently flooded land (reservoirs). Estimates from peat extraction are derived from the Mineral Extraction in Great Britain Business Monitor PA1007 which gives data on volumes of peat sold; and the Directory of Mines and Quarries (DMQ) which gives the location of peat extraction sites.
- With the exception of wetlands, a Tier 3 methodology with country-specific emissions factors is used for carbon stock changes for the other land types.
- A Tier 1 approach is used for all N_2O and methane emissions, and emissions from wetlands.

Uncertainty

- The areas undergoing land use change represents the largest source of uncertainty in the sector. This is because the last CS was conducted in 2007 and represents only a small sample of the UK's countryside, which is not spatially-explicit. Extrapolation is therefore required for the whole of the UK and over time to the current year.
- By land use type, forestry has the lowest level of uncertainty at -30%, and wetlands the highest at 50%.
- Uncertainties associated with the carbon pool are generally much greater than those in above ground biomass trees. For example, the inventory does not capture emissions from trees planted on organic soils, and all sources of peatland emissions.
- Although CO_2 emissions are estimated using a Tier 3 methodology, uncertainty was 93% in 2014, compared with 41% for methane and 26% for N_2O estimates.

Forward look

- There is ongoing work to update the inventory to capture new sources of emissions and removals, apply more representative emissions factors and to better track changes in land use. It is important these are completed on time.
- The most significant changes to the inventory are expected to come from the inclusion of all peatland emissions. We will advise on how this affects emissions targets when evidence is available on their impacts and the potential to abate these.

Key messages

- Waste emissions had higher uncertainty (36%), compared to the economy-wide emissions (3%) in 2014.
- Uncertainties are attributed to a range of issues such as incomplete information on activity data and imperfect understanding of certain biological processes.
- Methane emissions from landfill account for over 70% of the sector's emissions. Work should progress on addressing the uncertainties that exist in estimating emissions from this source.

Waste emissions

- Waste emissions accounted for almost 4% (19 $MtCO_2e$) of UK GHG emissions in 2014. By gas, methane accounted for 93% of waste emissions, N_2O (5%) and CO_2 (2%).
- Landfill accounts for 71% of waste emissions and are entirely methane. Other key sources are wastewater treatment (20%), biological treatment of wastes, such as composting and anaerobic digestion (7%), and waste incineration without energy recovery (2%).
- Since 1990, waste emissions have declined by 73%. Over 98% of this reduction is due to the decline in landfill emissions as a result of reduced biological waste going to landfill, investment in methane capture technology and improved management at landfill sites. More recently, waste emissions fell by 11% in 2014.

Figure A12: Waste emissions by source, 2014

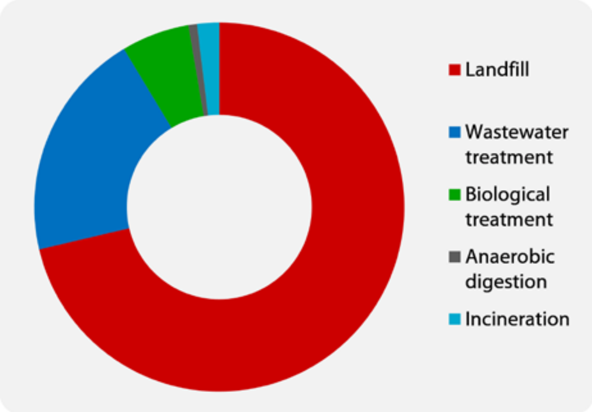
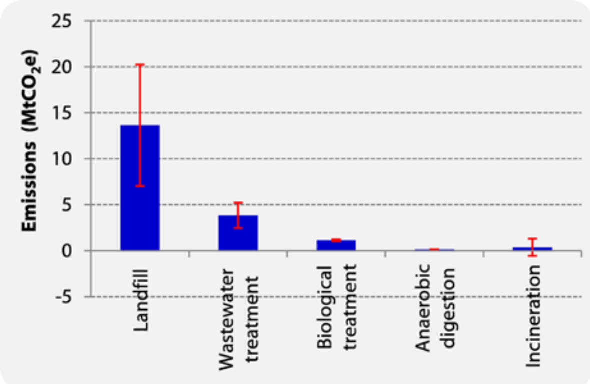


Figure A13: Waste emissions and uncertainty, 2014



Methodology and data sets

- Around a fifth of waste emissions are calculated using the Tier 1 methodology approach, with the remainder using Tier 2.
- Landfill emissions are modelled using the Methane Emissions from Landfill model (MELmod) since 2008. This takes account of the quantity of biodegradable waste sent to landfill, properties of waste streams such as methane yield and decay rates, and quantity of methane emissions avoided at landfill sites, due to methane recovery, utilisation and flaring to CO_2.
- National data on waste quantities, composition, properties and disposal practices over several decades are used to estimate landfill emissions.

- **Wastewater treatment:** emissions are based on a Tier 1 methodology with country-specific time series activity data covering the handling, treatment and discharge of domestic, commercial and industrial waste water.
- **Biological waste treatment:** uses a Tier 1 approach used for emission estimates for composting, anaerobic digestion of non-agricultural wastes and mechanical biological treatment. Range of datasets used e.g. from Waste and Resources Action Programme (WRAP) and the Association of Organics Recycling.
- **Waste incineration** emissions use a mix of Tier 1 and 2 methodologies with either country-specific or default emissions factors for a range of waste streams such as MSW, sewage sludge, animal carcases and crematoria.

Uncertainty

- Overall emissions uncertainty was high in 2014 (36%), implying a range of 12-26 $MtCO_2e$.
- The biggest source of uncertainty is waste incineration (253%), although this only accounts for 2% of waste emissions.
- Of more significance is landfill, which accounts for over 70% of emissions and has an uncertainty of 48%. Uncertainty is due to imperfect understanding of methane yield and decay rates; use of default oxidation values to estimate fugitive emissions and incomplete data prior to 2008 on quantity of methane flared.
- Use of high Tier 1 default values for wastewater treatment due to limited data availability means emissions from this source are probably an over estimation, and the uncertainty is 36%.

Forward look

- Planned inventory improvement focuses on the two largest sources of emissions in the sector. For waste water treatment, this includes developing N_2O emissions factors from waste water.
- For landfill, emissions factors, model parameters and activity data are being kept under review.

Key messages

- Fluorinated gases (F-gases) uncertainty was 8.8% in 2014. It is higher than economy-wide CO_2 uncertainty.
- There are significant discrepancies between atmospheric measurements and inventory for one F-gas. Revisions to the models for estimating emissions from refrigeration, air conditioning, aerosols and metered dose inhalers required.
- Revisions to the GWPs of all F-gases are anticipated.

F-gases emissions

- F-gases comprised 3% of UK GHG emissions in 2014. This share has been stable since 2009.
- Emissions rose 1% in 2014.
- 96% of emissions HFCs, 2% SF_6, 2% PFCs and very low NF_3.
- 78% of emissions are from refrigeration and air conditioning and 13% are from aerosols and metered dose inhalers.

Methodology and data sets

- **Refrigeration and air conditioning**: Industry stakeholders develop assumptions on equipment stocks, market growth and equipment lifetimes, which feed into a model to calculate loss rates of HFCs during manufacture, operational lifetime and disposal.
- Estimated consumption from the model is compared with annual refrigerant sales from the British Refrigerant Association.
- Model has been refined following the analysis of discrepancies with atmospheric measurements of HFCs.

Figure A14: F-gas emissions by source, 2014

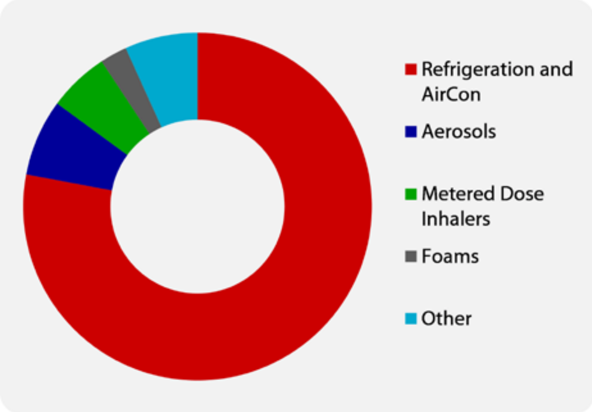
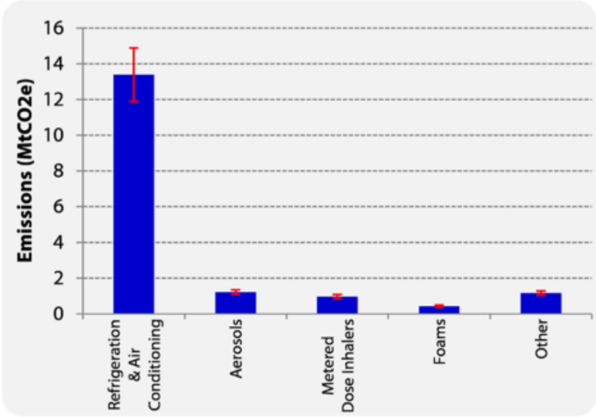
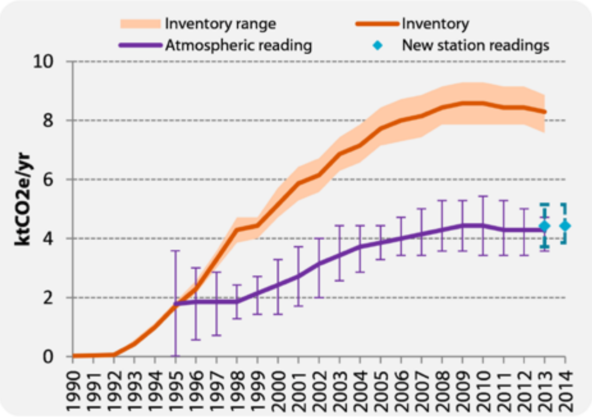


Figure A15: F-gas emissions and uncertainty, 2014



- **Aerosols:** Fluid consumption data are provided by the British Aerosol Manufacturers' Association. 1% of emissions are from the manufacturing process and the remainder are from lifetime and disposal. Imports and exports are taken into account before lifetime and end of life emissions are calculated to ensure only those used and disposed of within UK are included.
- **Metered Dose Inhalers (MDI):** NHS prescription data provides an estimate of the number of MDIs used each year, from 1998-2014. Data are extrapolated backwards for 1990-97.

Figure A16: External validation of HFC-134a emissions



Uncertainty

- F-gases uncertainty was 8.8% in 2014, which was higher than average economy wide uncertainty.
- NF_3 has highest relative uncertainty of 47%, but contribute very little uncertainty to overall F-gases uncertainty as these emissions represent such a small proportion of F-gases emissions.
- HFCs have relative uncertainty of 9.23%, but are a much larger proportion of F-gases emissions, so contribute the most to F-gases uncertainty.
- Uncertainty arises mainly from the emission factors.
- HFC-134a emissions extrapolated from atmospheric measurements have risen at half the rate of the inventory estimates. The refrigeration and air conditioning model has been revised as a result of this, but inventory emissions are still significantly higher.
- In order to fully reconcile the estimates from the inventory and the atmospheric measurements, further revisions are likely to be required to the refrigeration and air conditioning model as well as revisions to the method of calculating emissions from aerosols, as the discrepancy is sufficiently large that revisions to only one model are unlikely resolve the issue.

Forward look

- The refrigeration and air conditioning model requires updating and further studies of emissions from aerosols are needed to understand the discrepancy between inventory and atmospheric emissions estimates.
- Introduction of IPCC AR5 guidelines will include changes to the GWPs of most F-gases, resulting in a reduction in emissions in $MtCO_2e$ of around 5%.

Key messages

- Devolved administrations (DAs) compile their own GHG emission inventories, based on the methodology used for the UK. However, activity data are not as widely available in the DAs, particularly for the transport and building sectors.
- Uncertainty in emissions estimates for Scotland (10%) and Northern Ireland (7%) were than the UK average (3%) in 2014. Wales and England are the same as the UK average.
- Afforestation targets and inclusion of peat emissions are likely to lead to higher uncertainty in the Scottish inventory in future.

Figure A17: Emissions and uncertainty in the devolved administrations, 2014

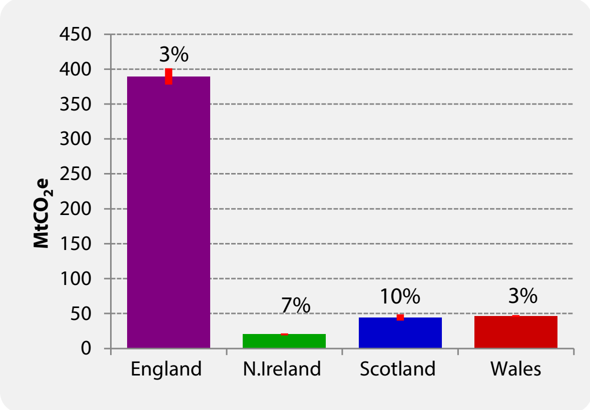
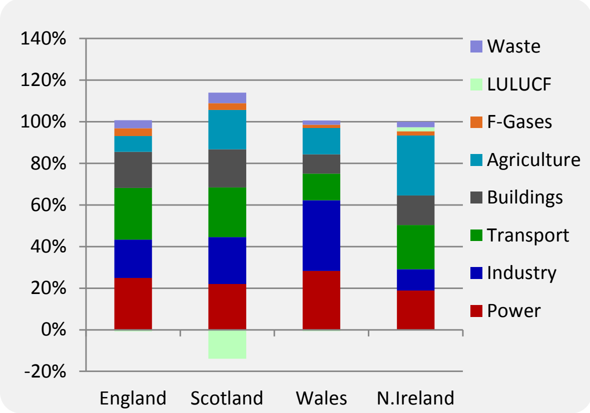


Figure A18: Devolved administration emissions by sector, 2014



Devolved administrations GHG emissions

- Scotland accounted for 8.6% of total UK GHG emissions in 2014, emitting 44.4 $MtCO_2e$.
- Wales accounted for 9.0% of UK GHG emissions in 2014, with emissions of 46.4 $MtCO_2e$.
- Northern Ireland accounted for 4.0% of UK GHG emissions in 2014, with emissions of 20.3 $MtCO_2e$.
- For Wales, a higher proportion of emissions come from the Industry sector than the rest of the UK, 33% compared to a national average of 22%. Northern Ireland has a greater proportion of emissions from agriculture at 29% compared with10% in the UK. Scotland is a large carbon sink, with LULUCF reducing emissions by 6 $MtCO_2e$, representing 14% of emissions.
- Emissions in Scotland fell faster than the UK as a whole, with a 41% reduction in emissions since 1990 compared with 38% in the UK. Wales and Northern Ireland have seen significantly lower emissions reduction than the UK average, with 18% and 17% falls respectively.

Methodology and data sets

- Specific emissions data on the devolved administrations comes from the NAEI's Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland. Where possible, the same methodology is used to calculate emission estimates as for the UK Inventory.

- However, using a bottom-up methodology is not possible for all emissions sources in each DA as the data are not as detailed as for the UK. In these cases estimates are derived from UK totals using proxy statistics to disaggregate activity data (e.g. fuel consumption data). Box A2 sets out key areas where the DA inventory differs from the UK.
- The same emission factors are used in the DA inventories as in the UK, and it is assumed that the emission factor uncertainties are the same as for the UK. This approach maintains consistency with UK uncertainty estimates.

Uncertainty

- Uncertainty in Scotland's GHG inventory was 10% in 2014, compared with 3% for the UK as a whole. This is due to the large number of LULUCF sources and sinks in Scotland, a sector with high uncertainty. Scotland also has relatively high contribution to its overall GHG total from methane and N_2O.
- Welsh GHG emissions had a 3% uncertainty level in 2014 in line with the UK average.
- Northern Irish emissions had a 7% uncertainty level in 2014. Like Scotland, this is higher than the UK average due to the contribution of LULUCF and agriculture sectors.
- Northern Ireland has a higher share of methane and N_2O than the other DAs. These gases have greater levels of emission factor uncertainty, also contributing to higher overall uncertainty.

Specific areas of interest in DA

- **LULUCF and agriculture**. Scotland's ambitious Climate Change Plan set a target of increasing forest cover from 17 per cent to 25 per cent of the land mass. As uncertainty is higher in this sector, a larger forestry sector will lead to higher overall uncertainty in the Scottish inventory.
- **Introduction of peat to the inventories** It is expected that future inventories will include the carbon effects of peat sinks/sources. With large moorland areas of around 20% of Scotland's landmass, Scotland's emissions are likely to be significantly affected by this inclusion. Due to limited current knowledge of the extent and science of peat emissions, the uncertainty attached to these emissions is likely to be high, further increasing Scotland's GHG uncertainty levels. The Scottish Climate Change Plan already includes peatland emissions despite them not appearing in the inventory.
- **Port Talbot Steel Works** has a large effect on Welsh GHG emissions. The restart of the No.4 Blast Furnace in February 2013 increased Industry emissions by 26%, or 3.5 $MtCO_2e$. The emissions from the blast furnace are well understood and reported, therefore the uncertainty is small.

Forward look

- Recent work has focussed on minimising the amount of proxy data to calculate activity data, such as the 2010 mapping update for the industry sector or the new approach to uncertainty modelling adopted this year.
- However, there continues to be potential for errors in the distribution of UK fuel use across the regions due to data gaps and inconsistencies in devolved administration energy use data. Further data collection to fill gaps would help produce more robust estimates.

Box A2. Methodological issues in the DAs GHG inventories

Key areas where the GHG inventory methodology and data sources differ across DAs are:

- For transport estimates, a complete set of transport fuel consumption data (similar to those available for the UK as a whole) are not available for England, Scotland, Wales or Northern Ireland separately. Instead, two methods are used to estimate road traffic emissions. The bottom-up approach uses regional vehicle km data from the Road Traffic Survey to estimate road transport CO_2emissions in each DA. A top-down approach uses regional vehicle km data as a means to proportion the total UK road transport CO_2 emissions between each DA region. The difference in results at DA level largely reflects the difference in the results at UK level between bottom-up calculated fuel consumption using vehicle km data and top-down fuel consumption factors.

- Digest of UK Energy Statistics (DUKES) data are available at the sub-national level, but are less detailed than UK-level statistics. Data where no sub-national geographical breakdown is possible include fuels used for aviation, national navigation, and non-energy purposes, as well as heat sold and derived gases. These excluded fuels account for around 15% of total final energy consumption in the UK. Any differences in DA energy estimates are calibrated to UK DUKES data to ensure consistency across all DAs. The lack of consistent and comprehensive fuel use or fuel sales data from across the DAs (especially for solid and liquid fuels) leads to significant potential errors in the distribution of UK fuel use across the regions. Expert judgement and proxy data are used to address data gaps and inconsistencies in DA energy use data over the time series. Sub-national energy statistics have only been produced by DECC since 2003, so before this date, UK trends are extrapolated backwards for each of the DAs.

- Gas and electricity consumption Northern Ireland data are not directly comparable with Great Britain data, due to differences in market structure. The split between domestic, commercial and industrial consumption has only been carried out recently by Airtricity.

- DA-specific commercial and industrial waste data is very limited or not available at all; the method uses the available estimates of overall UK compositions of waste landfilled in different years, based on waste surveys, and combines the UK-wide data with DA-specific estimates of total landfilling of commercial, and industrial, waste for given years (interpolated from the available survey evidence).

- Where no direct activity data are available, such as for a majority of F-gases, proxies are used to allocate UK emissions estimates across the DAs. For example, population is used for air conditioning units and aerosols.

Source: https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1606140849_DA_GHGI_1990-2014_Report_Appendices_v1.pdf, http://www.gov.scot/Resource/0047/00478832.pdf, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/579258/Sub-national_Methology_and_Guidance_Booklet_2016.pdf

Committee on Climate Change

Committee on Climate Change
7 Holbein Place
London
SW1W 8NR

www.theccc.org.uk

@theCCCuk