NPL REPORT CCM 2

UNDERSTANDING THE UK GREENHOUSE GAS INVENTORY

An assessment of how the UK inventory is calculated and the implications of uncertainty

DAVID BUTTERFIELD

COMMISSIONED BY THE COMMITTEE ON CLIMATE CHANGE

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Commissioned by the Committee on Climate Change

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II. Table of acronyms

Acronym	Definition
ACUMEN	Assessing, Capturing & Utilising Methane from Expired & Non-operational landfills
AFOLU	Agriculture, Forestry and Other Land
AGI	Above Ground Installations
AGWP	Absolute Global Warming Potential
AMEC	Amec Foster Wheeler
ANPR	Automatic Number Plate Recognition
AQPI	Air Quality Pollutant Inventory
AWMS	Animal Waste Management Systems
BCMS	British Cattle Movement Society
BEIS	Department for Business, Energy and Industrial Strategy
CAA	Civil Aviation Authority
CCC	Committee on Climate Change
CEH	Centre for Ecology and Hydrology
CH_4	Carbon monoxide
CMP	Meeting of Parties to the Kyoto Protocol
CO	Carbon monoxide
COP	Conference of the Parties
CO_2	Carbon dioxide
CRF	Common Reporting Format
DDOC	Dissimilable Degradable Organic Carbon
DECC	Deriving Emissions linked to Climate Change
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment Food & Rural Affairs
DERV	Diesel Fuel used in Road Vehicles
DIAL	Differential Absorption Lidar
DOC	Degradable Organic Carbon
DUKES	Digest of UK Energy Statistics
EEA	European Environment Agency
EEMS	Environmental Emissions Monitoring System
EMEP	European Monitoring and Evaluation Programme
EPA	Environmental Protection Agency
ERT	Expert Review Team
ESD	Effort Sharing Decision
ETS	Emissions Trading Scheme
FIRMS	Fire Information for Resource Management System
FOD	First Order Decay
GHG	Greenhouse Gas
GHGI	Greenhouse Gas Inventory
GLs	IPCC Guidelines for National GHG Inventories
$GgCO_2e$	Giga gram of carbon dioxide equivalent
GPG	Good Practice Guidelines
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
ISR	Northern Ireland Statistics
ISSB	International Steel Statistics Bureau
KCA	Key Category Analysis
KP	Kyoto Protocol
$KtCO_2e$	Kilotons of carbon dioxide equivalent
LNG	Liquefied Natural Gas
LULUCF	Land Use, Land- Use Change and Forestry
MAFF	Ministry of Agriculture, Fisheries and Food
MCF	Methane Correction Factor
MDO	Moderately Decomposing Organics
MLC	Monitoring Landscape Change
MMR	EU Monitoring Mechanism Regulation

$MtCO_2e$	Million tonnes of carbon dioxide equivalent
NAEI	National Atmospheric Emissions Inventory
NAME	Numerical Atmospheric dispersion Modelling Environment
NF_3	Nitrogen trifluoride
NHS	National Health Service
NIR	National Inventory Report
NIS	National Inventory Systems
NISC	National Inventory Steering Committee
NMVOC	Non-Methane Volatile Organic Compounds
NO_X	Nitrous Oxides
NPL	National Physical Laboratory
NTS	National Transmission System
ONS	Office for National Statistics
PDF	Probability Density Functions
PFC	Perfluorocarbons
PRNG	Pseudo-Random Number Generator
QA	Quality Assurance
QC	Quality Control
RDO	Rapidly Decomposing Organics
SF_6	Sulphur hexafluoride
SDO	Slowly Decomposing Organics
SO_2	Sulphur dioxide
SPRI	Scottish Environment Protection Agency
SWDS	Solid Waste Disposal Sites
TFI	IPCC Task Force on National Greenhouse Gas Inventories
TSGB	Transport Statistics GB
UKMY	United Kingdom Minerals Yearbook
UKPIA	United Kingdom Petroleum Industry Association
UNFCCC	United Nations Framework - Convention on Climate Change

III. Executive Summary

Every year the Department of Business, Energy and Industrial Strategy (BEIS) compiles a Greenhouse Gas Inventory (GHGI) which quantifies annual emissions. The Committee on Climate Change uses this to help recommend future carbon budgets as well as to report to Parliament on performance against the budgets. The emissions in the GHGI are estimates and therefore contain uncertainties - in both what is included and in the accuracy of the data used. To deliver these estimates information is collected and analysed from a wide range of sources – from national energy statistics through to data collected from individual industrial plants.

The aim of this report is to understand the implications of uncertainty in the Greenhouse Gas Inventory (GHGI) for to setting carbon budgets and reporting to Parliament.

The primary audience of this report is the Committee on Climate Change (CCC) and BEIS. The insights are intended to be used by the CCC to inform their annual progress analysis and carbon budget setting. The report can also be used to inform government, funders and researchers about where to focus their efforts to have the biggest impact on the reduction of uncertainties in the UK inventory.

The report outlines the current UK Inventory methodology, provides an overview of GHG estimates across sector and associated uncertainties, and highlights time-series trends and revisions over time. It draws out key insights around issues such as robustness, reliability and uncertainty of the inventory data and what these imply for both setting carbon budgets and monitoring progress.

Key insights are:

- The UK Government and international community can have confidence in the UK GHG inventory. The overall uncertainty is 3%, the third lowest by international comparison to other major emitting countries.

- Overall uncertainty has fallen over the last years, as the UK inventory methodology has improved. This is particularly true for non-CO_2 gases.

- To calculate the uncertainty of the total inventory emissions, the uncertainty of the individual sources are combined as the square root of the sum of squares. This means that the sectors with the largest individual uncertainties have a proportionally much greater impact on the overall uncertainty compared to sectors with small uncertainties.

- Agriculture, land use and waste contribute the largest sources of uncertainty to the UK inventory:
    - Agriculture accounts for only 9% of the total CO_2 equivalent emissions, but contributes to 36% of uncertainty in the total inventory emissions. Uncertainties around the emission factors and activity data are high.
    - Land use change contributes 8% of the total emissions but is responsible for 32% of the total uncertainty in the UK inventory. In this case emission factors are the main sources of uncertainties.
    - The waste sector constitutes 3% of the total CO_2 equivalent emissions yet contributes 18% to the total uncertainty. Emission factors are the main issues for the sector uncertainties with activity data also playing a role.

- External validation of the inventory through atmospheric measurements is happening and is important. Improvements in monitoring and modelling are resulting in convergence of emissions estimates and are highlighting inconsistencies in the inventory, which reflects the value of this activity. The UK's lead here has been recognised by international committees to further improve validation methods such as the work of the Intergovernmental Panel on Climate Change's Task Force on National Greenhouse Gas Inventories.

- The Key Category Analysis (KCA) ranking system – which helps to prioritise improvements to the inventory - only assesses the contribution of a source and its rate of change, and does not take into account the uncertainty in specific sources. As a result, it is difficult to decide where improvements are best delivered where two sources have similar emissions. Therefore, the method could be improved by taking into account the associated uncertainty.

1 NPL ASSESSMENT OF CURRENT INVENTORY METHODOLOGY

The National Atmospheric Emissions Inventory (NAEI) is composed of the GHG Inventory (GHGI) and the Air Quality Pollutant Inventory (AQPI).

The UK inventory is used to enable the UK to help make policy decisions about where to focus emissions reduction policies, to track progress against emission reduction targets, to meet its international treaty obligations and to help with best practice sharing internationally.

The GHG inventory covers the **seven direct GHGs** under the Kyoto Protocol (KP) [2]:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF_6)
- Nitrogen trifluoride (NF_3)

Also reported are **four indirect GHGs**:

- Nitrogen oxides (NO_x);
- Carbon monoxide (CO);
- Non-methane volatile organic compounds (NMVOC);
- Sulphur dioxide (SO_2).

GHGs contribute directly to climate change owing to their radiative forcing effect (warming of the atmosphere). HFCs, PFCs, SF_6 and NF_3 are collectively known as the 'F-gases'. The largest contributor to global warming is carbon dioxide; methane and nitrous oxide contribute a smaller proportion, typically <10%, and the contribution of F–gases is even smaller at <5%, in spite of their high Global Warming Potentials (GWP).

Nitrogen oxides, carbon monoxide and Non-Methane Volatile Organic Compounds (NMVOCs)are included in the inventory because they can produce increases in tropospheric ozone concentrations and this increases radiative forcing. SO_2 is included because it contributes to aerosol formation which can either warm or cool the atmosphere. Emissions of indirect N_2O from emissions of NO_x and NH_3 are also estimated and reported as a memo item, these emissions are not included in the national total [3].

The GHG inventory (GHGI) is compiled according to IPCC 2006 Guidelines [4]. Each year the inventory is updated to include the latest data available. The UK submits a report to the UNFCCC annually via a consolidated report which contains all EU countries (called the Monitoring Mechanism Regulation [MMR]). The UK's report includes the emissions of Overseas Territories that have ratified the KP.

Most sources are reported in detail. The main exceptions are the emissions of individual halocarbon species and certain F-gas categories, which cannot always be reported individually because some of these are considered commercially sensitive data. Consequently, emissions data are aggregated to protect this information. However, it is still possible to report the total GWP, and therefore the total global warming potential of all UK GHGs [3].

Emissions estimates are made using methodologies corresponding mostly to the detailed sectoral Tier 2 or Tier 3 methods in the IPCC Guidelines. Tiers 1 to 3 are summarised as:

Tier 1 Simple methods with default data.
Tier 2 Country specific emission factors and other data.

Tier 3 Complex approaches including modelling. Compatibility with Tiers 1 & 2 needs to be maintained.

Properly implemented, all tiers are intended to provide unbiased estimates. The provision of different Tiers should enable inventory compilers to use methods consistent with their resources and to focus their efforts on those categories of emissions and removals that contribute most significantly to national emission totals and trends.

Table 1 shows the sectors that have the highest emissions or the largest associated uncertainty in emissions.

IPCC Category	Description	Relevant gases	Importance
1A1a	Power stations	CO_2, CH_4 & N_2O	Emission total
1B2b4 & 1B2b5	Natural gas leaks from the transmission networks	CO_2, & CH_4	Emission total & uncertainty
3A	Enteric Fermentation	CH_4	Emission total & uncertainty
3B	Manure Management	CH_4 & N_2O	Uncertainty
3D	Agricultural Soils	N_2O	Emission total & uncertainty
4B	Cropland	CO_2, CH_4 & N_2O	Uncertainty
4E	Settlements	CO_2, CH_4 & N_2O	Uncertainty
5A	Solid Waste Disposal on Land (Landfill)	CH_4	Emission total & uncertainty

Table 1: IPCC Sectors with highest UK emissions or associated uncertainties

Changes in the calculation methodology between 2015 and 2016 (2013 & 2014 Inventories) have led to a significant reduction in the uncertainty of emission totals, especially for N_2O. There has also been a significant drop in total CH_4 emissions between 2013 and 2014, while the change in total emissions is within the uncertainty limits. Each year there are revisions in the way the emission totals are calculated, mainly due to changes in methods, more accurate activity data or more appropriate emission factors. Each time there is a revision, all previous year's emissions totals are recalculated to improve the accuracy and reduce the uncertainties of data in the inventory. **In 2016, the total 1990 UK GHG estimates were revised from 761MtCO_2e in 2001 to 800MtCO_2e in 2016.**

This assessment shows for most sectors and for all gases the percentage uncertainty is not equal to the percentage contribution to total emissions, meaning that **different subsectors have very different uncertainties associated with the calculation method.** The analysis shows that these differences are due to the uncertainties associated with the activity data or the emission factor or a combination of both.

When analysing the emissions from the three largest GHG contributors (CO_2, CH_4 & N_2O), the majority of the uncertainty in the GHGI comes from the Agriculture, Land Use and Waste sectors, with these three sectors contributing to 86% of the uncertainty in the total inventory emissions, while only contributing to 20% of the total emissions. The power, transport and industry sectors contribute 62% towards the total GHG emissions. As these sources are well characterised and use mainly country specific emission factors, together they contribute to 10% of the uncertainty in the total inventory emissions. All the other sectors contribute to the final 4% of the uncertainty in the total inventory emissions.

The GHGI is reported to the UNFCCC using the Intergovernmental Panel on Climate Change (IPCC) sectors and subsectors in the National Inventory Report, however the inventory can also be divided into sectors more relevant to use by the Committee for Climate Change (CCC). The assessment of uncertainty on the Inventory has been performed both by IPCC sector and by CCC sector.

Breaking down the emissions totals and their uncertainty by methodology (the IPCC Tiers), shows that Tier 2 is used in the majority of cases and accounts for 66% of emissions with an uncertainty of 3%. Tier 1 methods account for 2% of all emissions with an uncertainty of 16% and Tier 3 methods for 32% of emissions with an uncertainty of 5%. The largest sources of Tier 3 emissions are CO_2 emissions from the Transport and Land Use Sectors.

As well as reporting emissions by IPCC category, emissions are also calculated by sector. A breakdown of emissions and uncertainties for CO_2, CH_4 and N_2O from each sector shows that for CO_2, power, transport and industry sectors contribute 26%, 24% and 22%, respectively, to the total CO_2 emissions whilst these sectors standard uncertainties are 2.7Mt CO_2e (12%), 1.9 Mt CO_2e (9%) and 3.1 Mt CO_2e (14%), respectively.

In contrast, Land Use Change contributes 10% to the emissions (sinks and sources) while it has a standard uncertainty of 9.1 MtCO_2e (41%) and therefore a major contributor to uncertainties in the GHGI. For CH_4, agriculture, waste and industry sectors are the largest CH_4 sources, each contributing 51%, 33% and 14%, respectively, to the total CH_4 emissions. Waste in particular contributes disproportionately to uncertainty with a CH_4 standard uncertainty of 6.7 Mt CO_2e (49%). Agriculture on the other hand has a standard uncertainty of 5.4 MtCO_2e (39%) whilst industry only that of 0.9 Mt CO_2e (7%); both contribute a lower percentage to the uncertainty than they do to the emission total for CH_4. For N_2O in contrast, Agriculture is again the largest source, however contributing 74% of the emission total yet contributing 7.8 Mt CO_2e (59%) to the uncertainty of N_2O emissions. Most of the other sectors have a 1:1 or 1:2 contribution to the emission total and standard uncertainty respectively.

If the CCC sectors are broken down into sub-categories, similar characteristics to the IPCC sub-sector breakdown is seen, with some sources having very varied uncertainties attributed to emission factor and activity data. **For CO_2 most sources in each sub-sector have their own uncertainties for activity data and emissions factors, whilst for CH_4 and N_2O most sources in each sub-sector have very similar or identical percentage uncertainties for both, as they cannot always be split.**

When compared to other European, North American and Australasian countries the UK Inventory has the third lowest uncertainty when all sectors, including LULUCF, are compared (Figure 1).

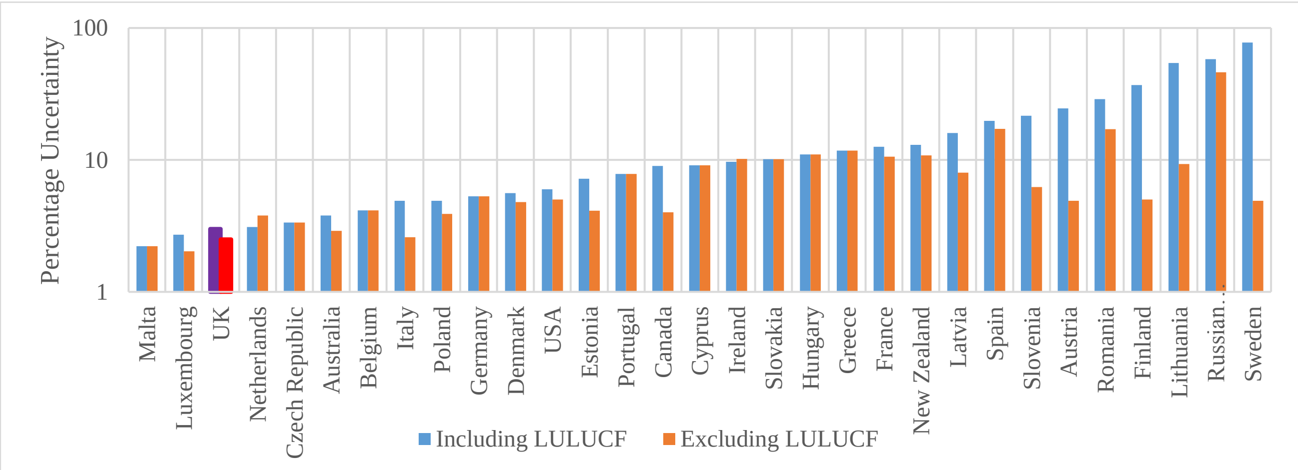


Figure 1: Comparison of uncertainties in different countries' 2014 inventories (note log scale on y-axis)

The UK uses a Key Category Analysis (KCA) ranking system as a tool to aid the prioritisation of improvement work to the Inventory. The KCA ranking system works by allocating a score based on how high categories rank in the base year, the most recent year level assessments and the trend assessment for the Approach 1 KCA including LULUCF. For example, if CO_2 from road transport liquid fuel use is the 4th highest by the base year level assessment, 3rd highest by the most recent year level assessment and has the 5th highest trend assessment then its score would be 12 (the sum of 4, 3 and 5). The categories are then ranked from lowest score to highest, with draws in score resolved by the most recent year level assessment. This system only assess the contribution of a source and its rate of change but does not take into account the uncertainty in specific sources. Therefore, the biggest emitters are normally ranked lowest, however these are normally well characterised sources with low uncertainties.

The method could be improved by taking into account the associated uncertainty (Approach 2: using uncertainty as a ranking factor), as this will provide better guidance on where accuracy in the inventory could be improved.

Figure 2 shows a subset of 2014 methane emission estimates and their uncertainties. Taking the uncertainties into account it is difficult to tell if the emission estimates for natural gas transmission, manure management and waste water handling are any different from each other. With the large uncertainty in the estimate for biological treatment of solid waste it would be difficult to estimate the amount of abatement accurately from this source. **The inclusion of uncertainty is essential for improving the accuracy of the inventory.**

The IPCC have recently reviewed the calculation methodologies used to compile the inventory. The largest impact of this is the potential increase in the methane global warming factor; from 25 to 28, or to 34 if the climate-carbon feedback is taken into account. Any change in GWP has a direct proportional effect in estimated emission totals. In addition, implementation of the method changes due to the KP Wetlands Supplement {IPCC, 2014 #20} will affect the emission estimates for all of Sector 4: LULUCF for the second commitment period from 2013 to 2020.

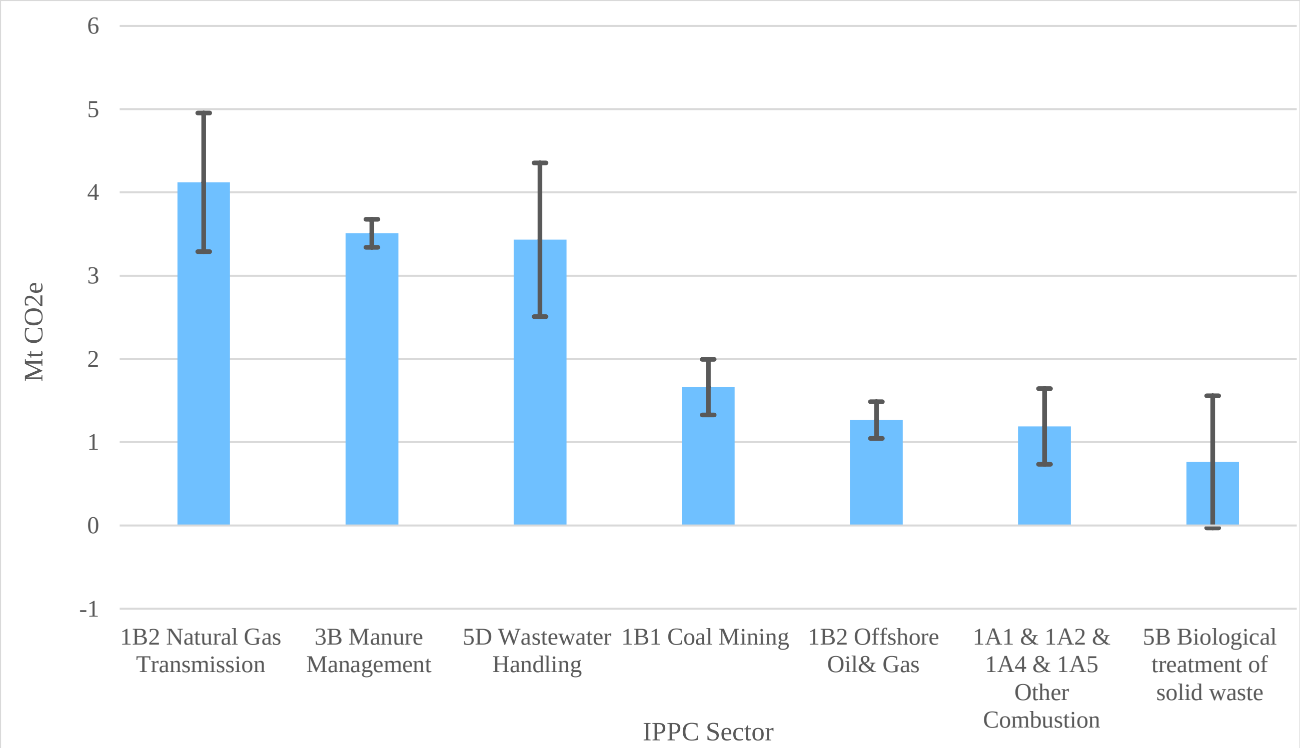


Figure 2: Subset of 2014 methane emission estimates and their uncertainties

UK Government has a research programme that derives independent GHG estimates for the UK using in-situ high-precision, high-frequency atmospheric observations of the Kyoto gases and a range of other trace gases. This is referred to as the UK DECC (Deriving Emissions linked to Climate Change) network. The recent addition of three mainland monitoring sites has resulted in significant improvements in spatial and temporal resolution, improving UK estimates and enabling Devolved Administration emission estimates to be calculated from atmospheric observations. **Even though the background baseline concentration of methane is increasing over the time, due to increased worldwide emissions, the agreement between the UK emission estimates (which have fallen over time), and the reverse modelled emissions (from the Met Office model InTem [see section 10.1]) has improved over the same period. Also, the introduction of the three new sites has reduced the uncertainties associated with the UK top-down emission estimates**.

As well as the DECC Network, the NAEI compares the inventory approach (Bottom-Up) with a Top Down emission calculation based on total national fuel sales (DUKES) to verify emission totals. **These two approaches agree to within 2% for UK CO_2 emission estimates and this provides verification of the reported Sectorial Approach emission estimates for Fuel Combustion Activities. This may be expected as similar input data is used for both top down and bottom up methods as the predominant emission source is fuel use.**

Since 2002, the UK NAEI has been externally reviewed by technical experts on a regular basis. These include bilateral reviews with other EU Countries, an UNFCCC annual review and the production of peer reviewed literature. Following a UN Expert Review Team recommendation, **a qualitative uncertainty analysis of the inventory was implemented by the Inventory Agency in 2016. This qualitative uncertainty analysis supports the Key Category Analysis and helps determine the highest priority emission sources in the UK where methodological improvements could be applied to improve the accuracy of emission estimates**, or more detailed reporting can be used to improve transparency.

As well as annual final emission estimates, provisional quarterly and annual emission estimates by source sector are published by BEIS. These are based on provisional inland energy consumption statistics, published in Energy Trends. **The annual provisional emissions estimates are subject to revision when the final estimates are published each February, however they provide an indication of emissions in the last full calendar year. Historically provisional annual estimates have been within two percent of final estimates.**

2 COMPILATION AND CONTENT OF THE UK EMISSIONS INVENTORY

2.1 PURPOSE AND OBJECTIVES OF THE INVENTORY

The UK inventory is used to enable the UK to help make policy decisions about where to focus emissions reduction policies, to track progress against emission reduction targets, to meet its international treaty obligations and to help with best practice sharing internationally.

The Marrakesh Accords of the Kyoto Protocol define the requirements for National Inventory Systems (NIS). This includes the need to establish legal, procedural and institutional arrangements to ensure that all parties to the Protocol report and improve the quality of their GHG emission inventories in accordance with relevant decisions made by the UNFCCC. The UK was required to have a NIS in place by the end of 2005 under EU legislation [1]. The GHGI within the NAEI is the NIS for the UK.

The estimates calculated by the GHGI helps to provide information on important sources and trends in emissions and removals (sinks) [5]. The data enables:

- The UK to track its progress towards international commitments on GHGs under the UNFCCC and the European Union's EU Monitoring Mechanism Regulation (MMR) (see blue box for more details).
- The UK Government to form evidence based policy decisions.
- Improved understanding of the relationship between GHG emissions and removals to temperature change and other environmental factors, improving mitigation and adaptation planning.
- Tracking progress in historical emissions and removal trends, which allows policy makers and environmental groups to identify and prioritise successful programmes to reduce emissions.

The UK submits a report to the UNFCCC annually via a consolidated report which contains all EU countries (called the MMR). The UK's report includes the emissions of Overseas Territories that have ratified the KP.

2.2 HOW IS THE GHGI COMPILED?

The GHGI is compiled according to IPCC 2006 Guidelines (see [4]) and the inventory is updated annually to include the latest data available. Improvements to the methodology (e.g. from new data sources, new guidance from IPCC, or new research) are backdated as necessary to ensure a consistent time series.[3]. Emissions estimates are made using methodologies corresponding mostly to the detailed sectoral Tier 2 or Tier 3 methods in the IPCC Guidelines.

Methodological changes are made to take account of new research and data sources, any new guidance from IPCC, relevant work or emission factors from sources such as EMEP-EEA and the US EPA, or from specific research programmes sponsored by BEIS and other UK Departments. The UK National Inventory System has a formal inventory improvement programme, managed by the National Inventory Steering Committee (NISC) (see Section 3 for more details). This is aimed to both improve the UK GHGI data quality and develop inter-Departmental and Agency working relationships to integrate inventory related information from across Government [3].

United Nations Framework Convention on Climate Change (UNFCCC)

The UNFCCC is an international treaty established to provide a coherent international approach to tackling climate change and preparing for its effects. It was adopted in 1992 at the 'Earth Summit' in Rio de Janeiro by most of the World's countries.

A significant achievement of the UNFCCC has been to establish a framework for reporting GHG emissions and removals using a common process that is internationally comparable. Whilst the treaty is not legally binding, it can establish protocols (such as the Kyoto Protocol) to set legally binding emissions limits. Each country within the protocol must report their final GHG emission estimates in a National Inventory Report (NIR) by the 15 April each year. Periodically, the UK also submits a document that provides a summary of UK emissions trends, as well as outlining progress towards emissions reduction targets.

The Paris Agreement of 2015 will replace the KP and enter into force in 2020, and will continue with the requirement for countries to submit their national inventories. The UNFCCC has made clear its intentions to reduce uncertainty and improve the transparency and accuracy of its reporting processes.

The UK's geographical area reported to the UNFCCC includes the UK, its Crown Dependencies (Guernsey, Jersey and the Isle of Man) and Overseas Territories that have ratified the KP (the Cayman Islands, the Falkland Islands, Bermuda, Montserrat and Gibraltar) [5].

Monitoring Mechanism Regulation (MMR)

The EU MMR is designed to allow the EU to report the UNFCCC as a single entity (effectively as a country) and to ensure there is a system across the EU to combine information and to make informed policy decisions. Each EU member state reports GHG emission and removal estimates to the European Commission each year as well as providing projections on future policies and measures every 2 years [6].

The MMR only includes the UK and Gibraltar, and not the Crown Dependencies and other Overseas Territories, as these are not part of the EU. It is ‘not yet clear’ how Brexit will affect the UK’s participation in the MMR [7].

Global Warming Potential (GWP)

Direct GHGs have different radiative efficiencies and lifetimes in the atmosphere. The GWP was developed as a simple means of providing a measure of the relative radiative effects of the emissions of different gases. By weighting the emission of a gas with its GWP it is possible to estimate the total contribution to global warming of UK GHG emissions. The index is defined as the cumulative radiative forcing between the present and a future time horizon caused by a unit mass of gas emitted now, expressed relative to that of CO_2 [3]:

$$\textit{Mass of GHG} * \textit{GWP} = \textit{CO}_2 \textit{ equivalent mass}$$

Since 2015, submissions to the UNFCCC use GWPs defined on a 100-year time horizon from the 4th Assessment Report (AR4). The most recent IPCC assessment report (AR5) contains updated GWPs which are not yet used for UK national reporting (Table 2) (see Section 8.2 for more details).

Gas (GHG)		**GWP (AR4 and UK reporting)**	**GWP (AR5)**
Carbon dioxide	CO_2	1	1
Methane	CH_4	25	28
Nitrous oxide	N_2O	298	265
Sulphur hexafluoride	SF_6	22,800	23,500
Nitrogen trifluoride	NF_3	17,200	16,100

**Hydrofluorocarbons and perfluorocarbons not listed here as GWP varies between different species. See [8] for GWPs of all GHGs.*

Table 2: GWPs of GHGs on a 100-year horizon used for UK National reporting and from latest IPCC figures [8]

3 INSTITUTIONAL ARRANGEMENTS FOR PREPARING THE INVENTORY – QUALITY ASSURANCE AND QUALITY CONTROL PROCESS

BEIS is responsible for submitting the UK NAEI to the UNFCCC through the EU monitoring mechanism. Ricardo Energy & Environment complies the inventory on behalf of BEIS. in collaboration with Aether, Centre for Ecology and Hydrology (CEH), Amec Foster Wheeler (AMEC), Rothamsted Research and SKM Enviros. They are funded by the BEIS, Department for Environment, Food and Rural Affairs (Defra), the Welsh Government, the Scottish Government and the Department of Environment, Northern Ireland.

The National Inventory Steering Committee (NISC) was established by the Department of Energy and Climate Change (DECC) in 2006 to provide the official review and approval of the national inventory prior to submission to the UNFCCC. The NISC oversees the UK GHGI and has a remit to assist the GHG inventory team to manage and improve formulation of the inventory across the stakeholders involved.

Ricardo Energy & Environment is responsible for producing the emissions estimates for Common Reporting Format (CRF) categories: Energy (CRF sector 1), Industrial Processes and Product Use (CRF sector 2), and Waste (CRF Sector 5). Ricardo Energy & Environment is also responsible for inventory planning, data collection, quality assurance (QA) as well as quality control (QC), inventory management and archiving.

Aether provides support for QA and QC processes in the compilation of emissions data, compiles the emission inventories for the Devolved Administrations, the Crown Dependencies and Overseas Territories and provide estimates for emissions from the rail sector.

Agricultural sector emissions (CRF sector 3) are produced by Rothamsted Research, under contract to the Department for Environment, Food & Rural Affairs (Defra).

LULUCF emissions (CRF sector 4) are calculated by the UK Natural Environment Research Council's Centre for Ecology and Hydrology (CEH), under separate contract to the Science Division of BEIS. The Kyoto Protocol - Land Use, Land Use Change and Forestry (KP-LULUCF) information is also produced by CEH. The mechanism for generating the KP-LULUCF data and the quality control and assurance procedures applied are an integral part of the UK's National Inventory System (NIS) [1].

Figure 3 shows the organisational structure of the UK's National Inventory System (NIS) and Figure 4 is a diagram from the National Inventory Report (NIR) showing how its elements are laid out.

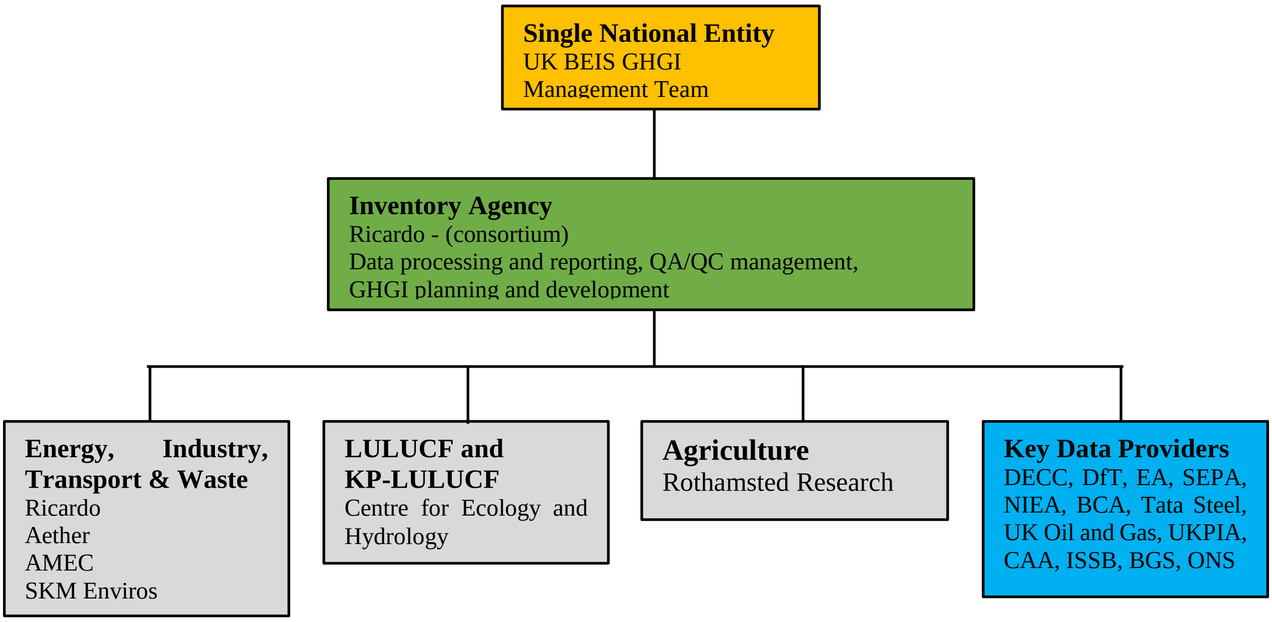


Figure 3: Organisational structure of the UK's National Inventory System [1]

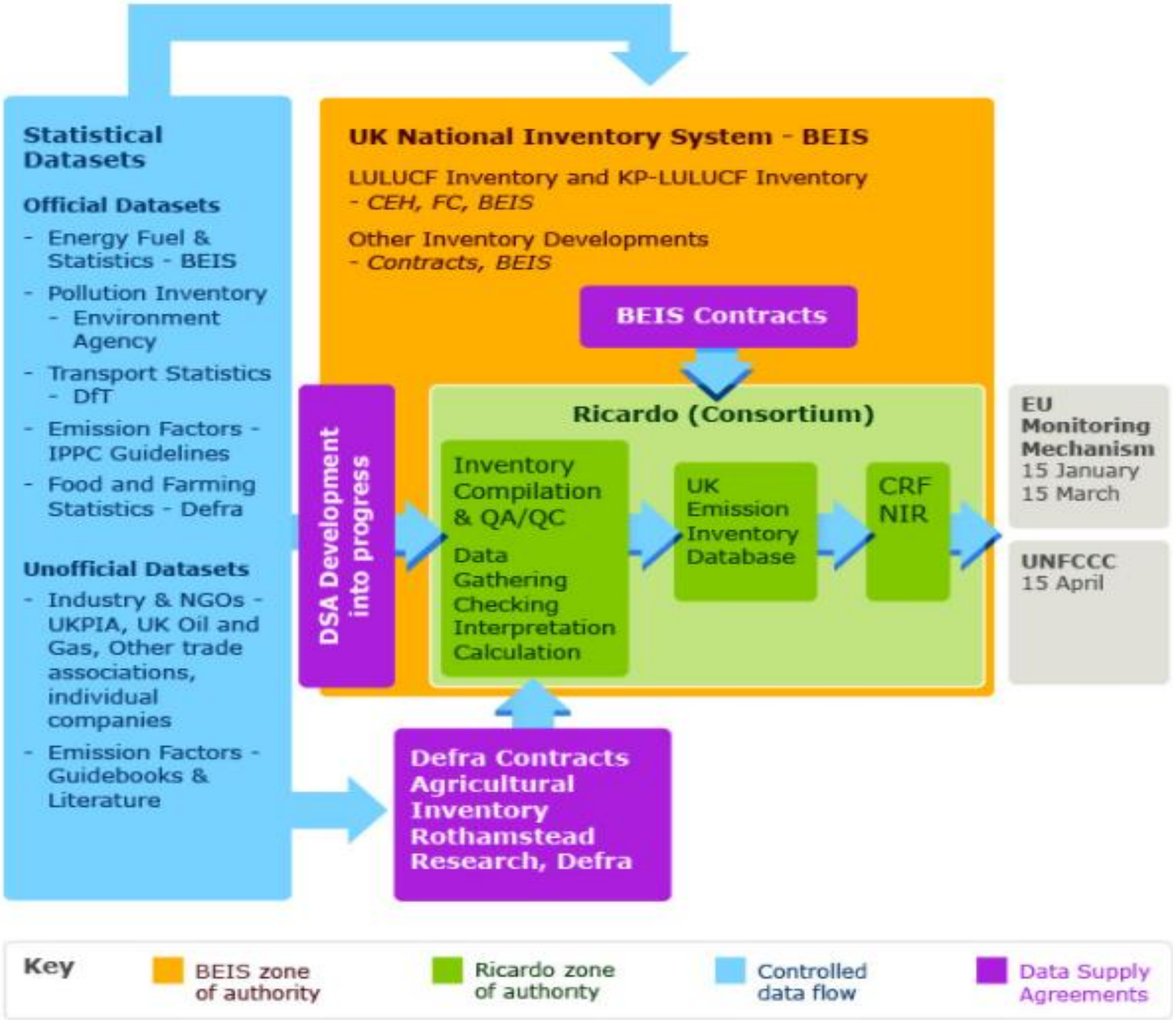


Figure 4: Structure of the UK's National Inventory System (NIS) and its main elements [1]

4 KEY SOURCE CATEGORIES AND GASES

This section covers how the emission totals are calculated using the Tier 1, 2 & 3 approaches and how emission factors and the associated activity data are compiled.

Figure 5 shows a flow diagram outlining the annual process used to calculate the GHGI.

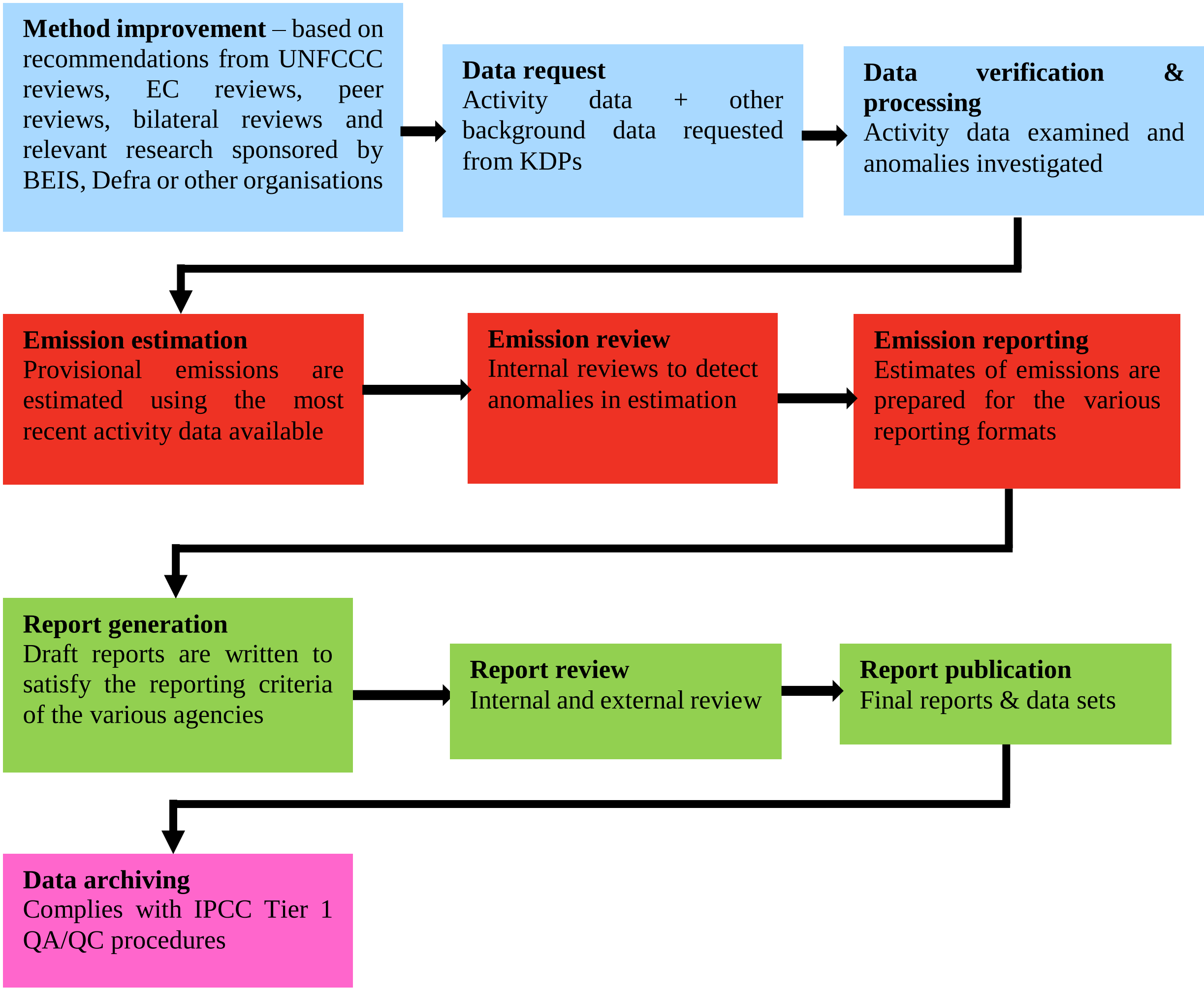


Figure 5: Flow diagram of the annual reporting process

4.1 CALCULATION METHODOLOGY

The emissions estimates for a specific source is calculated using either a Tier 1, Tier 2 or Tier 3 approach depending on the detailed level of data available. The tiers are summarised below:

Tier 1 Simple methods with default data.
Tier 2 Country specific emission factors and other data.
Tier 3 Complex approaches including modelling. Compatibility with Tiers 1 & 2 needs to be maintained.

The direct and indirect GHGs reported in the UK GHGI are estimated using methodologies which mostly correspond to the detailed sectoral Tier 2 and 3 methods in the IPCC Guidelines.

Emissions are generally estimated using the following equation:

$$Emission\ estimate = Emission\ Factor * Activity\ Data$$

Where:

Emission Factor = the amount of GHG emitted per unit of activity, i.e. CO_2 per km;
Activity data = the total amount of activity for that sector, i.e. km driven by petrol fuelled cars.

The following shows a summary of the emission totals in the Inventory:

- Combustion of fossil fuels contribute ~80% of total GHG emissions.
- Agricultural sector contribute ~10% of total GHG emissions.
- Industrial processes contribute ~5% of total GHG emissions.
- Waste sector <3% of total GHG emissions.

The LULUCF sector contains absorbers (sinks) as well as sources of CO_2 emissions. The LULUCF sector fell from a source of 0.25 $MtCO_2e$ in 1990 to a sink of 9 $MtCO_2e$ in 2014 due to changes in N_2O calculation (see Table 10).

Table 3 shows which sectors have the highest emissions or the largest associated uncertainty in emissions:

IPCC Category	Description	Relevant gases	Tier	Emission calculation method	Impact
1A1a	Power stations	CO_2, CH_4 & N_2O	2	EF * AD	Emission total
1B2b4 1B2b5	Natural gas leaks from the high-pressure transmission network Natural gas leaks from the low & medium pressure distribution networks, above ground installations and point of use.	CO_2, & CH_4	3	Periodic fugitive emission surveys UK Gas Network Leakage Model Natural gas compositional data	Emission total & uncertainty
3A	Enteric Fermentation	CH_4	2	Annual Agricultural Census Animal data Digestibility of feed	Emission total & uncertainty
3B	Manure Management	CH_4 & N_2O	2	Annual Agricultural Census. Animal waste management systems	Uncertainty
3D	Agricultural Soils	N_2O	2	7 Direct emission routes + 2 indirect emission routes. British Survey of Fertiliser Practice	Emission total & uncertainty
4B	Cropland	CO_2, CH_4 & N_2O	3/1	Land use area, annual Agricultural Census, British Survey of Fertiliser Practice, Forest model	Uncertainty
4E	Settlements	CO_2, CH_4 & N_2O	3/1	Land use area, Land-use definitions and classification system, Forest model and soil carbon	Uncertainty
5A	Solid Waste Disposal on Land (Landfill)	CH_4	2	Mass of waste, Dissimilable Degradable Organic Carbon, Methane Correction Factor, Molar Fraction of methane, Decay rate	Emission total & uncertainty

Table 3: IPCC sectors that have the highest emissions or the largest associated uncertainty in emissions (in $MtCO_2e$)

The following sub-sections give an overview of the importance of the subcategory and observations alongside improvements to the calculation method. The percentages of the overall uncertainty presented in the following sections show the relative contribution of each sectors' uncertainty to the total inventory uncertainty based on the calculations given in Section 5. This provides an indication of the contribution of these sectors to the total uncertainty.

4.1.1 Power Stations

Electricity and heat production account for 25% of the total CO_2 equivalent emissions for 2014, while only contributing to 2.7% of the uncertainty in the total inventory emissions. Activity data and emission factors for this sector are well understood, which results in low uncertainties in emission totals. Since there is a direct link between the carbon emitted and the carbon content of the fuel, it is possible to estimate CO_2 emissions accurately.

For the 2014 inventory, default emission factors for CH_4 and N_2O from the 2006 IPCC Guidelines have replaced old and uncertain UK-specific factors for some sector-fuel combinations. In the case of methane, the IPCC default factors are mostly higher so their use yields generally more conservative emission estimates. In the case of N_2O, the IPCC factors are mostly lower than the previous factors, so emission estimates are now lower. The new N_2O factors are approximately 70% of the previous figures for energy sector's coal and coke use and this leads to a significant reduction of N_2O emissions from 1A1a, equal to a reduction in total UK emissions of N_2O in 2013 of about 1%. Total fuel consumption also provides a relatively robust check of power emissions.

4.1.2 Natural Gas Distribution Leaks

Leaks of Natural Gas from the distribution network and point of use contribute 1% of the total CO_2 equivalent emissions for 2014, while contributing to 0.4% of the uncertainty in the total inventory emissions. Uncertainties in the emission estimates from leakage from the gas transmission and distribution network stem predominantly from the assumptions within the UK Gas Network Leakage Model. For above ground installations the methane content of the gas released is known to a high degree of accuracy, but the mass emitted is based on industry calculations.

Measurements of methane emissions from high pressure compressor and distribution facilities would help to characterise the nature and magnitude of these losses, thus reducing the uncertainties associated with relevant emission factor data.

Improvements in the Leakage Model would help to reduce uncertainties in the calculation of methane losses in the medium and low pressure distribution network and improve the quality of emission factors. However, improvements in the natural gas infrastructure through a roll out of pipe replacement is likely to have reduced emissions to a potentially greater degree than assumed in the Leakage model.

4.1.3 Enteric Fermentation

Emissions from enteric fermentation (methane produced during digestive process in ruminant animals) contributes 4.8% of the total CO_2 equivalent emissions for 2014, while contributing to 4.6% of the uncertainty in the total inventory emissions. The UK is currently undertaking research to improve activity data on typical forage diets for a range of livestock production systems and improvements on digestibility values for the different forage components. These measures should help to reduce the uncertainty in the emission estimates in this sector.

4.1.4 Manure Management

Manure management contributes 1% of the total CO_2 equivalent emissions for 2014, while contributing to 0.6% of the uncertainty in the total inventory emissions. The uncertainty for N_2O in 2014 was significantly reduced compared to previous years; 68% compared to 250%. This is due to the implementation of country specific values derived directly from the UK agriculture ammonia emission inventory. The evidence for this change in emission factor and uncertainty was from a literature review and a field measurement programme. The uncertainty in methane emissions was also reduced in 2014 to 4.8% from 30% as part of this work.

4.1.5 Agricultural Soils

Nitrous oxide emissions from agricultural soils contribute 3% of the total CO_2 equivalent emissions for 2014, while contributing to 25% of the uncertainty in the total inventory emissions. The calculation of uncertainty in activity data and emission factors has been revised for the 2014 inventory resulting in a greatly reduced uncertainty of 53% compared to 260% in previous years. The evidence for this change in emission factor and uncertainty comes from:

- For direct soil emissions; from a literature review and a field measurement programme.
- For manure management systems; from a literature review and a field measurement programme.
- Revised emission factor for nitrogen leaching/runoff factor; from a field measurement programme.

This has enabled the move from a Tier 1 methodology to a Tier 2 methodology.

4.1.6 Cropland

Cropland contributes 2.4% of the total CO_2 equivalent emissions for 2014, while contributing to 13% of the uncertainty in the total inventory emissions. The areas undergoing land use change are the biggest source of uncertainty in the inventory. Parameterisation of the forest model is the second largest source of uncertainty and the move to the CARBINE model (19 tree species) from the CFlow model (2 tree species) has helped to reduce uncertainties. Results from the latest National Forest Inventory has also provided additional information on carbon stocks in trees (2014) [9]. Emissions from cropland on drained organic soils has the largest uncertainty of the minor emission sources (i.e. not land use change) as the effects of drainage are highly uncertain.

The main change between the 1990-2013 inventory and the 1990-2014 inventory is the inclusion of biomass carbon stock changes arising from Cropland management activities. Corrected deforestation data has also been used to improve the inventory. Areas of Cropland that are losing carbon due to historical drainage were reassessed in 2013. This reassessment gives a more complete picture of the area of Cropland on drained organic soils than previous work in 1997. Current work in implementing the Wetlands Supplement may decrease this uncertainty in the methodology used to calculate emissions due to drainage.

The uncertainty in the land use change areas is currently being addressed by the development of a new vector-based approach, combining multiple sources of land use data and will be used for future submissions.

4.1.7 Settlements

Settlements (change of land use) contributed 1.2% of the total CO_2 equivalent emissions for 2014, while contributing to 4% of the uncertainty in the total inventory emissions. Estimates of the areas undergoing land use change are the biggest source of uncertainty in the LULUCF Inventory, but model choice and soil carbon parameters are also significant.

The activity data on areas of Forest Land converted to Settlement (deforestation) from 2000 onwards have been updated with data collated from multiple sources. This has substantially reduced the estimated area of forest land converted to settlement from 2000 onwards. The methodology and emission factors for calculating emissions from controlled burning following deforestation were updated to follow the IPCC 2006 guidance. Previous inventories had used the methodology and emission factors from the IPCC 2003 guidance.

As in Cropland, the uncertainty in the land use change areas is currently being addressed by the development of a new vector-based approach, combining multiple sources of land use data and will be used for future submissions. Work is being undertaken on carbon stock changes in perennial biomass in cropland and grassland: this will allow hedgerow areas (permanent vegetative boundaries between agricultural fields) to be separated out from the "Boundary and Linear features" habitat type and moved from the Settlement category to the Grassland category.

4.1.8 Landfill

Landfill contributed 2.7% of the total CO_2 equivalent emissions for 2014, while contributing 19% of the uncertainty in the total inventory emissions. There are many uncertainties in estimating methane emissions from landfill sites. The calculations are sensitive to the values assumed for the degradable organic carbon (DOC) present in different fractions of waste, and the amount of this that is dissimilable (i.e. is converted to methane and carbon dioxide), as well as to the quantity of methane combusted in engines and flares, and the oxidation factor. Uncertainty in the quantity of methane collected is also a major source of uncertainty in overall emission of landfill methane.

The methodology for calculating methane production in landfill sites has improved. Waste composition as well as commercial and industrial waste data have been updated, along with updated assumptions about the combustion of methane in landfill gas engines.

The following work was performed by NPL for Defra in 2014, to help better understand the methane emissions from landfills and could be used to further update the calculation methodology:

1. Compare the measurements of whole site methane emissions using the DIAL and tracer gas methods.
2. Compare these methane measurements against the estimates derived from walk-over surveys and to provide further data for the development of an empirical methane emission estimation method based on surface concentrations.
3. Provide reliable information on the quantity of methane emitted at the surveyed landfills. Provide methane emission data to the Defra ACUMEN project on emissions from closed landfill sites.
4. Quantify the emissions from different areas of a site, in particular: operational landfill, active and closed areas.
5. Provide data to allow the methane capture rates to be calculated for operational landfills (whole site and active area) and closed landfill if methane collection is being undertaken.
6. Inform understanding of the variability in emissions at an operational sites by providing a comparison between the previously measured methane emissions (2013) for the whole site and for different areas of the site.
7. Reduce uncertainty of oxidation of methane in soils

Changes in the calculation methodology between 2015 and 2016 has had significant effects on the uncertainty in emission totals, especially for N_2O. Figure 6 highlights these differences.

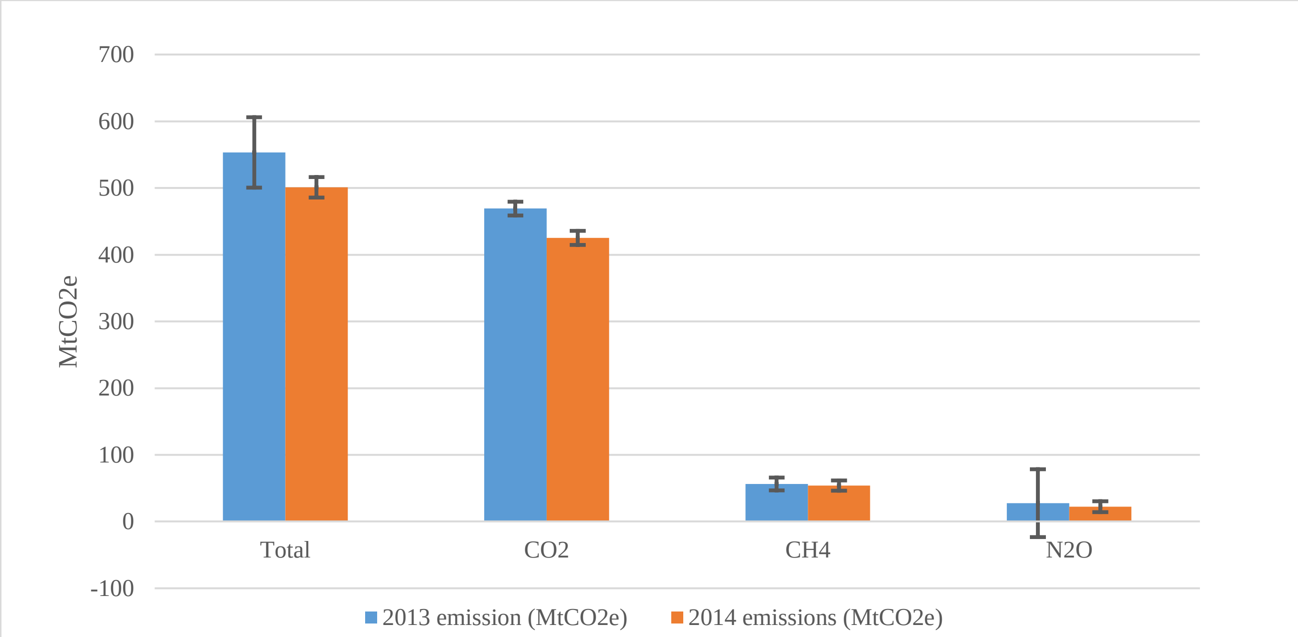


Figure 6: 2013 and 2014 emission estimates and their associated uncertainties

The uncertainty in the N_2O emissions has dropped from ±50 to ± 8 Mt. The change in CO_2 emissions is significant as the error bars do not overlap while the change in total emissions is within the uncertainty limits, primarily due to the uncertainty in the N_2O emissions.

A detailed description for the calculation and impact of uncertainty in emission totals is given in the following sections.

5 UNCERTAINTY IN GHGI AND HOW IS IT CALCULATED

Uncertainties in the input data used to calculate emission totals feed into the uncertainty of the overall emission totals and trends. Once the uncertainties in activity data, emission factor or emissions for a category have been determined, they may be combined to provide uncertainty estimates for the entire inventory in any year and the uncertainty in the overall inventory trend over time.

5.1 HOW IS UNCERTAINTY CALCULATED?

Uncertainty estimates for the GHGI are calculated using two methods: Approach 1 (error propagation) and Approach 2 (Monte Carlo simulation). This section reviews the methodology for both approaches and compares the results between them.

Error Propagation Approach (Approach 1)

The error propagation approach is summarised below, a more detailed description of Approach 1 can be found in the 2014 NIR peer review [10]. This mathematical approach has been defined and checked by the IPCC, and is clearly set out in the IPCC 2000 Good Practice Guidance [11] and the IPCC 2006 Guidelines [4].

The approach analysis estimates uncertainties by using the error propagation equation in two steps. The first combines emission factor, activity data and other estimation parameter ranges by category and GHG according to Eqn 1:

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \cdots..U_n^2} \qquad \text{Eqn 1}$$

Where:

U_{total}	=	the percentage uncertainty emission total
U_i	=	the percentage uncertainties associated with each individual emission source

The second combines uncertainties to calculate the overall uncertainty in national emissions according to Eqn 2:

$$U_{total} = \frac{\sqrt{(U_1.x_1)^2 + (U_2.x_2)^2 + \cdots..(U_n.x_n)^2}}{|x_1 + x_2 \ldots + x_n|} \qquad \text{Eqn 2}$$

Where:

U_{total}	=	the percentage uncertainty in National emission total
X_n		the emission total from individual sectors
U_n	=	the percentage uncertainty in emission from individual sectors

In practice, uncertainties found in inventory categories vary from a few percent to orders of magnitude, and may be correlated. This is not consistent with the assumptions of Eqns 1 and 2 that the variables are uncorrelated, and with the assumption of Eqn 2 that the coefficient of variation is less than 30 percent, but under these circumstances Eqns 1 and 2 provide an approximate result. Where uncertainties are large or uncertainty distributions are not normally distributed the Monte Carlo Simulation (Approach 2) method can be used [12].

Details of Monte Carlo Simulation for the 2015 GHGI

The background to the implementation of the Monte Carlo simulation is described in detail by Salway et al. (1998) (see [13]) with the estimates reported here revised to reflect changes in the latest inventory and improvements made in the model. The computational procedure is detailed below.

- The PDFs were mostly normal or log-normal, with one log-logistic PDF. The parameters of the PDFs were set by analysing the available data on emission factors and activity data, and by expert judgement.
- A calculation was set up to estimate the total emissions of each gas for the years 1990 and the latest reported year.
- Using the software tool @RISK™, each PDF was sampled at least 20,000 times, such that the emission calculations performed produced a converged output distribution.
- The distribution of errors in the parameter values was calculated from the difference between 2.5 and 97.5 percentile values in the distribution, as a percentage of the distribution mean.
- The uncertainties used for the fuel activity data were estimated from the statistical difference between the total supply and demand for each fuel. Data on the statistical difference between supply and demand for individual sectors are not available. This means that the quoted uncertainties refer to the total fuel consumption rather than the consumption by a particular sector, e.g. coal consumed in the residential sector. Hence, to avoid underestimating uncertainties, it was necessary to correlate the uncertainties used for the same fuel in different sectors.
- The uncertainty in the trend between 1990 and the latest reported year, according to gas, was also estimated.

5.1.1 Comparison between uncertainty methods

Table 4 compares the emissions estimates and trends in emissions of these approaches:

Method of uncertainty estimation	**Emissions estimate Mt CO_2 equivalent**		**Uncertainty percentage over period (95% CI) (1990 to 2013)**
	1990	**2014**	
Error propagation	803.7	518.2	2.5
Monte Carlo	800.1	518.5	3.6

Table 4: Comparison of central estimate and uncertainty on trend calculated by Approach 1 & 2 methods

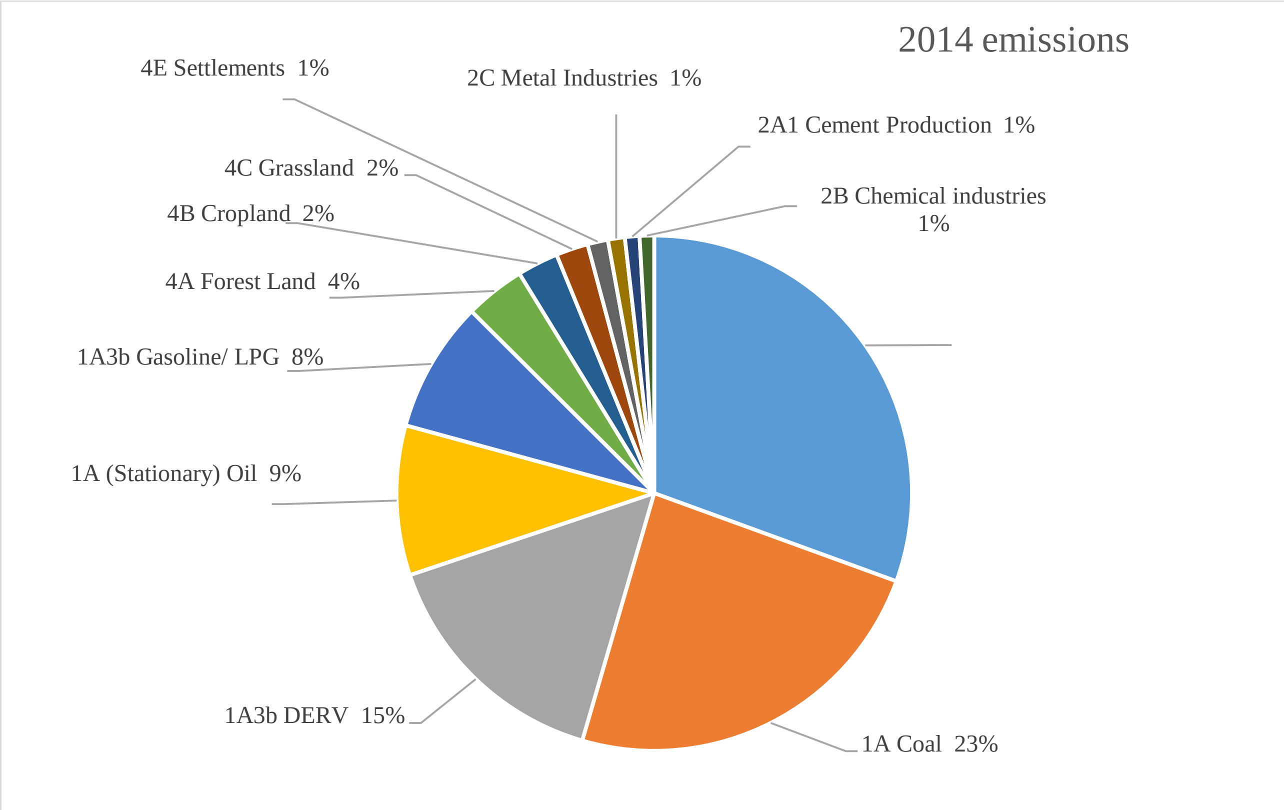
There will always be differences between the results from both approaches as the error propagation approach uses only normal distributions and some uncertainty sources are correlated. Also for calculating the uncertainty in trends, Approach 1 cannot account for changes in inventory structure between 1990 and 2014. However, the emission totals for 1990 agree to within 0.5% and there is effectively no difference between the central estimates for 2014 when using both approaches. These differences are insignificant when compared to the overall uncertainty in emission totals, 4.9% and 2.9% for 1990 and 2014 respectively. The difference in trend uncertainties are also insignificant when compared to the overall trend between 1990 and 2014 of -35% (95% uncertainty values of -32% to -39%).

5.2 UNCERTAINTY BREAKDOWN BY IPCC SECTOR

Emissions for the three gases from each subsector are given in Figure 7 to Figure 9. The largest emitters are plotted for readability, all amounts are in Mt CO_2e.

The percentage for the total emission chart is the percentage contribution to the emission estimate, while for the uncertainty chart the standard uncertainties in emission areas plotted as a bar chart. These standard uncertainties are combined as a sum of squares to give the overall combined standard uncertainty (Eqn 1).

In the following sections we have summed the uncertainty estimates from each source to given total uncertainty across all sources. This total is used to estimate the contribution of that source to overall uncertainty. However, as the overall uncertainty across all sources in the inventory is estimated as a sum of squares, these two do not match. The former method was constructed by NPL as it is thought useful to consider each source or sector might affect economy-wide emissions uncertainty. However, care should be taken in interpreting precise contributions to overall uncertainty and these are only meant to be indicative.



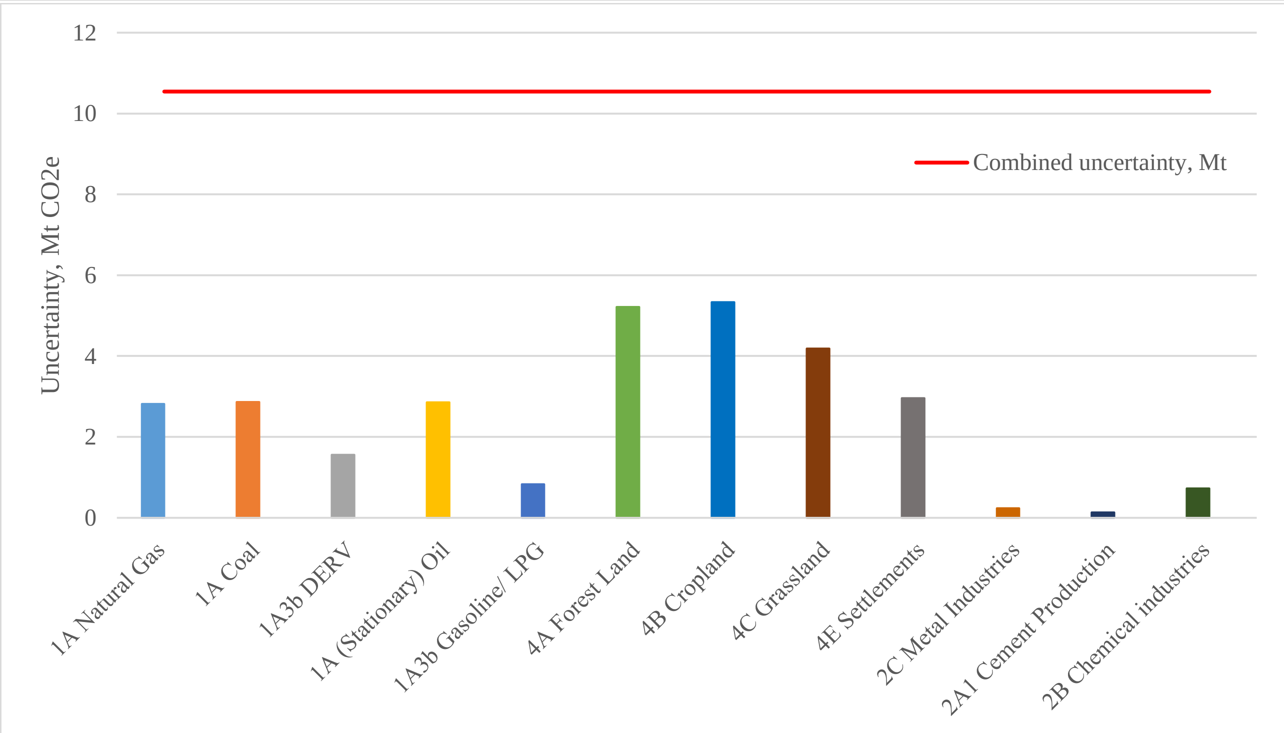


Figure 7: 2014 CO_2 emissions and standard uncertainties

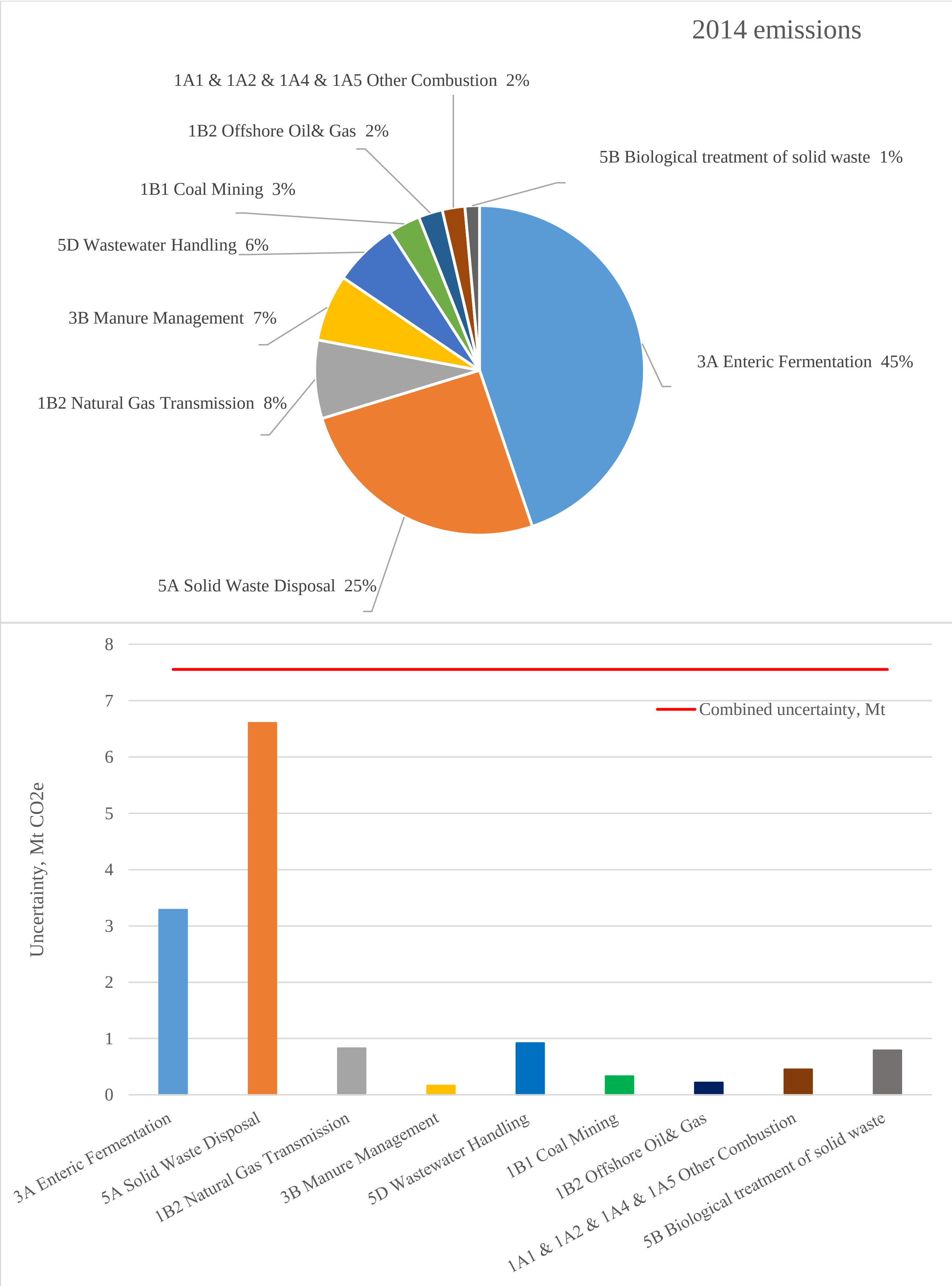
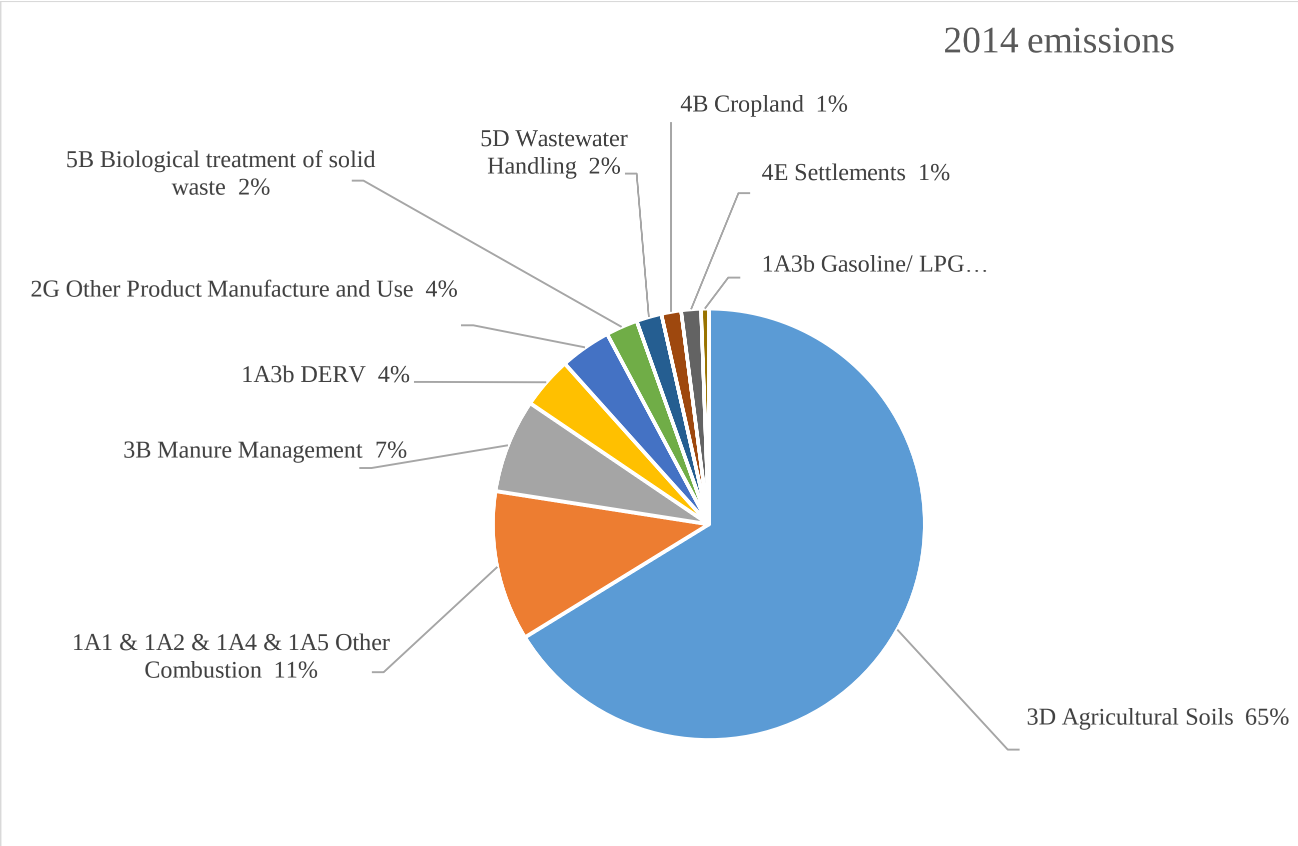


Figure 8: 2014 CH_4 emissions and standard uncertainties



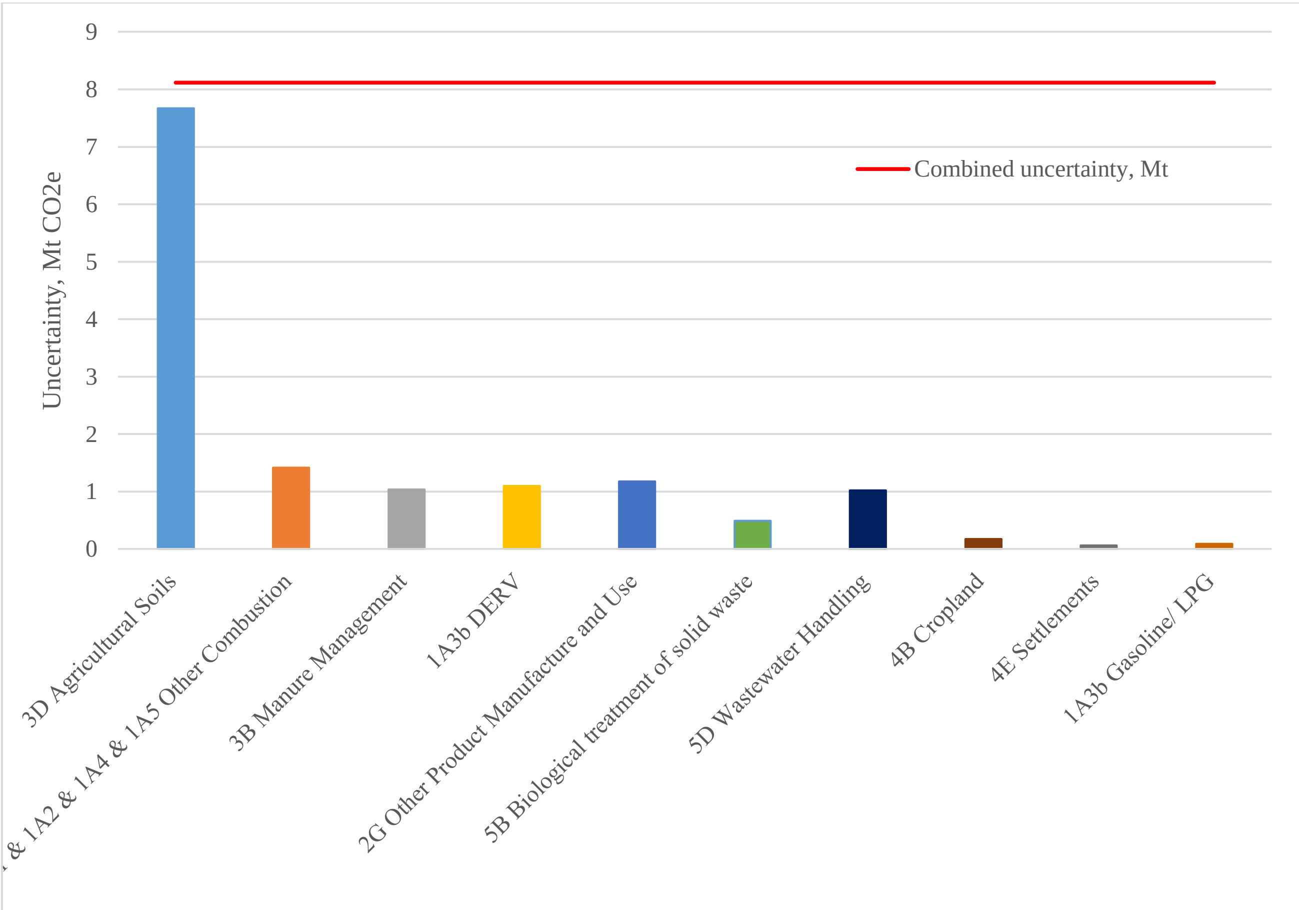


Figure 9: 2014 N_2O emissions and standard uncertainties

As the different calculation method summaries suggested, for most sectors and for all gases the percentage uncertainty is not equal across all emission sources and gases.

The differences between the uncertainty in the activity data and the uncertainty in emission factor for the three gases across their subsectors is shown in Figure 10 to Figure 12. The size of the bubble indicates the magnitude of the emission estimate in that subsector:

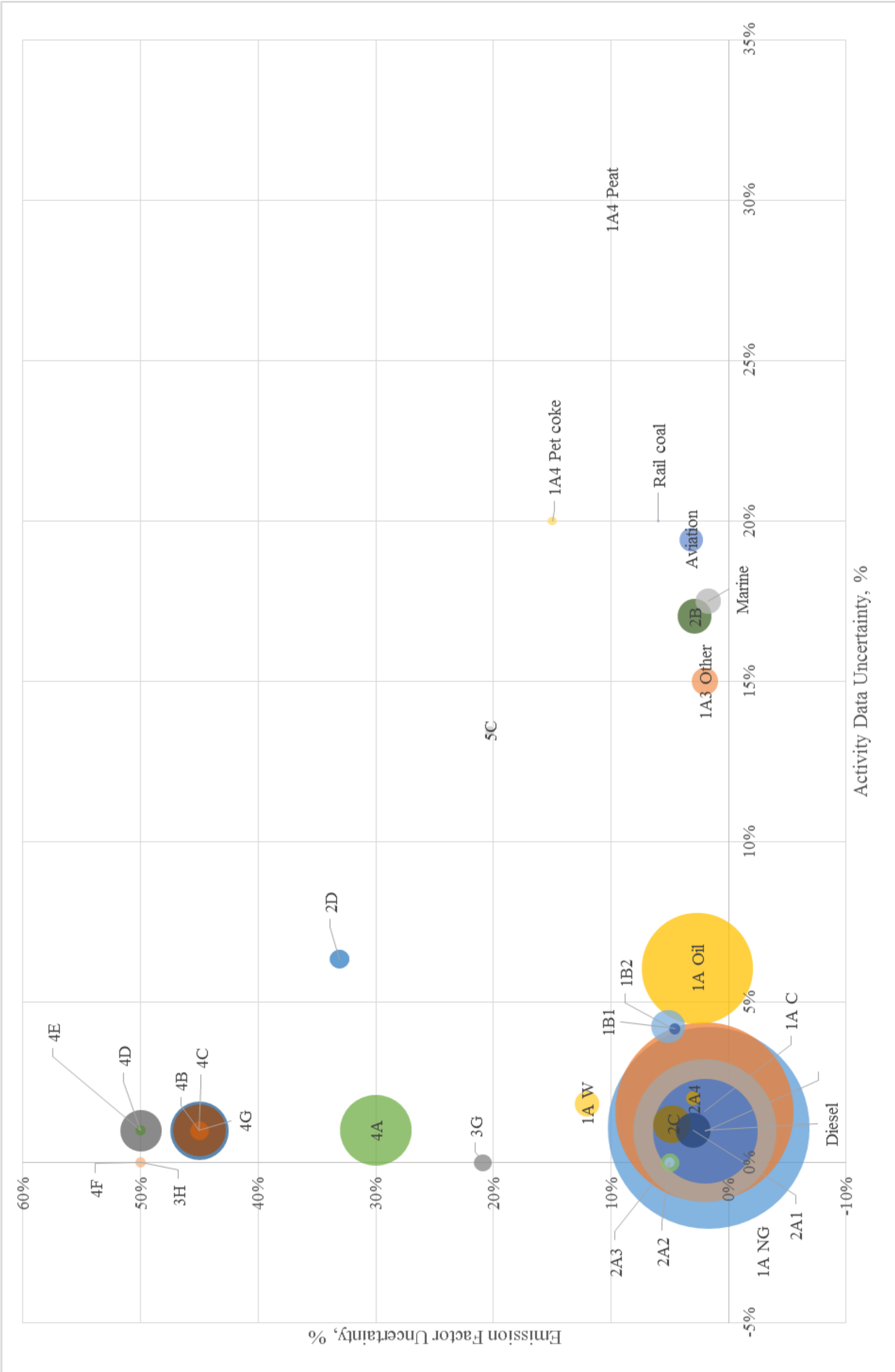


Figure 10: 2014 CO_2: Uncertainty in activity data and emission factors

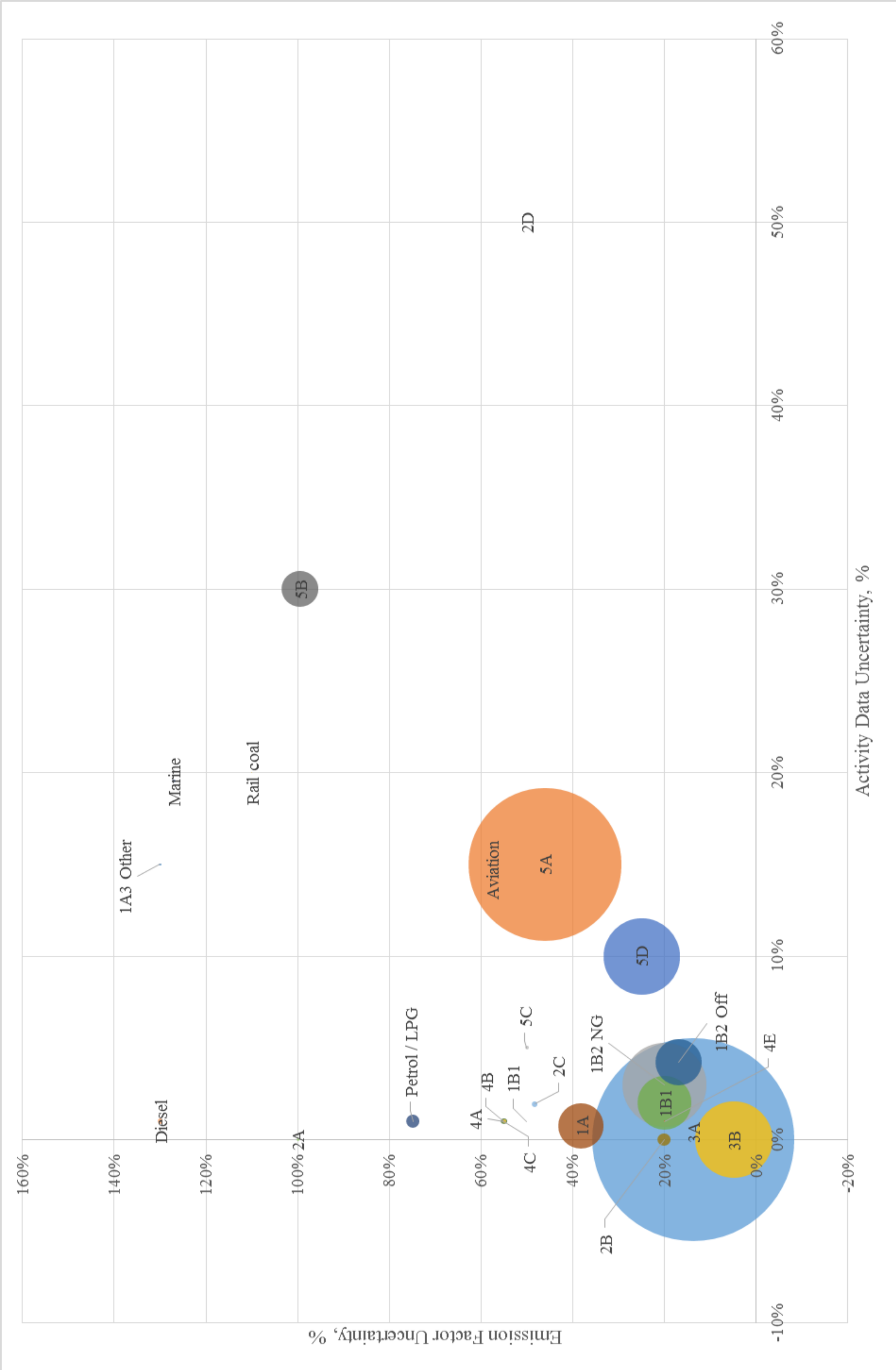


Figure 11: 2014 CH_4: Uncertainty in activity data and emission factors

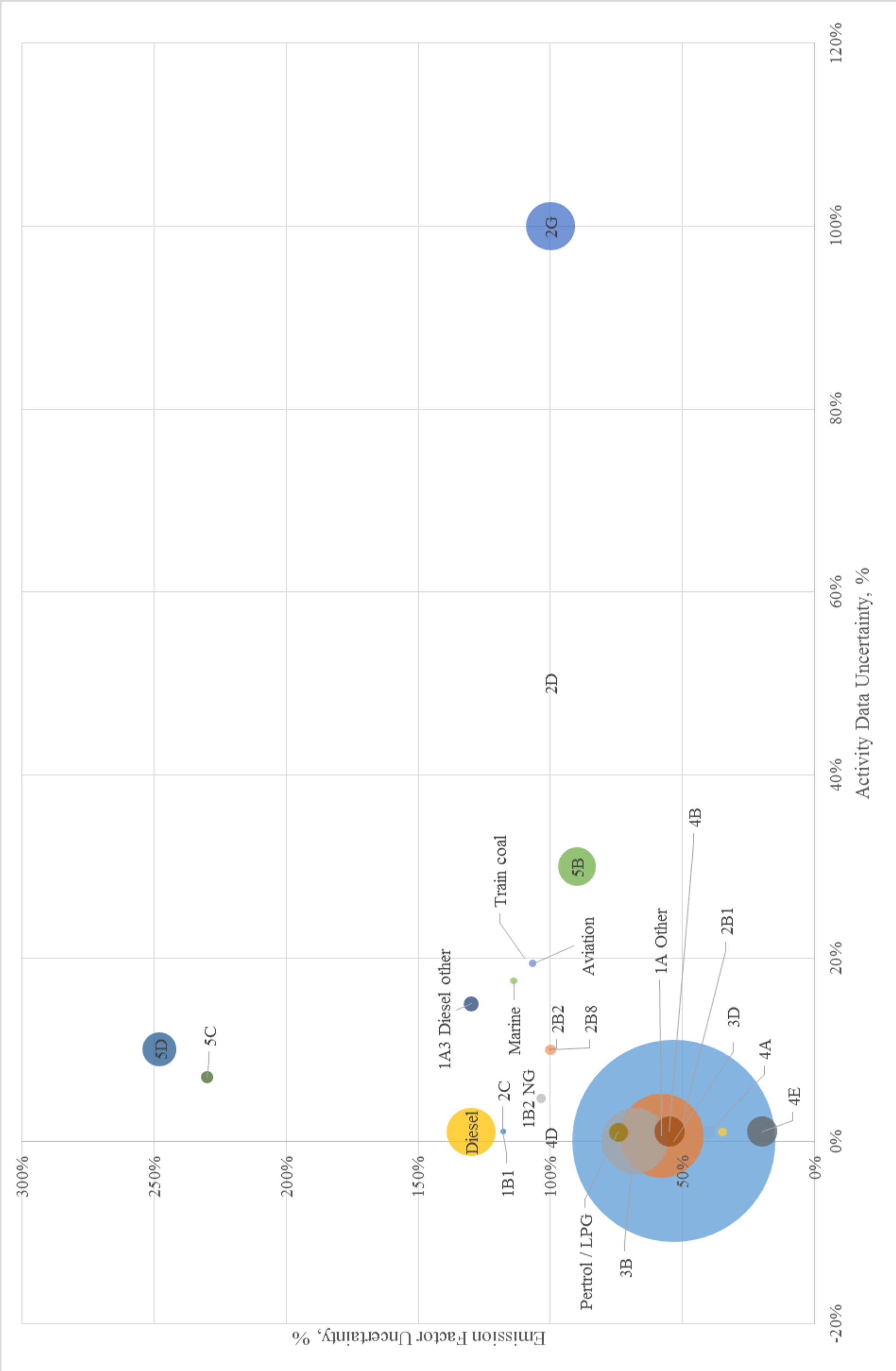


Figure 12: 2014 N_2O: Uncertainty in activity data and emission factors

The above show the large spread of uncertainties in activity data and emission factor for the different calculation methods.

5.2.1 Breakdown by IPCC Tier Methodology

The IPCC allows 3 key tiered methods for calculating emission totals. Tier 1 uses simple methods with IPCC default emission factors. Tier 2 uses country specific emission factors and other data while tier 3 uses a modelling approach that provides compatibility with the Tier 1 & 2 approaches. As the default emission factors used in the Tier 1 methodology are generic and not country specific, the associated uncertainties are much higher than for Tier 2 methods. Tier 3 models try to model emissions from complex sources and therefore have varying levels of uncertainty. Breaking down the GHGI by Tier demonstrates how the uncertainty varies across the 3 approaches and each Tier's contribution to the uncertainty total.

Table 5a, 5b & 5c give a breakdown of the emissions and their uncertainties across the 3 Tiers of IPCC calculation methodology:

Tier	**1**	**2**	**3**
Emissions, Mt CO2e	4.63	309.71	166.48
Combined standard Uncertainty, Mt CO2e	0.55	4.95	9.29
% Uncertainty	12.0	1.6	5.6

Table 5a: CO_2 emissions and uncertainty by IPCC calculation methodology

Note: Sinks for CO_2 have been included as positive amounts for calculation purposes.

Tier	**1**	**2**	**3**
Emissions, Mt CO2e	4.68	41.92	7.28
Combined standard Uncertainty, Mt CO2e	1.03	7.49	0.93
% Uncertainty	22.0	17.7	12.7

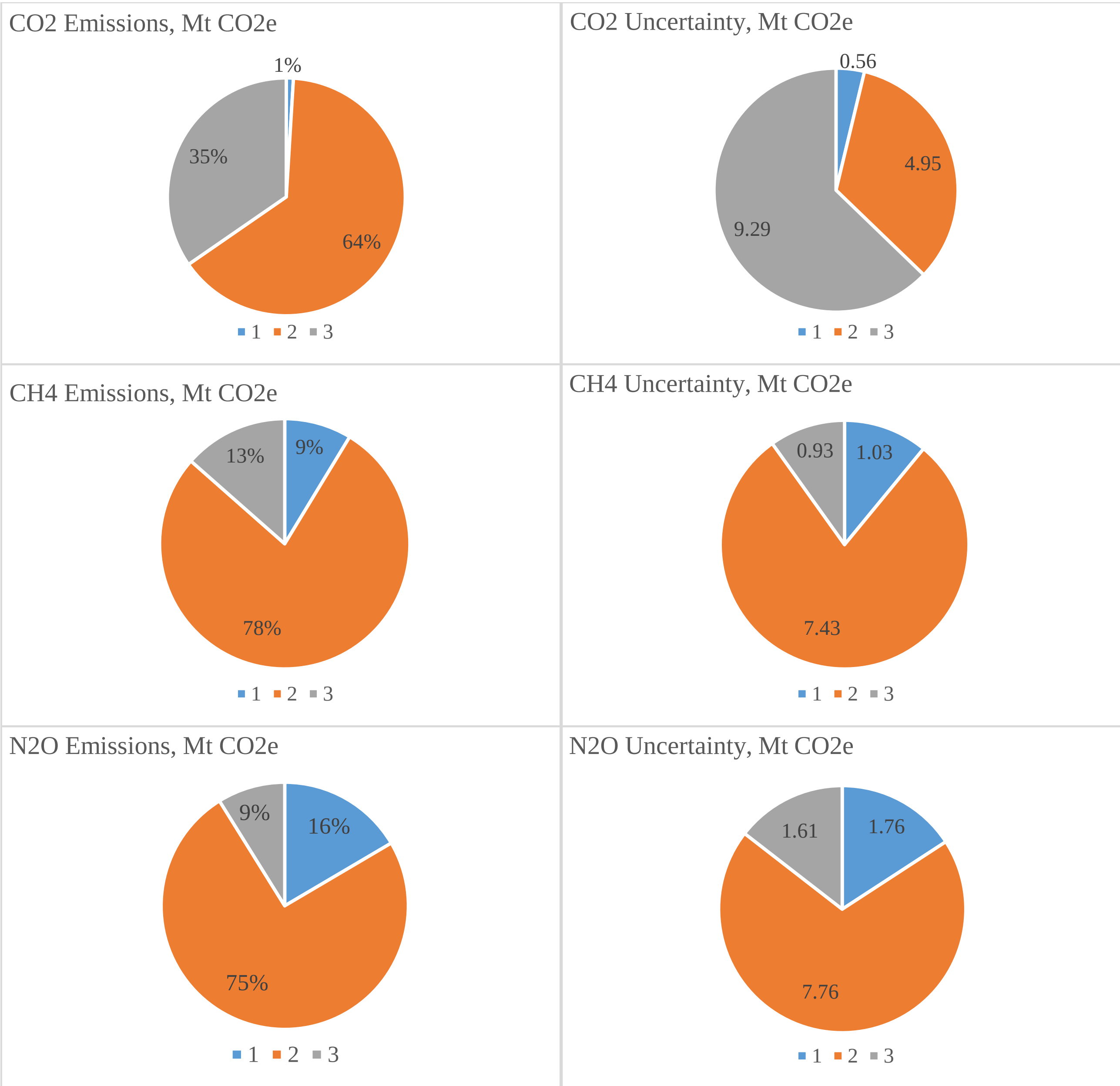
Table 5b: CH_4 emissions and uncertainty by IPCC calculation methodology

Tier	**1**	**2**	**3**
Emissions, Mt CO2e	3.65	16.47	1.96
Combined standard Uncertainty, Mt CO2e	1.76	7.76	1.62
% Uncertainty	78.2	47.1	82.6

Table 5c: N_2O emissions and uncertainty by IPCC calculation methodology

These tables are also represented in graphical in Figure 13 on the next page.

The percentages for each slice in the left hand column are the total emissions and their standard uncertainties given in the right hand column.



Key:

Tier 1 Blue
Tier 2 Orange
Tier 3 Grey

Figure 13: 2014 Tier 1 to 3 emissions and standard uncertainties

It is clear that Tiers 1 & 3 are more uncertain than Tier 2 emissions. Improvements in the methods used for sub-sectors that use Tiers 1 or 3to calculate emissions will have the largest impact on the accuracy of the inventory, compared to sub-sectors that use Tier 2. Table 6 list the Tier 1 & 3 sub-sectors.

	Sub-sectors	
GHG	**Tier 1**	**Tier 3**
CO_2	2A2 Lime Production 2D Non Energy Products from Fuel and Solvent Use 3G Liming 3H Urea application to agriculture 4D Wetland 5C Waste Incineration	1A3 Other Diesel 1A3a Aviation Fuel 1A3b DERV 1A3b Gasoline 1A3d Marine Fuel 1B1 Solid Fuel Transformation 2A3 Glass Production 2A4 Other process use of carbonate 2B Chemical Industries 4A Forest Land 4B Cropland 4C Grassland 4E Settlements 4F Other Land 4G Other Activities
CH_4	1A1 & 1A2 & 1A4 & 1A5 Other Combustion 1A3c Coal 2C Iron & Steel Production 2D Non-energy Products from Fuels and Solvent Use 3F Field Burning 4A Forest Land 4B Cropland 4C Grassland 4E Settlements 5C Waste Incineration 5D Wastewater Handling	1A3 Other Diesel 1A3a Aviation Fuel 1A3b DERV 1A3b Gasoline 1A3d Marine Fuel 1B1 Coal Mining 1B1 Solid Fuel Transformation 1B2 Natural Gas Transmission 1B2 Offshore Oil & Gas 2A Minerals Industry 2B Chemical Industry
N_2O	1A1 & 1A2 & 1A4 & 1A5 Other Combustion 1A3c Coal 1B1 Fugitive Emissions from Solid Fuels 2C Iron & Steel Production 2D Non-energy Products from Fuels and Solvent Use 3F Field Burning 4A Forest Land 4B Cropland 4C Grassland 4D Wetland 4E Settlements 5C Waste Incineration 5D Wastewater Handling	1A3 Other Diesel 1A3a Aviation Fuel 1A3b DERV 1A3b Gasoline 1A3d Marine Fuel 2B1 Ammonia Industry 2B2 Nitric Acid Production 2B3 Adipic Acid Production 2B8 Petrochemical and Carbon Black Production 2G Other Product Manufacture and Use

Table 6: Sub-sectors contributing to Tier 1 & 3 Emission totals in the 2014 inventory

5.2.2 Uncertainty breakdown by CCC Sector

As well as reporting emissions by IPCC category, emissions are also calculated by CCC sector. A breakdown of emissions and standard uncertainties for the CCC sectors is given in Figure 14.

The percentage for the total emission chart is the percentage contribution to the emissions estimate, while for the uncertainty chart the combined standard uncertainties in emissions are plotted as a bar chart. These standard uncertainties are combined as a sum of squares to give the combined standard uncertainty (Eqn 1).

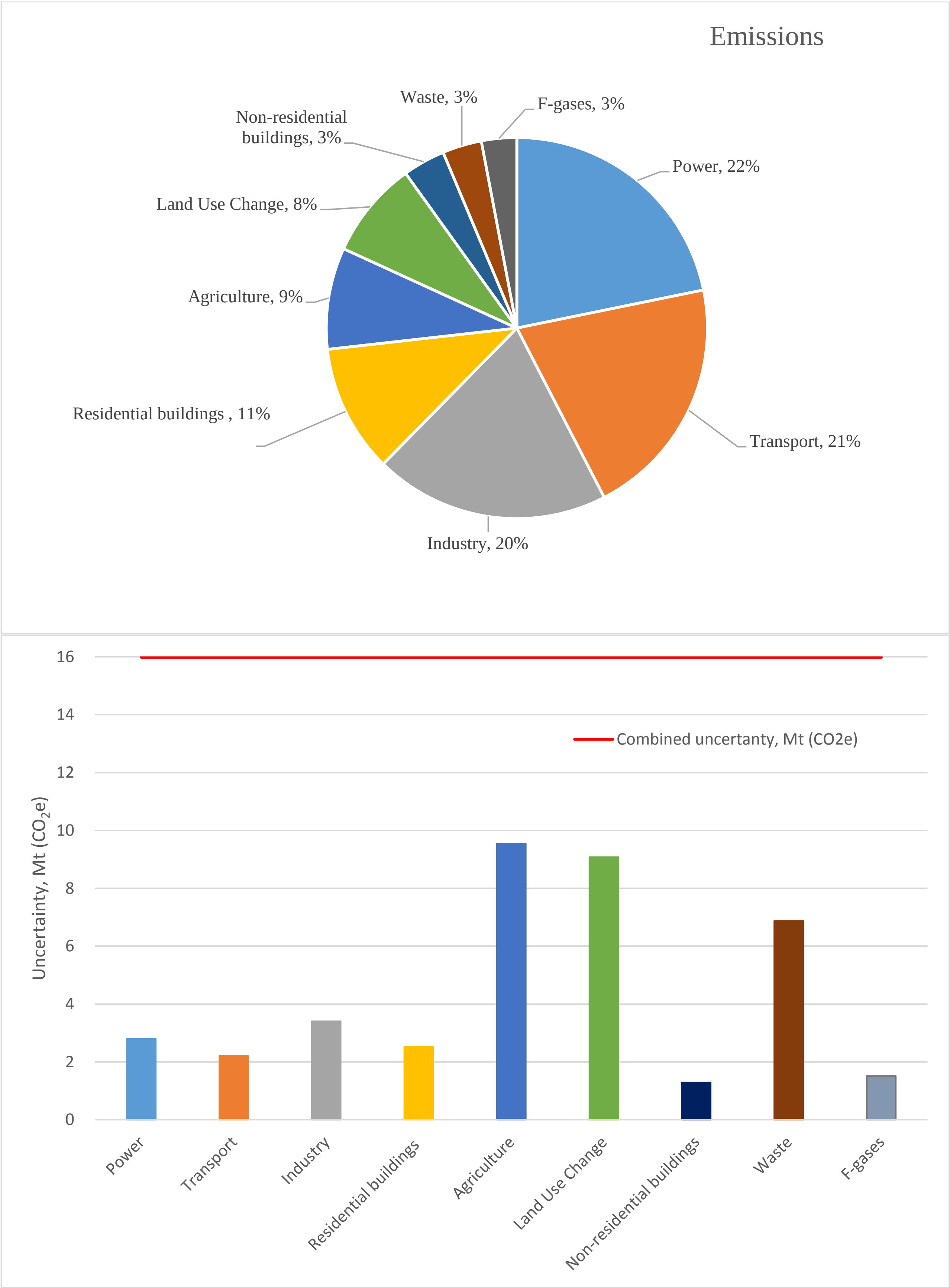


Figure 14: 2014 Total emissions and standard uncertainties by CCC sector

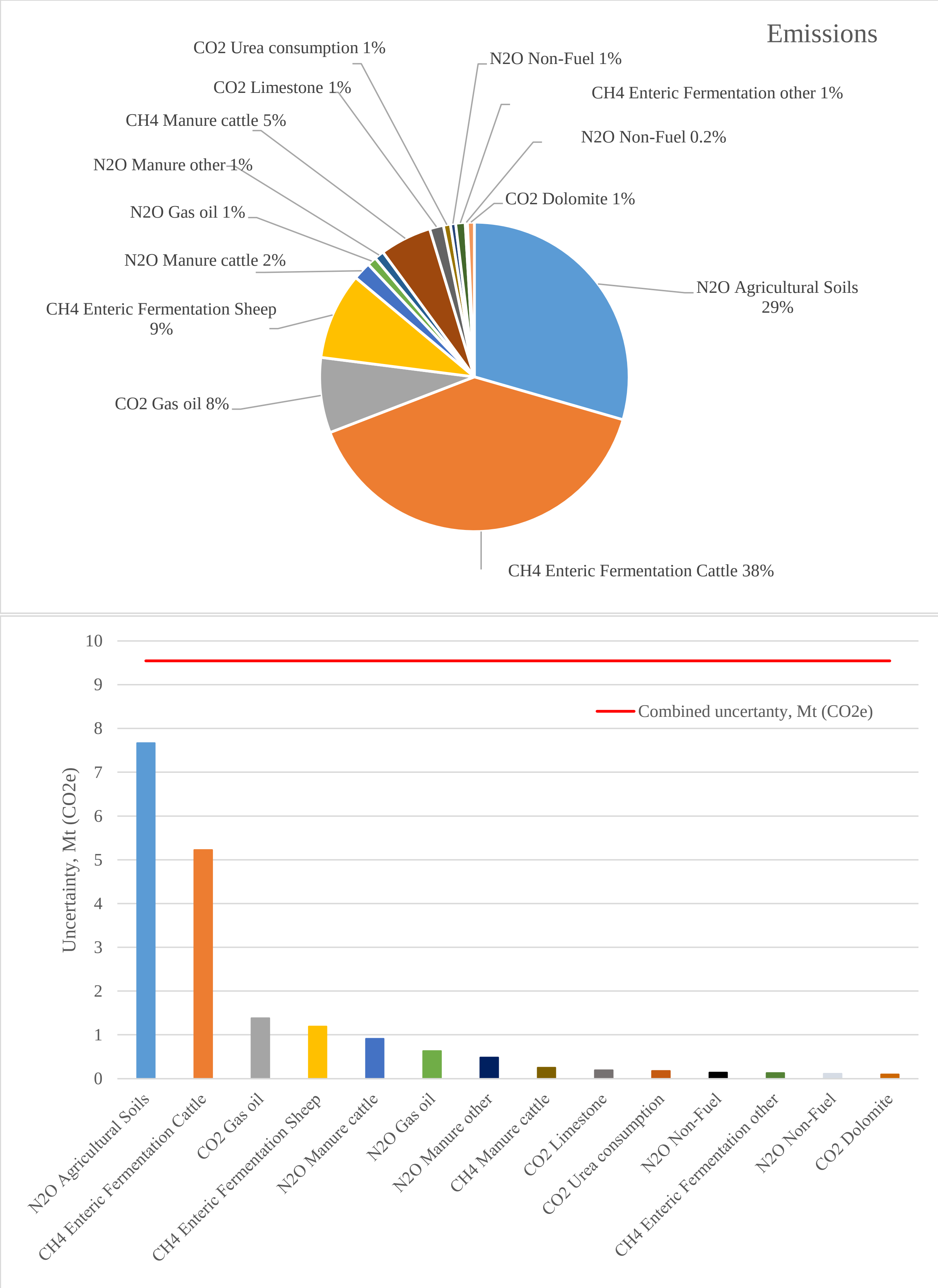


Figure 15: 2014 largest standard uncertainties and emissions from the Agriculture Sector

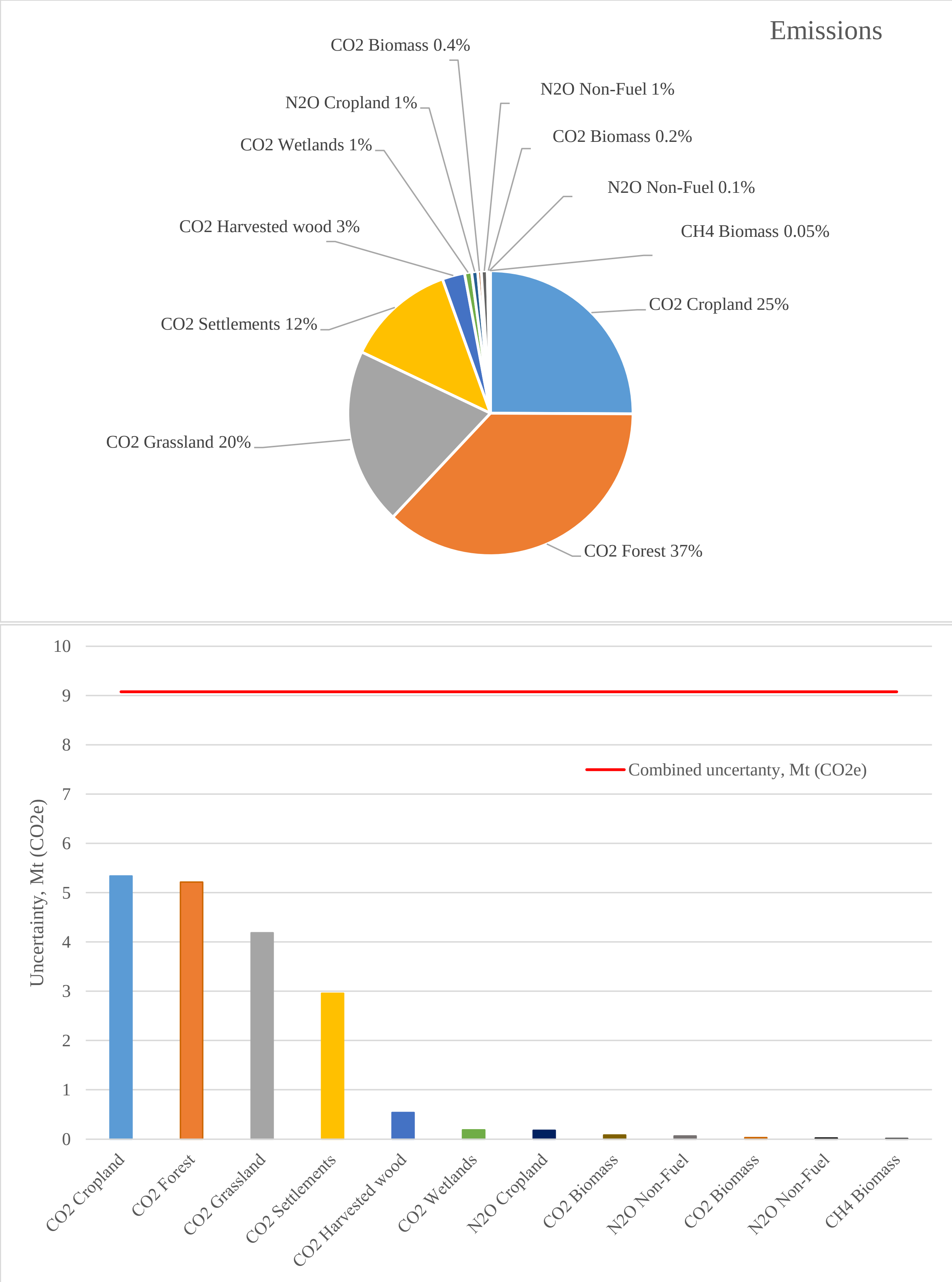


Figure 16: 2014 largest standard uncertainties and emissions from the Land Use Sector

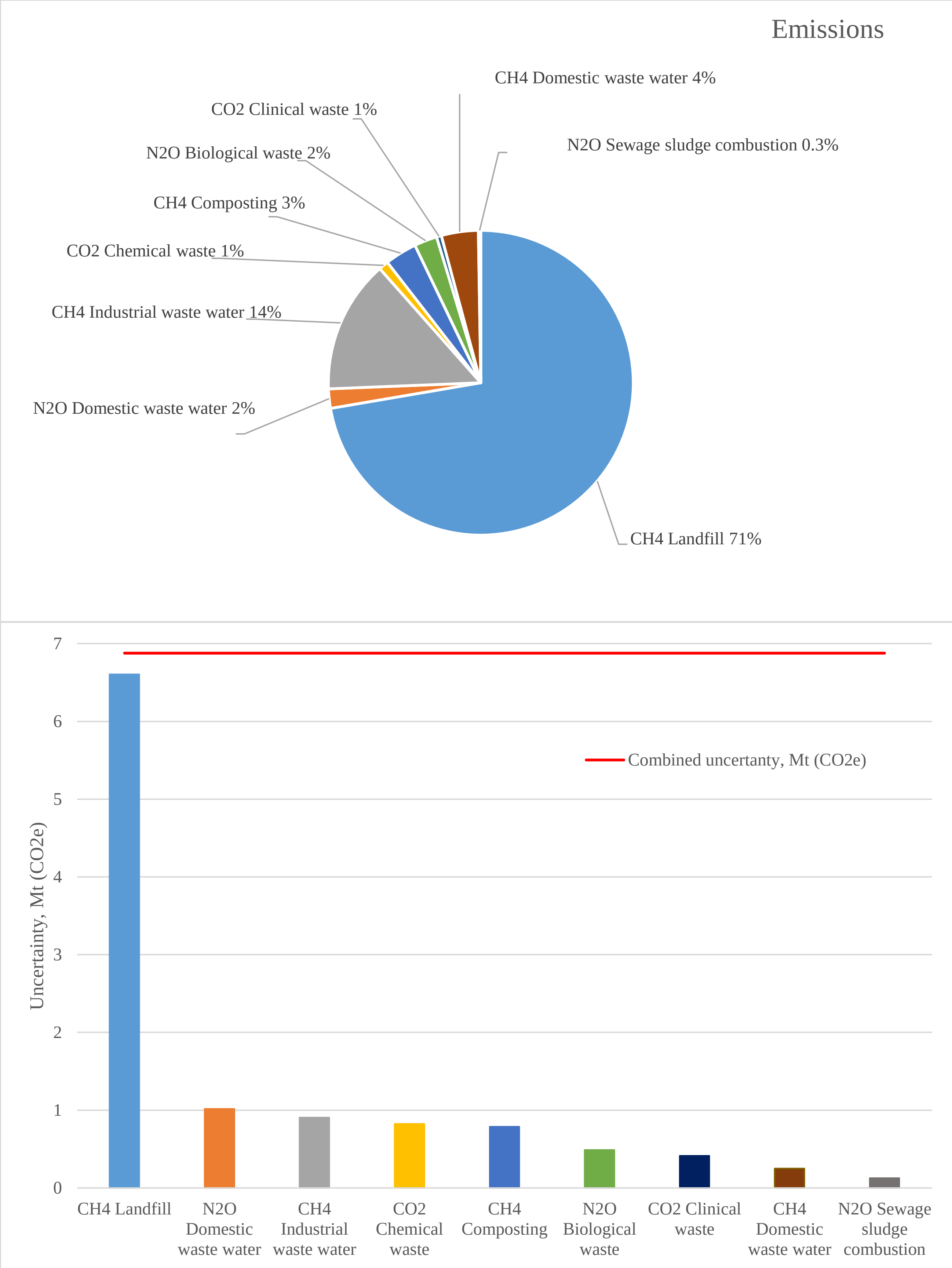


Figure 17: 2014 largest standard uncertainties and emissions from the Waste Sector

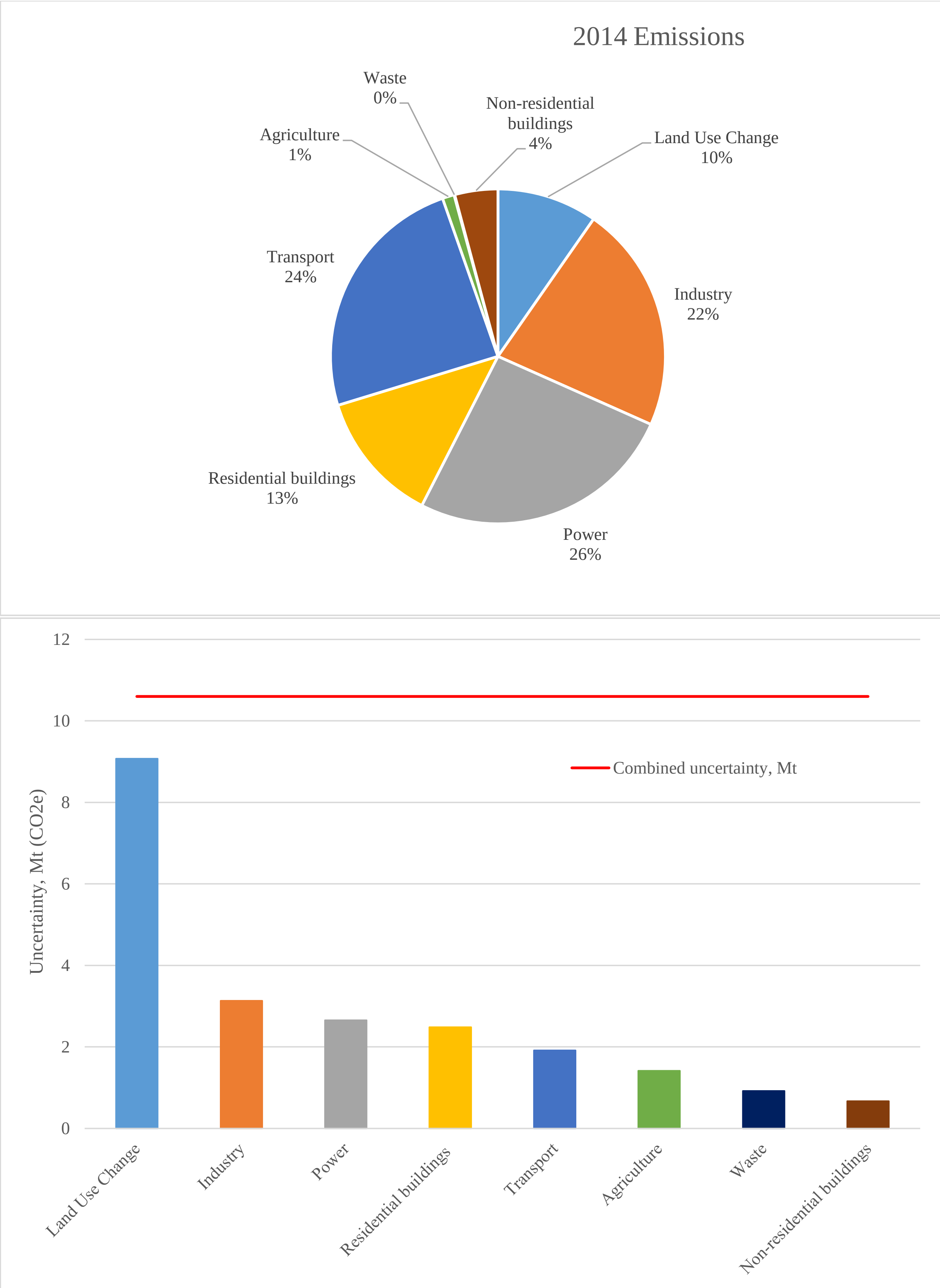


Figure 18: 2014 CO_2 Emissions and standard uncertainties by CCC Sector

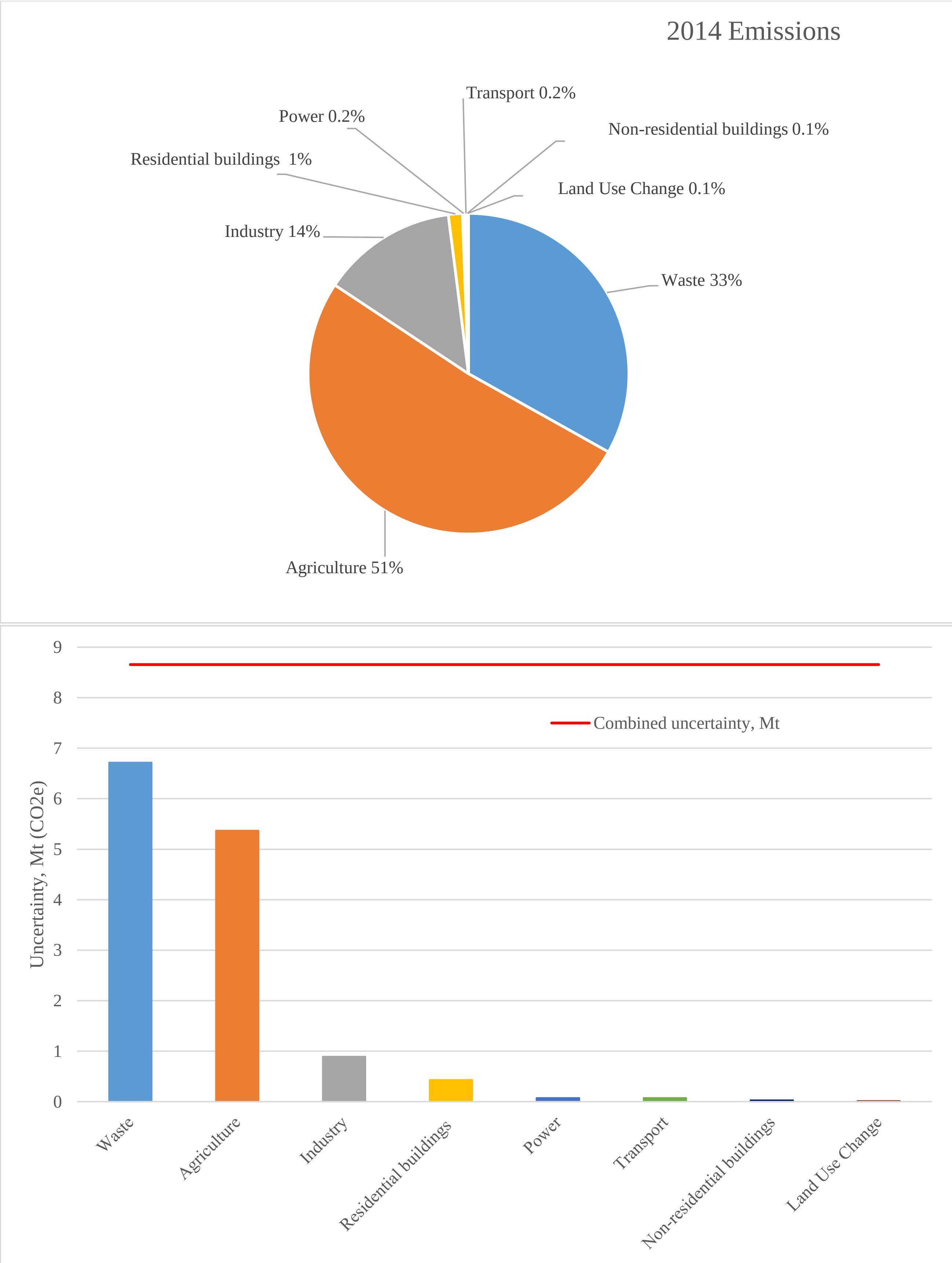


Figure 19: 2014 CH_4 Emissions and standard uncertainties by CCC Sector

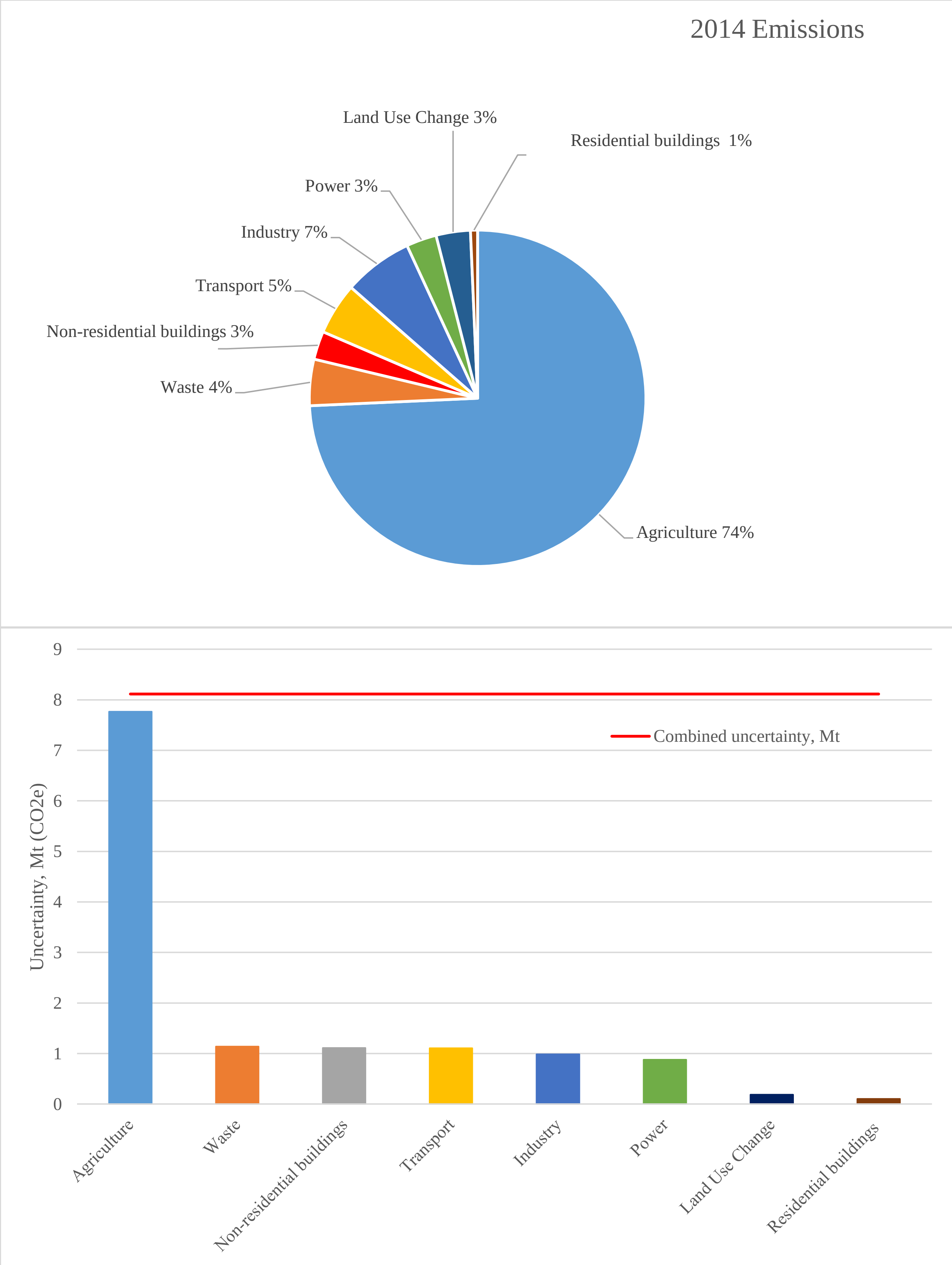


Figure 20: 2014 N_2O Emissions and standard uncertainties by CCC Sector

For CO_2 it can be seen that the power, transport and industry sectors contribute 26%, 24% and 22%, respectively, to the total CO_2 emissions whilst these sectors standard uncertainties are 2.7 Mt CO_2e (12%), 1.9 Mt CO_2e (9%) and 3.1 Mt CO_2e (14%), respectively. In contrast, Land Use Change contributes 10% to the emissions (sinks + sources) while it has a standard uncertainty of 9.1 Mt CO_2e (which is a relative uncertainty of 41%).

For CH_4 it can be seen that the agriculture, waste and industry sectors are the largest CH_4 sources, each contributing 51%, 33% & 14%, respectively, to the total CH_4 emissions. Waste contributes disproportionately to uncertainty with a CH_4 standard uncertainty of 6.7 Mt CO_2e (49%). In contrast agriculture has a standard uncertainty of 5.4 Mt CO_2e (39%) and industry of 0.9 Mt CO_2e (7%), both contribute a lower percentage to the uncertainty than they do to the emission total for CH_4.

For N_2O, Agriculture is again the largest source, contributing 74% of the emission total whilst only contributing 7.78 Mt CO_2e (59%) to the uncertainty of N_2O emissions. Most of the other sectors have a 1:1 or 1:2 contribution to the emission total and standard uncertainty respectively.

If the 8 CCC sectors are broken down into sub-categories covering different emission sources, similar characteristics to the IPCC sub-sector breakdown are seen with some sources having very varied uncertainties attributed to emission factor and activity data. For CO_2 most sources in each sub-sector have their own individual percentage uncertainties, whilst for CH_4 and N_2O most sources in each sub-sector have very similar or identical percentage uncertainties for activity data and emission factors. Figure 21 and Figure 22 shows uncertainties in activity data and emission factors, relative emission totals, and show the contrast between these 2 cases.

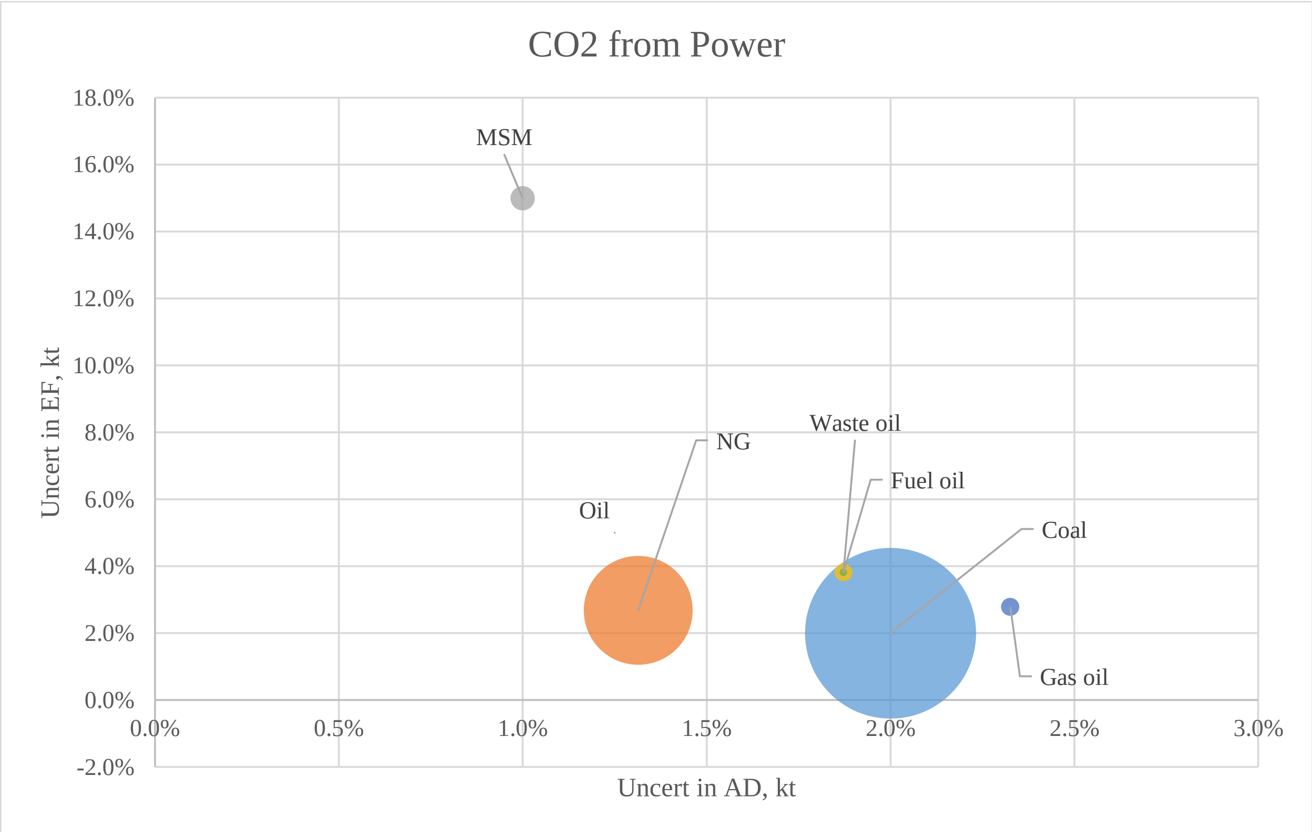


Figure 21: CO_2 uncertainty in activity data and emission factor for the Power sub-sector

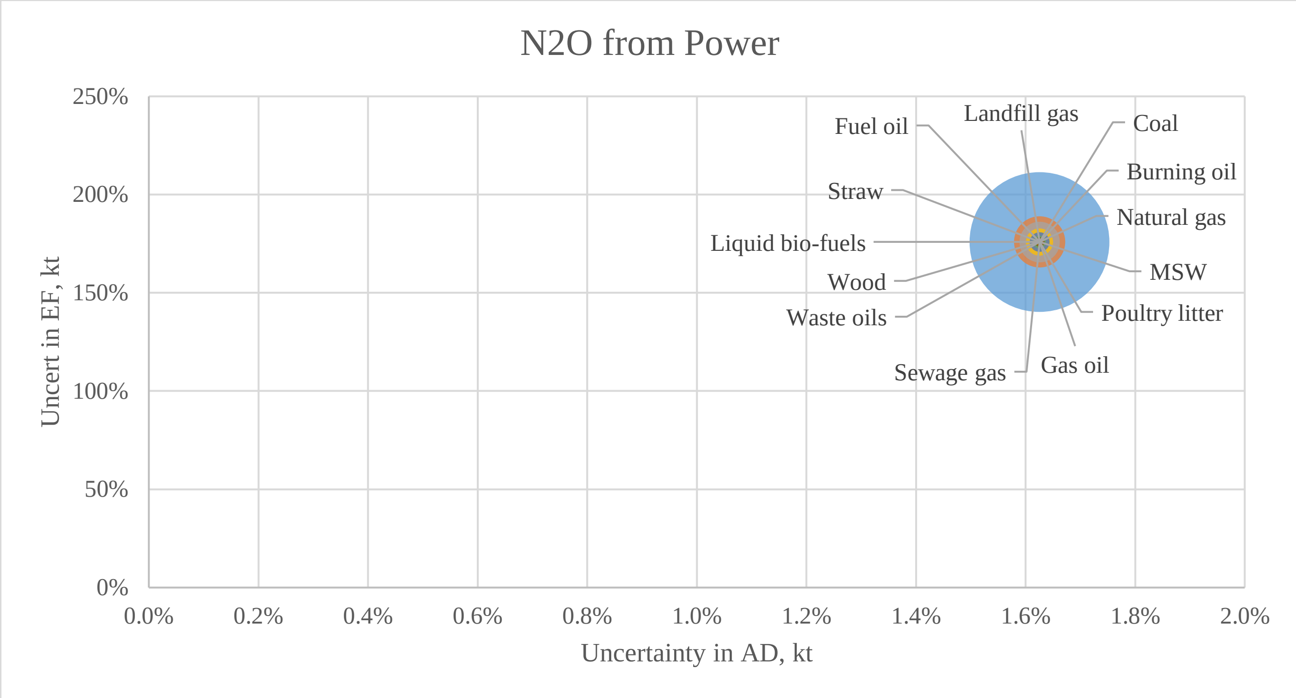


Figure 22: N_2O uncertainty in activity data and emission factor for the Power sub-sector

Each source for CO_2 has its own uncertainty for activity data and emission factor whilst for N_2O the uncertainty in emission factor and activity data is identical irrespective of which fuel is burnt.

5.3 INTERNATIONAL COMPARISON OF INVENTORY UNCERTAINTY

Figure 24 shows how the uncertainty of the 2014 UK GHGI compares to other countries in Europe, North America, Australia, New Zealand and the Russian Federation. Countries have been ranked in increasing uncertainty in the complete inventory including LULUCF from left to right. The UK has the third lowest uncertainty and has been highlighted in purple and red bars.

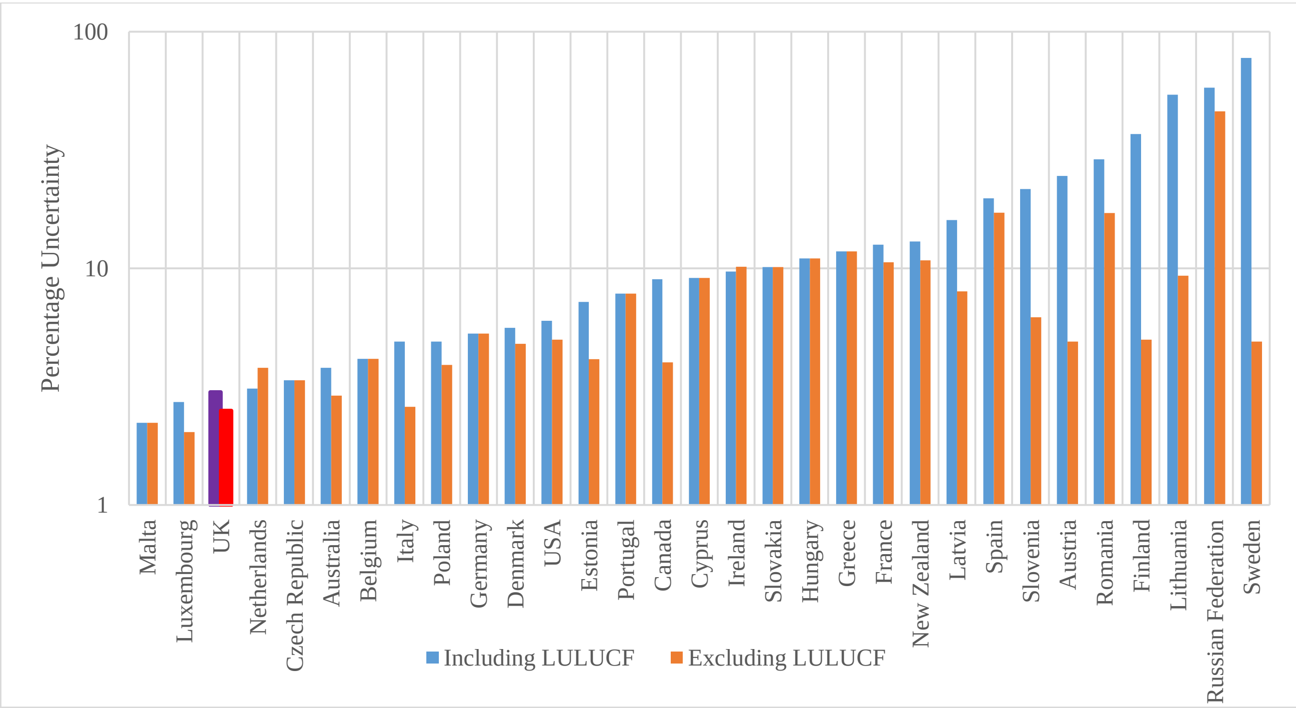


Figure 23: Comparison of uncertainties in different countries' 2014 inventories

6 OVERVIEW OF QA/QC SYSTEM FOR GHGI

The current NAEI complies with the Tier 1 procedures outlined in the 2006 IPCC Guidelines [12] and has been extended to include a range of on-going bespoke sector specific QA/QC activities to comply with Tier 2. The Inventory Agency (Ricardo Energy & Environment) is fully accredited to BS EN ISO 9001:2008 ('Quality Management Systems'). This accreditation provides additional institutional standards which the Inventory Agency has to apply to all projects and ensures that the wider company conforms to good practice in project management and quality assurance. A QA/QC plan sets out a timeline for QA/QC checks, designed to fit in with compilation and reporting requirements for all UK GHG and Air Pollutant reporting commitments.

Much of the data received for the UK GHGI compilation comes from Government departments, agencies, research establishments or consultants working on behalf of UK government or for trade associations. Some of the organisations (e.g. BEIS, the Office of National Statistics and British Geological Survey) qualify as the UK's National Statistical Agencies referred to in IPCC Guidance and abide by strict statistical QA/QC standards. Other organisations (e.g. CEH, providing the LULUCF estimates and the Environment Agency, providing regulated point source data) supply important datasets for the Inventory and have their own QA/QC systems. CEH is implementing a QA/QC system for LULUCF following the methodology of Ricardo Energy & Environment [14].

6.1 KEY IMPROVEMENTS

The National Inventory Steering Committee (NISC) helps prioritise improvements across the inventory. These improvements are designed to improve the transparency, accuracy, consistency, comparability, and completeness of the inventory. Incremental improvements are made routinely to ensure the inventory uses the most accurate activity data and emission factors.

Under the improvement programme, a review of the Key Category Analysis and Approach 1 uncertainty analysis has been carried out, in response to a recommendation from the UNFCCC Expert Review Team (ERT). 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, uncertainty or the trend.

6.1.1 Key Category Analysis (KCA)

The Key Category Analysis (KCA) ranking system is an additional tool that the UK has developed to aid in the prioritisation of improvement work. There are two approaches to performing the KCA system:

Approach 1

This approach allocates a score based on how high categories rank in the base year, most recent year level assessments and the trend assessment, LULUCF. For example, if CO_2 from road transport liquid fuel use is the 4^{th} highest by the base year level assessment, 3^{rd} highest by the most recent year level assessment and has the 5^{th} highest trend assessment then its score would be 4+3+5=12. The categories are then ranked from lowest score to highest, with draws in score resolved by the most recent year level assessment. The assessments excluding LULUCF are ignored for this exercise, as the LULUCF sectors would only be included in half of the assessments and would therefore give an unrepresentative weighting. Table 7 gives the top 12 ranked categories from this analysis. Rank 1 has the highest influence on the GHG total emissions for the UK for 2014.

Rank	IPCC Code	IPCC Category	GHG
1	1A3b	Road transportation: liquid fuels	CO_2
2	1A1	Energy industries: solid fuels	CO_2
3	1A4	Other sectors: gaseous fuels	CO_2
4	5A	Solid waste disposal	CH_4
5	1A1	Energy industries: gaseous fuels	CO_2
6	1A1	Energy industries: liquid fuels	CO_2
7	1A2	Manufacturing industries and construction: solid fuels	CO_2
8	1A2	Manufacturing industries and construction: gaseous fuels	CO_2
9	3A1	Enteric fermentation from Cattle	CH_4
10	1A2	Manufacturing industries and construction: liquid fuels	CO_2
11	4A	Forest Land	CO_2
12	3D	Agricultural soils	N_2O

Table 7: Top 12 ranked categories from the Approach 1 analysis

A separate uncertainty analysis has been completed for the Key Categories for LULUCF activities under the KP. This analysis indicates the key categories of emissions and removals are (KP category, gas, associated UNFCCC category):

- Afforestation and Reforestation, CO_2, Conversion to Forest Land.
- Deforestation, CO_2, Conversion to Grassland, Conversion to Settlements.
- Forest Management, CO_2, Conversion to Forest Land.
- Cropland Management, CO_2, Cropland.
- Grazing Land Management, CO_2, Grassland.

Approach 2

Following the 2006 IPCC Guidelines [12], the UK also performs a KCA for both level and trend, which takes into account uncertainties, calculated using the Approach 1 method for uncertainty estimates. While the Quantitative Approach 1 method is used to aid for the prioritisation of future improvement work, the inclusion of uncertainty is essential for improving the accuracy of the inventory.

7 ASSESSMENT OF COMPLETENESS

The National Inventory Steering Committee (NISC) are responsible for reviewing methodologies, activity data, emission factors and emission estimates at a sectoral level. The committee is responsible for ensuring that the inventory meets international standards of quality, accuracy and completeness, and is delivered on time each year to the EU MMR and the UNFCCC. Where inventory improvement research is commissioned by the NISC, the research reports are reviewed and approved for use within the UK GHGI compilation by members of the NISC, managed by BEIS, as part of the pre-submission review process [15].

The NISC meets twice a year to agree the prioritisation, funding, implementation and review of items on the UK inventory improvement programme. The NISC incorporate the KCA, uncertainty analysis, qualitative analysis and recommendations from reviews of the UK GHG inventory to steer decisions on which improvements are the most important. Key categories with high uncertainty are given priority over non-key categories or categories with a low uncertainty. The annual inventory review feedback from the UNFCCC and outcomes from QA/QC checks and reviews carried out under the MMR and Effort Sharing Decision, as well as sector-specific peer- or bilateral review findings are also considered to guide decisions on UK GHGI improvement priorities.

A review meeting is held annually between BEIS and the Inventory Agency to develop a comprehensive list of inventory improvement items for discussion, prioritisation and implementation via the NISC [3].

7.1 GENERAL ASSESSMENT OF COMPLETENESS

The UK GHG inventory aims to include all anthropogenic sources of GHGs. Some sources are not estimated in the UK GHG inventory due to insufficient activity data or unsuitable emission factors being identified. However, emissions from these sources are considered to be negligible in the UK. The reasons for those sources being omitted are reported to the UNFCCC. The completeness of the KP-LULUCF inventory is also reported but the requirements for reporting under the KP are met by the NIR report for the UNFCCC.

The UK also does not report emission estimates in certain sectors as the UK is considered not to emit GHGs from these sectors. Sectors not reported in the 2014 inventory are listed below:

2B4 CAPROLACTAM, GLYOXAL AND GLYOXYLIC ACID PRODUCTION
2B5 CARBIDE PRODUCTION
2C2 FERROALLOYS PRODUCTION
2C5 LEAD PRODUCTION
2E2 TFT FLAT PANEL DISPLAY
2E3 PHOTOVOLTAICS
2E4 ELECTRONICS INDUSTRY –HEAT TRANSFER FLUID
3C RICE CULTIVATION
3E PRESCRIBED BURNING OF SAVANNAS
4F OTHER LAND
6 OTHER

Table 8 summarises the sectors where and why the UK has not submitted emission estimates.

GHG	Sectors	Source/sink	Explanation
CO_2, CH_4 & N_2O	4A, 4B, 4C & 4D	Emissions and removals from drainage and rewetting and other management of organic and mineral soils	Insufficient information for reporting emissions from drainage
CO_2, CH_4 & N_2O	4A, 4B, 4C & 4D	Emissions and removals from drainage and rewetting and other management of organic and mineral soils	Insufficient information for reporting emissions from rewetting
CH_4	3D	Agricultural Soils	Not estimated due to insufficient data. Emissions are expected to be very small
CO_2	LULUCF	4C Grassland, Grassland Remaining Grassland/Biomass Burning/Wildfires	Assumed to be replaced by re-growth within the year
CO_2	LULUCF	4C Grassland, Land converted to Grassland/Biomass Burning/Wildfires	Assumed to be replaced by re-growth within the year
CO_2	Waste	5.A Solid Waste Disposal/5.A.1 Managed Waste Disposal Sites/5.A.1.a Anaerobic	Emissions of CO_2 are biogenic and therefore are excluded
CH_4	Waste	5.C Incineration and Open Burning of Waste/Chemical Waste	High temperature combustion process therefore emissions of CH_4 are understood to be small. No suitable emission factor identified.
CH_4	Waste	5.C Incineration and Open Burning of Waste/Municipal Solid Waste	Data not available, emissions understood to be negligible.
CO_2	Waste	5.C Incineration and Open Burning of Waste/5.C.2 Open Burning of Waste/5.C.2.2 Non-biogenic/5.C.2.2.b/ Accidental fires (buildings)	No suitable emission factor has been identified, emissions are believed to be negligible

GHG	Sectors	Source/sink	Explanation
CO_2	Waste	5.C Incineration and Open Burning of Waste/5.C.2 Open Burning of Waste/5.C.2.2 Non-biogenic/5.C.2.2.b/ Accidental fires (vehicles)	No suitable emission factor has been identified, emissions are believed to be negligible
N_2O	Waste	5.C Incineration and Open Burning of Waste/5.C.2 Open Burning of Waste/5.C.2.2 Non-biogenic/5.C.2.2.a Municipal Solid Waste	Data not available, emissions are understood to be negligible
N_2O	Waste	5.C Incineration and Open Burning of Waste/5.C.2 Open Burning of Waste/5.C.2.2 Non-biogenic/5.C.2.2.b/ Accidental fires (buildings)	No suitable emission factor has been identified, emissions are believed to be negligible
N_2O	Waste	5.C Incineration and Open Burning of Waste/5.C.2 Open Burning of Waste/5.C.2.2 Non-biogenic/5.C.2.2.b/ Accidental fires (vehicles)	No suitable emission factor has been identified, emissions are believed to be negligible
N_2O	Waste	5D Wastewater Treatment and Discharge/5.D.2 Industrial Wastewater	Emissions are believed to be insignificant compared to domestic waste water, and no method is provided
CO_2	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 Solvent use	Indirect CO_2 emissions from the oxidation of VOCs are not mandatory for reporting under the UNFCCC reporting guidelines.
CO_2	Industrial Processes and Product Use	2.H Other/2.H.2 Food and beverages industry	No appropriate data available
N_2O	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 /Solvent use	Data not readily available. Emissions are believed to be negligible

Table 8: Sectors where the UK has not submitted emission estimates due to insufficient data being available and where emissions are likely to be negligible

The 2016 submission (2014 inventory) contains new categories that were previously included within other categories (Table 9).

Sub Category			Emission Source
2G3B	Other Food	Cream Consumption	Based on UK cream consumption statistics (Defra) and Danish GHG Inventory method (2015)
2G4	Chemical industry	Other process sources	Manufacture of nitrous oxide and transfer to gas cylinders Catalyst manufacturing process
N_2O combined emission estimate for 2G - Other Product Manufacture and Use			**831 Kt CO_2e**

Table 9: New categories included in the 2016 submission (2014 inventory)

8 RE-CALCULATION, IMPROVEMENTS AND FUTURE DEVELOPMENTS

Changes in calculation methodology, improvements to future inventories and future developments driven by changes to IPCC and KP Methodologies are discussed in the following sections.

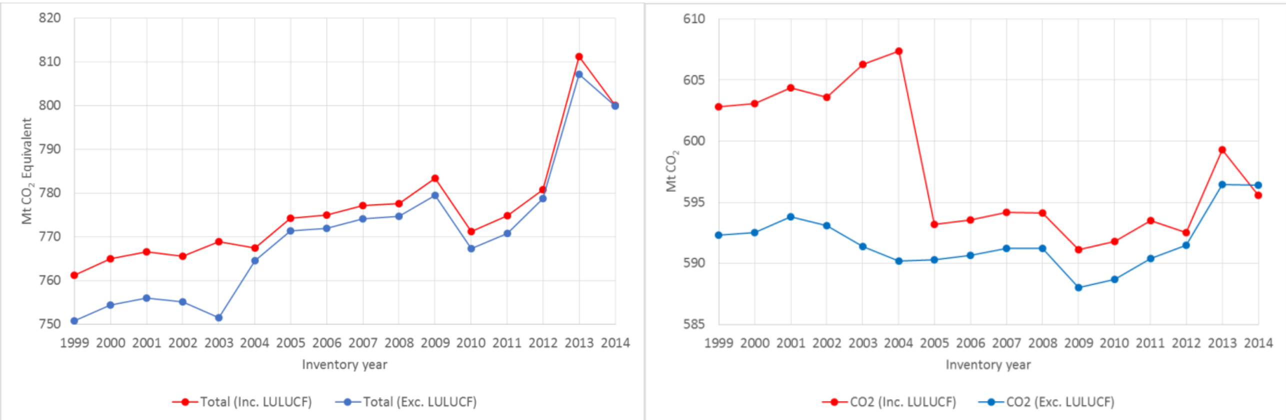
8.1 RECALCULATIONS

The calculation methodology for the Inventory is updated on a yearly basis due to changes in:

1. Reporting guidelines under which the submissions are made (i.e. 1996 IPCC Guidelines for National GHG Inventories [16] or 2006 IPCC Guidelines [12].
2. Emission estimation methodology, including revisions to assumptions or conversion factors.
3. Emission factors applied.
4. Activity data.

Due to these changes all emission estimates in previous inventories are recalculated to ensure consistency between years and ensure that the estimates are at the lowest uncertainty levels. Changes due to item 1 above are predictable and infrequent as the IPCC only update their guidelines every few years (1992, 1994, 1996, 2000, 2003, 2006 & 2013). Changes to items 2 & 3 are generally in response to new evidence from external reviews, literature studies or results of additional measurements, these are therefore predictable changes. Changes due to item 4 are not necessarily predictable due to changes in human behaviour or more commonly missing or inaccurate data used in the original compilation process. Where activity data is missing, existing data it is often interpolated to fill the gap and then the correct data used in the next year’s inventory. The emissions for the interpolated points are corrected by recalculation.

Figure 24 shows the recalculations on base year (1990) due to changes in inventory methodology for the 1999 to 2014 Inventories.



(a) CO_2e emissions (b) CO_2 emissions

Figure 24: Recalculations on the 1990 base year for Total CO_2e (a) and CO_2 (b) emissions from recalculations performed between 2001 and 2016.

The main changes in total CO_2e and CO2 emission totals occurred in the 2004, 2005, 2009, 2010, 2013 & 2014 Inventories. Table 10 summarises these changes:

Inventory (submission year)	Change	CO_2 / CO_2e
2004 (2006)	Change in calculation methodology for methane emissions from landfills	CO_2e
2005 (2007)	Separation of sinks and sources for CO_2 in the LULUCF sector First year that the LULUCF sector is considered as a sink instead of a source	CO_2
2009 (2011)	Review of the inputs to the waste to landfill model New source "application of sewage sludge to agricultural land" for N_2O Changes in estimates for coastal shipping and rail leading to a reduction in CO_2 of 2,398 kt.	CO_2e CO_2
2010 (2012)	Correction to the landfill model reducing CH_4 emissions by 13.073 $MtCO_2e$	CO_2e
2013 (2015)	Changes in UNFCCC & IPCC guidelines + new GWPs resulted in a ~30 $MtCO_2e$ increase.	CO_2e
2014 (2016)	Updated methodology for Grassland leading to a reduction of -3.985 $MtCO_2e$ N_2O country specific emission factors for manure management and agricultural soils resulting a emission reduction of 7.509 $MtCO_2e$ LULUCF sector - 1990-2014 inventory shows the sector becoming a sink from 1991, ten years earlier than in the 1990-2013 inventory	CO_2 CO_2e

Table 10: Major changes to calculation methodology for 1990 emission totals

8.2 IMPROVEMENTS AND FUTURE DEVELOPMENTS

IPCC and KP documents which will impact on the calculation methodologies used are described below.

8.2.1 IPCC 2013-AR5 – Global Warming Potentials

Updated GWPs were published in the IPCC 2013-AR5 report [17]. If and when they are implemented they will increase the emission estimates for previous years. The proposed GWP for methane is for an increase from 25 to 28 and may rise to 36 if the method accounting for climate-carbon feedback is adopted. This feedback takes into account indirect effects of changes in carbon storage due to changes in climate. GWPs with feedback have a higher level of uncertainty than those without, however taking into account feedback is more conservative, as the GWPs are higher and more complete. Other gases GWPs are also updated in AR5 but their contributions are smaller than methane's.

The GWP values have changed from previous assessments due to new estimates of lifetimes, impulse response functions and radiative efficiencies. These are updated due to improved knowledge and/or changed background levels. Because CO_2 is used as reference, any changes for this gas will affect all metric values via Absolute Global Warming Potential (AGWP) changes. Increases in the AGWP of the reference gas lead to corresponding decreases in the GWPs for all non-CO_2 gases. Continued increases in the atmospheric levels of CO_2 will lead to further changes in GWPs.

The radiative forcing from emissions of CH_4 for 2011 relative to 1750 is 0.97 [0.74 to 1.20] W m−2 [17]. This is much larger than the concentration-based estimate of 0.48 [0.38 to 0.58] W m−2 (unchanged from AR4). This difference in estimates is caused by concentration changes in ozone and stratospheric water vapour due to CH_4 emissions and other emissions indirectly affecting CH_4. After a decade of near stability, the recent increase of CH_4 concentration led to an enhanced RF compared to AR4 by 2% and it is very likely that the RF from CH_4 is now larger than that of all halocarbons combined [17].

8.2.2 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands

The Wetlands Supplement extends the content of the 2006 IPCC Guidelines [12] by filling gaps in the coverage and providing updated information to reflect scientific advances(such as updated emission factors). It covers inland organic soils and wetlands on mineral soils, coastal wetlands including mangrove forests, tidal marshes and seagrass meadows and constructed wetlands for wastewater treatment. The coverage of the 2006 IPCC Guidelines on wetlands was restricted to peatlands drained and managed for peat extraction, conversion to flooded lands, and limited guidance for drained organic soils. The guidance in the Wetlands Supplement is not intended to change the allocation of wetlands for reporting purposes [18].

The Wetlands Supplement includes substantial changes to the methods in the 2006 IPCC Guidelines [12] for soil organic matter and refines the subcategories within all land-use categories. This will make necessary the recalculation of results from previous years to produce a consistent time series. Categories that may be affected by the implementation of the Wetlands supplement are:

4B Cropland
4C Grassland
4D Wetlands

The UK has a research programme investigating the implementation of the 2013 Wetlands Supplement Guidance for the UK, which will affect the way that emissions will be reported, i.e. moving emissions from one subcategory to another or implementing new subcategories.

8.2.3 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol

A 2013 report from the Task Force on National GHG Inventories [19] provides supplementary methods and good practice guidance for estimating anthropogenic GHG emissions by sources and removals by sinks resulting from land use, land-use change and forestry (LULUCF) activities.

The need to review and update Chapter 4 of the Good Practice Guidelines (GPG) for-LULUCF for the second commitment period arises because:

- The rules for reporting and accounting of LULUCF activities for the second commitment period under the KP differ in some respects from the rules for the first commitment period;
- Updating is needed in the light of the decision to use the 2006 IPCC Guidelines for the second commitment period under the KP;
- The new rules for the treatment of LULUCF in the second commitment period of the KP contain, amongst other things, new provisions, which are not covered in the existing GPG-LULUCF, on Forest Management; natural disturbances in Forest Management and Afforestation and Reforestation areas; Harvested Wood Products; and Wetland Drainage and Rewetting.

Implementation of the method changes due to the KP supplement will affect the emission estimates for all of Sector 4: LULUCF for the second commitment period from 2013 to 2020.

9 PROVISIONAL VS FINAL EMISSIONS ESTIMATES

As well as calculating annual final emission estimates, provisional quarterly and annual emission estimates by source sector are published by BEIS. The provisional estimates of net carbon dioxide emissions (total emissions – carbon sinks) are based on provisional inland energy consumption statistics, which are published in the BEIS Energy Trends publication. Estimates of non-CO_2 gases are assumed to be the same as in the previous year, and that these emissions will be spread evenly over the year. **From the start of 2016 the geographical coverage of the provisional estimates has changed from UK and Crown Dependencies to UK only.**

There are uncertainties associated with all estimates of GHG emissions. Although for any given year considerable uncertainties may surround the emissions estimates for a pollutant, it is important to note that trends over time are likely to be much more reliable because all years are recalculated using the same methodology, removing any systematic effects. It is also important to note that the provisional estimates are subject to a greater range of uncertainty than the final figures for earlier years.

GHG provisional estimates are allocated into sectors as follows:

- Energy supply;
- Business;
- Transport;
- Public;
- Residential;
- Agriculture;
- Industrial process;
- Land use land use change and forestry (LULUCF);
- Waste management.

As with the final emission estimates these high-level sectors are made up of a number of more detailed sectors, which follow the definitions set out by the IPCC, and which are used in international reporting tables which are submitted to the UNFCCC every year.

The annual provisional emissions estimates are subject to revision when the final estimates are published each February, however, they provide a quarterly indication of emissions in the last full calendar year. Historically, provisional annual estimates have been within 2% of the final figures, although there are larger differences within specific sectors.

CO_2 emission estimates are also calculated on a temperature adjusted basis. CO_2 emissions are indirectly influenced by external temperatures: demand for fuel and space heating rises in cold temperatures, therefore resulting in higher emissions during colder than average periods. Temperature adjusted quarterly emissions estimates therefore remove the effect of ambient temperatures. In a particularly cold winter quarter, for example, this will result in temperature adjusted emissions being lower than actual emissions, reflecting the lower fuel consumption which would have occurred if temperatures had been at average levels (based on the 30 year period 1981-2010). Temperature adjustment is determined by the average number of heating degree days in each quarter published in Energy Trends [20]. **During 2013, 2014 and 2015 both temperature adjusted and non-adjusted emissions have fallen.**

10 EXTERNAL VALIDATION OF INVENTORY ESTIMATES

The UK GHG Inventory is verified using two independent methods:

- DECC GHG Network;
- Bottom Up versus Top Down comparison.

10.1 DECC GHG NETWORK

UK Government has a research programme that derives independent emission estimates for the UK using in-situ high-precision high-frequency atmospheric observations of the Kyoto gases and a range of other trace gases at the Mace Head Atmospheric Research Station (west coast of the Republic of Ireland), Angus (north of Dundee), Talcolneston (Norfolk), and Ridge Hill (Herefordshire). This is referred to as the UK DECC (Deriving Emissions linked to Climate Change) Network. The UK Met Office uses the Lagrangian dispersion model NAME (Numerical Atmospheric dispersion Modelling Environment) to sort the observations made at the monitoring stations into those that represent northern hemisphere baseline air masses and those that represent regionally polluted air masses arriving from Europe [3].

The Met Office inversion modelling system, InTEM (Inversion Technique for Emission Modelling), is then used to estimate the magnitude and spatial distribution of the UK and European emissions that best support the observations. InTEM links the observation time-series with the NAME air history estimates of how surface emissions dilute as they travel to the observation stations. This method provides a fully independent estimate of annual emission trends for the UK. The technique has been applied to 3 year rolling subsets of the data. The recent addition of the 3 mainland monitoring sites has resulted in significant increases in spatial and temporal resolution, improving UK estimates and enabling Devolved Administration emission estimates to be calculated from Atmospheric Observations. The uncertainties associated with the UK emission estimates are also expected to decrease.

Figure 25 shows the Monthly and Annual Baseline measurements of methane from the DECC GHG Network.

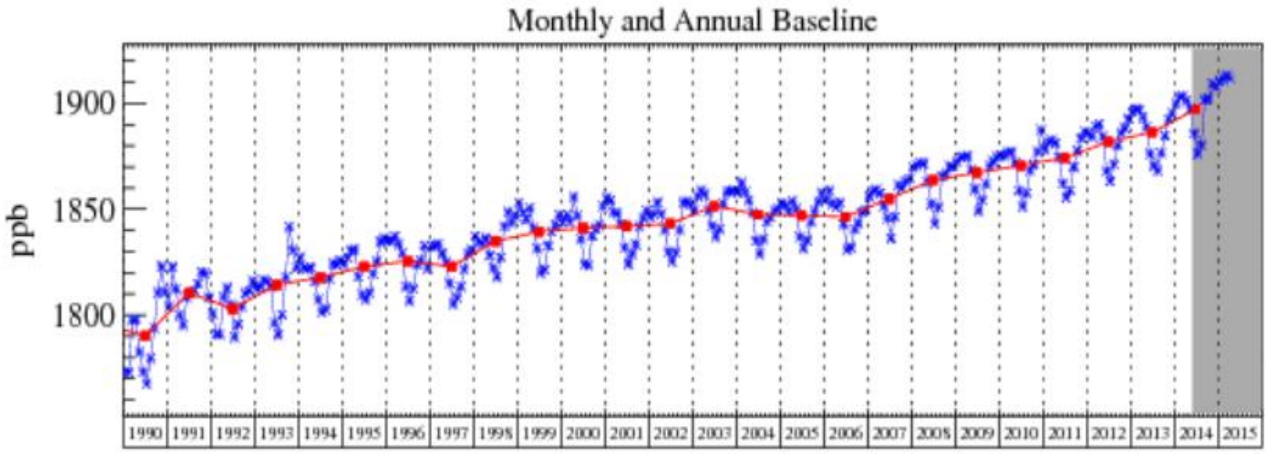


Figure 25: Baseline concentrations of Methane measured by the DECC network [21]

The inversion InTEM method is then used to calculate the estimated emissions required to generate the measured concentrations. Figure 26 compares these InTEM results with the GHGI. The blue dashes are the InTEM estimates using measurements from Mace Head only and the cyan shaded bars the uncertainty in the inversion result represented as the 5^{th} and 95^{th} percentiles. The black dot and line show the InTEM result and uncertainty from the complete GHG Network covering the UK from 2014. The GHGI estimates are in orange, while the red uncertainty bars represent the 5^{th} and 95^{th} percentiles.

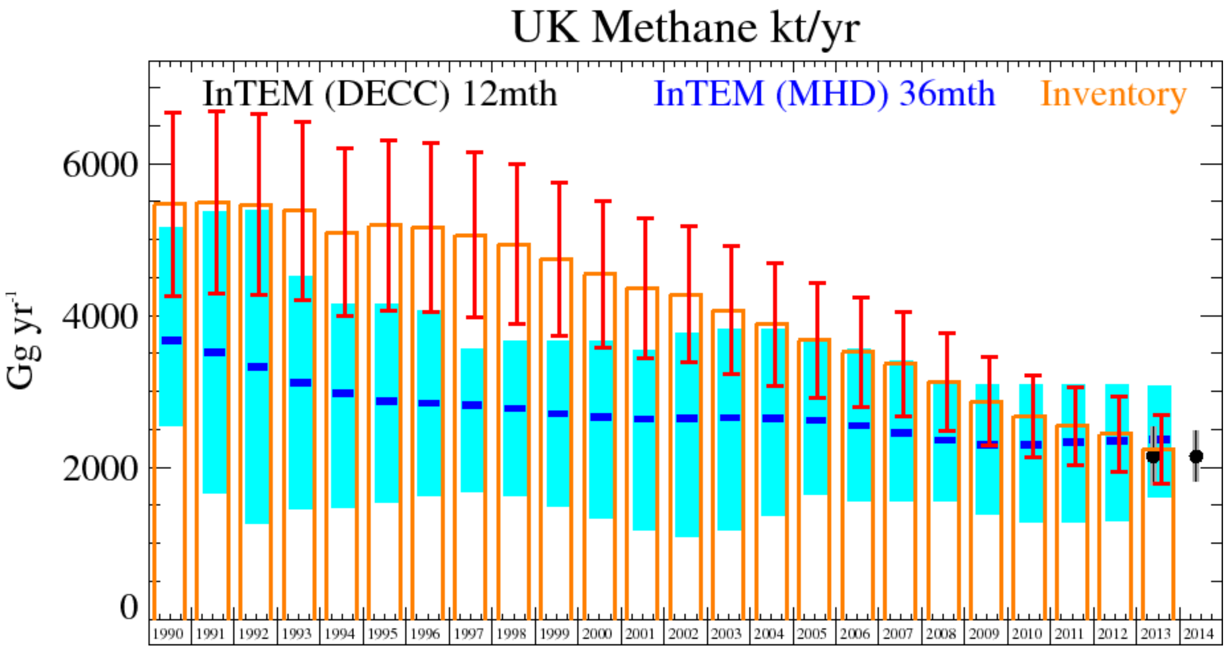


Figure 26: Inferred methane emission estimates from baseline measurements (InTEM) and actual emissions estimates from GHGI [21]

Even though the background baseline concentration of methane is increasing over the time, due to increased worldwide emissions, the agreement between the UK emission estimates (which have fallen over time), and the reverse modelled emissions (InTem) has improved over the same period.

Similar charts are available for other GHGs, and more information on the methodology are available in the DECC GHG Network 2015 Annual Report [21]

10.2 Bottom Up versus Top Down comparison

The UK GHG inventory is compiled using a detailed Sectoral Approach (Bottom Up) methodology, to produce sector-specific inventories of the 10 pollutants in accordance with the IPCC reporting format. To provide a comparison against the detailed Sectoral Approach inventory estimates, the Inventory Agency also calculates alternative UK emission estimates for carbon dioxide from energy sources in the UK, using the IPCC Reference Approach (Top Down). This compilation method calculates emission estimates from National Statistics on production, imports, exports, stock changes and non-energy uses of fossil fuels: crude oil, natural gas and solid fuels. The Reference Approach inventory method utilises different sections of the UK national energy statistics, combining aggregated data on fuel inputs and outputs from the overall UK economy, using top-level data on oils, gas and solid fuels to assess the UK carbon balance for combustion sources. This more simplistic, non-source-specific methodology provides a useful quality check against the more rigorous Sectoral Approach.

The Reference Approach typically produces UK CO_2 emission estimates that are within 2% of the more detailed Sectoral Approach. This is due to statistical differences between production-side and demand-side fuel estimates within national energy statistics, the exclusion of carbon estimates from specific activities (e.g. carbon within coke and coal deliveries to the iron and steel and non-ferrous metal industries) and the more aggregated approach to applying emission factors to activity data across fuel types in the Reference Approach.

The Reference Approach – Sectorial Approach comparison shows very close consistency between the two datasets for the UK, and provides verification of the reported Sectorial Approach emission estimates for 1A. This may be expected as similar input data is used for both top down and bottom up methods as the predominant emission source is fuel use

10.2.1 Improvements to Reference Approach in 2015

The Reference Approach calculations were extensively revised in the 2015 inventory cycle, due to the use of the new 2006 IPCC Guidelines [12] which introduced several methodological changes and clarifications compared to the method described under the 1996 GLs [16]. The changes implemented improved the accuracy, completeness and transparency of the data, partly in response to UNFCCC Expert Review Teams (ERT) recommendations from centralised reviews [22].

The Inventory Agency also conducted additional analysis on the outputs of the Reference Approach to reconcile the differences observed between Reference Approach and Sectorial Approach outputs. In previous years, ERTs have commented that whilst the overall Reference Approach – Sectorial Approach outputs are very closely comparable, the fuel-specific comparisons show greater disparity in the UK inventory. Therefore, the Inventory Agency developed a method to effectively "bridge" the gap by deriving an amended Reference Approach total through applying corrections to sources of known difference in source data and methods. This approach derived an "amended" Reference Approach output, which shows much closer comparison to the Sectorial Approach totals across all fuels and all years. **This approach has enabled the UK Inventory Agency to identify and quantify the sources of difference between the two approaches, and improve the overall verification of the Sectorial Approach totals [22].**

11 EXTERNAL ASSESSMENT OF GHGI

Following a UN Expert Review Team recommendation, a qualitative uncertainty analysis of the inventory was implemented by the Inventory Agency during 2016. This supports the KCA and helps determine the where methodological improvements could be provided to the inventory, where it should be more detailed, and which areas are highest priority sources. This assessment is undertaken within the inventory cycle, as well as through a post-submission review of data sources, methods and feedback from the MMR and UNFCCC ERTs [3].

The UK participates in a number of bilateral exchanges and the current contract makes allowances for biennial bilateral reviews of the GHGI. This aims to learn from good practice in other countries as well as to provide independent expertise to review estimates. The UKs programme of peer review is managed by the NISC as part of the improvement programme. External peer review is applied in two cases:

1. When new methods have been developed for important source categories;
2. On a rolling programme to determine whether methods should be improved due to the availability of new datasets and assumptions (focussing on key categories).

In addition, the UK participates in the annual UNFCCC review. Table 11 provides a summary of recent reviews.

Year	Review
2015	Bilateral review with Denmark on the Energy and Industrial Process Sectors
2015	Multi-lateral review on QAQC - UK, Denmark, France and the Netherlands
2006 - 2014	Annual UNFCCC review
2014	Independent Review of the UK KP LULUCF Inventory Estimates
2014	Bilateral review with Germany on the energy and waste sectors
2012	Peer review of all Sectors except Sector 5 -conducted by EC Technical Experts
2011	Bilateral review of F-gases (2E, 2F) between Austrian, German and UK inventory

Table 11: Summary of recent UNFCCC review

12 CONCLUSION

This report reviews the current inventory methodology, including the rationale for producing the inventory, the process in developing it, the main stakeholders involved and its completeness. It examines key source categories and gases, and draws on analysis to determine the level of uncertainty in the inventory and the implications this has.

In summary, the UK has a robust and accurate inventory when compared internationally. Uncertainty has consistently fallen as new methodologies are incorporated.

The agriculture, land use change and waste sectors contribute the largest sources of uncertainty to the UK inventory, together accounting for 65% of uncertainty in the 2014 inventory, despite contributing 20% of total emissions.

When compared internationally, the UK has an overall uncertainty of 3%, which is the third lowest by international comparison. Only Malta and Luxembourg – which have less complex economies and therefore fewer sources of emissions - have a lower overall uncertainty than the UK when compared to the rest of Europe, North America, Australasia and the Russian Federation.

This accuracy is in part due to a comprehensive internal and international review process to ensure that the methodologies employed in producing the UK GHGI incorporate the latest scientific research, international processes and good practice guidance.

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