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UK Greenhouse Gas Inventory, 1990 to 2015

Annual Report for Submission under the Framework Convention on Climate Change

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Preface

This is the United Kingdom's National Inventory Report (NIR) submitted in 2017 to the United Nations Framework Convention on Climate Change (UNFCCC). It contains national greenhouse gas emission estimates for the period 1990-2015, and descriptions of the methods used to produce the estimates. The report is prepared in accordance with decision 24/CP.19[1] and includes elements required for reporting under the Kyoto Protocol, as outlined in the *Annotated outline of the National Inventory Report including reporting elements under the Kyoto Protocol*[2]. This submission constitutes the UK's submission under the Kyoto Protocol.

The greenhouse gas inventory (GHGI) is based on the same datasets used by the UK in the National Atmospheric Emissions Inventory (NAEI) for reporting atmospheric emissions under other international agreements. The GHGI is therefore consistent with these other air emissions inventories where they overlap.

The greenhouse gas inventory is compiled on behalf of the UK Department of Business, Energy and Industrial Strategy (BEIS) Science and Innovation for Climate and Energy (SICE) Directorate, by Ricardo Energy & Environment. We acknowledge the positive support and advice from BEIS throughout the work, and we are grateful for the help of all those who have contributed to this NIR. A list of the contributors can be found in **Chapter 18**.

The GHGI is compiled according to IPCC 2006 Guidelines (IPCC, 2006). Each year the inventory is updated to include the latest data available. Improvements to the methodology are backdated as necessary to ensure a consistent time series. Methodological changes are made to take account of new data sources, or new guidance from IPCC, and new research, sponsored by BEIS or otherwise.

1 FCCC Decision 24/CP.19. Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf

2 http://unfccc.int/files/national_reports/annex_i_ghg_inventories/reporting_requirements/application/pdf/annotated_nir_outline.pdf

Units and Conversions

Emissions of greenhouse gases presented in this report are normally given in Gigagrammes (Gg), Million tonnes (Mt) and Teragrammes (Tg). Global Warming Potental (GWP) weighted emissions are also provided. To convert between the units of emissions, use the conversion factors given below.

Prefixes and multiplication factors

Multiplication factor	Abbreviation	Prefix	Symbol
1,000,000,000,000,000	10^{15}	peta	P
1,000,000,000,000	10^{12}	tera	T
1,000,000,000	10^{9}	giga	G
1,000,000	10^{6}	mega	M
1,000	10^{3}	kilo	k
100	10^{2}	hecto	h
10	10^{1}	deca	da
0.1	10^{-1}	deci	d
0.01	10^{-2}	centi	c
0.001	10^{-3}	milli	m
0.000,001	10^{-6}	micro	μ

1 kilotonne (kt)=10^3 tonnes=1,000 tonnes

1 Mega tonne (Mt)=10^6 tonnes=1,000,000 tonnes

1 Gigagramme (Gg) = 1 kt

1 Teragramme (Tg) = 1 Mt

Conversion of carbon emitted to carbon dioxide emitted

To convert emissions expressed in weight of carbon, to emissions in weight of carbon dioxide, multiply by 44/12.

Conversion of Gg of greenhouse gas emitted into Gg CO_2 equivalent

Gg (of GHG) * GWP = Gg CO_2 equivalent.

The GWP is the Global Warming Potential of the greenhouse gas. The GWPs of greenhouse gases used in this report are given in **Table 1.1.**

Abbreviations for Greenhouse Gases and Chemical Compounds

Type of greenhouse gas	Formula or abbreviation	Name
Direct	CH_4	Methane
Direct	CO_2	Carbon dioxide
Direct	N_2O	Nitrous oxide
Direct	HFCs	Hydrofluorocarbons
Direct	PFCs	Perfluorocarbons
Direct	NF_3	Nitrogen trifluoride
Direct	SF_6	Sulphur hexafluoride
Indirect	CO	Carbon monoxide
Indirect	NMVOC	Non-methane volatile organic compound
Indirect	NO_x	Nitrogen oxides (reported as nitrogen dioxide)
Indirect	SO_2	Sulphur oxides (reported as sulphur dioxide)

HFCs, PFCs, NF_3 and SF_6 are collectively known as the ‘F-gases’.

IPCC categories

IPCC Category	Source Description
1	**Energy**
1A	**Fuel Combustion Activities**
1A1	**Energy Industries**
1A1a	Public Electricity and Heat Production
1A1b	Petroleum refining
1A1c	Manufacture of Solid Fuels and Other Energy Industries
1A2	**Manufacturing Industries and Construction**
1A2a	Iron and Steel
1A2b	Non-ferrous Metals
1A2c	Chemicals
1A2d	Pulp, Paper and Print
1A2e	Food Processing, Beverages and Tobacco
1A2f	Non-metallic minerals
1A2gvii	Mobile combustion in manufacturing industries and construction
1A2gviii	Stationary combustion in manufacturing and construction: Other
1A3	**Transport**
1A3ai	International Aviation
1A3aii	Civil Aviation
1A3b	Road Transportation
1A3c	Railways
1A3di	International Navigation
1A3dii	National Navigation
1A3e	Other (to be specified)
1A4	**Other sectors**

IPCC Category	Source Description
1A4a	Commercial / Institutional Combustion
1A4b	Residential
1A4c	Agriculture / Forestry / Fishing
1A5	**Other (not elsewhere specified)**
1A5a	Other, Stationary (including Military)
1A5b	Other, Mobile (including military)
1B	**Fugitive Emissions from Fuels**
1B1	**Fugitive Emissions from Solid Fuels**
1B1a	Coal Mining and Handling
1B1b	Solid fuel transformation
1B1c	Other (to be specified)
1B2	**Oil and natural gas**
1B2a	Oil
1B2b	Natural gas
1B2c	Venting and flaring
2A	**Mineral Products**
2A1	Cement Production
2A2	Lime Production
2A3	Glass Production
2A4	Other Process uses of Carbonates
2B	**Chemical Industry**
2B1	Ammonia Production
2B2	Nitric Acid Production
2B3	Adipic Acid Production
2B4	Caprolactam, Glyoxal and Glyoxylic Acid Production
2B5	Carbide production
2B6	Titanium Dioxide Production
2B7	Soda Ash Production
2B8	Petrochemical and Carbon Black Production
2B9	Fluorochemical Production
2B10	Other
2C	**Metal Production**
2C1	Iron and Steel production
2C2	Ferroalloys Production
2C3	Aluminium Production
2C4	Magnesium Production
2C5	Lead Production
2C6	Zinc Production
2C7	Other Metal Production
2D	**Non-energy Products from Fuels and Solvent Use**
2D1	Lubricant Use
2D2	Paraffin Wax Use
2D3	Other
2E	**Electronics Industry**
2E1	Integrated Circuit or Semiconductor
2E2	TFT Flat Panel Display
2E3	Photovoltaics
2E4	Heat Transfer Fluid
2E5	Other

IPCC Category	Source Description
2F	**Product Uses as Substitutes for ODS**
2F1	Refrigeration and Air Conditioning Equipment
2F2	Foam Blowing Agents
2F3	Fire Extinguishers
2F4	Aerosols
2F5	Solvents
2F6	Other
2G	**Other Product Manufacture and Use**
2G1	Electrical Equipment
2G2	SF_6 and PFCs from Other Product Use
2G3	N_2O from Product Uses
2G4	Other
2H	**Other**
3	**Agriculture**
3A	Enteric Fermentation
3B	Manure Management
3C	Rice Cultivation
3D	Agricultural Soils
3E	Prescribed Burning of Savannas
3F	Field Burning of Agricultural Wastes
3G	Liming
3H	Urea Application
3I	Other Carbon-containing Fertilisers
3J	Other
4	**Land use, land use change and forestry**
4A	Forest Land
4B	Cropland
4C	Grassland
4D	Wetlands
4E	Settlements
4F	Other Land
4G	Harvested Wood Products
4H	Other
5	**Waste**
5A	Solid Waste Disposal
5B	Biological Treatment of Solid Waste
5C	Incineration and Open Burning of Waste
5D	Wastewater Treatment and Discharge
5E	Other
6	**Other**

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Executive Summaries

ES.1.1 Background Information on Climate Change

Countries that have signed and ratified the Kyoto Protocol are legally bound to reduce their greenhouse gas emissions by an agreed amount. A single European Union Kyoto Protocol reduction target for greenhouse gas emissions of -8% compared to base-year levels was negotiated for the first commitment period, and a Burden Sharing Agreement allocated the target between Member States of the European Union. Under this agreement, the UK reduction target was -12.5% on base-year levels. The first commitment period of the Kyoto Protocol was from 2008 to 2012.

The second commitment period of the Kyoto Protocol applies from 2013 to 2020 inclusive. For this second commitment period, the EU and the Member States communicated an independent quantified economy-wide emission reduction target of a 20 percent emission reduction by 2020 compared with 1990 levels (base year) ("the EU2020 target"). The EU2020 target is based on the understanding that it will be fulfilled jointly by the European Union and the Member States. The EU2020 target is unconditional and supported by EU legislation in place since 2009 (The EU Climate and Energy Package). This Kyoto target will cover the UK, and the relevant Crown Dependencies and Overseas Territories for whom the ratification is extended.

The Climate Change Act[3] became UK Law on the 26th November 2008. This legislation introduced a new, more ambitious and legally binding target for the UK to reduce GHG emissions to 80% below base year by 2050, with legally binding five year GHG budgets. The independent Committee on Climate Change (CCC) was set up to advise the UK Government on the setting and meeting of UK carbon budgets as well as monitoring progress against them scope and level of UK carbon budgets.

Further information on the UK's action to tackle climate change can be found on the following Government Department websites:

https://www.gov.uk/government/organisations/department-for-business-energy-and-industrial-strategy

https://www.gov.uk/government/policies/adapting-to-climate-change

ES.1.2 Background Information on Greenhouse Gas Inventories

The UK ratified the United Nations Framework Convention on Climate Change (UNFCCC) in December 1993, and the Convention came into force in March 1994. Parties to the Convention are committed to develop, publish and regularly update national emission inventories of greenhouse gases (GHGs).

This is the United Kingdom's National Inventory Report (NIR) submitted in 2017 to the UNFCCC and convering both the UK's submission under the Kyoto Protocol and the Convention. It contains national greenhouse gas emission estimates for the period 1990-2015, and the descriptions of the methods used to produce the estimates. The report is prepared in

[3] Climate Change Act 2008. http://www.legislation.gov.uk/ukpga/2008/27/contents

accordance with decision 24/CP.19[4] and includes elements required for reporting under the Kyoto Protocol.

The UK Greenhouse Gas Inventory is compiled and maintained by a consortium led by Ricardo Energy & Environment – the **Inventory Agency** – under contract to the UK Department for Business, Energy and Industrial Strategy (BEIS). Ricardo Energy & Environment is directly responsible for producing the emissions estimates for 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, QA/QC and inventory management and archiving. Aether, a member within the consortium, is responsible for compiling emissions from railways and for the UK's Overseas Territories (OTs) and Crown Dependencies (CDs).

Forestry emissions and removals in the Land Use, Land-Use Change and Forestry sector (CRF sector 4) are calculated by Forest Research and the remainder of the sector is calculated and compiled by the UK Centre for Ecology and Hydrology (CEH), both partners within the consortium. Agricultural sector emissions estimates (CRF sector 3) are produced by Rothamsted Research, under contract to the UK Department for Environment, Food and Rural Affairs (Defra).

BEIS, Defra and the Devolved Administrations also fund research contracts to provide improved emissions estimates for certain sources such as fluorinated gases, landfill methane, enteric fermentation and shipping; information from these programmes is fed into the inventory via the national inventory system.

The inventory covers the seven direct greenhouse gases under the Kyoto Protocol (NF_3 was included under the Doha Amendment). These are as follows:

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

These gases contribute directly to climate change owing to their positive radiative forcing effect. Also reported are four indirect greenhouse gases:

- Nitrogen oxides;
- Carbon monoxide;
- Non-Methane Volatile Organic Compounds (NMVOC); and
- Sulphur oxides (reported as SO_2).

Emissions of indirect N_2O from emissions of NO_x and NH_3 are also estimated as a memo item. These emissions are not included in the national total.

Unless otherwise indicated, percentage contributions and changes quoted refer to net emissions (i.e. emissions minus removals), based on the full coverage of UK emissions including all relevant Overseas Territories and Crown Dependencies, consistent with the UK's submission to the UNFCCC under the Kyoto Protocol.

The UK inventory provides data to assess progress of the UK's commitments under the Kyoto Protocol, the UK's contribution to the EU's targets under the KP, progress towards the UK

[4] FCCC Decision 24/CP.19. Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf

Government's own Carbon Budgets and to meet commitments as a as a Party to the UN Framework Convention on Climate Change. Geographical coverage for these four purposes differs to some extent, because of the following:

1) The UK Government Carbon Budgets apply to the UK only, and exclude all emissions from the UK's Crown Dependencies and Overseas Territories.
2) Kyoto Protocol coverage (the 'GBK' submission). For the second commitment period, we report in this submission on the following provisional basis:
    a. Crown Dependencies (Guernsey, Isle of Man and Jersey)
    b. Overseas Territories (Cayman Islands, Falkland Islands and Gibraltar)
3) The MMR coverage (the 'GBE' submission). The UK's commitments under the EU Monitoring Mechanism Regulation, which has been set up to enable the EU to monitor progress against its Kyoto Protocol target, only includes the UK and Gibraltar, since the Crown Dependencies and other Overseas Territories are not part of the EU.
4) UNFCCC coverage (the 'GBR' submission). The UK's ratification of the UNFCCC has been extended to Bermuda, the Cayman Islands, the Falkland Islands, Gibraltar, Guernsey, the Isle of Man and Jersey and the UK reports an inventory on this basis.

Emissions data for Coverage 1 are reported here for information and to facilitate comparison between different publications. Coverage 2 is used for the data in the CRF tables submitted to the UNFCCC under the Kyoto Protocol. Coverage 3 is used for the data in the CRF tables submitted under the MMR. Coverage 4 is used for the data in the CRF tables submitted to the UNFCCC under the Convention. **Table ES 2.1** to **Table ES 2.2** show CO_2 and the direct greenhouse gases, disaggregated by gas and by sector for geographical Coverage 2. **Table ES 3.2** and **Table ES 3.3** show emissions for the Kyoto basket based on Coverage 2 and 3, respectively.

Table ES 4.1 has data on indirect greenhouse gas emissions, for geographical coverage 2.

ES.1.3 Background Information on Supplementary Information Required under Article 7, paragraph 1, of the Kyoto Protocol.

Background information on supplementary information required under Article 7, Paragraph 1 of the KP is presented in **Section 1.1.3.**

ES.2 SUMMARY OF NATIONAL EMISSION AND REMOVAL RELATED TRENDS, AND EMISSIONS AND REMOVALS FROM KP-LULUCF ACTIVITIES

ES.2.1 GHG Inventory

Table ES 2.1 Emissions of GHGs in terms of carbon dioxide equivalent emissions including all estimated GHG emissions from the Crown Dependencies and relevant Overseas Territories, 1990-2015. (Mt CO_2 Equivalent)

Table ES2.1	Mt CO_2 Equivalent											% change
	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	1990 - 2015
CO_2 (Inc. net LULUCF)	597.9	559.7	558.1	557.7	480.7	499.2	456.3	476.6	464.9	423.7	406.2	-32%
CO_2 (Exc. net LULUCF)	594.6	559.1	559.9	562.9	488.1	506.7	464.0	483.6	473.0	432.7	415.1	-30%
CH_4 (Inc. net LULUCF)	135.3	128.8	111.0	89.3	72.4	68.2	65.3	62.4	57.2	54.4	52.6	-61%
CH_4 (Exc. net LULUCF)	135.2	128.8	111.0	89.3	72.3	68.2	65.3	62.4	57.2	54.3	52.6	-61%
N_2O (Inc. net LULUCF)	51.3	41.9	31.4	27.3	23.8	24.2	23.1	22.9	22.8	23.5	23.2	-55%
N_2O (Exc. net LULUCF)	48.9	39.5	29.2	25.4	22.1	22.5	21.4	21.3	21.3	21.9	21.7	-56%
HFCs	14.4	19.1	9.9	13.1	15.6	16.5	14.9	15.5	15.8	16.0	15.9	11%
PFCs	1.7	0.6	0.6	0.4	0.2	0.3	0.4	0.3	0.3	0.3	0.3	-80%
SF_6	1.3	1.3	1.8	1.1	0.6	0.7	0.6	0.6	0.5	0.5	0.5	-64%
NF_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6%
Total (Inc. net LULUCF)	801.8	751.3	712.8	688.9	593.3	609.0	560.7	578.3	561.5	518.2	498.7	-38%
Total (Exc. net LULUCF)	796.1	748.3	712.4	692.1	598.9	614.8	566.7	583.5	568.0	525.7	506.0	-36%

1. One Mt equals one Tg, which is 10^{12} g (1,000,000,000,000 g) or one million tonnes
2. Net Emissions are reported in the Common Reporting Format
3. Geographical coverage of this table includes the Crown Dependencies and the Overseas Territories which are provisionally included in the scope for the second commitment period of the Kyoto Protocol.

Table ES 2.1 presents the UK Greenhouse Gas Inventory totals by gas, including and excluding net emissions from LULUCF. The largest contribution to total emissions is CO_2, which contributed 81% to total net emissions in 2015. Methane emissions account for the next largest share (11%), and N_2O emissions make up a further 5%. Emissions of all of these gases have decreased since 1990, contributing to an overall decrease of 38%.

ES.2.2 KP-LULUCF Activities

KP-LULUCF activities relate to estimated emissions and removals from:

- Article 3.3, the net emissions or removals of Afforestation, Reforestation and Deforestation (ARD) since 1990; and
- Article 3.4, the net flux due to Forest Management (FM) since 1990 (mandatory for the second commitment period) and the elected activities of Cropland Management (CM), Grazing Land Management (GM) and Wetland Drainage and Rewetting (WDR). Accounting for emissions/removals from FM is on the basis of the Forest Management Reference Level (FMRL) (projected emissions/removals 2013-2020 under business-as-usual). Any additions to the UK's assigned amount resulting from Forest Management (removals exceeding the reference level) are capped at 3.5% of the national total emissions excluding LULUCF in 1990 times eight (the number of years in the second commitment period). There are insufficient data to allow reporting of Wetland Drainage and Rewetting activities in this submission but a programme of research and development is underway to enable reporting and accounting before the end of the second commitment period.
- Both Afforestation/Reforestation (AR) and Forest Management (FM) total emissions now include carbon stock changes in the Harvested Wood Products pool.

Table ES 2.2 details the emissions and removals from these activities which are included in the UK's emissions total for reporting under the KP.

Table ES 2.2 KP- LULUCF activities (Mt CO_2e)

	Base Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Article 3.3		0.8	1.1	1.4	1.6	1.9	2.1	2.3	2.4	2.5	2.7	3.3	3.4
Article 3.4 FMRL													
Article 3.4 Technical Correction to FMRL													
Article 3.4 Forest Management removals compared to FMRL and Technical Correction(capped)													
Article 3.4 Cropland Management	15.2	15.2	15.3	15.3	15.6	15.7	16.1	16.0	16.1	16.3	16.4	15.9	15.7
Article 3.4 Grazing Land Management	-7.5	-7.5	-7.3	-7.2	-7.0	-6.9	-6.8	-6.7	-6.6	-6.5	-5.7	-5.8	-5.8
Article 3.4 Wetland Drainage and Rewetting	*	*	*	*	*	*	*	*	*	*	*	*	*

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Article 3.3	3.3	3.4	3.2	3.1	2.7	2.6	2.3	2.3	2.1	1.5	1.2
Article 3.4 FMRL											
Article 3.4 Technical Correction to FMRL											
Article 3.4 Forest Management removals											

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
compared to FMRL and Technical Correction (capped)											
Article 3.4 Cropland Management	15.4	15.2	15.0	14.7	14.6	14.3	14.2	14.2	14.1	14.0	13.9
Article 3.4 Grazing Land Management	-5.8	-5.8	-5.9	-6.0	-6.0	-6.0	-6.1	-6.1	-6.2	-6.2	-6.3
Article 3.4 Wetland Drainage and Rewetting	*	*	*	*	*	*	*	*	*	*	*

	2013	2014	2015
Article 3.3	0.9	0.5	0.1
Article 3.4 FMRL	-8.3	-8.3	-8.3
Article 3.4 Technical Correction to FMRL	-7.6	-7.6	-7.6
Article 3.4 Forest Management removals compared to FMRL and Technical Correction (capped)	-3.7	-3.5	-2.8
Article 3.4 Cropland Management	13.6	13.4	13.3
Article 3.4 Grazing Land Management	-6.4	-6.4	-6.5
Article 3.4 Wetland Drainage and Rewetting	*	*	*

*Not yet reported (data and methodology under development)

Article 3.4 FMRL-related cells for 1990-2012 are blanked out because the FMRL is only calculated from, and applied, from 2013 onwards. Similarily for the Article 3.4 Technical Correction to FMRL cells (see section 11.5.2.3 for information on the technical correction to the FMRL calculated for the 2016 inventory).

ES.3 OVERVIEW OF SOURCE AND SINK CATEGORY EMISSION ESTIMATES AND TRENDS, INCLUDING KP-LULUCF ACTIVITIES

ES.3.1 GHG Inventory

Table ES 3.1 details total net emissions of GHGs, aggregated by IPCC sector.

Table ES 3.1 Aggregated emission trends per source category, including all estimated GHG emissions from the Crown Dependencies and selected relevant Overseas Territories (Mt CO_2 equivalent).

Table ES3.1	Aggregated emission trends per source category (Mt CO_2 equivalent)										
Source Category	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015
1. Energy	609.1	565.3	558.8	556.6	486.0	502.9	460.8	480.6	466.9	426.7	409.1
2. Industrial Processes and Product Use	66.5	60.8	40.6	39.7	32.8	35.5	32.0	32.3	34.4	34.1	33.6
3. Agriculture	53.6	52.9	49.9	46.4	44.2	44.4	44.3	43.8	44.1	45.0	44.9

Table ES3.1	Aggregated emission trends per source category (Mt CO_2 equivalent)										
Source Category	**1990**	**1995**	**2000**	**2005**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
4. LULUCF	5.7	3.0	0.5	-3.2	-5.6	-5.8	-6.0	-5.2	-6.5	-7.4	-7.4
5. Waste	66.9	69.3	63.0	49.4	36.0	32.0	29.6	26.8	22.7	19.8	18.4
Total (net emissions)	801.8	751.3	712.8	688.9	593.3	609.0	560.7	578.3	561.5	518.2	498.7

Footnotes: Geographical coverage of this table includes the Crown Dependencies and Overseas Territories which are provisionally included in the scope for the second commitment period of the Kyoto Protocol.

The largest contribution to greenhouse gas emissions is from the energy sector. In 2015 this contributed 82% to the total emissions. Emissions of CO_2, CH_4 and N_2O all arise from this sector. Since 1990, emissions from the energy sector have declined by 33%.

The second largest source of greenhouse gases is the agricultural sector. Emissions from this sector are mostly CH_4 and N_2O, with a small amount of CO_2. Since 1990, emissions from this sector have declined by 16%.

Industrial processes and product use makes up the third largest sector for greenhouse gas emissions in the UK, contributing just under 7% to the national total in 2015. Emissions of all seven direct greenhouse gases occur from this sector.

Land Use, Land-use Change and Forestry contains sinks as well as sources of CO_2 emissions. LULUCF was a net sink in 2015. Emissions from this sector occur for CO_2, N_2O and CH_4.

The remaining sector that contributes to direct greenhouse gas totals is waste. In 2015 this contributed 4% to the national total. This sector leads to emissions of CO_2, CH_4 and N_2O, with emissions occurring from waste incineration, solid waste disposal on land and wastewater handling. Emissions from this sector have steadily declined and in 2015 were 72% below 1990 levels.

Total net emissions have decreased by 38% since 1990.

ES.3.2 KP Basket and KP-LULUCF Activities

Table ES 3.2 presents final UK emissions for the first commitment period. The fixed base year figure is taken from the 1990 – 2004 inventory and is the total used to calculate the UK's Assigned Amount. The 2008 – 2012 figures are the final, reviewed figures for the UK inventory submitted in 2014. This was re-submitted following the UNFCCC review in September 2014, therefore the figures differ from the NIR submitted in April 2014. **Table ES 3.3** presents the same information as **Table ES 3.2** using MMR geographical coverage.

Table ES 3.4 presents the base year, and 2013 to 2015 emissions calculated from the 2017 inventory submission. KP LULUCF activities are defined differently under the second commitment period – Article 3.3 now includes Harvested Wood Products (HWP), and Article 3.4 (Forest Management) now reports emissions relative to the Forest Management Reference Level (FMRL). The FMRL does not apply prior to 2013, and therefore it is not appropriate to report a full time series.

The data in this table are all taken from the 2017 inventory submission (1990 – 2015).

- The base year emissions are made up of 1990 emissions for CO_2, CH_4 and N_2O, and 1995 for the F-Gases

- Emissions are presented as Mt CO_2 equivalent, using GWP values taken from the IPCC's Fourth Assessment Report (AR4).
- Emissions and removals associated with KP-LULUCF enter the table only through the rows labelled Article 3.3, Article 3.4 and Article 3.7. The definitions of Article 3.3 and 3.4 have changed from the first commitment period and so the time series is not comparable. A technical correction (TC) to the FMRL has been calculated for the 2017 inventory, see **Section 11.5.2.3**.
- Geographical coverage of this table includes the Crown Dependencies Jersey, Guernsey and the Isle of Man, and the Overseas Territories which are provisionally included in the scope for the second commitment period of the Kyoto Protocol has been extended. These are the Cayman Islands, Falkland Islands, and Gibraltar.

Table ES 3.5 presents the same information as **Table ES 3.4** using MMR geographical coverage.

Table ES 3.2 Kyoto basket of emissions, and emissions associated with Articles 3.3, 3.4 and 3.7 for the first commitment period (in Mt CO_2 equivalent) – KP1 Coverage.

	Fixed base year	2008	2009	2010	2011	2012
CO_2		536.7	487.4	505.0	464.0	483.4
CH_4		62.8	59.4	56.7	54.8	52.8
N_2O		38.4	36.2	37.1	35.7	35.4
HFCs		12.8	13.2	13.6	13.8	14.0
PFCs		0.2	0.1	0.2	0.3	0.2
SF_6		0.6	0.6	0.6	0.6	0.5
Grand Total		651.5	596.9	613.2	569.3	586.4
Article 3.3		-1.1	-1.3	-1.5	-1.7	-1.8
Article 3.4 (capped at -0.37 MtC)		-1.4	-1.4	-1.4	-1.4	-1.4
Article 3.7						
Kyoto Protocol Total	779.9	648.9	594.3	610.3	566.2	583.1

Footnotes:

- The Fixed Base Year is taken from the UK's Assigned Amount report. This report was submitted in 2006, based on emissions reported in the 1990-2004 Greenhouse Gas Inventory, and was subject to an official review in 2007, which concluded that this figure was correct. This base year is now fixed, and is the value that the UK is assessed against for its Kyoto Protocol first commitment period target.
- Emissions for 2008 – 2012 are taken from the 2014 submission of the UK inventory, including the recalculation of the inventory following the 2014 UNFCCC review.
- Emissions are presented as Mt CO_2 equivalent, using GWP values taken from the IPCC's Second Assessment Report.
- Emissions and removals associated with LULUCF enter the table only through the rows labelled Article 3.3, Article 3.4 and Article 3.7. The UK has chosen to account only for forest management under Article 3.4 during the first commitment period.
- Geographical coverage of this table includes the Crown Dependencies and the Overseas Territories which have joined the UK's instruments of ratification of the UNFCCC and first commitment period of the Kyoto Protocol.

Table ES 3.3 Kyoto basket of emissions, and emissions associated with Articles 3.3, 3.4 and 3.7 for the first commitment period (in Mt CO_2 equivalent) – MMR Coverage.

Table ES3.3	Fixed base year	2008	2009	2010	2011	2012
CO_2		533.7	484.4	502.0	461.1	480.5
CH_4		62.4	59.1	56.4	54.5	52.5
N_2O		38.2	36.1	37.0	35.6	35.3
HFCs		12.7	13.1	13.5	13.7	13.9
PFCs		0.2	0.1	0.2	0.3	0.2
SF_6		0.6	0.6	0.6	0.6	0.5
Grand Total		647.8	593.4	609.7	565.8	582.9
Article 3.3		-1.1	-1.3	-1.5	-1.7	-1.8
Article 3.4 (capped at -0.37 MtC)		-1.4	-1.4	-1.4	-1.4	-1.4
Article 3.7						
Kyoto Protocol Total	776.3	645.3	590.7	606.7	562.7	579.6

Footnotes:

- See table ES3.2 for full footnotes.
- The geographical coverage of this table is UK and Gibraltar only.

Table ES 3.4 Kyoto basket of emissions, and emissions associated with Articles 3.3, 3.4 and 3.7 for the secondcommitment period (in Mt CO_2 equivalent) - KP2 coverage

	Base year (current inventory)	2013	2014	2015	Base Year - 2015
CO_2	594.6	473.0	432.7	415.1	-30%
CH_4	135.2	57.2	54.3	52.6	-61%
N_2O	48.9	21.3	21.9	21.7	-56%
HFCs	19.1	15.8	16.0	15.9	-17%
PFCs	0.6	0.3	0.3	0.3	-45%
SF_6	1.3	0.5	0.5	0.5	-64%
NF_3	0.0	0.0	0.0	0.0	-47%
Grand Total	799.7	568.0	525.7	506.0	-37%
Article 3.3		0.9	0.5	0.1	
Article 3.4 Forest Management removals and HWP compared to FMRL and Technical Correction to FMRL (capped) plus Cropland Management and Grazing Land Management		-3.7	-3.5	-2.8	
Article 3.4 Cropland Management		13.6	13.4	13.3	
Article 3.4 Grazing Land Management		-6.4	-6.4	-6.5	
Article 3.7	0.2				
Kyoto Protocol Total	799.9	572.6	529.6	510.1	-36%

Footnotes:

- The data in this table are all taken from the 2017 inventory submission (1990 – 2015).
- The base year emissions are made up of 1990 emissions for CO_2, CH_4 and N_2O, and 1995 for the F-Gases
- Emissions are presented as Mt CO_2 equivalent, using GWP values taken from the IPCC's Fourth Assessment Report (AR4).
- Emissions and removals associated with KP-LULUCF enter the table only through the rows labelled Article 3.3, Article 3.4 and Article 3.7. The definitions of Article 3.3 and 3.4 have changed from the first commitment period and so the time series is not comparable. A technical correction (TC) to the FMRL has been calculated for the 2017 inventory, see section 11.5.2.3.
- Geographical coverage of this table includes the Crown Dependencies Jersey, Guernsey and the Isle of Man, and the Overseas Territories which are provisionally included in the scope for the second commitment period of the Kyoto Protocol. These are the Cayman Islands, Falkland Islands, and Gibraltar.

Table ES 3.5 Kyoto basket of emissions, and emissions associated with Articles 3.3, 3.4 and 3.7 for the second commitment period (in Mt CO_2 equivalent) – MMR Coverage

	Base year (current inventory)	2013	2014	2015	Base Year - 2015
CO_2	592.7	470.9	430.6	413.1	-30%
CH_4	134.8	56.8	53.9	52.2	-61%
N_2O	48.7	21.1	21.8	21.6	-56%
HFCs	19.1	15.7	15.9	15.8	-17%
PFCs	0.6	0.3	0.3	0.3	-45%
SF_6	1.3	0.5	0.5	0.5	-64%
NF_3	0.0	0.0	0.0	0.0	-47%
Grand Total	797.2	565.3	522.9	503.5	-37%
Article 3.3		0.9	0.5	0.1	
Article 3.4 Forest Management removals and HWP compared to FMRL and Technical Correction to FMRL (capped) plus Cropland Management and Grazing Land Management		-3.6	-3.5	-2.8	
Article 3.4 Cropland Management		13.6	13.4	13.3	
Article 3.4 Grazing Land Management		-6.4	-6.4	-6.5	
Article 3.7	0.2				
Kyoto Protocol Total	797.4	569.8	526.9	507.6	-36%

Footnotes:

- See table ES3.4 for full footnotes.
- The geographical coverage of this table is UK and Gibraltar only.

ES.4 OTHER INFORMATION

Table ES 4.1 lists the indirect greenhouse gases for which the UK has made emissions estimates. Nitrogen oxides, carbon monoxide and NMVOCs are included in the inventory because they can produce increases in tropospheric ozone concentrations and this increases radiative forcing. Sulphur oxides are included because they contribute to aerosol formation.

Table ES 4.1 Emissions of Indirect Greenhouse Gases in the UK, 1990-2015 (in kt).

Gas	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015
NO_x	2927	2350	1823	1613	1166	1143	1064	1093	1038	959	919
CO	7417	6006	4083	2967	2098	2008	1828	1835	1801	1740	1669
NMVOC	2949	2323	1633	1176	921	901	880	868	844	842	837
SO_2	3693	2377	1225	712	401	424	393	440	380	306	236

Footnotes:

Geographical coverage of the emissions in the table includes emissions from the Crown Dependencies and Overseas Territories which are provisionally included in the scope for the second commitment period of the Kyoto Protocol.

Since 1990, emissions of all indirect gases have decreased. The largest source of emissions for all the indirect gases is the energy sector. For NO_x, CO and SO_2, over 80% of emissions arise from activities within this sector. For NMVOC, 56% of emissions are from the industrial processes and product use sector, with other significant contributions from the energy sector.

Contacts

This work is part of the Science Research Programme of the Department of Business, Energy and Industrial Strategy. The Land Use Change and Forestry estimates were provided by the Centre for Ecology and Hydrology (CEH) Edinburgh with the support of Forest Research. Rothamsted Research provide the estimates of agricultural emissions.

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A copy of this report and related data may be found on the website maintained by Ricardo Energy & Environment for Defra and BEIS: http://naei.defra.gov.uk/

1 Introduction

This is the UK's 2017 National Inventory Report (NIR). From 2008 onwards, the NIR contains information required for reporting under the Kyoto Protocol as required by decision 15/CMP.1[5].

The National Inventory Report (NIR) is one element of the annual greenhouse gas (GHG) inventory that is required to be submitted to the UNFCCC by signatories to the Convention on 15th April of each year. The NIR is compiled in accordance with the revised UNFCCC reporting guidelines, see decision 24/CP.19[6].

The other elements of this submission include the reporting of GHG emissions by sources and removals by sinks in the Common Reporting Format (CRF) tables, and any other additional information in support of this submission.

The UK is a signatory to the Convention and is also a Party to the Kyoto Protocol. This means the UK is required to report supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol[7], with the inventory submission due under the Convention, in accordance with paragraph 3(a) of decision 15/CMP.1. This NIR contains this supplementary information in the appropriate sections.

1.1 BACKGROUND INFORMATION ON GREENHOUSE GAS INVENTORIES, AND CLIMATE CHANGE

1.1.1 Background Information on Climate Change

Countries that have signed and ratified the Kyoto Protocol are legally bound to reduce their greenhouse gas emissions by an agreed amount. A single European Union Kyoto Protocol reduction target for greenhouse gas emissions of -8% compared to base-year levels was negotiated for the first commitment period, and a Burden Sharing Agreement allocated the target between Member States of the European Union. Under this agreement, the UK reduction target was -12.5% on base-year levels. The first commitment period of the Kyoto Protocol was from 2008 to 2012.

The second commitment period of the Kyoto Protocol will run for eight years, from 2013 to 2020 inclusive. For this second commitment period, alongside the EU and its member States, the UK (including Gibraltar) communicated an independent quantified economy-wide emission reduction target of a 20 percent emission reduction by 2020 compared with 1990 levels (base year). The target for the European Union and its Member States is based on the understanding that it will be fulfilled jointly with the European Union and its Member States. The 20 percent emission reduction target by 2020 is unconditional and supported by legislation in place since 2009 (Climate and Energy Package). Once ratified this Kyoto target will cover the UK, and the relevant Crown Dependencies and Overseas Territories to whom ratification has been

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[5] 15/CMP.1 Guidelines for the preparation of the information required under Article 7 of the Kyoto Protocol. http://unfccc.int/resource/docs/2005/cmp1/eng/08a02.pdf#page=54

[6] 24/CP.19 Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf#page=2

[7] Kyoto Protocol to the United Nations Framework Convention on Climate Change. http://unfccc.int/resource/docs/convkp/kpeng.pdf

extended. As ratification is not yet complete the exact details of the UK's target for the second commitment period are still being finalised.

The Climate Change Act[8] became UK Law on the 26th November 2008. This legislation introduced a new, more ambitious and legally binding target for the UK to reduce GHG emissions to 80% below base year by 2050, with legally binding five year GHG budgets. The independent Committee on Climate Change (CCC) was set up to advise the UK Government on the setting and meeting of UK carbon budgets as well as monitoring progress against them scope and level of UK carbon budgets.

Further information on the UK's action to tackle climate change can be found on the following Government Department websites:

https://www.gov.uk/government/organisations/department-for-business-energy-and-industrial-strategy

https://www.gov.uk/government/policies/adapting-to-climate-change

1.1.2 Background Information on Greenhouse Gas Inventories

1.1.2.1 Reporting of the UK Greenhouse Gas Inventory

The UK ratified the UNFCCC in December 1993 and the Convention came into force in March 1994. Parties to the Convention are committed to develop, publish and regularly update national emission inventories of GHGs.

The UK's NIR is prepared in accordance with Decision 24/CP.19[9] and includes elements required for reporting under the Kyoto Protocol, as outlined in the *Annotated outline of the National Inventory Report including reporting elements under the Kyoto Protocol*[10]. In addition, the UK also reports GHG emissions by sources and removals by sinks in the CRF tables. The estimates are consistent with the IPCC 2006 Guidelines.

The UK Greenhouse Gas Inventory is compiled and maintained by a consortium led by Ricardo Energy & Environment – the **Inventory Agency** - under contract to the Science and Innovation for Climate and Energy Directorate in BEIS. Full details of the institutional arrangements for the preparation of the GHG inventory are explained in **Section 1.2.1.**

This report and corresponding CRF tables provide annual emission estimates submitted by the UK to the UNFCCC for the period 1990 to 2015. To fulfil both European Union Monitoring Mechanism Regulation (MMR)[11] and UNFCCC reporting requirements the UK prepares three sets of CRF tables and officially reports all sets. These three sets of tables present emission estimates for different geographical coverages:

1. **MMR CRF** (the 'GBE' submission)**:** Includes UK, and Gibraltar

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8 Climate Change Act 2008. http://www.legislation.gov.uk/ukpga/2008/27/contents

9 FCCC Decision 24/CP.19. Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf

10 Annotated NIR outline:

http://unfccc.int/files/national_reports/annex_i_ghg_inventories/reporting_requirements/application/pdf/annotated_nir_outline.pdf

11 REGULATION (EU) No 525/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0525&from=EN

2. **Kyoto Protocol CRF** (the 'GBK' submission)**:** Includes UK, Crown Dependencies (Jersey, Guernsey, Isle of Man) and the Overseas Territories (Cayman Islands, Falkland Islands, Gibraltar). Reporting under the first commitment period also included Bermuda under this scope.
3. **UNFCCC CRF** ('the 'GBR' submission)**:** Includes UK, Crown Dependencies (Jersey, Guernsey, Isle of Man) and the Overseas Territories (Bermuda, Cayman Islands, Falkland Islands, Gibraltar). This scope is not included in the submission to the EU under the MMR.

The main part of this report presents GHG emissions for the years 1990-2015, and discusses the reasons for the trends and any changes in the estimates due to revisions made since the last inventory. The Annexes provide supplementary detail regarding the methodology of the estimates, and include sections on the estimation of uncertainties and atmospheric verification of the inventory. Full time series of emission factors and other background data are included on the NAEI website and are uploaded as part of the UK's official submission.

The CRF consists of a series of detailed spreadsheets, with one set for each year. A copy of the CRF for each reported geographical coverage accompanies this report, available on the NAEI website.

1.1.2.2 Geographical coverage of UK emissions

The UK compiles and reports three different sets of CRF tables, each with a different geographical coverage of emissions to fulfil the reporting requirements of the MMR, the Kyoto Protocol, and the UNFCCC.

A major source of activity data for the UK inventory is provided by BEIS through the publication of the Digest of UK Energy Statistics (DUKES) (see **Table 1.6**). The geographical coverage of DUKES is the United Kingdom (BEIS, 2016). Shipments to the Channel Islands and the Isle of Man from the United Kingdom are not classed as exports, and supplies of solid fuel and petroleum to these islands are therefore included as part of the United Kingdom inland consumption or deliveries.

The definition of the UK used by BEIS accords with that of the "economic territory of the United Kingdom" used by the UK Office for National Statistics, which in turn accords with the definition required to be used under the European System of Accounts (ESA95).

Depending on the required reporting framework, the geographical coverage of the UK inventory presented in this NIR includes emissions from territories associated with the UK. These are:

- **Crown Dependencies (CDs)**

  The Crown Dependencies are the Isle of Man and the Channel Islands (Jersey and Guernsey). They are not part of the United Kingdom, and are largely self-governing with their own legislative assemblies and systems of law. The British Government, however, is responsible for their defence and international relations. The Crown Dependencies are not members of the European Union.

- **Overseas Territories (OTs),** formerly called Dependent Territories

  The Overseas Territories are the Cayman Islands, Bermuda, Falkland Islands, and Gibraltar. They are constitutionally not part of the United Kingdom. They have separate constitutions, and most Overseas Territories have elected governments with varying degrees of responsibilities for domestic matters. The Governor, who is appointed by, and represents, Her Majesty the Queen, retains responsibility for external affairs, internal security, defence, and in most cases the public service. Gibraltar is additionally a member of the European Union.

1.1.2.3 Greenhouse Gases Reported in the UK Inventory

The greenhouse gases reported are:

Direct greenhouse gases

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

Indirect greenhouse gases

- Nitrogen oxides (NO_x, as NO_2);
- Carbon monoxide (CO);
- Non-Methane Volatile Organic Compounds (NMVOC); and,
- Sulphur dioxide (SO_2).

These indirect gases have indirect effects on radiative forcing and estimates are requested by the UNFCCC guidelines.

In addition to the gases listed above, Parties may also report indirect emissions of N_2O resulting from NO_x and NH_3 emissions, from sources other than agriculture. These are included in the UK's inventory report and are reported as a memo item.

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

Most sources are reported in the detail required by the CRF. The main exceptions are the emissions from certain F-gas categories which are also considered commercially sensitive. Consequently, emissions data have been aggregated to protect this information. Appropriate steps to weight emission factors have been taken prior to aggregation, hence retaining the completeness of the UK inventory.

1.1.2.4 Global Warming Potentials of the Greenhouse Gases

The direct greenhouse gases have different effectiveness in radiative forcing. The GWP is a means of providing a simple measure of the relative radiative effects of the emissions of the various gases. 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. It is necessary to define a time horizon because the gases have different lifetimes in the atmosphere. **Table 1.1** shows GWPs defined on a 100-year horizon (IPCC, 2007). These are the GWP values required by FCCC/CP/2013/10/Add.3.

Table 1.1 GWP of Greenhouse Gases on a 100-Year Horizon used in the UK NIR

Gas		GWP
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
Hydrofluorocarbons		
HFC-23	CHF_3	14,800
HFC-32	CH_2F_2	675
HFC-41	CH_3F	92
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1,640
HFC-125	C_2HF_5	3,500

Gas		GWP
HFC-134	$C_2H_2F_4$	1,100
HFC-134a	$C_2H_2F_4$	1,430
HFC-143	$C_2H_3F_3$	353
HFC-143a	$C_2H_3F_3$	4,470
HFC-152	CH_2FCH_2F	53
HFC-152a	$C_2H_4F_2$	124
HFC-161	CH_3CH_2F	12
HFC-227ea	C_3HF_7	3,220
HFC-236cb	$CH_2FCF_2CF_3$	1,340
HFC-236ea	CHF_2CHFCF_3	1,370
HFC-236fa	$C_3H_2F_6$	9,810
HFC-245ca	$C_3H_3F_5$	693
HFC-245fa	$CHF_2CH_2CF_3$	1030
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794
Perfluorocarbons		
Perfluoromethane	PFC-14 -CF_4	7,390
Perfluoroethane	PFC-116 - C_2F_6	12,200
Perfluoropropane	PFC-218 - C_3F_8	8,830
Perfluorobutane	PFC-3-1-10 - C_4F_{10}	8,860
Perfluorocyclobutane	PFC-318 - c-C_4F_8	10,300
Perfluouropentane	PFC-4-1-12 - C_5F_{12}	9,160
Perfluorohexane	PFC-5-1-14 - C_6F_{14}	9,300
Perfluorodecalin	PFC-9-1-18b - $C_{10}F_{18}$	>7,500
Perfluorocyclopropanec	c-C_3F_6	>17,340
Sulphur hexafluoride		
Sulphur hexafluoride	SF_6	22,800
Nitrogen trifluoride		
Nitrogen trifluoride	NF_3	17,200

By weighting the emission of a gas with its GWP it is possible to estimate the total contribution to global warming of UK greenhouse gas emissions.

1.1.3 Background Information on Supplementary Information Required under Article 7, paragraph 1, of the Kyoto Protocol

Information relating to the supplementary information required under Article 7, Paragraph 1 of the Kyoto Protocol can be found in the relevant sections of this report.

Table 1.2 below summarises the background information relating to the supplementary information and provides cross-references to appropriate parts of the report where more detailed information is provided.

Table 1.2 Background information on supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol

Reporting element	Background information
Supplementary inventory information for activities under Article 3, Paragraphs 3 and 4	The reporting of KP-LULUCF is carried out by the Centre for Ecology and Hydrology (CEH) on behalf of BEIS. The UK has chosen to elect Forest Management, Cropland Management, Grazing Land Management and Wetland Drainage and Rewetting as activities under Article 3.4. The calculations follow the same method

Reporting element	Background information
	and use the same models as the UNFCCC estimates for LULUCF, which are also prepared by CEH. Further information can be found in **Chapter 11**.
Information on Kyoto Protocol units	The UK National Registry is operated and maintained by the Environment Agency on behalf of BEIS. Information on accounting of Kyoto Protocol units, including a summary of information reported in the standard electronic format (SEF) tables is provided in **Chapter 12**. SEF tables are reported alongside this report.
Changes in National Systems	The UK National System is managed and maintained by BEIS, who is the Single National Entity. Changes to the National System are reported in **Chapter 13** of this report.
Changes in National Registry	The UK National Registry is operated and maintained by the Environment Agency on behalf of BEIS. The National Registry is represented on the National Inventory Steering Committee. All changes in the National Registry are reported in **Chapter 14**.
Minimisation of adverse impacts in accordance with Article 3, Paragraph 14	The UK has undertaken several assessments, reviews and analysis projects to better understand the impacts its policies could have on developing countries, and how they could be addressed. We have supported many initiatives to advance knowledge transfer, research collaboration and capacity building. Further details on the UK's efforts to minimise adverse impacts is provided in **Chapter 15**.

1.2 INSTITUTIONAL ARRANGEMENTS FOR INVENTORY PREPARATION

1.2.1 Institutional, Legal and Procedural Arrangements for Compiling the UK inventory

The UK greenhouse gas inventory is compiled and maintained by a consortium led by Ricardo Energy & Environment – the **Inventory Agency** - under contract to the SICE Directorate in BEIS. Ricardo Energy & Environment is responsible for producing the emissions estimates for CRF categories Energy (CRF sector 1), Industrial Processes and Product Use (CRF sector 2), and Waste (CRF Sector 5). Land Use, Land-Use Change and Forestry emissions (CRF sector 4) are calculated by the UK Natural Environment Research Council's Centre for Ecology and Hydrology (CEH) with the support of Forest Research. The KP-LULUCF information is also produced by CEH with the support of Forest Research. 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 System. Aether, a member of the consortium, is responsible for compiling emissions from railways and for the OTs and CDs. Ricardo Energy & Environment is also responsible for inventory planning, data collection, QA/QC and inventory management and archiving.

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

1.2.1.1 The UK Greenhouse Gas National Inventory System (UK NIS)

The Marrakesh Accords of the KP (Decision 20/CP.7[12]) define the requirements for National Inventory Systems (NIS), including the need to establish legal, procedural and institutional arrangements to ensure that all parties to the Protocol estimate and report their GHG emissions in accordance with relevant decisions of the COP, facilitate UNFCCC Reviews and improve the quality of their inventories. Under related EU legislation set out in Decision 280/2004/EC[13] the UK was required to have in place its NIS by 31st December 2005. **Figure 1.** summarises the key organisational structure of the UK NIS and **Section 1.2** includes further detailed information on the roles and responsibilities of each of the key organisations.

Figure 1.2.1 Key organisational structure of the UK National Inventory System

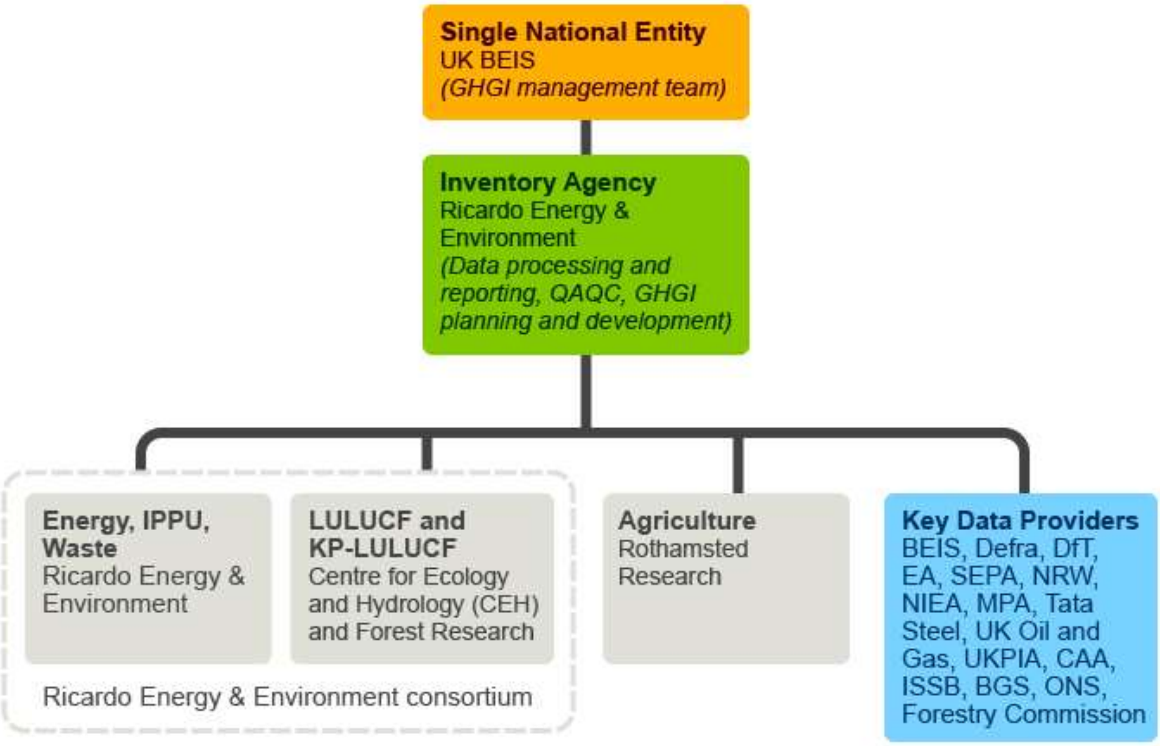
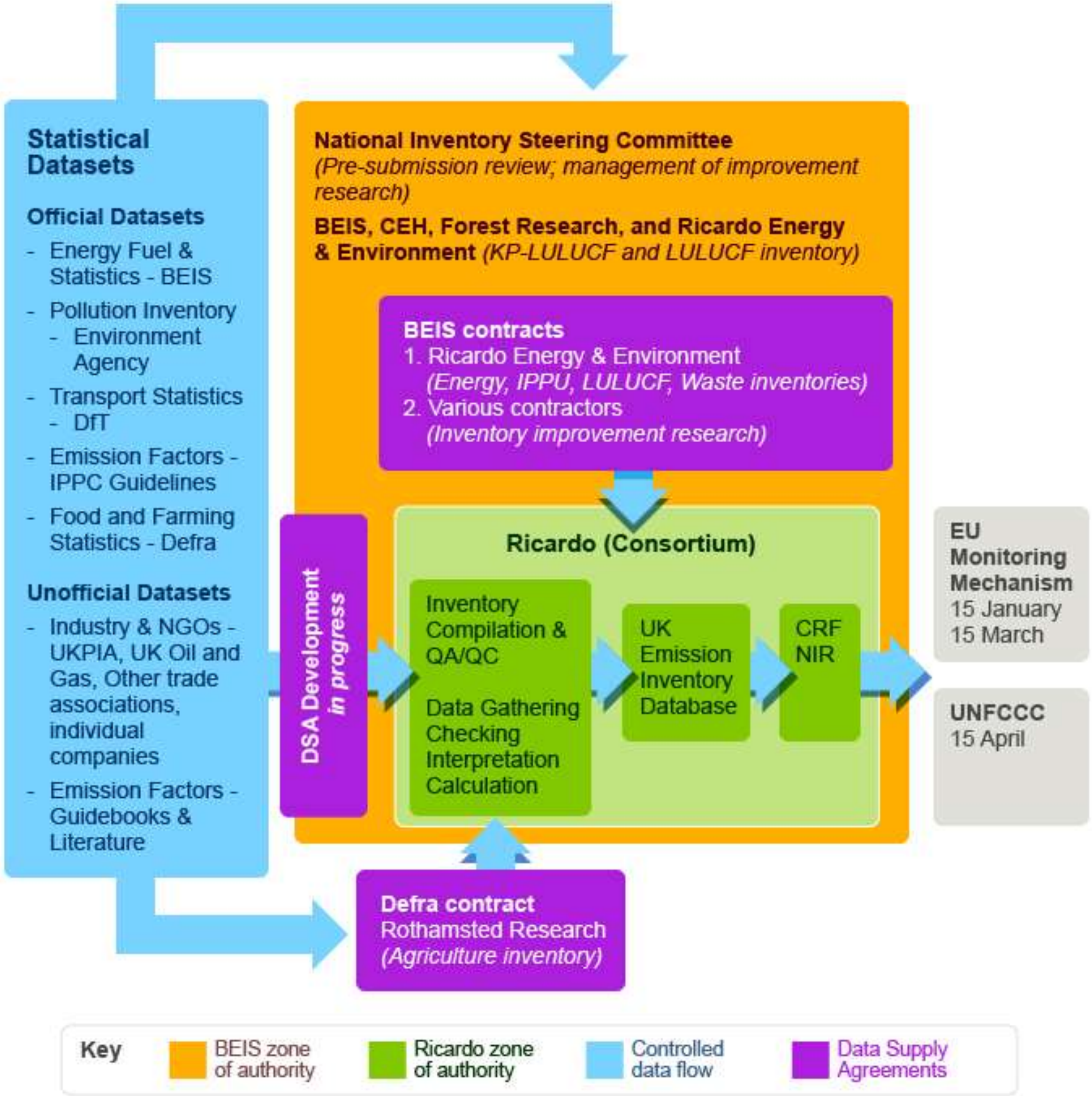


Figure 1.1 shows the main elements of the UK National Inventory System, including provision of data to the European Union under the terms of the Monitoring Mechanism Regulation. BEIS is the **Single National Entity** responsible for submitting the UK's GHGI to the UNFCCC. The Inventory Agency compiles the GHGI on behalf of BEIS, and produces disaggregated estimates for the Devolved Administrations within the UK.

12 20/CP.7 Guidelines for national systems under Article 5, paragraph 1, of the Kyoto Protocol http://unfccc.int/resource/docs/cop7/13a03.pdf

13 Decision No 280/2004/EC of the European Parliament and of the Council of 11 February 2004 concerning a mechanism for monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:049:0001:0001:EN:PDF

Figure 1.1.2 Main elements for the preparation of the UK greenhouse gas inventory



1.2.1.2 Legal Framework

The UK GHGI has been reported annually since 1994, and historically the acquisition of the data required has been based on a combination of existing environmental and energy legislation and informal arrangements with industry contacts and trade associations.

The legislation relied upon has been set up for other purposes, such as:

- Integrated Pollution Prevention and Control (IPPC) regulations (industrial point source emission data from UK environmental regulatory agencies); and,
- Statistics of Trade Act (UK energy statistics from BEIS).

To meet the standards required under the KP, the UK introduced new legislation specifically for national inventory purposes which took effect from November 2005[14]. This legislation makes provision for BEIS's Secretary of State to issue a notice in the event that information required for the inventory that has been sought voluntarily is not provided. The UK values voluntary participation and this legislation is intended as a last resort once all other avenues to elicit the required data, in the format and to the timing specified, have failed. The legislation includes penalties for failure to comply, and authority for entry to premises to obtain information required or verify information provided. This legislation was updated in 2014 (The Greenhouse Gas Emissions Trading Scheme (Amendment) Regulations 2014).

To ensure that the system works most effectively and to minimise the need for legislative action, BEIS is establishing data supply agreements (DSAs) with relevant organisations to build upon existing relationships with data supply organisations. These agreements formalise the acquisition of data and clarify the main requirements of quality, format, security and timely delivery of data for the national inventory. This process is on-going, through the National Inventory Steering Committee which is a forum of inventory stakeholders that BEIS chairs (see **Section 1.2.2.4** below).

There are currently DSAs in place with the Scottish Government, SEPA, NIEA, NRW and DfT.

1.2.2 Overview of Inventory Planning

As summarised in **Section 1.2.1**, the UK has designated authorities with clear roles and responsibilities. The following sections summarise the roles and responsibilities of key stakeholders in the UK's National Inventory System (NIS).

1.2.2.1 Single National Entity – BEIS

In 2016, BEIS was created from the Department of Energy and Climate Change (DECC) and the Department for Business, Innovation and Skills (BIS) and became the Single National Entity for the UK. This has been confirmed in writing to the UNFCCC Executive Secretary. BEIS has overall responsibility for the UK Greenhouse Gas Inventory and the UK National System and carries out this function on behalf of Her Majesty's Government and the Devolved Administrations (Wales, Scotland and Northern Ireland). BEIS is responsible for the institutional, legal and procedural arrangements for the national system and for the strategic development of the national inventory.

Within BEIS, the SICE Directorate administers this responsibility. The SICE Directorate coordinates expertise from across Government and manages research contracts to ensure that the UK Greenhouse Gas Inventory meets international standards set out in the UNFCCC reporting guidelines, the Kyoto Protocol and the IPCC 2006 Guidelines.

As the designated Single National Entity for the UK GHG NIS, BEIS has the following roles and responsibilities:

National Inventory System management and planning

- Overall control of the NIS development and function;
- Management of contracts and delivery of the GHG inventory; and,
- Definition of performance criteria for NIS key organisations.

[14] Greenhouse Gas Emissions Trading Scheme (Amendment) and National Emissions Inventory Regulations 2005 http://www.opsi.gov.uk/si/si2005/20052903.htm

Development of legal and contractual infrastructure

- Review of legal and organisational structure; and,
- Implementation of legal instruments and contractual developments as required to meet guidelines.

The contact point for the Single National Entity is provided on the **Contacts** page of the NIR.

1.2.2.2 Inventory Agency – Ricardo Energy & Environment Consortium

A new 3.5-year contract was established for the Inventory Agency in late 2016 following a competitive tendering exercise. Ricardo Energy & Environment leads the consortium responsible for compiling the inventory, under contract to BEIS. Ricardo Energy & Environment is responsible for all aspects of national inventory preparation, reporting and quality management. The consortium consists of:

- Ricardo Energy & Environment – lead contractor;
- CEH – overall responsibility for the LULUCF and KP-LULUCF estimates.
- Forest Research – responsible for forestland estimates that feed into the LULUCF and KP-LULUCF estimates.
- Aether – responsible for estimates from railways and the Overseas Territories (OTs) and Crown Dependencies (CDs); and, DA inventories.
- Ray Gluckman Consulting – contributions to the F-gas inventory.

Ricardo Energy & Environment together with the project partners prepares the National Atmospheric Emissions Inventory (NAEI) which is the core air emissions database from which the greenhouse gas inventory (GHGI) is extracted. This arrangement ensures consistency in reporting across all air emissions for different reporting purposes (UNFCCC, UNECE etc.). Activities include: collecting and processing data from a wide range of sources; selecting appropriate emission factors and estimation methods according to IPCC guidance; compiling the inventory; managing inventory QA/QC including QC of raw and processed data and data management tools, documentation and archiving, prioritisation of methodology and data improvements; carrying out uncertainty assessments; delivering the NIR (including CRF tables) by deadlines set to the EU Monitoring Mechanism Regulation (MMR) and the UNFCCC on behalf of BEIS; and assisting with Article 8 reviews under the KP.

As the designated Inventory Agency for the UK GHG National Inventory System, Ricardo Energy & Environment has the following roles and responsibilities:

Planning

- Co-ordination with BEIS to deliver the NIS;
- Review of current NIS performance and assessment of required development action; and,
- Scheduling of tasks and responsibilities to deliver GHG inventory and NIS.

Preparation

- Drafting of agreements with key data providers; and,
- Review of source data and identification of developments required to improve GHG inventory data quality.

Management

- Documentation and archiving;
- Dissemination of information regarding NIS to Key Data Providers; and,
- Management of inventory QA/QC plans, programmes and activities.

Inventory compilation

- Data acquisition, processing and reporting; and,
- Delivery of NIR (including associated CRF tables) to time and quality.

The Inventory Agency has formal systems in place to ensure that staff working on the inventory are well trained and able to carry out their duties effectively and efficiently. The technical competence of the staff is facilitated through a combination of the formal Ricardo Energy & Environment and inventory-specific staff management and training systems. Roles and responsibilities for all inventory team members are clearly defined, and a comprehensive system of QA/QC is in place. **Section 1.2.2.5** sets out the QA/QC plan in detail. Ricardo Energy & Environment systems ensure subcontractors are managed actively and deliver inputs to the inventory on time and to the specified quality.

The contact point for the Inventory Agency is provided on the **Contacts** page of the NIR.

Rothamsted Research, under contract to Defra, is responsible for the preparation and development of the agriculture inventory. Rothamsted Research conducts specific research in the agriculture sector and provides finalised GHG emissions data to Ricardo Energy & Environment for inclusion within the UK GHG inventory.

Rothamsted Research are directly responsible for compiling the agriculture sections of the CRF, and for maintaining documentation and archiving of their models and processes. Ricardo Energy & Environment are responsible for checking consistency between outputs.

1.2.2.3 Key Data Providers and Reference Sources

The organisations that provide the raw data to the UK GHGI include a wide range of Government Departments, non-Departmental public bodies and Government Agencies, private companies and industrial trade associations.

Within the UK GHG National Inventory System, organisations that are Key Data Providers have the following roles and responsibilities:

Data quality, Format, Timeliness, Security

- delivery of source data in the appropriate format and in time for inventory compilation, allowing for completion of required QA/QC procedures;
- assessment of their data acquisition, processing and reporting systems, having regard for QA/QC requirements;
- identification of any required organisational or legal development and resources to meet more stringent NIS data requirements, notably the security of data provision in the future; and,
- communication with BEIS, Ricardo Energy & Environment and their peers or members to help to disseminate information regarding the GHG inventory and National System.

Energy statistics required for compilation of the GHGI are obtained from DUKES, which is compiled and published annually by a team of energy statisticians within BEIS.

Information on industrial processes is provided either directly to the inventory agency by the individual plant operators or from:

- The Environment Agency's (EA) Pollution Inventory for England;
- Natural Resources Wales's (NRW) Pollution Inventory for Wales;
- The Scottish Environment Protection Agency's (SEPA) Scottish Pollutant Release Inventory; and
- The Northern Ireland Environment Agency's (NIEA) Northern Ireland Pollution Inventory.

Reporting to these UK inventories for the purposes of environmental regulation is a statutory requirement for industries under the Industrial Emissions Directive (IED) and Integrated Pollution Prevention and Control (IPPC). The data from these inventory sources is also used to quality check data provided voluntarily by companies directly to Ricardo Energy & Environment.

In addition, the inventory agency receives energy, fuel compositional data and emission estimates from all UK installations that operate within the EU Emissions Trading System, from detailed annual operator returns to the UK regulators of EU ETS (EA, SEPA, NRW, NIEA, BEIS Offshore Inspectorate). These data are used by the inventory agency and the BEIS energy statistics team to improve the UK energy balance and emission estimates for high-emitting source categories in the Energy and IPPU sectors (see **Annex 7** for further details).

The UK Natural Environment Research Council's Centre for Ecology and Hydrology (CEH) compiles estimates of emissions and removals from LULUCF as part of the Ricardo Energy & Environment consortium using land-use data and information on forestry from the Forestry Commission Research Agency (an executive agency of the Forestry Commission, known as Forest Research), Government Departments, Devolved Administrations and from other sources.

Rothamsted Research compiles the inventory for agricultural emissions using agricultural statistics from Defra and the Northern Ireland Department of Agriculture, Environment and Rural Affairs (NI DAERA).

1.2.2.4 The National Inventory Steering Committee, pre-Submission Review and Approval of the UK GHGI

To meet the detailed requirements of a National System and to ensure the UK efficiently and effectively works towards implementing best practices, a formal cross-Government body, the National Inventory Steering Committee (NISC) was formed in 2006. The NISC is tasked with the official consideration and approval of the national inventory prior to submission to the UNFCCC. This pre-submission review is achieved at a NISC meeting prior to the finalisation of the inventory, and any recalculations to the inventory are presented and discussed at this meeting.

One of the main roles of the committee is to assist the BEIS GHG inventory management team to manage and to prioritise the over-arching inventory QA and facilitate review and improvement and better communication between inventory stakeholders across Government Departments and Agencies.

Members of the Steering Committee include the Inventory Agency team at Ricardo Energy & Environment, other contractors, plus appropriate sector, legal and economic experts. These experts are responsible for reviewing methodologies, activity data, emission factors and emission estimates at a sectoral level and report their findings and recommendations to the steering committee on a regular basis. 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 Monitoring Mechanism Regulation and the UNFCCC. The NISC is responsible for agreeing the priorities for the UK GHGI improvement programme. 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.

Table 1.3 and **Table 1.4** below shows the main organisations engaged in the UK NISC, and their roles and responsibilities in relation to the preparation and development of the national inventory. These tables include organisations from the following categories, many of which are classed as key data providers:

- Government Departments;

- Government Agencies (e.g. environmental regulators);
- Industry bodies or associations; and,
- Consultants and invited experts.

The development of the inventory is driven through the NISC, which meets twice a year to discuss the outcomes of recent peer, internal and expert reviews and to agree the prioritisation, funding, implementation and review of items on the UK inventory improvement programme. The Key Category Analysis and the uncertainty analysis, qualitative analysis from Inventory Agency experts as well as recommendations from reviews of the UK GHG inventory are used as guidance to help the members of the NISC make 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 ESD, as well as sector-specific peer- or bilateral review findings are also considered to guide decisions on UK GHGI improvement priorities.

Following a UN Expert Review Team recommendation, a qualitative uncertainty analysis of the inventory is now implemented by the Inventory Agency. 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 used to improve transparency. This qualitative assessment is conducted by experts of the inventory team within the inventory cycle, including through a post-submission review of data sources, methods and feedback from the MMR and UNFCCC ERTs.

In spring each year, BEIS and the Inventory Agency hold a review meeting, at which the findings of the EU and UN reviews, internal post-submission review and qualitative analysis of source categories are discussed in order to develop a comprehensive list of inventory improvement items for discussion, prioritisation and implementation via the NISC.

Table 1.3 UK GHG National Inventory Steering Committee composition and responsibilities

Organisation	Role in relation to NISC	Key NISC responsibilities
BEIS - SICE Division	• GHG inventory manager • Manager of GHG research contracts • BEIS annual climate change statistics and indicators	• Administer functions of Single National Entity for the UK National Inventory System • Overall responsibility for inventory development, compilation and reporting • Manage GHG inventory research contracts • Act as NISC Chair • Ensure that UK GHGI conforms to EU and UN international standards and requirements
Defra – Atmosphere and Local Environment (ALE)	• AQ inventory manager • Manager of AQ research contracts	• Ensure that UK AQ inventory conforms to EU and UN international standards and requirements • Overall responsibility for AQ inventory development, compilation and reporting • With BEIS, ensure coordinated approach to improvements across GHG and AQ inventories, where relevant.
Defra	• Liaison between Defra and NISC	• Provide an analytical overview of all relevant Defra sectors • Provide link with Defra climate change mitigation team
BEIS – Carbon Budgets	• UK Climate Change Programme • Climate Change Act • Carbon budgets	• Inform NISC of UK programme developments • Explore links between inventory and carbon budgets and potential requirements for either area
BEIS – National Climate Change, Carbon Markets	• EU ETS • EU ETS Registry • EC Effort Sharing Decision	• Provide EU ETS fuel use and fuel characterisation datasets for determining industrial fuel use statistics and GHG emission from combustion sources • Provide updates of developments on the Effort Sharing Decision and EU ETS and any implications for future reporting requirements • Improve links between EU ETS registry and GHG inventory

Organisation	Role in relation to NISC	Key NISC responsibilities
BEIS – International Climate and Energy (ICE)	• International negotiations • MMR • UNFCCC	• Feed international emissions inventory expectations back to the NISC to ensure the UK complies and develops the inventory accordingly • Provide information on future international developments and changes to expectations • Provide advice on the implications of domestic changes to the inventory in an international arena
BEIS – SICE Division	• LULUCF Inventory manager	• Provide LULUCF inventory data that conforms to EU and UNFCCC international standards and requirements • Work with the NISC to ensure highest quality data
Defra – Farming and Food Science	• Agriculture Inventory Manager	• Providing agriculture inventory data that conforms to EU and UN international standards and requirements • Work with the NISC to ensure highest quality data
Defra – Water policy	• Waste-water	• To provide water policy expertise to the inventory • To assist in improving waste-water data quality
Defra – Waste	• Waste	• To provide waste policy expertise to the inventory, including landfill waste • To assist in improving landfill waste data quality
BEIS – Energy Statistics (DUKES)	• Energy statistics	• Annual publication of Digest of UK Energy Statistics (DUKES) • Providing energy statistics to inform the UK inventory

Organisation	Role in relation to NISC	Key NISC responsibilities
Regulators: • Environment Agency for England • Natural Resources Wales • Scottish Environment Protection Agency • Northern Ireland Environment Agency	• Pollution inventory • EU ETS Registry	• Management, compilation, QA/QC and reporting of pollutant emission inventories/registers under IPCC regulations, and EU ETS annual emission reporting • Ensure that the pollutant emission inventories for industrial processes regulated under IPC/IPCC (PI, SPRI, ISR) are presented in the required format and timescale for inventory estimation and reporting • Collate information in annual emission reports for EU ETS
BEIS Offshore Environmental Inspectorate	• Offshore oil and gas	• Providing offshore oil and gas industry annual activity and emission data to inform the UK inventory • Regulation of the offshore oil and gas industry, including management of the EEMS reporting system of environmental emissions from that sector
Department for Communities and Local Government (DCLG)	• Housing statistics • Local Government issues	• Publication of housing statistics each year; coordination of technical requirements of local authorities to assist in action on climate change • Providing housing statistics to inform the UK inventory
Department for Transport (DfT)	• Transport	• Publication of transport statistics each year • Providing transport statistics to inform the UK inventory
Devolved Administrations	• Inventories for Devolved Administrations	• General review function for completeness and accuracy of inventory from a devolved perspective • Review aspects of the UK GHG inventory that correspond to devolved issues, ensuring the integration of local datasets and specific research where appropriate.

Organisation	Role in relation to NISC	Key NISC responsibilities
GHG inventory contractor (Ricardo Energy & Environment)	• UK greenhouse gas inventory compilation and development	• Contractor responsible for the UK GHG inventory; activity data, methods, emission factors, emissions estimation, reporting and archiving • Deliver annual NIR and CRF submission to the UN and EU • Participate in sectoral expert panels as required
GHG inventory project partners (Aether)	• Inputs to greenhouse gas inventory compilation and development	• Contractor responsible for emissions from railways, and from Overseas Territories and Crown Dependencies • Joint role in managing the inventory improvement programme and development of QA/QC procedures
GHG inventory project partners (CEH)	• LULUCF inventory • KP-LULUCF inventory	• Contractor responsible for LULUCF inventory; activity data, methods, emission factors and removals estimation • Prepare and develop LULUCF inventory of emissions and removals and deliver on time for incorporation into the national inventory • Participate in sectoral expert panels as required
Agricultural inventory contractor (Rothamsted)	• Agriculture Inventory compilation and development	• Contractor responsible for agriculture inventory; activity data, methods, emission factors and emission estimation • Prepare and develop agriculture inventory and deliver on time for incorporation into national inventory • Participate in sectoral expert panels as required
BEIS – Analysis	• Energy modelling and projections	• Produce UK CO_2 projections

Table 1.4 Special Advisors to the UK GHG National Inventory Steering Committee

Organisation	Role in relation to NISC	Key NISC responsibilities
Met Office/University of Bristol	• Atmospheric measurements and interpretation at Mace Head, Ireland and other tall tower sites.	• Provide atmospheric measurements and interpretation of these data collected at Mace Head, for use in inventory data verification • Prepare comparison between estimated and observed emissions for the NIR
External reviewers	• Representation of industries, industry organisations and independent experts in the development of the national inventory	• Other experts or representatives may be asked to participate in sectoral expert panels or to review key sources or sources where significant changes to methods, activity data or emission factors have occurred e.g. ONS, UKPIA, Oil & Gas UK, Tata Steel, Electricity Supply Industry, international inventory experts etc.

1.2.2.5 UK Inventory Improvement Programme

Each year the inventory is updated to include the latest data available. Improvements to the methodology are made and are backdated to ensure a consistent time series. 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 NIS has a formal Inventory Improvement Programme, managed by the NISC. This achieves the dual aims of (i) progressing research to improve the UK GHGI data quality, and (ii) developing inter-Departmental/Agency working relationships to integrate inventory-related information from across Government.

The 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. A detailed and prioritised list of larger inventory improvement tasks is maintained by the Inventory Agency. The list is kept under review continually, and is formally reviewed annually at a NISC meeting. This list is prioritised by taking into account the Key Category Analysis (see **Section 1.5**), the quantitative uncertainty analysis, sector and pollutant expert judgements, and the future obligations of the inventory. The timing of the improvements and resourcing the work are important considerations for the NISC. The Single National Entity takes the final decision on timing and implementation of improvements to the inventory.

1.2.2.6 Integrated UK-DA GHGI improvement programme

The UK compiles a national level inventory, and in addition separate inventories for the Devolved Administrations (DAs). A single improvement programme is in place to manage improvements to these inventories.

During 2016-17, the integrated UK-DA GHGI improvement programme implemented a number of specific research projects to address inventory uncertainties and reporting requirements, including:

- Ammonia and methanol feedstocks – Estimates were made of the quantities of natural gas used in the manufacture of methanol and estimates were made of the quantities of carbon stored in methanol product and the quantities of CO_2 emitted during the production of methanol in the UK.
- Inclusion of the impact of taxi use in road transport emissions – Greenhouse gas emissions from London black cabs was calculated separately for the first time. Emissions are aggregated to the passenger cars category and are not reported separately.
- OT & CD update for agriculture and other sources – Methodology changes for emissions arising from enteric fermentation, manure management, soils and indirect emissions. Inclusion of estimates for several new sources, in particular indirect N_2O emissions of manure management systems and nitrogen input to soils due to mineralisation.
- Shipping – the UK shipping inventory model is currently undergoing a review and update. This is a longer term research project, which is expected to feed into the next inventory submission in 2018.
- Forestland – The CARBINE-SCA (Soil Carbon Accounting) soil and litter model has been integrated into the CARBINE forest carbon model used for the LULUCF forestland estimates.

Improvement priorities are discussed and agreed each April and incorporate the findings from the latest UNFCCC review of the inventory. Following on from the 2016 UNFCCC review, the following updates have been incorporated into this submission:

- Estimates of emissions of nitrous oxide from waste water decomposition now include 2 new parameters; $F_{NON-CON}$ and $F_{IND-COM}$ which accounts for unconsumed protein and commercial and industrial loads on municipal waste water systems respectively. These represent uplifts to the estimated N load in effluent and therefore higher N_2O emissions.
- Emissions from lubricant used for energy purposes (recovered lubricants burned in waste oil engines and intentional use of lubricants in 2 stroke engines) will be re-allocated from non-energy use to sectors for reporting energy use. As this is only an allocation issue the impact is not given below.

1.2.2.7 Agriculture inventory improvements

The UK GHG agricultural inventory is undergoing large improvements in order to better quantify emissions and reduce uncertainty. A consortia representing a wide range of scientific expertise has been put together to fulfil the requirements for improving the UK GHG agricultural inventory. In addition to this planned programme of improvement, a number of revisions were made to the inventory model for this reporting year to ensure compliance with the 2006 IPCC Guidelines; see **Section 5.1** for more information.

The agriculture improvement plan comprises:

1. Full implementation of the revised inventory structure providing improved spatial and temporal disaggregation, improved representation of UK-specific practices including uptake of relevant mitigation strategies and full accounting of nitrogen flows (including ammonia, nitrous oxide, nitric oxide and dinitrogen emissions to the atmosphere, nitrogen leaching to water and transformations between organic and inorganic forms of nitrogen) through the livestock and manure management chain (based on the outcome of Defra projects AC0114, AC0115 and AC0116).
2. Further improvement to the country-specific EF1 values for fertiliser applications, representing the influence of soil and climatic factors to derive spatially disaggregated emission factors (based on outcomes of Defra projects AC0116 and AC0114).
3. Implement UK-specific Tier 2 for enteric methane emissions from ruminant livestock based on metabolisable energy balance (based on outcome of Defra projects AC0115 and AC0116).
4. Review manure management EF and replace with country-specific values where sufficiently robust data exist.
5. Review UK livestock feed data and revise inventory parameters according to outcomes of Defra project SCF0203.
6. Continue to review the scientific literature to revise and refine UK-specific emission factors as relevant data arise.

1.2.3 Overview of Inventory Preparation and Management, Including for Supplementary Information Required under Article 7, Paragraph 1 of the Kyoto Protocol

For details of inventory preparation, see **Section 1.3**.

The Environment Agency is appointed as the UK Registry Administrator for the EU ETS/Kyoto Registry by BEIS. The UK for this purpose comprises England, Wales, Scotland, Northern Ireland, Offshore oil and gas installations and Gibraltar. The Environment Agency is a Government Agency.

Responsibilities of the Environment Agency include to:

- Manage the contractors responsible for maintaining the computer systems (Siemens for software/hosting the Registry and Trustis for digital certificates);
- Conform to the Kyoto Protocol and the COP/MOP decisions as implemented by the UNFCCC;
- Conform to the EU Registries Regulations as amended from time to time;
- Allow access for authorised users[15].
- Act on instructions from Competent Authorities to manage accounts; and,
- Assist registry users.

1.3 INVENTORY PREPARATION

1.3.1 GHG Inventory

The present UK GHG inventory for the period 1990-2015 was compiled in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

1.3.2 Data collection, processing and storage

The data acquisition task provides the fundamental activity data from which the GHG inventory is constructed. The process starts in June with the annual requests for data. A database which contains a list of contacts and datasets is used to track progress of the data acquired.

The following activities are carried out each year, in order, as the inventory is compiled:

Method improvement

Improvements to calculation methods are implemented before the inventory is compiled. These improvements are in part based on recommendations of UNFCCC reviews, EC reviews, peer reviews, bilateral reviews and relevant research sponsored by BEIS, Defra or other organisations.

Data request

Requests for activity data and background data are issued to a wide range of data suppliers. Each request is issued with a unique code, and a database is used to track the request and the data supplied from that request.

Data verification

Activity data received are examined. Anomalies are investigated, such as time series discrepancies, or large changes in values from the previous to the current inventory year.

Data processing

Data are prepared to allow emissions of direct and indirect GHG to be estimated.

Emission estimation

Provisional emissions are estimated using the most recent activity data available.

[15] Terms and Conditions at http://emissionsregistry.environment-agency.gov.uk/Default.aspx

Emissions review

A series of internal reviews are carried out to detect anomalies in the estimates (time series variations and year to year changes). Errors and omissions are then rectified.

Emissions reporting (including background data)

Estimates of emissions are prepared for the various reporting formats (e.g. IPCC, UNECE etc. including differing geographical coverages).

Report generation

Draft reports are written to satisfy the reporting criteria of the various agencies, e.g. the UNFCCC.

Report review

The reports are reviewed internally, by external contributing agencies, and by BEIS. Errors and omissions are then rectified.

Report publication

Final reports and data sets are then submitted via approved reporting routes, published in print and made available on publicly accessible web sites.

Data archiving

At the end of each inventory cycle, all data, spreadsheets, databases and reports are archived, allowing all data to remain traceable, should it be needed in future years.

The system outlined above complies with the Tier 1 QA/QC procedures outlined in Volume 1, Chapter 6 of IPCC, 2006.

Rothamsted Research and CEH, who are the sector experts for agriculture and LULUCF (including KP LULUCF), respectively, have their own systems in place for data collection. As the Inventory Agency responsible for compiling the overall inventory estimates, Ricardo Energy & Environment receives completed emission estimates from these organisations as part of the annual data collection process.

Ricardo Energy & Environment has work programmes in place with CEH and Rothamsted to help harmonise the quality systems used with those Ricardo Energy & Environment use in the core GHG inventory.

1.3.3 Quality assurance/quality control (QA/QC) procedures and extensive review of GHG inventory

The QA/QC plan for the UK inventory is explained in **Section 1.2.2.5**. Additional details of QA/QC in the LULUCF and Agriculture sectors can be found in **Chapter 6**, **Section 6.10** and **Chapter 5**, **Section 5.10** respectively.

1.4 METHODOLOGIES AND DATA SOURCES

1.4.1 GHG Inventory

The methods used to estimate emissions are described in detail in the relevant sections of this report. The direct and indirect GHGs reported are estimated using methodologies which mostly correspond to the detailed sectoral Tier 2/3 methods in the IPCC Guidelines.

Table 1.5 provides a brief summary of the methods used to estimate UK GHG emissions, which are described in more detail in the subsequent Chapters and Appendices.

Table 1.5 Summary of methods used to estimate emissions of the direct greenhouse gases

CRF sector	Comments on methods
1A	• Basic combustion module (fuel use * emission factor); • Transport models (see **MS 7, MS 8**, and, **MS 9**); and, • Carbon balance approach (See **MS 4**).
1B	• Carbon Balance approach (See **MS 4**); • BEIS EEMS inventory (See **MS 18**); and, • Gas leakage data from network operators (See **MS 20**).
2A	• Cement production: IPCC Tier 2 approach (see **Section 4.2.2**); • Lime production: Approach is comparable to IPCC Tier 2, although the Tier 1 default factor is used in the reporting of emissions; • Glass: IPCC Tier 2 approach, UK-specific factors from EU ETS; • Brickmaking: IPCC Tier 2 approach, UK-specific factors from EU ETS; and, • Other carbonates – FGD: Tier 1 approach for earlier part of time-series, Tier 2 for years covered by EU ETS.
2B	• Emissions calculated based on emissions data from industry, EU ETS and the environmental regulators' inventories, except for: • Use of EU and other MS statistics to estimate methanol manufactured in the UK • Use of IPCC default factors for CH_4 from ethylene oxide, acrylonitrile, carbon black in years where no environmental regulators' inventories data available; and, • Use of IPCC default factor for CO_2 from ethylene dichloride across full time-series.
2C	• Iron and Steel - 2 stage carbon balance and EU ETS/operator carbon factors for carbonate use and arc furnaces (see **MS 4**); • Spreadsheet model and operator reported emissions for aluminium and magnesium production; and, • Tier 1 approach for non-ferrous metal production.
2D	• Emissions calculated based on IPCC defaults for non-energy use of fuels; and, • IPCC method based as a proportion of the amount of fuel consumed for urea consumption in road transport.
2E, 2F	• Spreadsheet models to estimate emissions of F-gases.
2G	• Spreadsheet models to estimate emissions of F-gases; • NHS research into anaesthetic use; • Pollution inventory data for other uses of N_2O; and, • Statistics on cream consumption and Danish inventory assumptions for N_2O as a propellant for whipped cream.
3A	• Emissions calculated based on animal population data and appropriate EFs.
3B	• Emissions calculated based on animal population data and appropriate EFs.
3D	• Emissions calculated based on animal population data, fertilizer data and appropriate EFs.

CRF sector	Comments on methods
3F	• Emissions calculated based on IPCC methodologies and USEPA EFs.
3G	• Tier 1 approach for liming.
4	• Mathematical models used to estimate emissions and removals from Land-Use and Land Use Change; and, • CARBINE model used to estimate emissions and removals from Forestry, provided by Forest Research.
5A	• The Methane Emissions from Landfill model (MELmod).
5B	• UK waste activity data and IPCC default emission factors.
5C	• Country specific emission factors, partially based on Pollution Inventory data.
5D	• IPCC default method using country specific activity data for all N_2O and CH_4 from private waste-water management systems and industrial waste-water treatment; and, • Data from operator returns to the regulator for water company waste-water management.

The sources of data used are documented in the relevant sections of this NIR. Much of the activity data are taken from the key publications listed in **Table 1.6**. All sources are updated annually. References to these sources are hereafter abbreviated as shown in **Table 1.6**.

Table 1.6 Summary of sources of activity data used to estimate greenhouse gas emissions

Source (and publisher) *Short name*	**Relevant activity data contained in the source**
Digest of UK Energy Statistics (UK Department of Energy and Climate Change) *DUKES*	• Energy statistics for the UK (imports, exports, production, consumption, demand) of liquid, solid and gaseous fuels; and, • Calorific values of fuels and conversion factors.
Emissions Trading System (EU ETS regulatory agencies in the UK; data supplied via UK Department of Energy and Climate Change) *EU ETS*	• Emissions from installations and characteristics of fuels consumed; • Energy data are aggregated by sector and used to inform inventory estimates; and, • Fuel quality data are used to derive up to date carbon emission factors for major fuels in energy intensive sectors.
Transport Statistics GB (UK Department for Transport) *TSGB*	• Vehicle km according to vehicle type and road type; • Vehicle licensing statistics (split in vehicle km by fuel type); and, • Selected domestic and international civil aviation aircraft km flown.

Source (and publisher) *Short name*	**Relevant activity data contained in the source**
Northern Ireland Statistics: Inventory of Statutory Releases, transport data (NI Department of the Environment, NI Department for Regional Development) *ISR*	• Traffic count and vehicle km data for Northern Ireland; and, • Information on regulated processes in NI.
Civil Aviation Authority *CAA*	• Detailed domestic and international civil aviation aircraft km flown.
Pollution Inventory (Environment Agency and Natural Resources Wales) *PI*	• Information on emissions from regulated processes in England and Wales.
Scottish Pollutant Release Inventory (Scottish Environment Protection Agency) *SPRI*	• Information on regulated processes in Scotland.
United Kingdom Petroleum Industry Association *UKPIA*	• Refinery emissions; and • Lead and sulphur contents of fuels, benzene content of petrol, RVP of petrol.
Environmental Emissions Monitoring System (EEMS) (BEIS Offshore Inspectorate) *EEMS*	• Detailed inventory of oil and gas emissions.
UK Iron and Steel Industry Annual Statistics (International Steel Statistics Bureau) *ISSB*	• Energy production and consumption in the Iron and Steel industry; and, • Other statistics regarding the Iron and Steel industry.
United Kingdom Minerals Yearbook (British Geological Society) *UKMY*	• Statistical data on minerals production, consumption and trade.

Source (and publisher) *Short name*	**Relevant activity data contained in the source**
Annual Abstract of Statistics (Office for National Statistics) *ONS*	• Population data.
Department for Transport *ANPR*	• Automatic Number Plate Recognition (ANPR) data used to help define fleet composition on different road types in the UK.

Key data sources within the Energy sector are further elaborated in **Annex 3**. These include the annually updated data sets EEMS, the PI, SPRI and ISR listed above, and other one-off studies that are used across a number of source categories (Baggott et al., 2004 and Entec, 2010). DUKES is described in more detail in **Annex 4**.

1.5 DESCRIPTION OF KEY SOURCE CATEGORIES

1.5.1 GHG Inventory

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. **Table 1.7** to **Table 1.10** summarise the key source categories, for the latest reported year, and the base year, derived from the IPCC Approach 1 and 2 key category analyses. Tables are included for the analysis with and without LULUCF and for the base year and most recent year estimated. Details of the key source category analysis are given in **Annex 1**. A trend cannot be calculated for the base year alone, and so the tables for the base year only contain key source categories identified by level.

A key category ranking has been carried out, this is set out in

Table 1.11 and is explained below; it is referred to in **Table 3.1** when referencing which categories are or contain key categories within the energy sector.

The Key Category Analysis (KCA) ranking system is an additional tool that the UK has developed to aid in the prioritisation of improvement work. The KCA ranking system works by allocating a score based on how high categories rank in the base year and 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 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.

Following IPCC good practice, a qualitative analysis of the inventory has been made to identify key categories. Details of this analysis are given in **Annex 1**. This has not identified any further categories that are not already identified as part of the Approach 1 or Approach 2 analyses.

Table 1.7 Key Source Categories for the latest reported year (including LULUCF)

IPCC Code	IPCC Category	Greenhouse Gas	Identification Criteria
1A	Coal	CO_2	L2, T2
1A	Natural Gas	CO_2	L2, T2
1A	(Stationary)_Oil	CO_2	L2, T2
1A1	Energy industries: solid fuels	CO_2	L1, T1
1A1	Energy industries: liquid fuels	CO_2	L1, T1
1A1	Energy industries: gaseous fuels	CO_2	L1, T1
1A1	Energy industries: other fuels	CO_2	L1, T1
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	N_2O	L2
1A2	Manufacturing industries and construction: solid fuels	CO_2	L1, T1
1A2	Manufacturing industries and construction: liquid fuels	CO_2	L1, T1
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	L1, T1
1A3b	Road transportation: liquid fuels	CO_2	L1, T1
1A3b	DERV	CO_2	L2, T2
1A3b	Gasoline/ LPG	CO_2	L2
1A3b	DERV	N_2O	L2, T2
1A3c	Railways: liquid fuels	CO_2	L1, T1
1A3d	Domestic Navigation: liquid fuels	CO_2	L1, T1
1A4	Other sectors: solid fuels	CO_2	L1, T1
1A4	Other sectors: liquid fuels	CO_2	L1
1A4	Other sectors: gaseous fuels	CO_2	L1, T1
1A5	Other: liquid fuels	CO_2	L1, T1
1B1	Coal mining and handling	CH_4	T1, T2
1B2	Oil and gas extraction	CO_2	L1
1B2	Oil and gas extraction	CH_4	L1, T1
2A1	Cement production	CO_2	L1

IPCC Code	IPCC Category	Greenhouse Gas	Identification Criteria
2B	Chemical industry	HFCs	T2
2B2	Nitric acid production	N_2O	T1, T2
2B3	Adipic acid production	N_2O	T1, T2
2B8	Petrochemical and carbon black production	CO_2	L1
2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3	T1
2C1	Iron and steel production	CO_2	L1, T1
2C6	Zinc production	CO_2	T1
2F	Product Uses as Substitutes for ODS	HFCs	L2, T2
2F1	Refrigeration and air conditioning	HFCs, PFCs, SF_6 and NF_3	L1, T1
2F4	Aerosols	HFCs, PFCs, SF_6 and NF_3	T1
2G	Other Product Manufacture and Use	N_2O	L2, T2
3A	Enteric Fermentation	CH_4	L2, T2
3A1	Enteric fermentation from Cattle	CH_4	L1, T1
3A2	Enteric fermentation from Sheep	CH_4	L1, T1
3B	Manure Management	N_2O	L2
3B1	Manure management from Cattle	CH_4	L1
3D	Agricultural soils	N_2O	L1, T1, L2, T2
4A	Forest land	CO_2	L1, T1, L2, T2
4B	Cropland	CO_2	L1, T1, L2, T2
4C	Grassland	CO_2	L1, T1, L2, T2
4E	Settlements	CO_2	L1, T1, L2, T2
4G	Harvested wood products	CO_2	L1, L2
5A	Solid waste disposal	CH_4	L1, T1, L2, T2
5B	Biological treatment of solid waste	CH_4	T1, L2, T2
5B	Biological treatment of solid waste	N_2O	T2
5D	Wastewater Handling	CH_4	L1, T1, L2
5D	Wastewater Handling	N_2O	L2, T2

Table 1.8 Key Source Categories for the base year (including LULUCF)

IPCC Code	IPCC Category	Greenhouse Gas	Identification Criteria
1A	Coal	CO_2	L2
1A	Natural Gas	CO_2	L2
1A	(Stationary) Oil	CO_2	L2
1A1	Energy industries: solid fuels	CO_2	L1
1A1	Energy industries: liquid fuels	CO_2	L1
1A1	Energy industries: gaseous fuels	CO_2	L1
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	N_2O	L2
1A2	Manufacturing industries and construction: solid fuels	CO_2	L1
1A2	Manufacturing industries and construction: liquid fuels	CO_2	L1
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	L1
1A3b	Road transportation: liquid fuels	CO_2	L1
1A3b	Gasoline/ LPG	CO_2	L2
1A4	Other sectors: solid fuels	CO_2	L1
1A4	Other sectors: liquid fuels	CO_2	L1
1A4	Other sectors: gaseous fuels	CO_2	L1
1A5	Other: liquid fuels	CO_2	L1
1B1	Coal mining and handling	CH_4	L1, L2
1B2	Oil and gas extraction	CH_4	L1
1B2	Oil and gas extraction	CO_2	L1
1B2	Natural Gas Transmission	CH_4	L2
2A1	Cement production	CO_2	L1
2B	Chemical industries	CO_2	L2
2B	Chemical industry	HFCs	L2
2B2	Nitric acid production	N_2O	L1, L2
2B3	Adipic acid production	N_2O	L1, L2
2B8	Petrochemical and carbon black production	CO_2	L1
2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3	L1
2C1	Iron and steel production	CO_2	L1
3A	Enteric Fermentation	CH_4	L2
3A1	Enteric fermentation from Cattle	CH_4	L1
3A2	Enteric fermentation from Sheep	CH_4	L1
3B	Manure Management	N_2O	L2
3B1	Manure management from Cattle	CH_4	L1
3D	Agricultural soils	N_2O	L1, L2

IPCC Code	IPCC Category	Greenhouse Gas	Identification Criteria
4A	Forest land	CO_2	L1, L2
4B	Cropland	CO_2	L1, L2
4C	Grassland	CO_2	L1, L2
4E	Settlements	CO_2	L1, L2
5A	Solid waste disposal	CH_4	L1, L2
5D	Wastewater Handling	CH_4	L1, L2
5D	Wastewater Handling	N_2O	L2

Table 1.9 Key Source Categories for the latest reported year (excluding LULUCF)

IPCC Code	IPCC Category	Greenhouse Gas	Identification Criteria
1A	Coal	CO_2	L2, T2
1A	Natural Gas	CO_2	L2, T2
1A	(Stationary) Oil	CO_2	L2, T2
1A1	Energy industries: solid fuels	CO_2	L1, T1
1A1	Energy industries: liquid fuels	CO_2	L1, T1
1A1	Energy industries: gaseous fuels	CO_2	L1, T1
1A1	Energy industries: other fuels	CO_2	L1, T1
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	CH_4	L2
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	N_2O	L2
1A2	Manufacturing industries and construction: solid fuels	CO_2	L1, T1
1A2	Manufacturing industries and construction: liquid fuels	CO_2	L1, T1
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	L1, T1
1A3a	Domestic aviation: liquid fuels	CO_2	L1
1A3b	Road transportation: liquid fuels	CO_2	L1, T1
1A3b	DERV	CO_2	L2, T2
1A3b	Gasoline/ LPG	CO_2	L2
1A3b	DERV	N_2O	L2, T2
1A3c	Railways: liquid fuels	CO_2	L1, T1
1A3d	Domestic Navigation: liquid fuels	CO_2	L1, T1
1A4	Other sectors: solid fuels	CO_2	L1, T1
1A4	Other sectors: liquid fuels	CO_2	L1
1A4	Other sectors: gaseous fuels	CO_2	L1, T1
1A5	Other: liquid fuels	CO_2	L1, T1
1B1	Coal mining and handling	CH_4	T1, T2

IPCC Code	IPCC Category	Greenhouse Gas	Identification Criteria
1B2	Oil and gas extraction	CO_2	L1
1B2	Oil and gas extraction	CH_4	L1, T1
1B2	Natural Gas Transmission	CH_4	L2
2A1	Cement production	CO_2	L1
2B	Chemical industries	CO_2	L2
2B	Chemical industry	HFCs	T2
2B2	Nitric acid production	N_2O	T1, T2
2B3	Adipic acid production	N_2O	T1, T2
2B8	Petrochemical and carbon black production	CO_2	L1
2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3	T1
2C1	Iron and steel production	CO_2	L1, T1
2C6	Zinc production	CO_2	T1
2F	Product Uses as Substitutes for ODS	HFCs	L2, T2
2F1	Refrigeration and air conditioning	HFCs, PFCs, SF_6 and NF_3	L1, T1
2F4	Aerosols	HFCs, PFCs, SF_6 and NF_3	T1
2G	Other Product Manufacture and Use	N_2O	L2, T2
3A	Enteric Fermentation	CH_4	L2, T2
3A1	Enteric fermentation from Cattle	CH_4	L1, T1
3A2	Enteric fermentation from Sheep	CH_4	L1
3B	Manure Management	N_2O	L2
3B1	Manure management from Cattle	CH_4	L1
3D	Agricultural soils	N_2O	L1, T1, L2, T2
5A	Solid waste disposal	CH_4	L1, T1, L2, T2
5B	Biological treatment of solid waste	CH_4	T1, L2, T2
5B	Biological treatment of solid waste	N_2O	L2, T2
5D	Wastewater Handling	CH_4	L1, T1, L2
5D	Wastewater Handling	N_2O	L2, T2

Table 1.10 Key Source Categories for base year (excluding LULUCF)

IPCC Code	IPCC Category	Greenhouse Gas	Identification Criteria
1A	Coal	CO_2	L2
1A	Natural Gas	CO_2	L2
1A	(Stationary) Oil	CO_2	L2
1A1	Energy industries: solid fuels	CO_2	L1
1A1	Energy industries: liquid fuels	CO_2	L1
1A1	Energy industries: gaseous fuels	CO_2	L1

IPCC Code	IPCC Category	Greenhouse Gas	Identification Criteria
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	N_2O	L2
1A2	Manufacturing industries and construction: solid fuels	CO_2	L1
1A2	Manufacturing industries and construction: liquid fuels	CO_2	L1
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	L1
1A3b	Road transportation: liquid fuels	CO_2	L1
1A3b	Gasoline/ LPG	CO_2	L2
1A4	Other sectors: solid fuels	CO_2	L1
1A4	Other sectors: liquid fuels	CO_2	L1
1A4	Other sectors: gaseous fuels	CO_2	L1
1A5	Other: liquid fuels	CO_2	L1
1B1	Coal mining and handling	CH_4	L1, L2
1B2	Oil and gas extraction	CO_2	L1
1B2	Oil and gas extraction	CH_4	L1
1B2	Natural Gas Transmission	CH_4	L2
2A1	Cement production	CO_2	L1
2B	Chemical industries	CO_2	L2
2B	Chemical industry	HFCs	L2
2B2	Nitric acid production	N_2O	L1, L2
2B3	Adipic acid production	N_2O	L1, L2
2B8	Petrochemical and carbon black production	CO_2	L1
2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3	L1
2C1	Iron and steel production	CO_2	L1
3A	Enteric Fermentation	CH_4	L2
3A1	Enteric fermentation from Cattle	CH_4	L1
3A2	Enteric fermentation from Sheep	CH_4	L1
3B	Manure Management	N_2O	L2
3D	Agricultural soils	N_2O	L1, L2
5A	Solid waste disposal	CH_4	L1, L2
5D	Wastewater Handling	CH_4	L1
5D	Wastewater Handling	N_2O	L2

Table 1.11 Key category ranking

KCA rank	IPCC Code	IPCC Category	Greenhouse Gas
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	1A2	Manufacturing industries and construction: solid fuels	CO_2
6	1A1	Energy industries: liquid fuels	CO_2
7	1A1	Energy industries: gaseous 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	3D	Agricultural soils	N_2O
12	4A	Forest land	CO_2
13	1A4	Other sectors: solid fuels	CO_2
14	4B	Cropland	CO_2
15	1B2	Oil and gas extraction	CH_4
16	1B1	Coal mining and handling	CH_4
17	4C	Grassland	CO_2
18	4E	Settlements	CO_2
19	1A4	Other sectors: liquid fuels	CO_2
20	2F1	Refrigeration and air conditioning	HFCs, PFCs, SF_6 and NF_3
21	2C1	Iron and steel production	CO_2
22	3A2	Enteric fermentation from Sheep	CH_4
23	1A5	Other: liquid fuels	CO_2
24	5D	Wastewater treatment and discharge	CH_4
25	1A3d	Domestic Navigation: liquid fuels	CO_2
26	1B2	Oil and gas extraction	CO_2
27	3B1	Manure management from Cattle	CH_4
28	2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3
29	1A3c	Railways: liquid fuels	CO_2
30	1A3a	Domestic aviation: liquid fuels	CO_2
31	2F4	Aerosols	HFCs, PFCs, SF_6 and NF_3

KCA rank	IPCC Code	IPCC Category	Greenhouse Gas
32	1A1	Energy industries: other fuels	CO_2
33	2B8	Petrochemical and carbon black production	CO_2
34	4G	Harvested wood products	CO_2
35	2A1	Cement production	CO_2
36	2B2	Nitric acid production	N_2O
37	2B3	Adipic acid production	N_2O
38	5B	Biological treatment of solid waste	CH_4
39	2C6	Zinc production	CO_2

1.5.2 KP-LULUCF analysis

A separate uncertainty analysis has been completed for the Key Categories for LULUFC activities under the KP. The full details of this analysis are given in CRF Table NIR 3, reproduced in **Table A 1.8.1** in **Annex 1**. This analysis indicates the key categories of emissions and removals are (KP category, associated UNFCCC category, gas):

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

1.6 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

This section presents the QA/QC system for the UK greenhouse has inventory (GHGI), including the approaches used for verification and treatment of confidentiality issues. The current system complies with the Tier 1 procedures outlined in the Guidelines (IPCC, 2006) and has been extended to include a range of bespoke sector specific QA/QC activities to comply with Tier 2. Ricardo Energy & Environment, the Inventory Agency, is also fully accredited to BS EN ISO 9001:2008 (see **Box 1.1**). 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.

1.6.1 Description of the current QA/QC system

The National Atmospheric Emissions Inventory and the UK Greenhouse Gas Inventory are compiled and maintained together by Ricardo Energy & Environment (the Inventory Agency), on behalf of the UK Department for Business, Energy & Industrial Strategy (BEIS) and the Department for Environment, Food and Rural Affairs (Defra). Ricardo Energy & Environment prepares the GHG submissions to the EC under the MMR and to the UNFCCC. The data compilation for some source sectors of the UK inventory are performed by other contractors (i.e. Rothamsted Research compile the agriculture sector under contract to Defra, and CEH compile the land use, land-use change and forestry sector under sub-contract to Ricardo Energy & Environment). Much of the data received by Ricardo Energy & Environment for the UK GHGI compilation come from other 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 the 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 (detailed below). Whilst these organisations have their own QA/QC systems, Ricardo Energy & Environment is responsible for co-ordinating inventory-wide QA/QC activities relating to the submitted datasets. In addition, Ricardo Energy & Environment is working continuously with organisations supplying data to the GHG inventory to encourage them to demonstrate their own levels of QA/QC that comply with either 2006 IPCC Guidelines or the UK's National Statistics standards.

The UK inventory QA/QC system encompasses a wide range of activities to cover:

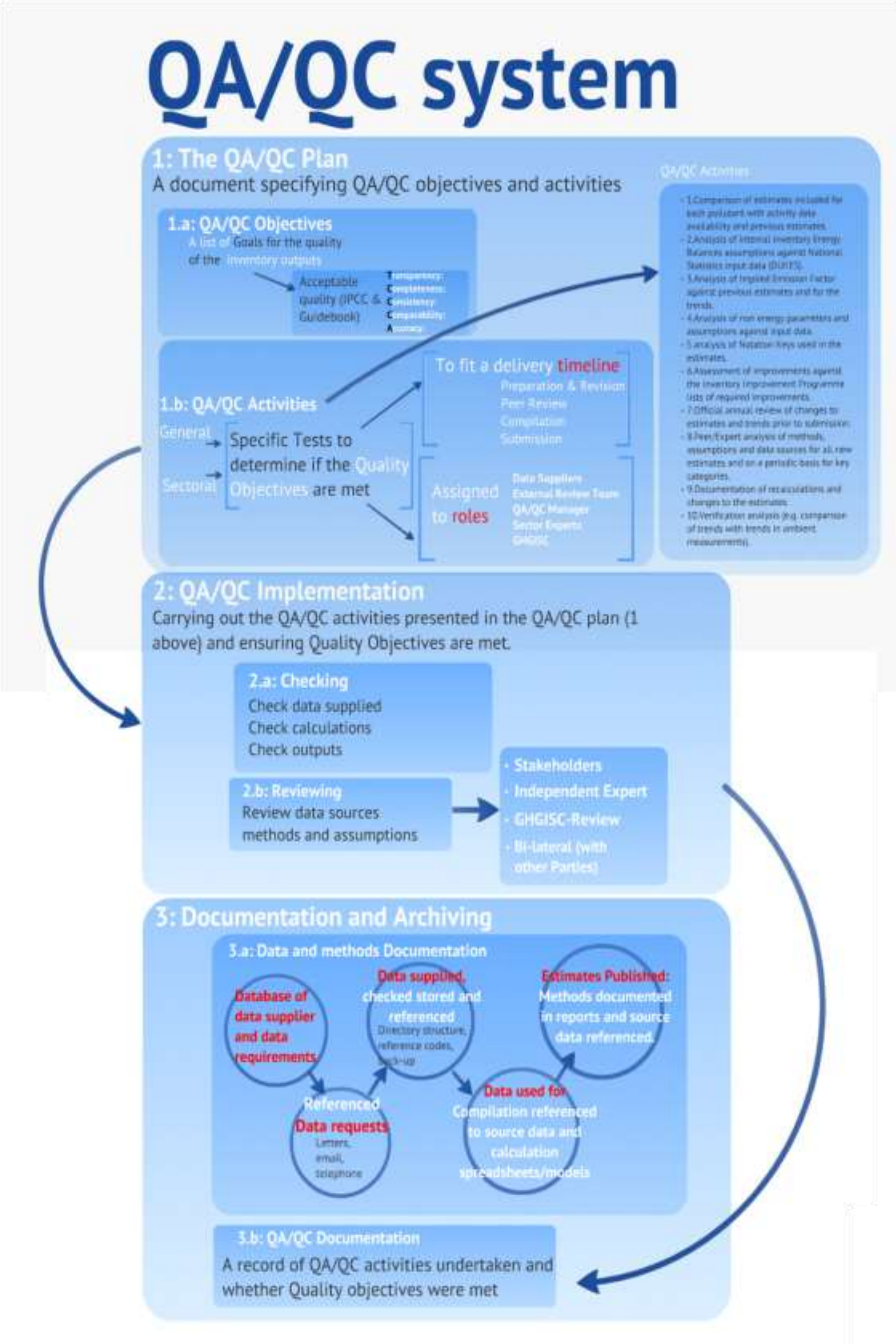
- inventory planning tasks, including: *review of historic data and methods, identification of improvement priorities, data and method selection, inventory team training and development*;
- inventory compilation and reporting tasks, including: *management and documentation of data flows from raw data through calculation of emission estimates to reporting, input data requests/acquisition, management of compilation processes and quality checking systems, documentation of data, methods and assumptions, assessment of key source categories and uncertainties, reporting of inventory outputs*;
- inventory checking tasks, including: *raw data checks, inventory model / calculation checks, source-specific and cross-cutting output checks, checking reasons for changes compared to previous inventory estimates, emission trend checks, emission factor checks*; and,
- inventory QA review tasks, including: *pre-submission reviews, post-submission reviews, peer reviews, bilateral reviews, expert reviews*.

1.6.1.1 Overview of the UK QA/QC plan

An overview of the UKs GHGI QA/QC system is illustrated in **Figure 1.2** below. The UK inventory QA/QC system includes three core components.

1. The QA/QC Plan is a document maintained by the GHGI's QA/QC manager (at Ricardo Energy & Environment) and defines the specific Quality Objectives and QA/QC activities required in undertaking the compilation and reporting of GHG estimates. The plan sets out source-specific and general (cross-cutting) activities to ensure that quality objectives are met within the required inventory reporting time-frame. The QA/QC plan also assigns roles and responsibilities for the inventory agency team, and records the key outcomes from inventory QA activities in order to underpin a programme of continuous improvement.
2. QA/QC implementation includes the physical undertaking of the QA/QC activities throughout the data gathering, compilation and reporting phases of the annual inventory cycle and in accordance with the QA/QC plan.
3. Documentation and Archiving. Documentation is embedded within the UK's compilation tools. The NIR transparently describes the data sources, methods, assumptions and QA/QC implementation used in producing the GHG inventory including records of activities undertaken, findings/issue logs, recommendations and any necessary actions taken or planned. Archiving ensures a complete backup and storage of all material used for the compilation of the estimates.

Figure 1.2: QA/QC system used within UK greenhouse gas inventory



Box 1.1: BS EN ISO 9001:2008 Accreditation

In addition to the UK's own GHGI specific QA/QC system, through Ricardo Energy & Environment, the Inventory has been subject to ISO 9000 since 1994 and is now subject to BS EN ISO 9001:2008. It is audited by Lloyds Register Quality Assurance (LRQA) and the Ricardo Energy & Environment internal QA auditors. The NAEI has been audited favourably by LRQA on four occasions in the last 12 years. The emphasis of these audits was on authorisation of personnel to work on inventories, document control, data tracking and spreadsheet checking, and project management. As part of the Inventory management structure there is a nominated officer responsible for the QA/QC system – the QA/QC Co-ordinator. Ricardo Energy & Environment is currently accredited to BS EN ISO 9001:2008. Lloyds Register Quality Assurance carried out a three yearly recertification audit of Ricardo Energy & Environment in September and October 2014. Ricardo Energy & Environment successfully passed the recertification, with no major non compliances, and a new certificate was issued. Ricardo Energy & Environment is currently certificated both for the Quality Assurance ISO 9001:2008 and Environmental Management System ISO 14001 standard.

Specific details of the QA/QC plan, implementation, documentation and archiving are provided below.

1.6.1.2 Scope of the QA/QC plan

The scope of the QA/QC plan includes:

1. Calculation of greenhouse gas estimates and reporting to UNFCCC and MMR (including emissions and removals from all sources and gases)
2. Calculation of air pollutant estimates and reporting to UNECE (including emissions from all sources and pollutants)
3. Calculation of estimates and reporting to UK National Statistics
4. Identification and phased implementation of incremental improvements to the QA/QC system.

1.6.2 Improvements to the QA/QC System

The QA/QC plan and procedures are constantly subject to review and improvement. In 2014, BEIS (formerly DECC) and Defra commissioned an independent review of the NAEI QA architecture, through a series of audits on 15 of the NAEI models. The review was conducted by Hartley McMaster, and was aimed at assessing the NAEI QA systems against the requirements of IPCC guidance, BEIS model QA guidance and the wider Government guidelines for model integrity (HMT Aqua Book). The findings of the HM review have underpinned several of the QA system improvements implemented by Ricardo in the 1990-2015 inventory compilation cycle, and further model-specific QA improvements may be considered for future work.

In May 2015, the UK took part in a multi-lateral review hosted by the German inventory agency, engaging with the QA managers from the inventories of the Netherlands, France, Germany and Denmark. The main objective of the review was to exchange examples of best practice and different country approaches to implementing the new 2006 IPCC GLs for QAQC. In particular, several areas of ambiguity in the GLs were discussed and a common view sought on how to address and prioritise the new QA guidance.

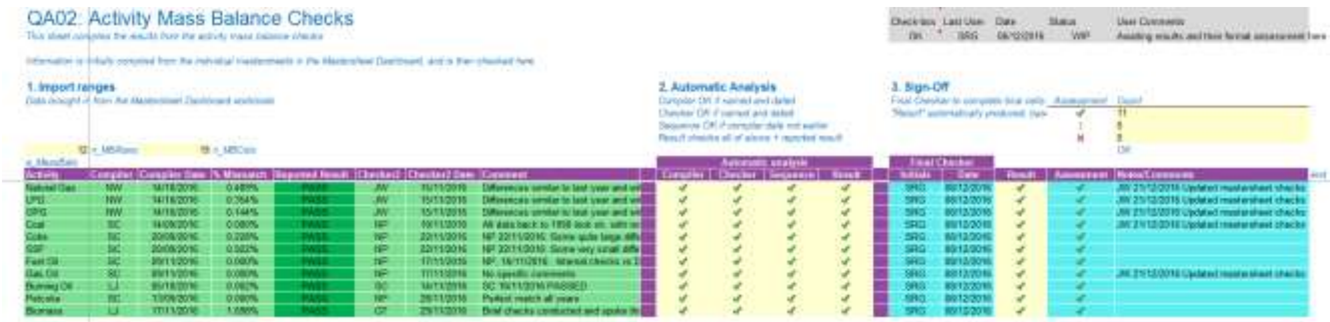
The following is a list of the main improvements made to the inventory QA/QC system during the 2017 submission:

- Enhancements to the central QA/QC dashboard developed to track and document progress of checking routines. The dashboard summarises the checks done in several dimensions, including by GHG, by model, and by sector. A summary of this dashboard is also now shared with BEIS, summarising the checks done on the inventory (see **Figure 1.3** and **Figure 1.4** for screenshots of the dashboard, during the inventory compilation process);

- Further improvements to inventory model design to ensure consistent and transparent documentation of model compilation, QC, version control, with supporting guidance to for inventory compilation team;
- Model upgrades for a number of inventory models, to re-build and test inventory models against UK Government QA guidelines; this process included third party reviews of models upgraded;
- Continued improvements and streamlining to the QA systems to improve handling of data on LULUCF within the UK data management and reporting systems.
- Increased automation of activity data transfer between the NAEI database and CRF tables to reduce errors.

Figure 1.3: QA/QC dashboard example. Summary of model checks, part way through compilation

Figure 1.4: QA/QC dashboard example. Summary of activity mass balance checks



1.6.2.1 Quality Objectives

The key objectives of the QA/QC plan are to ensure that the estimates in the GHG and air pollutant inventories are of a suitably high quality and will meet the methodological and reporting requirements for UK submissions to the UNECE and UNFCCC, as set out within national inventory reporting guidance from the Intergovernmental Panel on Climate Change (IPCC)[16] and European Environment Agency (EEA)[17]. The inventory data quality objectives

[16] 2006 IPCC Guidelines for National Greenhouse Gas Inventories: http://www.ipcc-nggip.iges.or.jp/public/2006gl/

[17] EMEP/EEA air pollutant emission inventory guidebook – 2013: http://www.eea.europa.eu/publications/emep-eea-guidebook-2013

are to achieve the principles of Transparency, Completeness, Consistency, Comparability and Accuracy (TCCCA):

- **Transparent in:**
    - o The description of methods, assumptions, data sources used to compile estimates in internal (spreadsheets and other calculation tools) and published material (e.g. the NIR) and on the inclusion of national and EU wide assumptions (e.g. source category detail and the split between EU ETS and non EU ETS sources, implementation of policies and measures, carbon contents of fuels, site specific estimates, national statistics such as population, GDP, energy prices, carbon prices etc.).
    - o The documentation of QA/QC activities and their implementation using internal checklists and summarised in relevant public material (e.g. NIR).

- **Complete:** and include all relevant (anthropogenic) emission/removal activities, using representative data for the national territory for socio-economic assumptions and policies and measures for all required years, categories, gases and scenarios.
- **Consistent:** across trends in emissions/removals for all years (especially where applicable between the historic and projected estimates) and that there is internal consistency in aggregation of emissions/removals. Where possible, the same methodologies are used for the base year and all subsequent years and consistent data sets are used to estimate emissions or removals from sources or sinks.
- **Comparable:** with other reported emission/removal estimates through use of the latest reporting templates and nomenclature consistent with reporting requirements. Using the correct IPCC category level and consistent units for expressing mass of emissions/removals by gas, split between EU ETS and non EU ETS sources, scenarios, units for parameters and of input parameters with EU assumptions (e.g. energy prices, carbon price, population etc.).
- **Accurate:** ensuring the most accurate methods are used in the application of methods, minimising the uncertainty in assumptions and in use of data sources used for the estimates and inclusion of national and EU wide assumptions.

The overall aim of the inventory QA/QC system is to meet the above objectives, and to minimise the risk of errors in the UK inventory data such that emission estimates are not knowingly over- or under-estimated as far as can reasonably be judged.

The inventory QA/QC system also reflects that quality is one of three often competing attributes for a given project scope: quality, time, and resources. Noting that the complete set of UK GHGI and AQPI estimates contain a large number of large and small contributors to emissions/removals, ***key category analysis*** is used to prioritise the most important categories (i.e. the highest-emitting source categories in the UK and/or the most uncertain sources). More resources and time are typically directed towards method development, compilation, reporting and associated QA/QC activities for these key source categories, with simpler methods and less rigorous approaches typically applied to lower-emitting / more certain (non-key) source categories.

1.6.2.2 Roles and Responsibilities

The QA/QC plan sets out specific responsibilities for the different QA (review) and QC (data controls, checking) activities and to different roles within the inventory compilation and reporting team. These are embedded within compilation and processing spreadsheets and databases. Training and project management communication across the inventory agency ensures that these responsibilities are clear, with specific tasks and checks signed-off at appropriate stages throughout the inventory process. The following responsibilities are outlined in the QA/QC plan:

- **QA/QC Manager ("Senior Analyst")**: Coordinates all QA/QC activities and manages the contributions from data suppliers, sector experts and independent experts and undertakes cross cutting QA/QC activities. Maintains the QA/QC plan, co-ordinates action across the team to: set quality objectives, communicate and implement QA/QC activities, identify training and development needs (individual, systematic);
- **Knowledge Leaders**: Lead the technical development and implementation of the NAEI programme, supporting the QA manager and Project management team in delivering the project to meet technical requirements of international reporting as well as UK-specific and other output quality expectations. Manage periodic review and perform final checking activities on data and report submissions.
- **Project Manager**: Manages project finances and manage/attend project meetings, communicating project tasks and requirements to the team. Manage team resources and support QA Manager, Technical Director and Knowledge Leaders in identifying and resolving resource limitations (e.g. skills gaps, continuity planning);
- **Task Managers /Sector Experts**: Task managers (or sector experts) are responsible for the maintenance of task documentation (e.g. compiler manual, scope documents, quality checking records and correspondence) and task QA Plan to include: definition of checking requirements; timeline delivery of work; coordination of task sign-off; identification of team training requirements and risk management. They perform sector specific review and checking activities and report to the QA/QC Manager. Sector Experts also collaborate with data suppliers and other key stakeholders to review data quality (input data and outputs), perform quality checks on supplied information, assess and report on uncertainties associated with NAEI outputs. Identify improvement requirements for their tasks / sectors and promote / implement cross-cutting QAQC improvements by sharing best practice and engaging in team communication activities; and,
- **External Review experts:** Provide expert/peer review of projections for specific sectors and report to the **QA/QC Manager**.

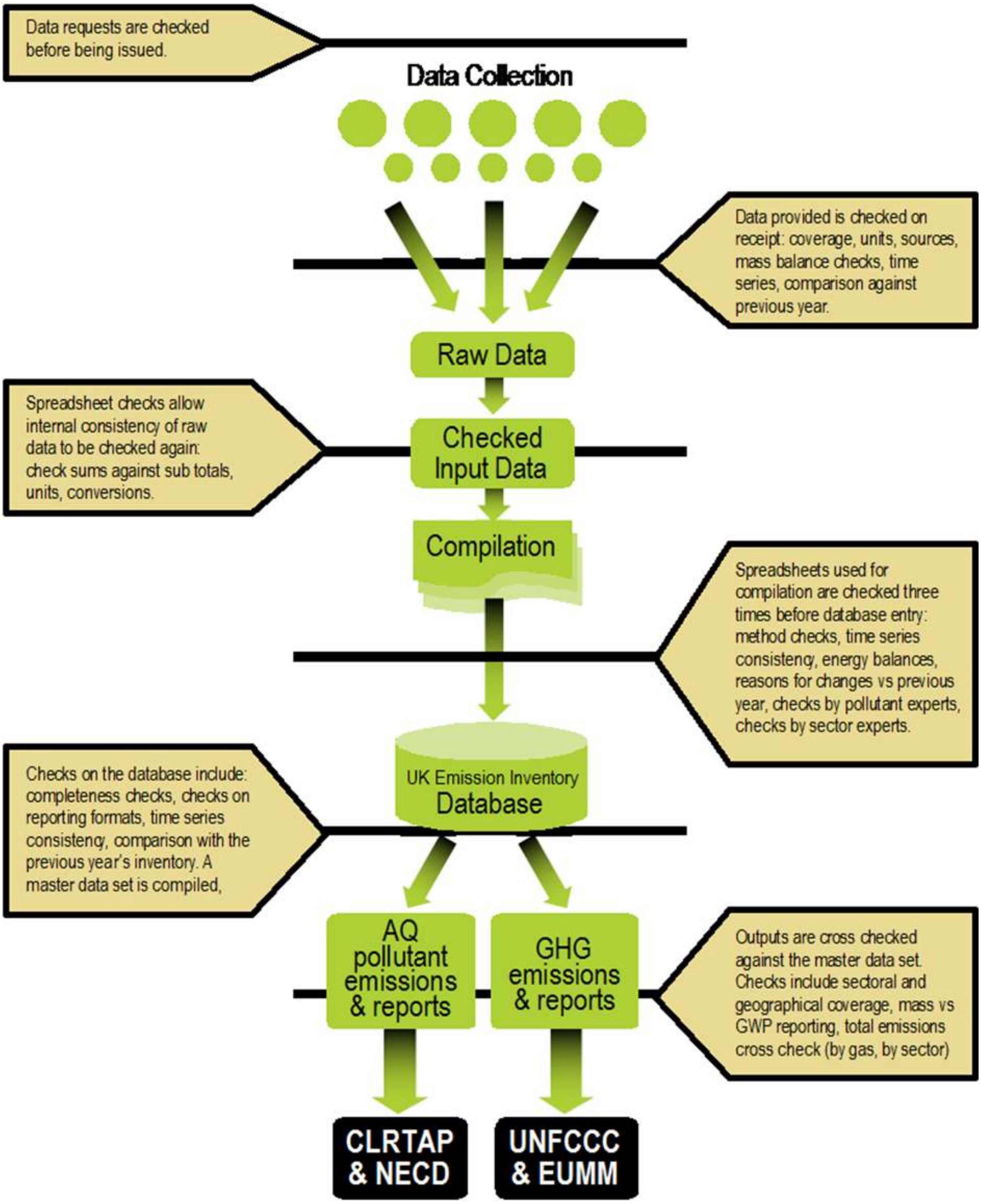
1.6.2.3 Timeline

The QA/QC plan sets out a detailed timeline for QA/QC checks. The timeline is designed to fit in with compilation and reporting requirements for all UK GHG and Air Pollutant reporting commitments.

1.6.2.4 Quality Control and Documentation

The UK's GHGI Quality Control (checking, documentation and archiving) occurs throughout the data gathering, compilation and reporting cycle**. Figure 1.5** illustrates the process of data checks used within the UK greenhouse gas inventory. The horizontal bars symbolise 'gates' through which data does not pass until it meets the quality criteria and the appropriate checks have been performed.

Figure 1.5 Quality Checks throughout the UK inventory compilation process



Checking and documentation is facilitated by specific custom data storage and handling systems and procedures developed for the GHGI compilation that include:

1. **A database of contacts** containing uniquely referenced data on suppliers, data users, detailed data requirement specifications (including requirements for supplier QA/QC and uncertainty information) and data supplied to and delivered from the GHGI. This database tracks all data sources and suppliers used for the estimation of emissions/removals with unique references that are used to tag datasets through the

inventory compilation process. The contacts database also tracks all outputs from the GHGI including formal submissions and data supplied in response to informal and ad-hoc data requests.

2. **<u>Individual data processing tools</u>** are used to prepare the majority of source data into suitable AD and EFs for UK emissions estimates. These data processing tools (spreadsheets and Database models) are uniquely identified and include ***QC procedures, summaries and source data referencing and documentation within them***. QC procedures are embedded in the tools which provide ***sector specific checks*** (e.g. energy/mass balance) and implied emission factor checking for default and country specific emission factors. The QC procedures within each tool/spreadsheet include ***calculation input/output checking*** cells and flags to identify calculation errors. ***The QC summary*** sheets in each tool/spreadsheet include links to QC activities that need to be performed, flags for the QC activities, their status and sign off; details of source data; key assumptions, methods, data processing activities and progress; the scope of activities, gases and years included; relationships with other processing spreadsheets (where inter-dependencies exist); records of authorship; version control and checking. All relevant ***cells in the data processing spreadsheets are colour coded*** for ease of reference indicating whether the cells are calculation cells, output cells, checking cells or data input cells. All input cells carry a reference to the unique data source and data supplier held in the contacts database so all source data can be traced back to its originator and date of supply. ***All spreadsheets are subject to second-person checking*** prior to data uploading to the NAEI database.

3. **<u>A core database (NAEI database) of AD and EFs</u>** with embedded tier 1 QC routines and data source and data processing referencing. The database provides the quality assured data source of emission/removal estimates used for reporting (including CRF population), responding to ad-hoc queries or deriving other downstream estimates (e.g. emissions by Devolved Administration and emissions by Local Authority). The detailed Activity Data and Emission Factor components for each estimate are held within the central database and include all sources, activities, gases/pollutants (GHGI and AQPI) and years. The majority of data in the database are imported directly from the individual data processing tools/spreadsheets (described above). ***Data transparency:*** All data points in the database carry a reference that pinpoints either the upstream data processing tools used to derive the data, the external data source and supplier or both. It also includes details of the date entered, the person uploading the data, its units (to ensure correct calculation), and a revision or recalculation code (which ensures that recalculations of historic data can be easily traced and summarised in reports). ***Automated data import routines*** used to populate the database minimise transcription errors and errors resulting from importing data that has not been properly checked. This process extracts output data from the upstream data processing tools/spreadsheets and can be controlled by the Inventory Agency via a data import dashboard. The automated system ensures that data is only uploaded to the database once it meets specified QA/QC criteria of data checking, completion and consistency. A number of ***detailed QC checking queries***[18] are embedded within the database that support the annual QA activities defined in the QA/QC Plan and include:

    a. Checks with previous submissions for changes due to recalculations or errors at a detailed level (a designated auditor identifies sources where there have

[18] A full list is included in the QA/QC plan.

been significant changes or new sources. Inventory compilers are then required to explain these changes to satisfy the auditor)[19]

b. Assessment of trends and time series consistency for selected key sources
c. Mass balance checks to ensure that the total fuel consumptions in the GHG inventory are in accordance with those published in energy National Statistics from BEIS
d. Other activity data checks (e.g. production and consumption with National Statistics)
e. Implied Emission Factor checks (assessing trends in IEF and comparison with previous submissions)
f. A consistency check between IPCC output and CORINAIR formatted output.

4. **Data extraction checking routines and procedures:** Data exported from the NAEI database and entered into reporting tools (e.g. the CRF Reporter tool) are finally checked against the direct database output totals to ensure that any inconsistencies are identified and rectified prior to submission. This includes interrogating the output xml from the CRF software and comparing this against a series of queries from the NAEI database to compare both emissions and activity data.

5. **Official annual reports to UNFCCC and UNECE** provide full documentation of inventory estimation methodologies, data sources and assumptions by source sector, key data sources and significant revisions to methods and historic data, where appropriate. In addition the annual report to the UNFCCC includes details of planned prioritising improvements identified by the Inventory Agency and agreed by the National Inventory Steering Committee, and from Expert and Peer Reviews. Any data presented in reports are checked against accompanying submission datasets and the NAEI database.

6. **Archiving**: At the end of each reporting cycle, all the database files, spreadsheets, on line manuals, electronic source data, records of communications, paper source data, output files representing all calculations for the full time series are frozen and archived on a central server. An annual report outlining the methodology of the inventory and data sources is produced. Electronic information is stored on hard disks that are regularly backed up. Paper information is archived in a Roller Racking system with a simple electronic database of all items references in the archive.
   - The agriculture inventory (compiled by Rothamsted Research, North Wyke) is backed up on a daily basis on their network storage system. This system is mirrored with the Rothamsted Research Harpenden site, comprising an offsite backup.
   - At CEH, all data and information relating to the LULUCF inventory is stored on a networked drive (accessible only by the project team) which is backed up daily by CEH computer support. There is a separate folder for each inventory year and at the end of an inventory cycle the final versions of all datasets remain unchanged for back reference if required. In addition to this the model code used within CEH for inventory compilation is stored in a subversion repository to ensure a clear record of all amendments and iterations.

1.6.2.5 Quality Assurance and Verification

Quality Assurance and verification activities provide an objective, independent review of inventory source data, methods and assumptions. These activities are primarily conducted to

[19] This is somewhat more detailed than the recalculation explanations required by Table 8 in the CRF, as it is based on the more disaggregated source sectors used in the NAEI database.

assess compliance with reporting requirements (e.g. comparing UK inventory methods against international guidelines) and also to identify areas for future inventory improvement. QA and verification activities include:

1. Assessment of improvements against recommendations and the Inventory Improvement Programme lists of required improvements.
2. Official annual review of changes to estimates and trends, prior to submission, by stakeholders supplying key datasets and by UK government departments responsible for the inventory reporting.
3. Peer/Expert review of methods, assumptions and data sources for new / revised estimates and on a periodic basis for key categories to determine whether methods should be improved due to the availability of new datasets and assumptions (focussing on key categories).
4. Documentation of recalculations and changes to the estimates.
5. Verification analysis (e.g. comparison of trends with trends in ambient measurements).

1.6.2.5.1 NISC annual review

Annually and prior to submission the National Inventory Steering Committee (NISC) review the emissions inventory datasets. The NISC is tasked with the official consideration and approval of the national inventory prior to submission to the UNFCCC. The NISC comprises key stakeholders, including the Single National Entity (BEIS) (see Institutional Arrangements section), who have an understanding of the GHG estimates and input data sources.

1.6.2.5.2Stakeholder Consultation with Key Data Providers

The inventory agency consults with a wide range of stakeholders in order to ensure that the UK inventory uses the best available data and research, interprets information from data providers correctly and improves outputs to address user requirements. The inventory agency plans and participates in a series of one-to-one meetings and engagement activities each year. Stakeholder consultation activities completed to date during the compilation of the 1990-2015 inventory include:

<u>Department for Business, Energy & Industrial Strategy</u>

- The inventory agency met with the BEIS energy statistics team that produces the Digest of UK Energy Statistics to discuss what changes (to both activity and methodology) were expected in the 2016 publication of the statistics, and to clarify some outstanding queries. Subsequently, improvements to the inventory activity data were identified and implemented for the 2017 submission, including:
    - Derivation of a consistent time series of activity data for wood use in the residential and industrial sectors; the BEIS team had derived revised activity data for 2013 onwards and therefore an extrapolation of the revised DUKES methodology was derived for earlier years in the time series;
    - Improved understanding of the scope of reported data within the UK energy statistics on renewables, biomass/biofuels and fossil and bio-carbon sources in waste-derived fuels. This has led to several revisions in the assumptions applied to generate emission estimates, including revision of the NCVs applied to activity data to derive emission estimates from combustion of biomass in several sectors.
    - Improved understanding of the data sources and uncertainties associated with the DUKES data for commodities such as lubricants, leading to a change in approach to reconciling sector-specific lubricant estimates with overall UK demand statistics.

- Consultation with the BEIS Offshore Inspectorate to request clarifications on the scope of EEMS reported data for several individual installations, to ensure correct interpretation of the available data.

Environmental Regulators

- Meetings, teleconferences and emails with sector experts and emission inventory analysts from the environmental regulatory agencies in the UK (Environment Agency - EA, National Resources Wales - NRW, Scottish Environment Protection Agency - SEPA and Northern Ireland Environment Agency - NIEA) and plant operators. These were undertaken to address source-specific emission factor uncertainties and obtain up to date information regarding site-specific activities, abatement and changes to plant design or scope of reporting.
- As in previous years we have contacted environmental regulators to clarify discrepancies between the Pollution Inventory (PI) and EU ETS, and other data sources, including to work through PI/SPRI data clarifications for the 2017 submission

Other data providers

- Consultation with gas network operators regarding data reporting discrepancies for the gas supply sector across recent years, and to obtain new estimates of leakage from the UK gas transmission system including from gas storage installations following changes to storage capacity in recent years.
- Consultation with the UK Solid Fuel Association to seek any new data on fuel sales, fuel composition and type, and the main sectors into which SFA members sell their products.
- Consultation with industry contacts in the waste management sector and within Defra to identify and assess the usefulness of new activity data on commercial and industrial waste disposed to landfill, for inclusion within the UK landfill model.
- Consultation with non-ferrous metal operators to obtain new information to help improve estimates of petroleum coke use by the sector.
- Consultation with the British Aerosols Manufacturers Association (BAMA) to obtain new data on non-MDI aerosol emissions and to seek insights into F-gas market responses to the EU F-gas Regulations.

1.6.2.5.3 Expert, Peer and Bilateral Reviews

The UK's programme of bilateral and external peer reviews is managed by the NISC as part of the improvement programme. Bilateral reviews are initiated with other countries as a means to learn from good practice in other countries as well as to provide independent expertise to review estimates. The UK has participated in a number of bilateral exchanges and the current contract makes allowances for biennial bilateral reviews.

Since 2002, the UK has implemented a programme of peer reviews by experts outside of the organisation responsible for the 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 and EU review processes.

Review activities to date are summarised in the table below.

Table 1.12 Summary of Peer and Bilateral review activities

Review description	Summary
2006 - 2016: Annual UNFCCC review	Annual review by the UNFCCC expert review team. Reviews highlight reporting issues of transparency, completeness, consistency, comparability or accuracy that need to be resolved by the UK. A list of the current issues and their status are provided in Chapter 10. No annual review was carried out by the UNFCCC in 2015 due to delays in reporting.
2016: Review under the Effort Sharing Decision	A full review was conducted for all Member states. Reviews highlight reporting issues of transparency, completeness, consistency, comparability or accuracy that need to be resolved by the UK. A list of the current issues and their status are provided in Chapter 10.
2015: Review under the Effort Sharing Decision	Although a full review for all Member States was not conducted, the UK volunteered for the second stage of the review to consider any potentially significant issues. None were found with the UK submission.
2015: Bilateral review with Denmark, focussing on energy and IPPU sectors.	Bilateral review with Denmark, focusing on energy, and industrial processes and product use. Also considered the changes made to the UK NIR for the 2015 submission, in the absence of a formal UNFCCC review. The findings of the review fed into the compilation of the 2016 inventory submission.
2015: Multi-lateral review with Germany, France, Netherlands, Denmark, on QAQC.	The UK participated in a multi-lateral review workshop hosted by the German UBA inventory team, to consider the IPCC 2006 Guidelines on QAQC and review implementation across all participating countries to exchange best practice, identify any areas of ambiguity and/or difference in Member State approach to QA implementation. The findings fed into a paper submitted by UBA to the EU Working Group 1 for inventory agencies.
2014: Independent Review of the UK Kyoto Protocol LULUCF Inventory Estimates	Preparatory review to the UNFCCC assessment of UK KP reporting.
2014: Bilateral review with Germany, focussing on the energy and waste sectors	Bilateral review with Germany, focusing on the energy balance, iron and steel, refineries, the chemical industry and waste and biofuels. The recommendations from this review fed into the UK inventory improvement programme.
2012: Peer review of all except Sector 5. Conducted by EC Technical Expert Review Team	The review focussed on non LULUCF sectors and provided a report for each Member State (including the UK) highlighting recommendations for improvements as well as documentation of any revised estimates as a result of the review. The UK made 3 minor (in total ~ 0.1%) revisions as recommended by this review for lime production and burning of biomass for energy to address underestimates, and for Dairy Cattle to address an over estimate. The review also presented another 20 recommendations for the UK to consider.
2011: Bilateral review of F-gases (2E, 2F) between Austrian, German and UK inventory teams	The object of the review was to share methods, experiences and potential data sources across the three teams and to provide recommendations on how to improve each of the inventories for these sectors. The recommendations for the UK were added to the UK GHGI improvement programme for consideration by the NISC.
2010 and **2008**: Peer review of Refrigeration and air conditioning	Assumptions about leakage rates and the mix of HFC fluids in each sub-sector were peer reviewed, by a workshop of experts in 2008. Losses during manufacture/initial charging and at decommissioning in the original refrigeration sector model were generally based on factors recommended by the IPCC or the recommendations from

(2F1) with Industry experts; SKM Enviros	this workshop. The model was again peer reviewed by SKM Enviros in 2010, and has since been replaced by new research in 2011.
2009: Peer review of LULUCF (5). BEIS funded peer review, CRH independent team	BEIS funded an external peer review of the research programme that provides LULUCF emissions estimates to the Greenhouse Gas Inventory in 2009. In addition, in 2009 the LULUCF inventory project was audited by an independent CEH team to confirm compliance with the Joint Code of Practice, where the project was praised for its high standards.
2008: Bilateral review of Agriculture (4) with the French inventory team	The objectives of the review were to develop emissions inventory capacity in collaboration with France, and to provide elements of expert peer review to meet quality assurance requirements under national inventory systems e.g. Article 5, paragraph 1, of the Kyoto Protocol and European Union Monitoring Mechanism (EUMM) e.g. 280/2004/EC. Specific activities undertaken included sharing good practice between the UK and France and the development of ideas for efficient future technical collaboration.

1.6.2.5.4 Capacity building and knowledge sharing

The UK actively participates in capacity building and knowledge sharing activities with other countries. These initiatives are usually led by the NISC but also include some projects led by Ricardo Energy & Environment (the inventory agency) and funded by the EU and EEA through the European Topic Centre on Air and Climate Mitigation. The list below highlights some recent examples of these activities.

1. Study tour by representatives of the Israeli Ministry of Environmental Protection and Central Bureau of Statistics, who compile the GHG inventory for Israel.
2. Knowledge sharing with Chinese energy statisticians on GHG emissions trading and statistics.
3. Capacity building activities in South Africa in the agricultural sector.
4. Knowledge sharing with the Romanian GHG inventory team during December 2011 to support the improvement of energy sector reporting.
5. Knowledge sharing with the Chinese Energy Research Institute regarding the UK experience of integrating facility-level data into the national inventory and outlining all of the QA procedures that govern energy and emissions data from facility to sector to national level within the UK, to support their efforts in developing a national system of data management to account for GHG emissions, working from provincial and facility-level data.
6. Capacity building in Spain – invited presentation of the UK agricultural inventory improvements and further conversations with Spanish government representatives.
7. Knowledge sharing with Russian and French inventory teams.
8. CEH participation in annual yearly knowledge sharing with European LULUCF inventory compilers at EU Joint Research Council LULUCF meetings.
9. Knowledge sharing with the Vietnam inventory team.
10. Capacity building workshop with Balkan EU accession countries on National System development.
11. Study visit by delegation from the Chinese National Center for Climate Change Strategy and International Cooperation (NCSC) as part of their week-long visit to the UK arranged by BEIS. Ricardo hosted representatives from NCSC, BEIS and Welsh Government, presenting on compilation and usage of national, devolved, local and city inventories.

12. Knowledge sharing between CEH LULUCF inventory compilers and Maltese LULUCF inventory compilers in 2016.

1.6.3 Verification

BEIS 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 on the west coast of the Republic of Ireland. The UK Met Office employs the Lagrangian dispersion model NAME (Numerical Atmospheric dispersion Modelling Environment) to sort the observations made at Mace Head into those that represent northern hemisphere baseline air masses and those that represent regionally-polluted air masses arriving from Europe. 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 and provide a fully independent estimate of annual emission trends for the UK. The technique has been applied to 3 year rolling subsets of the data.

Since 2013, work has extended to three new sites across the UK, at Angus (north of Dundee), Talcolneston (Norfolk), and Ridge Hill (Herefordshire), to create the UK DECC (Deriving Emissions linked to Climate Change) Network. The Angus site was then replaced by a site at Bilsdale in the north of England. The data from these additional sites has resulted in significant increases in spatial and temporal resolution, and hence, improvement in UK estimates. The uncertainties associated with the UK emission estimates have also decreased.

Most recently a comparison of inventory estimates of HFC-134a with those modelled through the InTEM system has suggested that the inventory may be over estimating its HFC-134a emissions. Further analysis of the mobile air conditioning sector of the inventory, the main UK source of HFC-134a, has suggested several parameters with high uncertainty that may be the source of the difference. Revisions to the refrigeration and air conditioning model (to review assumptions following the implementation of the EU f-gas regulations, and to look consider computational errors in the model) have been made, and this comparison is now in better agreement.

The complete results of the verification using the atmospheric observations and a more detailed description of the modelling method used are given in **Annex 6** of the UK NIR.

1.6.4 Treatment of Confidentiality

Many of the data necessary to compile the UK inventory are publicly available. The main exception relates to the reporting of emissions from SF_6, PFCs and HFCs from some sources. For example, private companies that have provided data to estimate emissions of these gases from training shoes have provided data on condition that the data remains confidential, and it is therefore not possible to report emissions of PFC or HFC species from this source in isolation. Therefore, a number of sources are reported in combination, and estimates of the total emissions in the main IPCC categories are provided.

In addition, industrial production data are commercially sensitive in a handful of cases, such as cement production and adipic acid production. For adipic acid production, whilst emissions data are reported openly, the production data (required within the CRF to derive Implied Emission Factors to enable cross-party benchmarking) are reported as confidential using the notation key “C”. For cement, data for clinker production in Great Britain are reported since these are publically available. UK data are not used since this would allow the calculation of clinker production for Northern Ireland, which is supplied in confidence.

Detailed EU ETS data are also supplied by the regulators to the Inventory Agency, which allows further analysis of the data to develop new emission factors or to cross check fuel use data with other sources. This detailed data set is not publically available, and therefore information obtained from the analysis of this data is suitably aggregated before it can be explicitly reported within the CRF tables or the NIR.

The UK National Inventory Reports from the 1999 NIR onwards, and estimates of emissions of GHGs, are all publicly available on the web; see http://naei.defra.gov.uk/

1.7 GENERAL UNCERTAINTY EVALUATION

1.7.1 GHG Inventory

The UK GHG inventory estimates uncertainties using both Approach 1 (error propagation) and Approach 2 (Monte Carlo simulation) described by the IPCC. Approach 1 provides estimates of uncertainty by GHG according to IPCC sector. Approach 2 considers the correlations between sources and provides estimates of uncertainty according to GHG in 1990 and the latest reporting year, and by IPCC sector.

Approach 2 (Monte Carlo simulation) suggests that the uncertainty in the combined GWP weighted emissions of all the greenhouse gases is 5% in 1990 and 3% in 2015. The trend in the total GWP weighted emissions expressed as the fall between 1990 and 2015 is -38%, with a 95% confidence interval of between -35% and -41%.

A full description of the uncertainty analysis is presented in **Annex 2**.

1.8 GENERAL ASSESSMENT OF COMPLETENESS

1.8.1 GHG Inventory

The UK GHG inventory aims to include all anthropogenic sources of GHGs. Table 9 of the CRF shows sources of GHGs that are not estimated in the UK GHG inventory, and the reasons for those sources being omitted.

Completeness of the KP-LULUCF inventory is reported in **Chapter 11**.

2 Trends in Greenhouse Gas Emissions

2.1 DESCRIPTION AND INTERPRETATION OF EMISSION TRENDS FOR AGGREGATED GREENHOUSE GAS EMISSIONS

Total emissions of direct greenhouse gases have decreased by 38% between 1990 and 2015 and 3.8% between 2014 and 2015. This decline between 1990 and 2015 is driven predominantly by a decrease in emissions from the energy sector – particularly from power stations (IPCC category 1A1a). The following sections of this report provide an interpretation of this trend, focusing on the trends by gas, and by source sector. The decline between 2014 and 2015 is primarily due to a significant switching from coal use to other, less carbon intensive fuels and renewables.

Unless otherwise indicated, percentages quoted are relative to net emissions (i.e. emissions including removals from LULUCF). The geographical coverage used for calculating all figures is the UK and the Crown Dependencies and Overseas Territories to whom the UK's ratification of the UNFCCC has been extended and are provisionally included in the scope for the second commitment period of the Kyoto Protocol.

The percentage changes presented in this chapter are calculated from emission estimates held at full precision within a database, therefore they may differ slightly from those that could be calculated from rounded figures presented in this report.

Table 2.1 UK Greenhouse Gas Emissions by Gas, 1990-2015 in Mt CO_2e

Emission Year	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3	Total
1990	598	135	51	14.4	1.7	1.3	0.0004	802
1995	560	129	42	19.1	0.6	1.3	0.0008	751
2000	558	111	31	9.9	0.6	1.8	0.0017	713
2005	558	89	27	13.1	0.4	1.1	0.0003	689
2010	499	68	24	16.5	0.3	0.7	0.0003	609
2011	456	65	23	14.9	0.4	0.6	0.0003	561
2012	477	62	23	15.5	0.3	0.6	0.0003	578
2013	465	57	23	15.8	0.3	0.5	0.0004	562
2014	424	54	23	16.0	0.3	0.5	0.0004	518
2015	406	53	23	15.9	0.3	0.5	0.0004	499

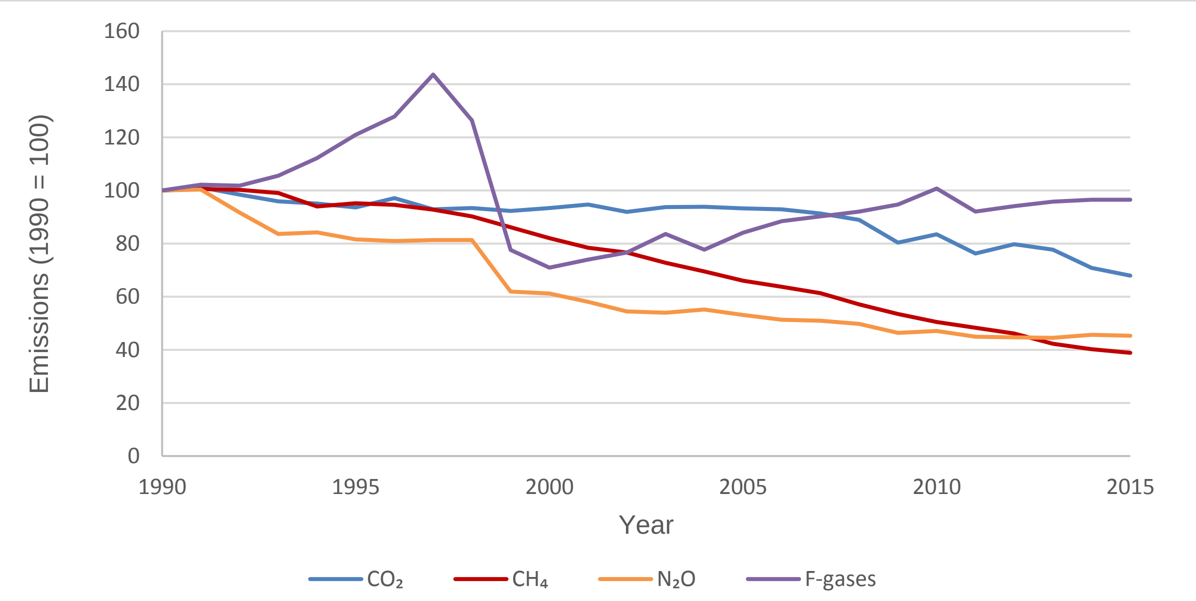
2.2 DESCRIPTION AND INTERPRETATION OF EMISSION TRENDS BY GAS

The largest contributor in terms of CO_2 equivalent is CO_2 at 81% of the weighted emission in 2015. CH_4 contributes 10.5% and N_2O 4.7%. In spite of their high GWPs the contribution of fluorinated greenhouse gases is small at around 3.4% of total GHG emissions. This is because their mass emissions are very small.

Table 2.2 UK Greenhouse Gas Emissions by Gas in 1990 and 2015

Unit	Year	CO_2	CH_4	N_2O	F-Gases	Total
Mt CO_2e	**1990**	598	135	51	17.3	802
	2015	406	53	23	16.7	499
% Share	**1990**	75%	17%	6%	2%	100%
	2015	81%	11%	5%	3%	100%

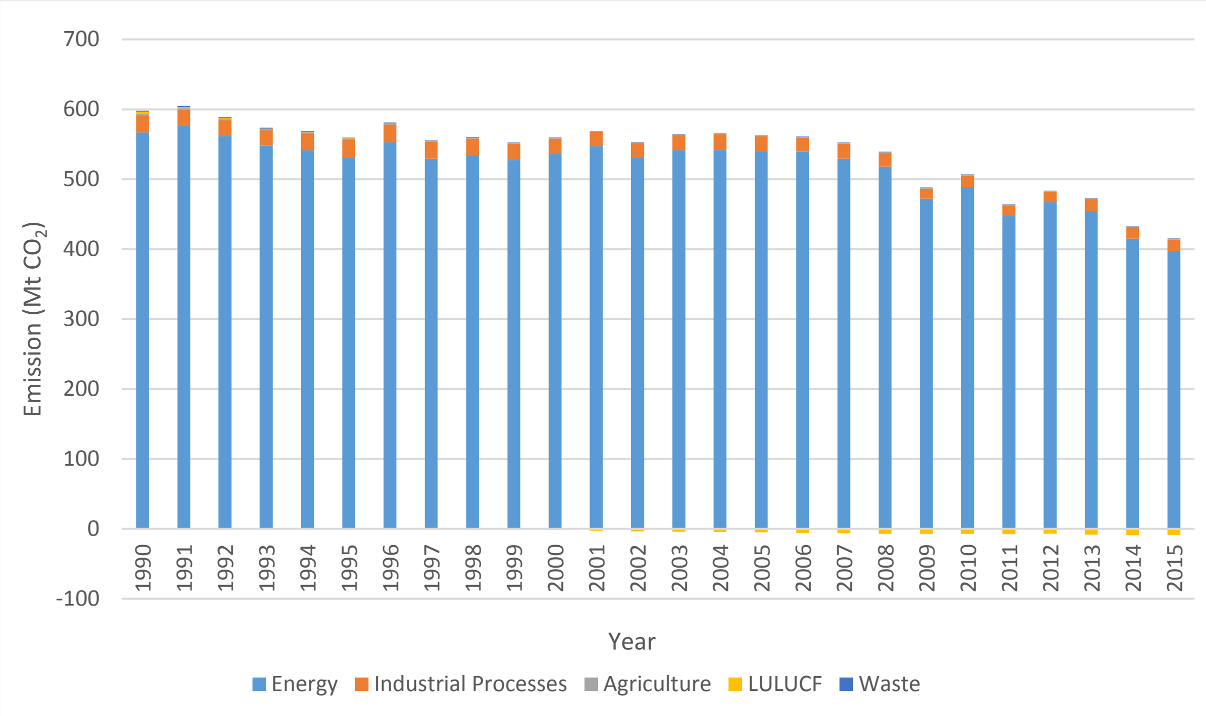
Figure 2.1 Trend in Greenhouse Gas Emissions by Gas, 1990 to 2015, relative to 1990 Emission Levels.



2.2.1 Carbon Dioxide

In 2015, CO_2 emissions were 406 Mt CO_2 equivalent, 32% below the 1990 level and 4.1% below the 2014 level. The trend in CO_2 emissions is illustrated in **Figure 2.2**, which shows that the total emissions are dominated by the energy sector, which is the main driver for the declining trend in emission, through fuel switching, structural change, and improvements in end-use efficiency. Because of the strong link between power generation and CO_2 emissions, short term trends can be dominated by UK temperatures. In cold years like 1996 and 2010 there is an increase in demand for power for heating and in warm years like 2011 and 2014 there is a decrease. **Figure 2.2** includes net emissions and removals of CO_2 from LULUCF.

Figure 2.2 UK CO_2 Emissions Trend by Sector for 1990 to 2015



2.2.2 Methane

Figure 2.3 illustrates the trend in emissions of methane, broken down by source. Methane is the second most significant greenhouse gas in the UK after CO_2, and has decreased by 61% since 1990 and 3.3% since 2014. In 2015, methane emissions were 53 Mt CO_2 equivalent.

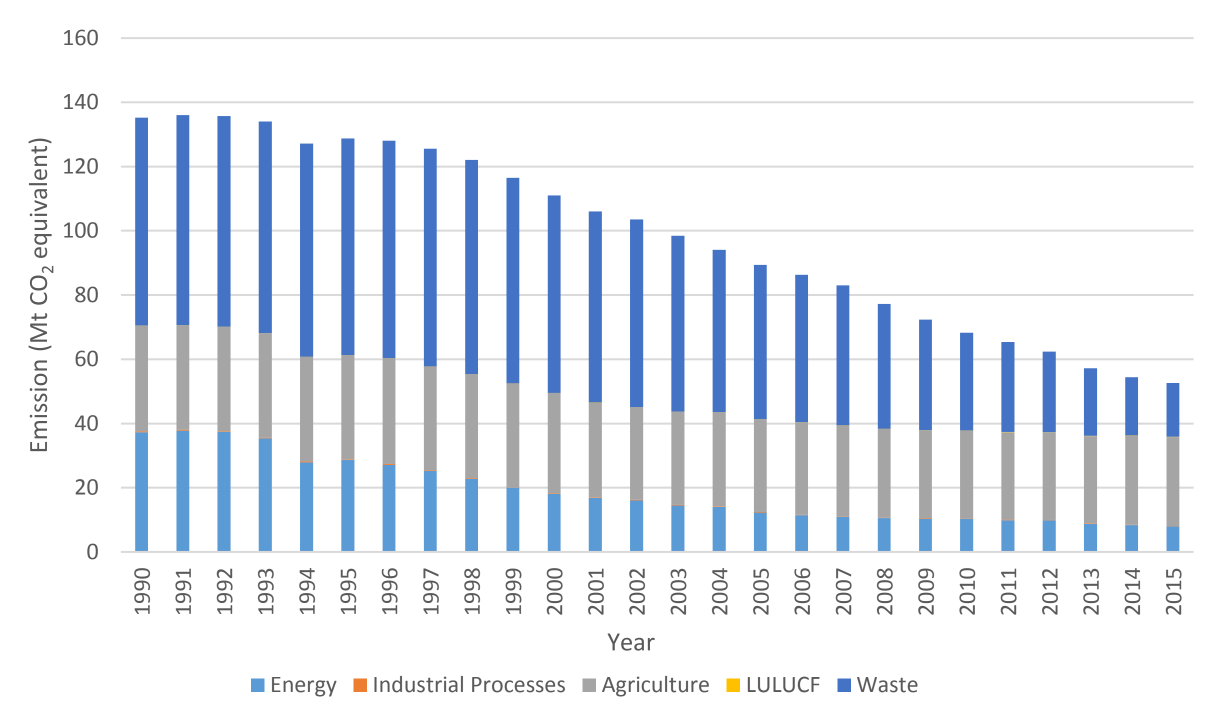
The major sources of methane are agriculture, waste disposal, leakage from the gas distribution system and coal mining. Emissions from all these sources have declined since 1990, and the main reasons for these are:

- In the energy sector, emissions have reduced by 79% since 1990 and 5.3% since 2014. The main causes for the long term reduction are reduced coal mining activity and improvements to the gas distribution network. Decreases in this sector have contributed 36% to the total decrease in methane emissions since 1990 and 25% to the total decrease in net methane emissions since 2014[20];
- Total emissions in the waste sector have decreased by 74% from 1990 to 2015 and 8% from 2014 to 2015 due to increased implementation of methane recovery systems at landfill sites. The reduction in emissions in this sector is responsible for 58% of the total decrease in methane emissions since 1990 and 78% of the net decrease in methane emissions since 2014[20];
- Emissions from agriculture have decreased by 16% since 1990 and increased by 0.4% since 2014[20], following the trend of livestock numbers. This sector is responsible for 6% of total reductions in methane emissions.

[20] The contribution of the energy and waste sectors to the net decrease in methane emissions since 2014 total more than 100% because the agriculture sector actually shows increases in methane emissions overall when compared to 2014.

Emissions from LULUCF and Industrial Processes and other product use are not significant sources of methane in comparison to the other sectors.

Figure 2.3 UK CH_4 Emissions (Mt CO_2e) Trend by Sector for 1990 to 2015



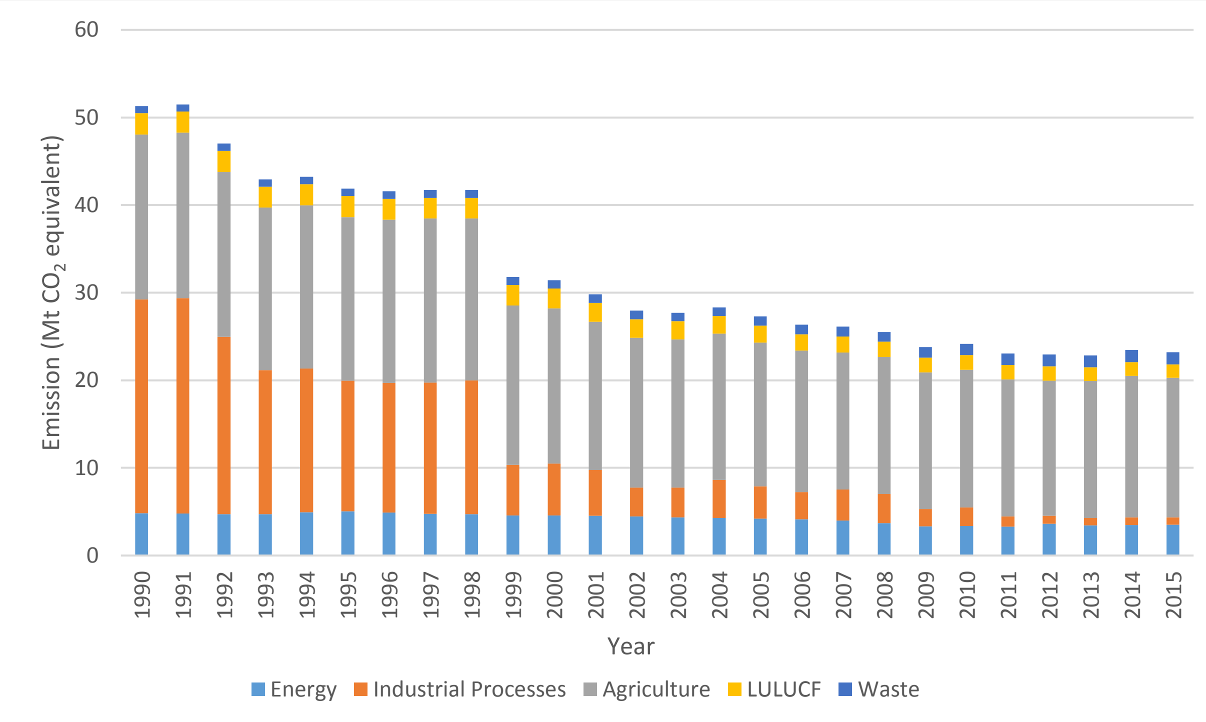
2.2.3 Nitrous Oxide

Figure 2.4 illustrates the trend in emissions of N_2O. The main anthropogenic sources are agriculture, waste and industrial processes. In 2015, emissions of N_2O were 23 Mt CO_2 equivalent. Emissions have declined 55% since 1990 and decreased by 1.0% since 2014, and the main reasons for these reductions are:

- The agriculture sector is a major source of N_2O emissions, contributing 69% to total emissions of N_2O in 2015. Emissions from this sector have decreased by 15% since 1990, mostly due to a decrease in emissions from sector 3D, agricultural soils, driven by a fall in synthetic fertiliser application;
- Although total emissions are dominated by agriculture, the trend in emissions across the time series is driven by a significant reduction in emissions from Industrial Processes and other product use. In 1990, nitric and adipic acid production were both significant sources of N_2O, contributing 46% to total N_2O emissions whereas in 2015, these sources accounted for only 0.19%. This has been a result of nitric acid production plant closures combined with the installation of abatement equipment at the adipic acid plant in 1998 (the effect of this can be seen in **Figure 2.4**), which itself closed in early 2009. Emissions from Industrial Processes have decreased by 97% from 1990 to 2015, contributing 84% to the total decline in N_2O emissions since 1990. Emissions from Industrial Processes have decreased by 2.9% from 2014 to 2015, but this represents a decrease of only 0.025 Mt CO_2 equivalent.
- Fuel combustion is also a significant N_2O source, with total emissions from the energy sector contributing 15% to total N_2O emissions in 2015. Emissions from this sector have decreased by 27% since 1990. A 1.6% increase in emissions is due to a number of factors since 2014, the most important of which include increasing N_2O emissions from the road transport sector (in particular heavy goods vehicles and buses),

emissions from mobile agricultural machinery and flaring at upstream oil production sites. The most significant sources within this sector are road transport, industrial combustion and power generation. Both industrial combustion and power generation have shown decreases in emissions since 1990. Road transport emissions increased between 1991 and 1995, and since 2009. Recent increases are due to increases in vehicle kilometres travelled. Otherwise, the time-series is consistently decreasing, primarily due to the changing catalyst technologies, some of which reduce NO_X emissions by converting it to N_2O, the sulphur content of fuel impacts the effectiveness of catalysts and fuel switching, as there's a significant difference in the nitrogen emission from petrol and diesel vehicles. The overall change in the N_2O emissions from the transport sector between 1990 and 2015 is a decrease of 18.8%.

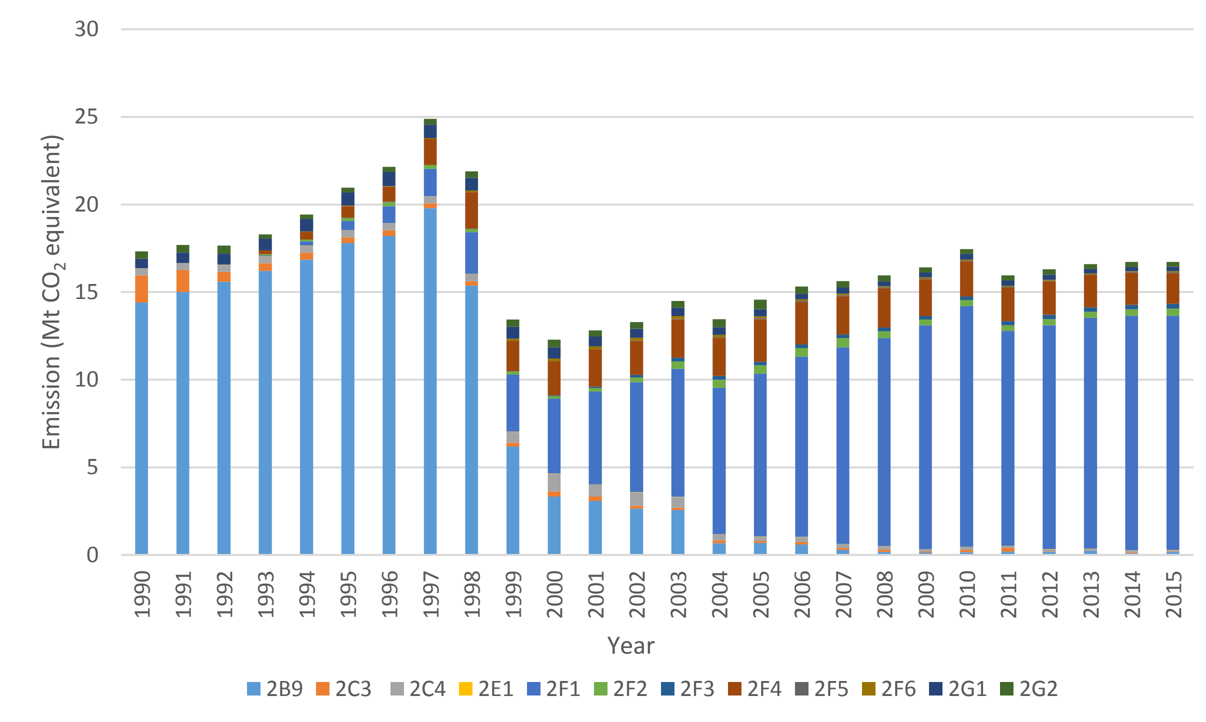
Figure 2.4 UK N_2O Emissions (Mt CO_2e) Trend by Sector for 1990 to 2015



2.2.4 Fluorinated-Gases

Emissions of the F-gases (HFCs, PFCs, NF_3 and SF_6) totalled 17 Mt CO_2 equivalent in 2015. Emissions have decreased by 20% since 1995, the base year used for F-gases, mainly driven by the fall in emissions from F-gas manufacture (sector 2B9), due to the installation of abatement equipment at two of the three manufacturers. The reduction would be much greater if it wasn't mostly offset by the large increases in use of HFCs as substitutes for ozone depleting substances, particularly in refrigeration and air conditioning. Emissions have increased by 0.1% since 2014.

Figure 2.5 UK F- Gas Emissions (Mt CO_2e) Trend by Sector for 1990 to 2015



The IPCC source categories referred to in **Figure 2.5** are:

2B9: Fluorochemical Production

2C3: Aluminium Production

2C4: Magnesium Production

2E1: Integrated Circuit or Semiconductor

2F1: Refrigeration and Air Conditioning Equipment

2F2: Foam Blowing Agents

2F3: Fire Extinguishers

2F4: Aerosols

2F5: Solvents

2F6: Other Product Uses as Substitutes for ODS (in this case transportation of refrigerants)

2G1: Electrical Equipment

2G2: SF_6 and PFCs from Other Product Use (including trainers, electronics, AWACS, tracer gas and particle accelerators)

2.3 DESCRIPTION AND INTERPRETATION OF EMISSION TRENDS BY CATEGORY

Table 2.3 below presents a summary of total GWP weighted emissions by sector. No direct GHGs are reported under Solvents and Other Product Use.

Table 2.3 Total GWP weighted emissions by sector, 1990-2015 (Mt CO_2e)

Year	Energy	Industrial Processes and other Product Use	Agriculture	LULUCF	Waste
1990	609	67	54	6	67
1995	565	61	53	3	69
2000	559	41	50	0	63
2005	557	40	46	-3	49
2010	503	36	44	-6	32
2011	461	32	44	-6	30
2012	481	32	44	-5	27
2013	467	34	44	-7	23
2014	427	34	45	-7	20
2015	409	34	45	-7	18

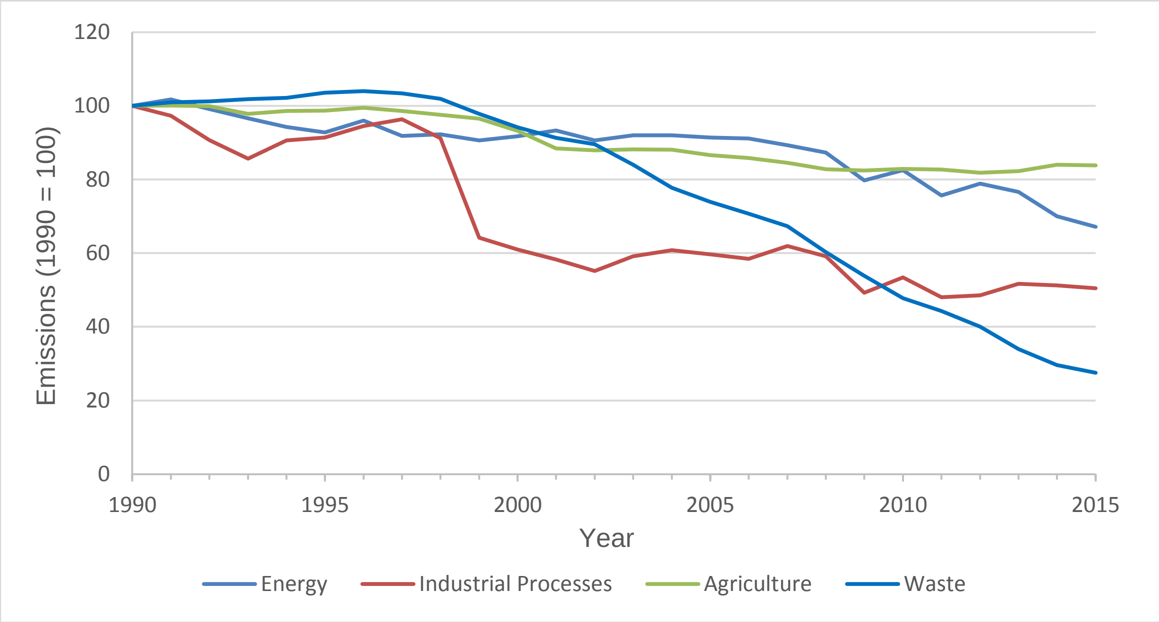
Total emissions are dominated by the energy sector in both 1990 and 2015, contributing 76% to total net emissions in 1990 and 82% in 2015. Emissions from all sectors have declined between 1990 and 2015, with the largest decline in percentage terms from the LULUCF sector, which has gone from a net source to a net sink. In absolute terms, the largest overall decline is in the energy sector.

Table 2.4 Emissions by sector in 1990 and 2015, the emissions trend and share of the UK GHG Inventory total

Sector	Emissions (Mt CO_2e)		Trend	Share	
	1990	2015	1990-2015	1990	2015
Energy	609	409	-33%	76%	82%
Industrial Processes and other product use	67	34	-50%	8%	7%
Agriculture	54	45	-16%	7%	9%
LULUCF[a]	6	-7	-229%	1%	-1%
Waste	67	18	-72%	8%	4%
Grand Total	802	499	-38%	100%	100%

[a] The trend relative to the base year appears extreme because emissions change from a net source to a net sink between 1990 and 2015

Figure 2.6 Trend in GHG emissions by sector for 1990 to 2015, Relative to 1990 Emission Levels[21]



2.3.1 Energy

The largest contribution in 2015 was from the energy sector, which contributed 82% to the total emissions. Energy sector emissions have declined by 33% since 1990 and 4.1% since 2014.

For CO_2; 97% of total net emissions came from this sector in 2015. Energy industries (category 1A1) were responsible for 34% of the sector's CO_2 emissions in 2015. There has been an overall decline in emissions from this sector of 43% since 1990. During the early 1990s, after the privatisation of the power industry in 1990, there was a strong move away from coal and oil generation towards use of gas. Between 2010 and 2012 the trend reversed to see coal use increase, but since then the decreasing trend has continued; the gas use trend also reversed to decrease between 2011 and 2013. Non-nuclear renewable energy generation has over tripled between 2010 and 2015.

Between 1990 and 2003, there was a 20% increase in the amount of electricity generated[22]; this has since dropped to 1% below 1990 generation levels in 2015, between 1990 and 2015 there has been a 49% decrease in CO_2 emissions from power stations (Sector 1A1a). There are several reasons; firstly, the shift towards use of Combined Cycle Gas Turbine (CCGT) stations rather than conventional steam stations burning coal or oil – CCGT stations operate at a higher thermal efficiency, for example in 2013 they operated on average at 47% efficiency, whilst coal-fired stations operated on average at 36% efficiency. Secondly, the calorific value of natural gas per unit mass carbon is higher than that of coal and oil. Thirdly, there has been an increase in electricity generated from non-fossil fuel energy sources, due to increased use of wastes and renewable energy sources, which in 2015, including nuclear energy, provided 44% of UK electricity generation.

Emissions from category 1A2 – Manufacturing Industries and Construction contributed 13% to overall net CO_2 emissions in the UK in 2015. Since 1990, these emissions have declined by

[21] LULUCF is not included on this graph as it would make the other trends difficult to discern, see **Table 2.3** for the numeric trends

[22] Data from DUKES table 5.1.3

44%, mainly as a result of a decline in the emissions from the Iron and steel industry. This sector has seen a significant decrease in coke, coal and fuel oil usage, with an increase occurring in the emissions from combustion of burning oil and waste.

Emissions of CO_2 from 1A3 (Transport) are dominated by road transport (1A3b), which in 2015 were responsible for 97% of the total emissions from transport. Emissions from road transport peaked in 2007 at 11% above 1990 levels. Carbon dioxide emissions from road transport have declined since 2007 back almost exactly to 1990 levels mostly due to improvements in average fuel efficiency of vehicles, switching from petrol to diesel cars and a reduction in traffic volumes. The increased displacement of fossil fuels by biofuels since 2002 has also had a significant impact on total CO_2 emissions as carbon emissions from the consumption of biofuels are not included in the UK totals. Emissions of CO_2 from domestic aviation (1A3a) increased by 66% between 1990 and 2005, but have since shown a decrease of 39% since 2005 and are now just 1% above 1990 levels. This is because of a move to use more fuel efficient aeroplanes in 2006 and a smaller number of air miles being flown.

Emissions of CO_2 in the domestic sector (1A4b) account for 75% of CO_2 emissions in 1A4. Emissions from this sector changed little between 1990 and 2009 but have declined more recently. The effect of annual temperatures can produce some large variations between any two years. Fuel consumption data since 1990 indicates a general trend in fuel switching in these sectors, away from more carbon-intensive fuels such as coal, coke, fuel oil and gas oil, towards natural gas. This shift has partly been driven by fuel prices but also through the growth of the UK gas supply network (most notably in Northern Ireland).

Methane emissions in the energy sector are mostly from fugitive emissions (1B). In 1990, 64% of these emissions came from the production of solid fuels (1B1); however, these emissions have decreased by 84% and now make up just 21% of fugitive CH_4 emissions. Fugitive emissions from oil and gas operations (1B2) have also decreased over this period, by 59%.

N_2O emissions from the energy sector have decreased by 27% since 1990 and accounted for 15% of total N_2O emissions in the UK during 2015. Of this, 27% arose from energy industries (1A1). Within this category, emissions from public electricity production (1A1a) have shown a 54% decrease since 1990. Over this period the use of coal has decreased and the use of natural gas increased, as emissions of N_2O per GWh is significantly lower for natural gas use than coal in power generation, this represents a significant reduction in N_2O emissions.

The other major contribution towards N_2O emissions within the energy sector is the transport sector (1A3) (32%). Road transport emissions increased between 1991 and 1995, and since 2009, consistently decreasing otherwise. The trend is driven by 3 key factors; the changing catalyst technologies (some of which reduce N_2O, but others reduce NO_X emissions by converting it to N_2O, hence increasing N_2O emissions), the sulphur content of fuel (which has decreased significantly due to regulation) impacts the effectiveness of catalysts and fuel switching, as there's a significant difference in the nitrogen emission from petrol and diesel vehicles. The overall change in the N_2O emissions from the transport sector between 1990 and 2015 is a decrease of 19%.

2.3.2 Industrial Processes and Other Product Use

Emissions of direct greenhouse gases within this sector have decreased by 50% since 1990. For 2015, 47% of emissions in this sector were of CO_2, although this made up only 4% of all CO_2 emissions. Only small quantities of CH_4 and N_2O came from this sector in 2015, whilst 100% of F-gases are assigned to industrial processes and other product use.

Since 1990, emissions of CO_2 have fallen by 35%, driven by reductions in activity in a number of key sectors. In particular, CO_2 emissions from 2A1 (cement manufacture) have fallen by 39% due to closure of many kilns and decreasing cement production. Emissions from 2C1 (iron and steel) have fallen by 23%, also due to site closures and decreasing production, and the UK's only primary lead/zinc smelter closed in 2003. The recent upward trend in CO_2 emissions is driven by the iron and steel industry, from which emissions increased by 78% between 2011 and 2013 primarily due to the reopening of a large site that was mothballed in 2010, changed ownership in 2011 and restarted production in 2012. Since 2013, emissions from the sector have declined by 12%, driven largely due to the closure of one site in 2015.

Between 1990 and 2015, emissions of N_2O from this sector declined by an estimated 97% due to reductions in emissions from adipic acid manufacture (a feedstock for nylon) and nitric acid production. N_2O emissions from nitric acid manufacture show falls due to the closure of 4 plants between 2000 and 2008 and due to the installation of abatement technology in the larger of the remaining plants in 2011. Emissions from adipic acid manufacture were reduced significantly from 1998 onwards due to the retrofitting of an emissions abatement system to the only adipic acid plant in the UK, which subsequently closed in April 2009.

Since 1990, emissions of HFCs have increased by 11%. The largest contribution to this sector in 2015 arises from category 2F1 – refrigeration and air conditioning equipment. In 2015, these contributed 84% to the overall emissions of HFCs. Emissions from this category arise due to leakage from refrigeration and air conditioning equipment during its manufacture, lifetime and disposal. Emissions from aerosols contribute the next largest percentage (11%) to overall HFC emissions. In this category, it is assumed that all the fluid is emitted in the year of manufacture. This category contains mainly industrial aerosols and also metered dose inhalers (MDI). Emissions from the manufacture of flurochemicals have decreased by 99.9% since 1990, due to plant closures and the installation of abatement equipment.

PFC emissions have declined by 80% since 1990. A significant source of PFC emissions is aluminium production, which is formed as a by-product during the process of aluminium smelting. Since 1990, emissions arising from aluminium production have decreased by more than 99% due to significant improvements in process control, an increase in the rate of aluminium recycling and the closure of aluminium plants.

The use of SF_6 in magnesium foundries contributed 17% towards total SF_6 emissions in 2015, and national emissions of SF_6 have decreased by 64% since 1990. Emissions from 2G – Other contributed the remaining 83% towards emissions, which is dominated by emissions from electrical insulation. Emissions arise during the manufacture and filling of circuit breakers and from leakage and maintenance during the equipment lifetime. It also includes emissions from applications in the electronics industry, sports shoes, particle accelerators, AWACS and tracer gas.

2.3.3 Agriculture

Direct GHG emissions from agriculture in 2015 consisted of 62% CH_4, 35% N_2O and 3% CO_2. Total agricultural GHG emissions decreased by 16% between 1990 and 2015. CH_4 emissions have declined by 16%, driven mostly by a decline in emissions from enteric fermentation from cattle due to decreased cattle numbers. N_2O emissions have decreased by 15%, which has been driven by both a decline in animal numbers and a decrease in synthetic fertiliser application, particularly to grasslands.

2.3.4 Land Use, Land Use Change and Forestry

The UK has moved from being a net source of CO_2 from LULUCF activities in 1990 to a net sink for all years since 1996, or 2001 for all gases. As the LULUCF sector comprises both emissions and removals of greenhouse gases, expressing the change since 1990 on a percentage basis can be misleading. Total estimated emissions of direct greenhouse gases from the LULUCF sector fell from a source of 6 $MtCO_2e$ in 1990 to a sink of 7 $MtCO_2e$ in 2015. The land use categories which have the greatest effect on the net LULUCF emissions/removals are forest land (a net sink) and cropland (a net source). Forest land was a decreasing sink from 1990 to 2009 due to a lowering of the average age of trees as a consequence of historically low rates of afforestation during the 1990s, but has shown no clear trend in recent years. Emissions from cropland have decreased by 19% since 1990.

Compared to CO_2, emissions of CH_4 and N_2O are relatively low in this sector. Methane emissions from the forestry, cropland, grassland and settlements categories have increased by 59% since 1990. The main reason for the increase in methane emissions is the increase in deforestation areas (controlled burning emissions from deforestation) over the time series. The other source of methane is from wildfires and the time series for this is very variable. Emissions of nitrous oxide have decreased by 38% since 1990.

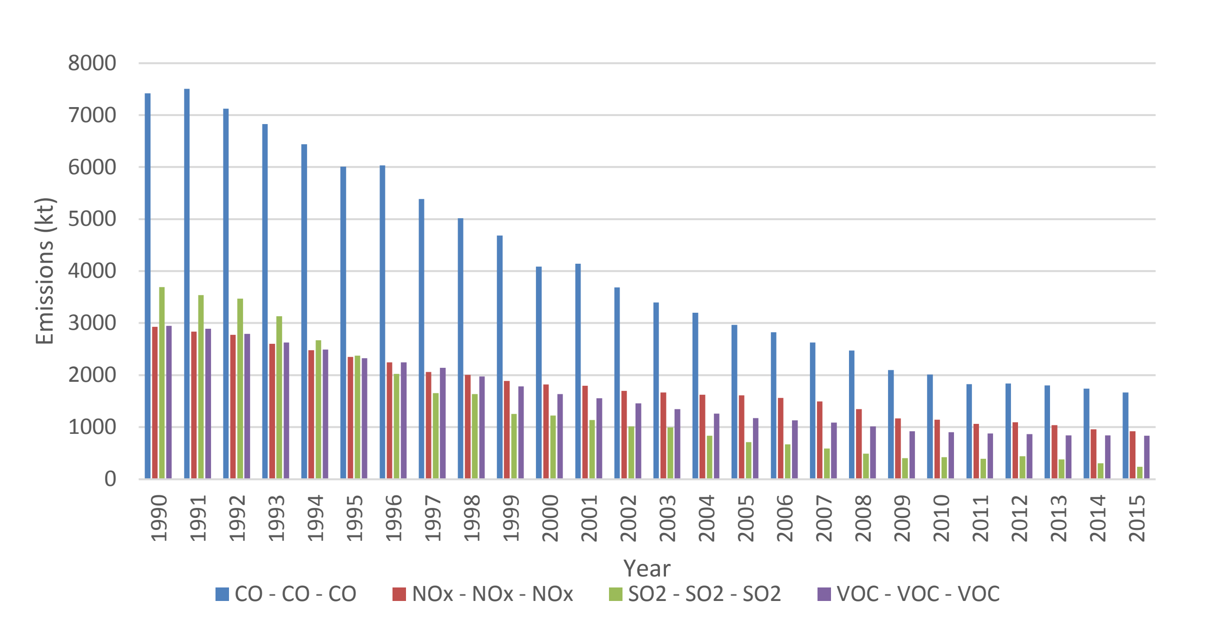
2.3.5 Waste

Overall emissions from the waste sector have decreased by 72% since 1990 and 7% since 2014. Over 99% of this reduction is due to a decline in methane emissions from landfill. Emissions estimates from landfill are derived from the amount of biodegradable waste disposed of to landfill and are based on a model of the kinetics of anaerobic digestion involving four classifications of landfill site. The model also accounts for the effects of methane recovery, utilisation and flaring. Since 1990, methane emissions from landfill have declined by 80% due to the implementation of methane recovery systems. This trend is likely to continue as all new landfill sites are required to have these systems and many existing sites may have systems retrofitted.

2.4 EMISSION TRENDS FOR INDIRECT GREENHOUSE GASES AND SO_2

The indirect greenhouse gases in the UK consist of Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Non-Methane Volatile Organic Compounds (NMVOC) and Sulphur dioxide (SO_2). Of these, NO_x, CO and NMVOC can increase tropospheric ozone concentration and hence radiative forcing. Sulphur dioxide contributes to aerosol formation in the atmosphere. This is believed to have a negative net radiative forcing effect, tending to cool the surface. Emission trends for the indirect greenhouse gases are shown in **Figure 2.7**.

Figure 2.7 UK Emissions of Indirect Greenhouse Gases for 1990 to 2015



2.4.1 Carbon Monoxide

In 2015, the total emissions of CO were 1,669 Gg, and since 1990, emissions have decreased by 77%.

Emissions of carbon monoxide from the energy sector contributed 81% to overall UK CO emissions in 2015, 28% of these emissions occur from transport (1A3). Since 1990, emissions from 1A3 have declined by 92%, which is mainly because of the increased use of three way catalysts, although a proportion is a consequence of fuel switching in moving from petrol to diesel cars.

Emissions from sector 1A2 contributed 25% to overall emissions of CO in 2015. Emissions from within this category mostly come biomass combustion and off-road vehicles used in manufacturing, industry and construction.

2.4.2 Nitrogen Oxides

In 2015, total emissions of NOx were 919 Gg, and since 1990, emissions have decreased by 69%.

98% of NOx emissions in the UK came from the energy sector in 2015. Since 1990 emissions from this sector have decreased by 69%, mostly as a result of abatement measures on power stations, three-way catalysts fitted to cars and stricter emission regulations on trucks. The main source of NO_x emissions from transport contributed 43% to the total emissions of NOx in the UK, 79% of which arising from road transport (1A3b). From 1970, emissions from transport increased (especially during the 1980s) and reached a peak around 1990. The reduction in emissions since 1990 is due to the requirement since the early 1990s for new petrol cars to be fitted with three way catalysts and the further tightening up of emission standards on these and all types of new diesel vehicles over the last decade.

Emissions from the energy industries (1A1) contributed 29% to total NOx emissions in the UK during 2015. Between 1990 and 2015, emissions from this sector decreased by 69%, the main reason for this was a decrease in emissions from public electricity and heat production (1A1a) of 76%. Since 1998 the electricity generators adopted a programme of progressively fitting low NO_x burners to their 500 MWe coal fired units. Since 1990, further changes in the electricity supply industry such as the increased use of nuclear generation and the introduction of CCGT plant have resulted in additional reduction in NO_x emissions.

Emissions from Manufacturing, Industry and Construction (1A2) have fallen by 66% since 1990. In 2015, emissions from this sector contributed 15% to overall emissions of NOx. Over this period, the industrial sector has seen a move away from the use of coal, coke and fuel oil towards natural gas and gas oil usage.

2.4.3 Sulphur Dioxide

In 2015, total emissions of SO_2 were 236 Gg, and since 1990, emissions have decreased by 94%.

93% of emissions of sulphur dioxide came from the energy sector in 2015, 58% of these emissions arose from energy industries (1A1). Since 1990, emissions from power stations (1A1a) have declined by 97%. This decline has been due to the increase in the proportion of electricity generated CCGT stations, other gas fired plants, the increase in the proportion of electricity generated in nuclear plants, and the application of Flue Gas Desulphurisation abatement equipment on several of the largest coal-fired power stations in the UK. CCGTs run on natural gas and are more efficient than conventional coal and oil stations and have negligible SO_2 emissions.

Emissions from Manufacturing, Industry and Construction (1A2) were responsible for 19% of UK emissions of SO_2 in 2015. Since 1990, emissions from this category have declined by 90%. This decline is due to the reduction in the use of coal and oil in favour of natural gas, and also some improvement in energy efficiency.

2.4.4 Non Methane Volatile Organic Compounds

In 2015, total emissions of NMVOCs were 837 Gg, and since 1990, overall emissions have decreased by 72%.

Emissions from the industrial processes and other product use sector contributed 56% to overall UK emissions of NMVOCs. 76% of these emissions in 2015 were from the Non-energy Products from Fuels and Solvent Use sector which contributed 43% to total NMVOC emissions in 2015 and since 1990 emissions have declined by 47%. Most of the remaining NMVOC emissions in the industrial processes and other product use sector are from the food and drink and chemicals industries.

28% of non-methane volatile organic compound emissions came from the energy sector in 2015. Of these, the largest contribution arises from the fugitive emissions of oil and natural gas (1B2), which contributed 13% towards the overall UK emissions of NMVOCs in 2015. This includes emissions from gas leakage, which comprise around 11% of the total for the energy sector, the remaining emissions arise from oil transportation, refining, storage and offshore. Emissions from transport (1A3) contribute 4.4% to overall emissions of NMVOC in the UK in 2015, but emissions from this sector have decreased by 96% since 1990.

2.5 EMISSION TRENDS FROM KP LULUCF ACTIVITIES

The main driver of the emission and removal trends for KP-LULUCF is the degree of forest planting achieved between the 1950s and the 1980s, followed by a period of reduced planting rates. As these forest stands have reached maturity and are now being harvested, the net removal of carbon dioxide from forest management has started to fall. For Article 3.3 activities, new planting expansion of forest area at an average of 24.0 kha per year since 1990 has produced a net removal from afforestation and reforestation that is currently similar in magnitude to the emission from deforestation. Deforestation emissions have however increased since 1990 due to harvesting of mature trees and the creation of open spaces within woodlands.

Harvested Wood Products (HWP) are included in the 2nd commitment period for KP as a carbon pool. For Afforestation land this category includes all domestically produced wood products since 1990. HWP from Deforestation land are estimated on the basis of instantaneous oxidation (i.e. the loss of carbon in the biomass pools is estimated but the carbon transfers to the atmosphere rather than to a HWP pool). The 2nd commitment period of KP uses a Forest Management Reference Level (FMRL), which supersedes the Forest Management Cap used in the 1st commitment period. The UK included HWP in the FMRL using first order decay functions. HWP from Forest Management are only included from 2013 as emissions from HWP from before the commitment period can be excluded as long as there is consistency between the FMRL and the accounting during the commitment period.

For the 2nd commitment period the UK has elected to report on additional Article 3.4 activities (Cropland Management, Grazing Land Management). Cropland Management and Grazing Land management are reported for the first time in this submission.

Figure 2.8 shows net emissions/removals from afforestation, reforestation and deforestation activities (Article 3.3). These activities were a net source of emissions in 1990, becoming a net sink from 1993 onwards.

Figure 2.9 shows the net emissions and removals of greenhouse gases from the Article 3.4 activities Forest Management, Cropland Management and Grazing Land Management. The emissions and removals from Forest Management are absolute values, not values relative to the FMRL.

Figure 2.8 Article 3.3 Emissions and Removals, by gas and by activity

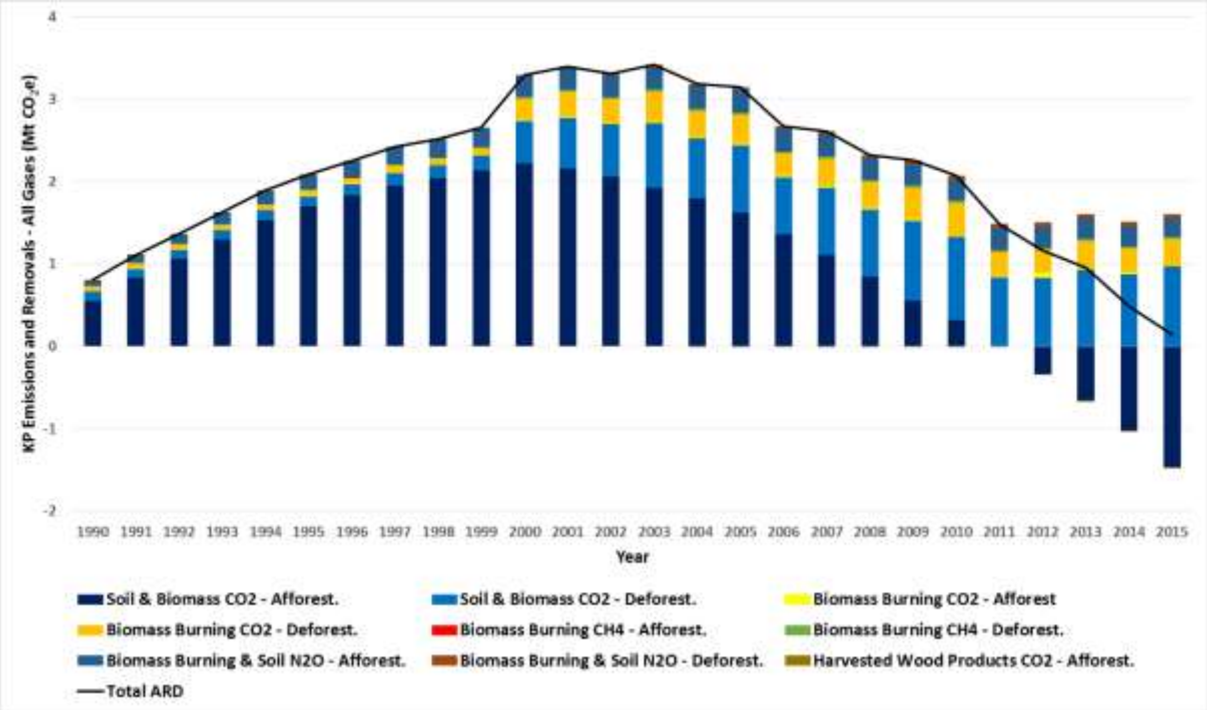
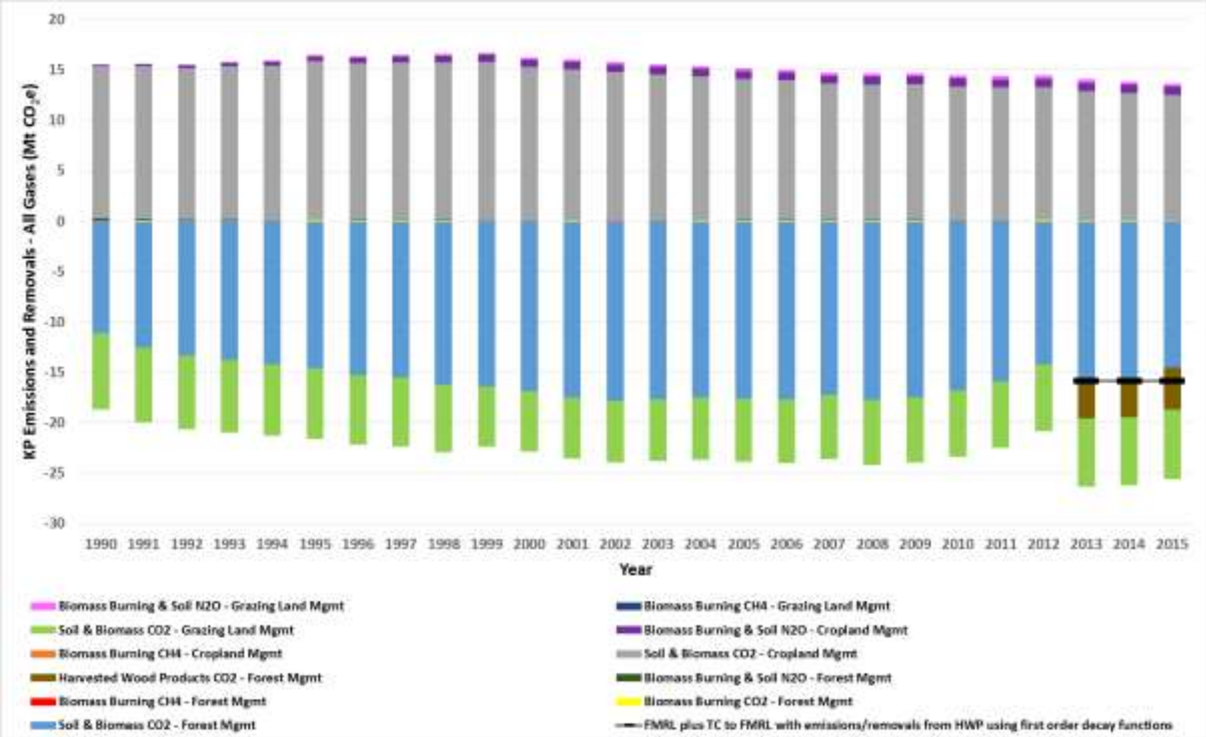


Figure 2.9 Article 3.4 Emissions and removals, by gas and activity



3 Energy (CRF Sector 1)

3.1 OVERVIEW OF SECTOR

Table 3.1 gives an overview of the energy sector. The Key Category Analyses (KCA) rank combines the KCAs, and gives an indication of which categories contain or are a Key Category. Smaller numbers relate to a higher ranking. More detail on how they're derived along with a KCA ranking summary table can be found in **Section 1.5.1**. The uncertainty estimate has been taken from Monte Carlo analysis.

Emission trends are presented for 1990-2015 and 2014-2015. A description of the trends and the main drivers behind these can be found in **Chapter 2**.

Table 3.1 Energy Sector Overview

Energy Greenhouse Gas Source and Sink Categories	KCA Rank[1]	Uncertainty[2]	2015 emissions total (Mt CO_2e)	1990-2015 trend[3]	2014-2015 trend[3]	Recalculation: 2014[4]	Recalculation-: 1990[4]	Methodology reference (NIR Section)
Total Energy			**407**	**-33%**	**-4%**	**-1%**	**-1%**	
A. Fuel combustion activities (sectoral approach)			**396**	**-30%**	**-4%**	**-1%**	**-1%**	
1. Energy industries			**133**	**-44%**	**-13%**	**-1%**	**-1%**	
a. Public electricity and heat production	2, 6, 7, 32	2%	104	-49%	-16%	-1%	-1%	**MS 1**
b. Petroleum refining	2, 6, 7, 32	15%	14	-24%	0%	0%	0%	**MS 1**
c. Manufacture of solid fuels and other energy industries	2, 6, 7, 32	3%	15	9%	5%	0%	0%	**MS 1, MS 2, MS 4**
2. Manufacturing industries and construction			**54**	**-44%**	**-5%**	**-2%**	**-1%**	
a. Iron and steel	5, 8, 10	9%	13	-39%	-11%	0%	0%	**MS 3, MS 4**
b. Non-ferrous metals	5, 8, 10	5%	1	-88%	-2%	-40%	-9%	**MS 3**
c. Chemicals	5, 8, 10	5%	4	-65%	-2%	-13%	0%	**MS 3**
d. Pulp, paper and print	5, 8, 10	6%	2	-56%	-3%	2%	0%	**MS 3**
e. Food processing, beverages and tobacco	5, 8, 10	5%	4	-41%	-1%	1%	-1%	**MS 3**
f. Non-metallic minerals	5, 8, 10	11%	3	-63%	6%	0%	0%	**MS 3**
g. Other (please specify)	5, 8, 10	5%	27	-32%	-3%	-1%	-1%	**MS 3, MS 6**
3. Transport			**118**	**2%**	**2%**	**-1%**	**-1%**	
a. Domestic aviation	30	20%	2	3%	0%	-10%	-11%	**MS 7**
b. Road transportation	1	2%	111	1%	2%	-1%	-1%	**MS 8**
c. Railways	29	18%	2	30%	-6%	0%	0%	**MS 9**
d. Domestic navigation	25	17%	2	9%	5%	-2%	-1%	**MS 10, MS 11, MS 12**
e. Other transportation		20%	1	125%	5%	0%	0%	**MS 6**
4. Other sectors			**90**	**-20%**	**3%**	**-1%**	**0%**	

Energy Greenhouse Gas Source and Sink Categories	KCA Rank[1]	Uncertainty[2]	2015 emissions total (Mt CO_2e)	1990-2015 trend[3]	2014-2015 trend[3]	Recalculation: 2014[4]	Recalculation-: 1990[4]	Methodology reference (NIR Section)
a. Commercial/institutional	3, 13, 19	3%	20	-20%	2%	0%	0%	**MS 5**
b. Residential	3, 13, 19	4%	64	-20%	4%	-1%	0%	**MS 5**, **MS 6**
c. Agriculture/forestry/fishing	3, 13, 19	31%	5	-20%	1%	-2%	0%	**MS 5**, **MS 6**, **MS 10**, **MS 13**
5. Other (as specified in table 1.A(a) sheet 4)			**2**	**-62%**	**-2%**	**0%**	**0%**	
a. Stationary	N/A	N/A	IE	N/A	N/A	N/A	N/A	
b. Mobile	23	8%	2	-62%	-2%	0%	0%	**MS 15**, **MS 16**
B. Fugitive emissions from fuels			**11**	**-74%**	**-3%**	**-1%**	**0%**	
1. Solid fuels		**12%**	**2**	**-92%**	**-14%**	**1%**	**0%**	
a. Coal mining and handling	16		1	-94%	-18%	1%	0%	**MS 17, MS 18**
b. Solid fuel transformation	16		0	-74%	-1%	0%	0%	**MS 4**
c. Other (as specified in table 1.B.1)	N/A	N/A	NO	N/A	N/A	N/A	N/A	
2. Oil and natural gas and other emissions from energy production		**34%**	**9**	**-49%**	**0%**	**-1%**	**0%**	
a. Oil	15, 26		0	-74%	-10%	0%	0%	**MS 19**
b. Natural gas	15, 26		4	-63%	-7%	-2%	0%	**MS 19**, **MS 20**
c. Venting and flaring	15, 26		5	-17%	7%	0%	0%	**MS 19**
d. Other (as specified in table 1.B.2)	N/A	N/A	NO	N/A	N/A	N/A	N/A	
C. CO_2 Transport and storage	**N/A**	**N/A**	**NO**	**N/A**	**N/A**	**N/A**	**N/A**	
1. Transport of CO_2	N/A	N/A	NO	N/A	N/A	N/A	N/A	
2. Injection and storage	N/A	N/A	NO	N/A	N/A	N/A	N/A	
3. Other	N/A	N/A	NO	N/A	N/A	N/A	N/A	
Memo items:(1)	**N/A**	**N/A**	**41**	**69%**	**-2%**	**2%**	**-1%**	
International bunkers	N/A	N/A	**41**	**69%**	**-2%**	2%	**-1%**	
Aviation	N/A	N/A	33	116%	1%	0%	-1%	**MS 7**
Navigation	N/A	N/A	7	-15%	-16%	13%	-1%	**MS 14**
Multilateral operations	**N/A**	**N/A**	**NE**	**N/A**	**N/A**	**N/A**	**N/A**	
CO_2 emissions from biomass	N/A	N/A	**36**	**1109 %**	**16%**	**11%**	**17%**	**MS 1, MS 3**, **MS 5**, **MS 8**
CO_2 captured	**N/A**	**N/A**	**NO**	**N/A**	**N/A**	**N/A**	**N/A**	

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3.2 FUEL COMBUSTION (CRF 1.A)

3.2.1 Comparison of Sectoral and Reference Approaches

The UK compares its Sectoral Approach (SA) and Reference Approach (RA) as one of the means of verification of its energy sector GHG estimates in accordance with the UNFCCC decision 24/CP.19 paragraph 40.

The Sectoral Approach is the detailed ‘bottom up’ sectoral methodology for estimating energy CO_2 emissions described in **Section 3.4**, The Reference Approach is a ‘top down’ approach for estimating energy CO_2 emissions using national fuel statistics that acts as a verification tool for the Sectoral Approach.

The RA-SA comparison shows very close consistency between the two datasets (once the major known differences are accounted for) for the UK, and provides verification of the reported SA emission estimates for 1A. The UK greenhouse gas inventory is compiled using a detailed Sectoral Approach methodology, to produce sector-specific inventories of the 10 pollutants in accordance with the IPCC reporting format. These UK GHGI emission estimates are based on bottom-up activity data, including:

- national energy statistics (DUKES) that present annual consumption of primary and secondary fuels within different economic sectors in the UK; and
- a wide range of other statistical datasets (e.g. raw material extraction and use, production statistics for minerals, metals, glass, cement, specific chemicals, waste statistics, livestock and crop data, land use survey information) to generate estimates of non-combustion emissions from other known sources.

As a verification of 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. This is a top-down inventory compilation method, which 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 very useful quality check against the more rigorous Sectoral Approach.

Differences between the RA and SA arise primarily 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. some 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.

Some minor adjustments to the reference approach has been made this year, mostly in response to review recommendations.

3.2.1.1 Discrepancies between the IPCC Reference and Sectoral Approach

The IPCC Reference Approach total can be compared with the IPCC Table 1A total for all fossil fuels, and under the new 2006 GLs approach the Reference Approach (RA) CO_2 estimates for the UK typically range between **0.5% lower to 2.4% lower** than the comparable bottom-up emission totals of the Sectoral Approach (SA).

There are a number of ‘known differences’ between the reference approach and sectoral approach which are discussed in the subsequent sections.

3.2.1.1.1Statistical Differences in Energy Balance Data

The SA is based on the demand side of the national energy statistics, which is some cases informs us to what quality of fuel may be used (e.g. petroleum coke used for anodes we expect to be calcined). The RA however, uses the supply side of the national energy statistics. The difference between the total of the supply and demand sides of energy statistics is the statistical difference, which is a cause of differences between the RA and SA. Because of evolving methodologies and improved data collection the statistical difference is generally quite small in later years, but as some data are not available for earlier years the gap is much more significant in the 90s.

The system of energy statistics operated by BEIS aims to keep UK statistical differences (without normalisation) at less than 0.5% of energy supply, for total supply and also for each fuel. Nevertheless, a proportion of the difference between the Reference Approach and the Sectoral Approach totals will be accounted for by statistical differences.

3.2.1.1.2Application of Carbon Factors: Aggregated (RA) vs. Detailed (SA)

In the RA the carbon balance is calculated based on the apparent consumption of fuels, for primary fuels (e.g. crude oil). This mean that the estimated carbon content of fuel that's transformed into other fuels (e.g. petroleum products) is assumed to be accounted for by the commodity balance for the primary fuel from which they're derived, which differs from the SA which estimates emissions at end use. Because the estimates of primary and derived fuel carbon contents are made independently, the estimated carbon content of the primary fuel to be transformed and the estimated carbon content of the resulting transformed secondary fuel can differ, particularly as primary fuels have a generally more variable carbon content. In general, we have greater confidence in the SA Carbon Emission Factors (CEFs) because they are fuel/process/site specific and the carbon content of end use fuels are less variable than primary fuels.

3.2.1.1.3Fuels Excluded from the UK RA

Emissions from use of waste oils, fossil-containing wastes, scrap tyres and waste solvents that are reported within the SA but are not included in the estimates for the RA in the UK. The RA doesn't include complete emissions from these fuels because there isn't complete reporting of these fuels in UK energy statistics; the data for the SA is based on EU ETS and operator data.

3.2.1.1.4Treatment of Blast Furnace Gas

Some emissions from the blast furnace gas are reported under IPCC source categories 1A1ci and 1A2 in the UK GHGI SA. In the RA totals, the carbon in the blast furnace gas is excluded from the total, as it is associated with the carbon content of coal and coke deliveries to the iron and steel industry.

3.2.1.1.5Deviations from National Statistics

The UK GHG SA method deviates from UK energy statistics for specific fuels (e.g. natural gas, OPG), in a handful of cases where industry data indicates higher usage than DUKES suggests. More details on deviations from DUKES can be found in **Annex 4.2.1**. As the reference approach is based on DUKES fuel balances, deviations from DUKES will lead to discrepancies between the SA and RA.

3.2.1.2 Comparisons of UK Emissions: Sectoral Approach vs. Reference Approach and *Amended* Reference Approach

Table 3.3 shows the percentage differences in CO_2 emissions from fuel combustion sources between the IPCC Reference Approach and the UK GHGI (Sectoral Approach) IPCC sector 1A, for each year since 1990 and the resulting comparison when we have accounted for most of the known differences. **Table 3.2** gives a summary of the RA/Amended RA-SA comparison for the 3 main fuel groups.

Table 3.2 Summary of RA/Amended RA-SA comparison

	Maximum RA/SA ratio	Minimum RA/SA ratio	Average RA/SA ratio	Average RA % deviation from SA[a]	Maximum amended RA/SA ratio	Minimum amended RA/SA ratio	Average amended RA/SA ratio	Average amended RA % deviation from SA[a]
Liquid Fuels	1.051	0.993	1.012	1.4%	1.017	0.980	0.999	0.7%
Solid Fuels	0.955	0.885	0.917	8.3%	1.035	0.970	1.009	1.4%
Gaseous Fuels	1.027	0.997	1.010	1.0%	1.007	0.994	1.000	0.1%
Total	**0.995**	**0.976**	**0.983**	**1.7%**	**1.013**	**0.990**	**1.002**	**0.4%**

[a] Note that the average deviation is the average of the absolute values of (RA/SA-1) for each year, as the average ratio has the potential to mask the scale of deviations by cancelling out higher and lower deviations.

It can be seen in **Table 3.2** that the reference approach for liquid fuels is generally higher (on average 1.2%[23]) than the sectoral approach; there are some years with larger deviations, the highest being a 5.1% deviation in 2000. In the adjusted RA the values are much closer to the SA (on average 0.1% lower), and the extreme deviations are significantly curtailed so that the greatest deviation in 1996 is less than 2%. There are still some stochastic variations from the SA, which are likely linked to statistical difference which is why the average deviation is significantly higher than the average % difference. By far the most significant difference between the adjusted and non-adjusted RA was our estimate of the impact of the difference in carbon between crude oil and derived petroleum fuels.

For solid fuels we can see that the RA is 4.5-11.5% lower than the SA in all years. This difference is primarily due to the fact that we believe that a significant amount of blast furnace gas is used for energy use (and report this in the energy sector), whereas the guidance recommends that blast furnace gas should be excluded from the RA.

From 2000 the RA for gaseous fuels, which is based on supply statistics, is consistently 0.4-1% higher than the SA and before then the relationship is less consistent. For gaseous fuels, once the known differences presented in national statistics between total supply and total production are accounted for, as well as known inventory deviations from national statistics, the adjusted RA is on average <0.01% lower than the SA and never deviates by more than 0.7%.

The overall comparison between the Reference Approach (RA) and the Sectoral Approach (SA) indicates that in most years the RA estimates are around 1.7% lower than the SA estimates. However, once the RA is amended for known differences, the comparison is much closer with a range of 1.3% higher (in 1992) to 1.0% lower (in 2011) than the SA; the adjusted RA is on average 0.2% higher than the SA.

Overall the SA-RA-amended RA comparison shows that there is very close consistency between the SA and amended RA datasets for the UK, and provides verification of the reported SA emission estimates for 1A.

[23] Note that the average deviation (in this case 1.6%) is the average of the absolute values of (RA/SA-1) for each year, whereas the average % difference (in this case 1.5%) would be the average of (RA/SA-1). Average deviation is always greater than or equal to absolute value of the average % difference.

Table 3.3 Comparison of the UK Sectoral Approach, IPCC Reference Approach and Amended Reference Approach (total CO_2)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Sectoral Approach 1A (Mt CO_2)	559.4	570.1	554.6	540.6	533.4	522.4	543.1	521.9	527.3	521.3	530.3	541.0	525.8
Reference Approach (Mt CO_2)	548.6	563.1	551.8	533.8	524.4	514.8	532.0	509.5	517.8	514.5	526.2	532.9	519.1
Reference Approach (Amended for known differences) (Mt CO_2)	537.1	551.8	541.8	525.2	512.4	505.3	523.0	497.1	509.3	504.7	519.1	525.4	512.4
RA/SA %	-1.9%	-1.2%	-0.5%	-1.3%	-1.7%	-1.5%	-2.1%	-2.4%	-1.8%	-1.3%	-0.8%	-1.5%	-1.3%
RA/SA (amended) %	0.1%	0.8%	1.3%	0.3%	0.6%	0.4%	-0.4%	0.0%	-0.2%	0.6%	0.6%	-0.1%	0.0%

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Sectoral Approach 1A (Mt CO_2)	535.9	536.3	534.1	534.2	523.8	513.1	467.4	484.6	443.2	463.4	450.5	410.5	393.1
Reference Approach (Mt CO_2)	525.0	526.6	527.2	523.7	511.8	503.8	459.1	476.2	432.6	454.0	442.7	401.6	387.7
Reference Approach (Amended for known differences) (Mt CO_2)	512.2	513.5	516.3	511.8	498.5	492.7	450.3	469.8	426.3	446.1	433.4	391.2	379.3
RA/SA %	-2.0%	-1.8%	-1.3%	-2.0%	-2.3%	-1.8%	-1.8%	-1.7%	-2.4%	-2.0%	-1.7%	-2.2%	-1.4%
RA/SA (amended) %	0.3%	0.6%	0.8%	0.3%	0.3%	0.3%	0.1%	-0.4%	-1.0%	-0.3%	0.3%	0.4%	0.8%

3.2.2 International Bunker Fuels (memo item)

International bunker emissions (international aviation and shipping) are not included in the national total but are reported separately.

These estimates are consistent with the revised Tier 3 method now adopted for aviation and described in **MS 7** and the revised Tier 2 method adopted for shipping as described in **MS 14.** The methods for the calculation of international bunker fuels are presented in the relevant method statements.

Each year the Inventory Agency confirms that the UK energy balance is consistent with data submitted to EUROSTAT and IEA and that the total fuel consumption used for the GHG estimates is consistent with the UK energy balance. For marine bunkers the UK GHG estimates are based on the difference between a bottom up calculation of domestic fuel use for domestic shipping (including military uses of fuels allocated to domestic) and the UK energy balance allocation for all marine fuels. This leads to a different domestic/international split in fuel use allocation for marine fuels from the allocations in the national energy statistics (DUKES) and submissions to IEA/EUROSTAT.

3.2.3 Feedstock and Non-Energy Use of Fuels

The methodology for estimating emissions from fuels used for non-energy purposes is set out in the relevant sections of this NIR. A summary of the method, including all non-energy uses is included in **Annex 3**.

The UK energy statistics (DUKES, 2016) contain an allocation for non-energy use for each fuel in the commodity balance tables. The UK inventory estimates emissions from fuels, including emissions arising from non-energy uses. In some cases, the inventory estimate for non-energy use does not agree with the DUKES allocation, and reallocations are made between energy and non-energy use for inventory reporting. In 2013, the Inventory Agency carried out research into non-energy uses of fuels; this was followed up by the DECC energy statistics team during 2014, and a series of revised allocations were introduced in the Digest of UK Energy Statistics 2014 (DECC, 2014), improving consistency between the inventory and the UK energy statistics. The activity data used for the national inventory and any deviations from the UK energy balance are presented and explained in **Annex 4**.

The evidence that the Inventory Agency uses to make estimates for NEU includes:

- annual reporting by plant operators (e.g. EU ETS returns include data on the use of process off-gases in the chemical and petrochemical production sector);
- periodic surveys or research by trade associations / research organisations / environmental regulators, such as to assess the fate of coal tars and benzoles, petroleum coke or waste oils, or the impact of regulations on solvents, waste, product design and use; and,
- information on the estimated split of stored: emitted carbon from feedstock chemicals in literature sources, including other country NIRs, where UK-specific information is not available.

In many cases the energy statistics allocate fuels to non-energy use that are used in chemical and petrochemical production processes where either:

- fossil carbon-containing off-gases are used for combustion in facility boilers; or
- products containing the “stored” carbon are subsequently used / partly combusted / disposed and degraded with some proportion of the “stored carbon” in products ultimately emitted to atmosphere.

In other instances, the allocation of fuels to "non-energy use" in the UK energy balance is contrary to other statistical evidence from industry or surveys that the Inventory Agency has access to in the compilation of the national inventory. For example, in the UK the allocation of petroleum coke to domestic and industrial combustion sources in the energy balance are missing for many years in the time series, whereas evidence from environmental reporting and research indicates that several industries use petroleum coke directly as a fuel or process input (e.g. cement kilns, chemical manufacturing processes, domestic fuel manufacturers).

3.2.4 Use of UK Energy Statistics in the GHG inventory

The main source of official national statistics and energy balances data used in the UK inventory is the Digest of UK Energy Statistics (BEIS, 2016), hereafter referred to as DUKES. This annual publication gives detailed sectoral energy consumption broken down by fuel type, and covering the entire time period relevant to the inventory. In many cases, these data are used directly in the inventory without modification. However, the activity data used to derive emission estimates in the UK inventory may not exactly match the fuel consumption figures given in DUKES and other national statistics. This occurs for one of four reasons:

- Data in DUKES and other national statistics are not always available to the level of detail required for inventory reporting. *For example, activity data within DUKES do not distinguish between fuel used in stationary and mobile combustion units. Emissions from these different types of appliances have to be separately reported in the inventory and furthermore they exhibit very different combustion characteristics and therefore require application of different emission factors in the UK inventory.*
- Data in DUKES and other national statistics are subject to varying levels of uncertainty, especially at the sector-specific level, and in some cases more accurate data are available from other sources. *For example, the EU Emissions Trading System provides more accurate fuel use data for several high-emitting industrial sectors which is used in preference to DUKES data.*
- DUKES and other national statistics do not include any data for a given source. *For example, DUKES does not provide any information on secondary fuels such as process off-gases that are derived from petroleum feedstocks and are commonly used as fuels in petrochemical and chemical industries.*
- Where the BEIS DUKES team make improvements to national energy statistics, they typically do not revise the full time series of data; usually, DUKES data are retrospectively revised for up to the 5 most recent years. This can lead to step changes in the DUKES time-series that are due to methodological differences rather than reflecting real changes in fuel use. Therefore, to ensure time series consistency of reported emissions, the inventory agency works with the BEIS energy statistics team to derive a defensible historic time series back to at least 1990 for use in the UK inventory. *For example, in DUKES 2015 the estimates for residential wood use were significantly revised due to new research into uptake of biomass combustion units. In this case, the data were only revised back to 2008 in the DUKES 2015 statistical publication, therefore new activity data for wood use in 1990-2007 were estimated by the inventory agency in consultation with the DUKES team, which are then used in the inventory in place of the published DUKES data.*

The rationale for those modifications or deviations from DUKES data that are made, and the sources of alternate data are discussed in the sections detailing methodology for each CRF source category that follow **Section 3**. A summary of all modifications is given in **Annex 4**.

The modifications described above involve changes to the sector-level estimates of fuel use used in the UK inventory, when compared with the original source data from DUKES. As a general rule, the overall demand for each fuel in the UK inventory is kept consistent with the overall demand for that fuel in DUKES; the Inventory Agency approach is such that in almost all cases, any modifications to the sector allocation of DUKES data is matched by an equal and opposite allocation change in another sector, to ensure a zero net change in fuel demand relative to DUKES. **Annex 4** includes a series of tables that demonstrate this consistency between the UK inventory and DUKES.

There are some exceptions to the general rule of consistency with DUKES, for petroleum coke and for OPG, where other statistical evidence indicates that the energy balance data for fuel combustion sources is incorrect, and where re-allocations of fuel use from the "non-energy use" lines in DUKES are made by the Inventory Agency (see **Annex 4**).

Apart from DUKES, the main other data source used for fuel use estimates in the inventory is the installation-level data available for processes covered by the EU Emissions Trading System (BEIS, 2016), which has been analysed and compared with the data from DUKES. Further details of the analysis of EU ETS and use of the data within the UK GHG inventory are given in **Annex 7**. Further fuel consumption data are taken from the Environmental Emissions Monitoring System (EEMS) data set (BEIS Offshore Inspectorate, 2016) and from data supplied by the UK Mineral Products Association (MPA, 2016), and from the UK solid fuel supply sector (Roberts, 2015). These are used to modify fuel use and emission estimates for 1A1c, 1A2f, and 1A4b respectively, and are described more fully in the sections below that deal with those source categories.

Fuel use estimates for transport sources also rely upon data taken from DUKES, with some further detail provided from other sources.

3.2.5 Biomass

Combustion of biomass and other biofuels is included in the UK energy statistics and also in the UK inventory. The inventory considers the possible use of such fuels in all subsectors of CRF 1A. The UK energy statistics reports biomass activity data that are complete for all UK consumption, presented across a number of source sectors (including: 1A1a, 1A2g, 1A3b, 1A4b and 1A4c). These data are not wholly consistent with the needs of inventory reporting, and it is likely that biofuels reported in 1A2g will include some consumption within 1A2d, 1A2e and 1A4a, but the inventory agency does not have any data on which to base estimates at this greater level of sector resolution.

Greenhouse gas emissions including CO_2 are estimated for these fuels and presented in the relevant sections of the CRF. The CO_2 emissions from biomass are, however, not added to the total UK emissions from fuel combustion and are instead recorded as a memo item. Emissions of N_2O and CH_4 from biomass combustion are included within the UK inventory totals although in the case of emissions from use of biofuels in road transport, the emissions are not reported separately, and are instead included in the emissions reported for petrol and DERV. The impact of biomass use on carbon stocks in the UK is recorded in the LULUCF sector; biomass imported into the UK will affect the LULUCF sector in the country from which the biomass is imported.

3.2.6 Unoxidized Carbon

When fuels are combusted, a small proportion of the carbon in the fuel is not fully oxidized. For example, unburnt carbon can remain in the ash left after combustion of coal. Emission estimates for CO_2 need to take account of any carbon in fuels that remains long-term in this unoxidized form.

In the UK Inventory, it is assumed that unoxidized carbon is only significant for solid fuels. For gaseous and liquid fuels, although some carbon might not be oxidized fully during combustion (for example emitted as VOC or particulate matter), based on discussions with fuel suppliers, it is assumed than any indefinite storage of unoxidized carbon will be sufficiently trivial to be ignored. For solid fuels, UK-specific assumptions are employed, either based on expert judgements provided by UK industry, or based on EU ETS returns. **Table 3.4** summarises the assumptions used.

Table 3.4 Levels of unoxidized carbon assumed for the UK GHGI

Fuel Type	Fuel sub-type	Source Sector	Years	Assumed unoxidized carbon	
				UK GHGI[c]	IPCC default
Gaseous	All fuels	All sectors	All	0%	0%
Liquid	All fuels (incl. petroleum coke)	All sectors	All	0%	0%
Solid	Coal	1A1a	1990-2004	2%[a]	0%
			2005	1.8%[b]	
			2006	2.0%[b]	
			2007	1.7%[b]	
			2008	2.0%[b]	
			2009	1.9%[b]	
			2010	1.9%[b]	
			2011	1.8%[b]	
			2012	1.7%[b]	
			2013	1.8%[b]	
			2014	1.8%[b]	
			2015	1.8%[b]	
		1A2f (cement)	All	0%	
		1A4b	All	0%	
		All others	All	0%	
	Anthracite	1A4b	All	0%	
	Coke, solid smokeless fuel	1A4b	All	0%	
		All others	All	0%	

[a] Expert judgements provided by UK fuel producers and fuel users (see Baggott *et al, 2004*).

[b] Calculated from site-specific EU ETS returns for all UK coal-fired power stations.

[c] From the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, unless otherwise stated.

3.3 CO_2 TRANSPORT AND STORAGE

Currently in the UK, CO_2 emitted from flue gases is not captured and stored. This source is not occurring for the UK.

3.4 METHOD STATEMENTS

The rest of the energy chapter is structured using a series of inventory compilation “method statements” in order to group together categories where the source data and methods are similar, thus avoiding unnecessary repetition of method descriptions and improving the clarity of the NIR. The method statements are numbered, and are cross referenced with the summary table for the sector (**Table 3.5**), and have been grouped broadly to combine method statements for stationary combustion, then mobile combustion, then fugitive sources.

Table 3.5 Method Statement Scope: IPCC and Source Categories

MS number	IPCC categories	Source categories
Stationary combustion		
MS 1	1A1a, 1A1b, 1A1ciii	Power stations, refineries and other energy industries (collieries, gas production, nuclear fuel production)
MS 2	1A1cii	Upstream oil and gas production - combustion
MS 3	1A2	Manufacturing industries and construction (excluding iron and steel use of derived fuels, and off road machinery)
MS 4	1A1ci, 1A2a, 1B1b, 2C1	Iron and steel, and coke manufacture
MS 5	1A4ai, 1A4bi, 1A4ci	Other stationary combustion
Mobile combustion		
MS 6	1A2gvii,1A3eii, 1A4bii, 1A4cii	Off-road machinery
MS 7	1A3a, *Memo item*	Aviation, International aviation
MS 8	1A3b	Road Transport
MS 9	1A3c	Railways
MS 9	1A3d, 1A4ciii	Shipping – coastal, and fishing in UK waters
MS 11	1A3d	Shipping between UK and Gibraltar, and between UK and OTs
MS 12	1A3d	Inland Waterways
MS 13	1A4ciii	Fishing outside of UK territorial waters
MS 14	*Memo item*	International shipping
MS 15	1A5b	Naval Shipping
MS 16	1A5b	Military aircraft
Fugitive sources *(Except 1B1b – see MS 4)*		
MS 17	1B1ai, 1B1aii, 1B1a2i	Coal mining and handling (excluding closed coal mines)
MS 18	1B1a1iii	Closed coal mines
MS 19	1B2	1B2 excluding: Oil refining, storage and distribution (1B2aiv to v) and natural gas distribution (1B2biii to v)
MS 20	1B2biv, 1B2bv	Gas leakage – transmission, distribution, point of use

MS 1 Power stations, refineries and other energy industries

Relevant Categories, source names

1A1a: Power stations

1A1b: Refineries

1A1ciii: Collieries, gas production and nuclear fuel production

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Burning oil, Coal, Colliery methane, Fuel oil, Gas oil, Landfill gas, Liquid bio-fuels, LPG, MSW, Naphtha, Natural gas, OPG, Orimulsion, Petrol, Petroleum coke, Poultry litter, Refinery miscellaneous, Scrap tyres, Sewage gas, Sour gas, Straw, Waste oils and Wood

[Note that this MS excludes: coke production, smokeless solid fuel production (both MS 4) and upstream oil and gas production (MS 2).]

Background

This Method Statement (MS) includes information about UK power stations, refineries and other energy industries.

Table 3.6 shows the number of power stations in the UK, by the type of fuel burnt. The main fossil fuels used by the UK electricity supply industry are bituminous coal and natural gas. The number of coal stations has decreased markedly across the time series, and the number of gas fired stations increased until 2012 but has declined since then. The share of total UK electricity generated in 2015 was 26% from coal and 30% from natural gas. Nuclear stations generated a further 24%, and almost all of the remaining 20% was generated from renewables (6%) or non-thermal sources such as wind and hydro (14%).

Biomass is being burnt at an increasing number of power generation sites to help electricity generators meet Government targets for renewable energy production. These sites use poultry litter, straw, or wood as the main fuel, whilst many coal-fired power stations have increased the use of biofuels such as short-rotation coppice to supplement the use of fossil fuels. Electricity is also generated in a large number of engines running on biogas at landfill sites and sewage treatment works. CO_2 emissions associated with biofuel combustion are estimated and reported as memo items, but not included here; these emissions will be reflected in the LULUCF carbon stocks of the country producing the fuel. Emissions of other greenhouse gases from biofuel use are estimated and included in the national inventory totals, in accordance with IPCC guidance on the treatment of biofuel-derived emissions.

Electricity is also generated at an increasing number of Energy from Waste (EfW) installations in the UK. Formerly classed as municipal solid waste (MSW) incinerators, all such installations have since the late 1990s been required to be fitted with boilers to raise power and heat, and their emissions are therefore reported under CRF source category 1A1 (electricity generation), rather than 5C (Waste Incineration). Prior to 1997 at least some MSW was burnt in older installations without energy recovery.

Table 3.6 Power stations in the UK by type

Year	Coal	Fuel oil	Gas oil	Gas	Waste	Biomass	Biogas	Nuclear Fission
1990	45	7	12	1	2	0	Unknown[a]	19
1995	24	6	13	18	4	2	Unknown[a]	16
2000	21	5	11	37	15	4	267	15
2005	17	3	13	49	20	5	461	12
2010	17	3	14	55	24	7	554	10
2012	16	3	13	56	26	9	565	9
2013	13	1	13	53	28	10	621	9
2014	13	1	13	51	34	10	628	9
2015	13	1	13	48	35	14	633	9

[a]Number of power stations for early years is unknown although emissions are reported, biogas consumption is obtained from DUKES.

Table 3.7 shows how the numbers of refineries vary over the period covered by the inventory. The UK had 8 operating refineries during 2015, of which 2 were small specialist refineries employing simple processes such as distillation to produce solvents or bitumen only. The remaining 6 complex refineries are much larger and produce a far wider range of products including refinery gases, petrochemical feedstocks, transport fuels, gas oil, fuel oils, lubricants, and petroleum coke. The crude oils processed, refining techniques, and product mix will differ from one refinery to another, influencing the energy use and emissions from the sector. A seventh crude oil refineries ceased operation in November 2014, and four other major refineries in operation in 1990 closed between 1997 and 2010.

Table 3.7 Refineries in the UK by type

Year	Crude oil refineries	Specialist refineries
1990	11	4
1995	11	4
2000	9	3
2005	9	3
2010	8	3
2012	7	3
2013	7	3
2014	7	2
2015	6	2

Much of the crude oil and natural gas input to the refineries comes from a large number of offshore installations in UK waters, together with a small number of onshore production facilities. Emissions estimates from these activities are described in **MS 2**, **MS 19** and **MS 20**. Coal is extracted in the UK from deep mines and open-cast sites. The UK production of coal (especially from deep mines) is a rapidly declining industry and levels of UK activity are far lower in recent years than in 1990. Emissions from combustion at UK collieries are covered in this MS. Fugitive emission estimates from these mining and extraction activities are included in **MS 17** and **MS 18.**

Nuclear fuel production is a very minor user of fossil fuel in the UK, and is included in this MS.

Key Data sources

Activity data:	DUKES, EU ETS, UK PIA
Emission Factors:	Carbon factors are predominantly derived from EU ETS data (2005 onwards) and from the 2004 Carbon Factors Review (Baggott et al., 2004), with some solid fuel factors derived from UK research (Fynes and Sage, 1994); non-CO_2 EFs are predominantly IPCC defaults (IPCC, 2006).

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]. The justification for use of several references, such as EU ETS, the 2004 Carbon Factors Review and Fynes and Sage, are presented in ***Annex 3.1.2****.*

Table 1.6 *gives additional information for common activity data sources.*

Method approach

The calculation of direct greenhouse gases for the sources covered by this MS is:

UK Emissions = EF x AD

The sources of emission factors and activity data are summarised under "key data sources" above, with a full list of emission factors set out in *"Energy_background_data_uk_2017.xlxs"*. The activity data are taken from DUKES, noting the exceptions set out under Assumptions & observations, below. **Annex 4** described the energy balance for the UK and how this is used for the inventory, and any deviations from these data.

Assumptions & observations

- **Power stations - gas oil / fuel oil / burning oil activity data**: DUKES reports less fuel oil burnt by power producers than is reported by operators either directly to the Inventory Agency or via the EU Emissions Trading System (EU ETS). For some years this is also true of gas oil, and in the case of burning oil, DUKES does not give any figures for any year. For each oil therefore, we take the larger of either the DUKES figure or the operator data each year. Where we choose to use the operator data, fuel is reallocated from industry (1A2) to power stations to ensure consistency with the operator data, while maintaining consistency with the overall UK fuel consumption data in DUKES;

[24] This can be found as one of the additional documents in on http://naei.defra.gov.uk/reports/reports?report_id=929. Note that there can be a delay between the NIR being published on the NAEI website after official submission.

- **Power stations** – oxidation factors (OF). All UK coal-fired power stations report to EU ETS and present installation-specific data on coal composition (carbon content), and the fuel OF. The weighted-average figure is reported in **Table 3.4** above. The range of OFs at UK coal-fired stations is typically 95-99%. There are some UK power stations that consistently report a low OF due to the grate design and nature of the coal fired; in 2015, the lowest OF reported is around 96.2%, whereas most stations report 98-99%. The factors presented in *"Energy_background_data_uk_2017.xlxs"* are the factors including consideration of the oxidation factor. The data for recent years are taken from installation-specific analysis through EU ETS, and from the underlying data we can derive the weighted average oxidation factor across all UK coal-fired power stations. The data for earlier years are all taken from the Carbon Factors review in 2004. The data may be low compared to the IPCC default, but they are based on country-specific analysis and the CEF is consistently low across the time series. For 1990-2004, the assumed oxidation factor for power station coal is 0.98. For 2005 onwards, CS oxidation factors are derived from the EU ETS data. These EU ETS data indicate that 0.98 is a defensible estimate.
- **Power stations – MSW**: The activity data reported in the UK inventory is a combination of fossil and bio-wastes and there has been analysis conducted by Defra on waste composition to derive a fossil carbon only factor, which is as used here. Table 28 of Defra report "WR1003 Biodegradability of municipal solid waste" presents the percentage split of biogenic and fossil carbon according to waste type, and these percentages have been applied to UK specific waste compositions.
- **Refineries - OPG activity data**: As noted in the Recalculation justification & summary of change section below, for OPG, discrepancies in activity data are evident between EU ETS and DUKES. Based on data from EU ETS and the refinery trade association, UKPIA, under-reports were identified in the UK energy balance data for the refinery sector from 2004 onwards, although not in all years. The estimates for 2004 in the UK GHGI are therefore based on UK Petroleum Industry Agency (UKPIA) data, whilst the data for 2006-2011 and 2013-2015 are based on EU ETS data. Data from DUKES are used for 2005 and 2012. Prior to 2004 the UK GHGI emission estimates based on DUKES energy data are closely consistent with UKPIA sector estimates, and are therefore retained; and,
- **Refineries - Petroleum coke activity data**: Similar to the issue noted above for OPG, comparison of the AD presented in DUKES versus the AD reported via the EU ETS indicates for several years that the DUKES AD are under-reported. The UK GHGI estimates from refinery petroleum coke use are therefore based on the higher value of DUKES or EU ETS and applying the EF for petroleum coke provided by UKPIA; EU ETS data are higher (and therefore used in the GHGI, deviating from DUKES) for all years 2005 to 2010 and again in 2013 and 2015. In 2011, 2012 and 2014, the DUKES data are higher than EU ETS and are therefore retained; we note, however that this is a possible over-report and leads to UK GHGI emission estimates for the sector as a whole being higher than EU ETS totals in 2012. The Inventory Agency retains this approach in order to use EU ETS emission estimates as a de-minimis, and taking a conservative approach to deriving the time series of refinery emissions. Note that the UK GHGI estimates for the refinery sector are also higher than the EU ETS figures for 2005: this is because DUKES reports higher consumption of other fuels (including fuel oil and natural gas) than given in EU ETS, rather than due to differences for OPG and petroleum coke as in 2012.

Recalculations

Activity data revisions include:

- Revisions to DUKES, particularly for 2014 (for MSW, and for all major refinery fuels), and also minor revisions to fuel use in downstream gas distribution (1A1ciii);

For emission factors:

- Revisions to assumed calorific values for wood and coal used in power stations leading to changes in emission factors for CH_4 and N_2O. These factors are taken from the 2006 IPCC Guidelines and are on an energy basis whereas the UK activity data are on a mass basis.

Quantitative information on recalculations is included in **Chapter 10**.

Improvements (completed and planned)

Completed: Recalculations and updates completed as described above.

Planned/Ongoing: Emission factors and activity data remain under annual review.

QA/QC

Specific QA/QC and validation exercises relevant to these source categories include:

- The Inventory Agency conducts extensive quality checks on the operator-reported EU ETS data covering: emissions, AD, EFs, NCVs. The QC assesses the fuel quality data, time-series consistency of reported data by installation, detailed source-specific EU ETS data against the installation-wide total emissions reported to the EU Transaction Log, and comparisons between DUKES and EU ETS AD to identify and resolve any potential mis-allocations or under-reports in the DUKES dataset. Findings are discussed with the BEIS energy statistics team and (where necessary) the EU ETS regulators and/or operators. This process has led to many significant improvements in UK GHGI accuracy;
- The comparison of the reference/sectoral approach;
- A bilateral exchange with Denmark in 2015, providing peer review and quality assurance in updating to 2006 Guidelines; and
- A bilateral exchange with Germany in 2014, providing peer review and quality assurance of the energy sector and refinery estimates. (Ricardo-AEA, 2014).

The energy AD used in these estimates that come from DUKES are subject to the UK Statistics Authority's *Official Statistics Code of Practice*[25]. The EU ETS data, is subject to its own QA process, defined and managed by the competent authority and compliant with EU rules.

Time series consistency

Activity data for petroleum coke and OPG consumption in refineries are based on DUKES data for certain years, and EU ETS or trade association (UKPIA) data for other years in the time series. This is described in the method approach section above. The differing data sources have been used to ensure a consistent complete coverage of emissions from refineries, addressing under-reports in DUKES and ensuring the time series consistency is maintained.

For some sources and fuels, carbon emission factors are taken from Baggott et al., for the period 1990-2003, and from ETS for 2005 onwards (2004 is interpolated). This makes best use of available data and the time series trend of EFs shows a smooth transition between data sources. We note that the key data providers that informed the 2004 Carbon Factors Review are the same operators of high-emitting plants (i.e. power stations, refineries, cement kilns,

[25] Available from http://www.statisticsauthority.gov.uk/assessment/code-of-practice

iron and steel works) that subsequently provide data to the EU ETS. Therefore, whilst the EU ETS data provides a larger dataset of more detailed, installation-specific fuel composition and hence carbon emission factors for recent years, the underlying source data available prior to EU ETS comes from the same operators. This means that, despite use of a smaller dataset prior to the availability of EU ETS data, the time series consistency of this approach is good.

For some sources, for example power station use of petroleum coke; the UK estimates are derived from mass-based data in the EU ETS, with the figure for 2005 applied back across the time series, and this time series on a mass basis is actually very stable.

Uncertainties

Uncertainties for both activity and emission factors are based on expert judgement. The uncertainty analysis set out in **Annex 2** provides details of these uncertainty values. Uncertainties in fuel use statistics are typically low. The carbon emission factors are based on UK specific data. 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. Non-CO_2 emissions are dependent on a greater number of parameters, and are largely based on defaults. As such, the uncertainties are higher, but since the emissions are smaller, this does not have a significant impact on the overall uncertainty of total GHG emissions.

MS 2 Upstream oil and gas production – fuel combustion

Relevant Categories, source names

1A1cii: Upstream gas production – combustion;

Upstream oil production - combustion;

Upstream oil and gas production – combustion at gas separation plant

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Gas oil, Natural Gas, LPG, OPG

Background

Crude oil and natural gas are produced mainly from a large number of offshore installations located in the North Sea, together with a small number of production facilities in the Irish Sea or on land. In addition, crude oil, gas and condensate are treated at onshore terminals in the UK. The emissions in 1A1cii comprise all of the fuel combustion emissions at these installations. LPG and OPG are used for fuel combustion at onshore terminals. Gas oil and natural gas (i.e. untreated natural gas, upstream of gas processing facilities) are widely used as fuels in combustion units across the upstream oil and gas industry.

Key Data sources

Activity Data: Primarily taken from DUKES (BEIS, 2016), with some supplementary data from the EU ETS and EEMS data sets (both from BEIS Offshore Inspectorate, 2016).

Emission Factors: Carbon factors for natural gas are derived from operator-reporting to EU ETS and EEMS (both from BEIS Offshore Inspectorate, 2016), supplemented by periodic analysis for the earlier years in the time series (UKOOA, 2005); the carbon factors for LPG and gas oil are derived from the 2004 Carbon Factors Review (Baggott et al, 2004); the carbon factor for OPG used at gas separation plant is taken from the IPCC 2006 Guidelines CEF for ethane. Methane and Nitrous Oxide EFs are based on operator reporting via EEMS from 1998 onwards with earlier data based on industry research (UKOOA, 2005).

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]. ***Table 1.6*** *gives additional information for common activity data sources.*

Method approach

Fuel consumption data for this source are largely taken from DUKES, with the exceptions noted below.

Amendments are made to DUKES activity data for LPG, OPG and natural gas, in consultation with the BEIS DUKES team as the combined EEMS and EU ETS activity data for these fuels are considered to be more complete. These deviations from DUKES are as follows:

- From 2003 onwards there are no data in DUKES for LPG/OPG use in oil & gas terminals and therefore EU ETS data are used to provide activity and emission estimates; and
- Prior to 2001 (when BEIS energy data gathering systems were updated) the collection of data on natural gas use at oil and gas facilities was incomplete. Therefore, the more complete and consistent data available from EEMS has been used to generate new estimates of natural gas use for the upstream sector back to 1990.

Operator reporting via the EEMS and EU ETS mechanisms both provide activity and emissions data from the consumption of gas oil and natural gas in combustion units in the upstream oil and gas industry. EU ETS data are only available from 2005 onwards and have an incomplete scope (i.e. not all combustion activities are included within EU ETS), whilst EEMS data are available from 1998 onwards with more limited periodic industry research available to inform activity and emission estimates for 1990-1997 (UKOOA, 2005).

Activity data for natural gas use from DUKES is compared against data reported via EEMS and EU ETS; where any DUKES under-reports are observed then the DUKES data are modified (see above). Carbon emission factors for natural gas are derived from the EEMS data and applied to the DUKES (or modified DUKES) activity data. The calculated (implied) emission factor is cross checked with UK specific natural gas emission factors to ensure that the upstream gas composition is broadly consistent with downstream gas CEFs.

The method for gas oil is simpler; the activity data are taken from DUKES and a carbon emission factor is applied that is derived from the 2004 Carbon Factors Review. There are no modifications to DUKES activity data, as analysis of the EEMS dataset is used by the BEIS energy statistics team in deriving the commodity balance estimates for gas oil, i.e. the EEMS data are ultimately the source of the DUKES allocation for the sector, so there are no data discrepancies.

For LPG and OPG combustion, the DUKES activity data are used from 1990-2002. For 2003 onwards, there are no DUKES data so the operator-reported activity data within EEMS are used, with (from 2008) the EU ETS activity data also considered. Carbon emission factors are derived from the 2004 Carbon Factors Review (for LPG) and from the IPCC 2006 GLs (for OPG).

Assumptions & observations

Emissions from OTs and CDs are Not Occurring for this source.

Recalculations

There have been no method changes but there have been minor recalculations due to some small changes in the interpretation of EEMS data, leading to reallocation of some emission sources within 1A1ci, and also some small changes in emission totals. DUKES data for natural gas fuel used in gas distribution have also changed slightly. The impact of changes is set out in **Section 10**.

Improvements (completed and planned)

Emission factors and activity data remain under review.

QA/QC

Specific QA/QC and validation exercises relevant to these source categories include:

- the comparison of the reference/sectoral approach;
- comparison of EEMS, EU ETS and DUKES activity data for natural gas combustion. The data underpinning DUKES estimates are gathered via the Petroleum Producers Reporting System (PPRS) which presents facility-level activity data that are compared against EEMS and EU ETS to identify and reconcile any data inconsistencies;
- comparisons between EEMS and EU ETS, to review installation-specific activity data and emissions data (and hence implied IEFs for each site and source) to identify any possible gaps in the EEMS dataset, using EU ETS as a de-minimis. The EU ETS data typically covers a smaller scope of activities on a given installation, but the data quality (AD, EFs) are third-party verified, whereas the EEMS dataset should be a comprehensive record of all combustion activities on upstream oil and gas installations but the data are subject to less rigorous QC.

The energy AD used in these estimates that come from DUKES are subject to the UK Statistics Authority's *Official Statistics Code of Practice*[25]. EU ETS data is subject to its own QA process.

Time series consistency

Extensive consultation over many years with the BEIS energy statistics team has enabled the Inventory Agency to clarify areas of the DUKES data that are incomplete for the upstream oil and gas sector, and to take steps to address these gaps. Wherever possible the Inventory Agency has filled activity data gaps with operator-reported estimates; this is possible as there are a defined number of installations that are active in this sector and their activities are generally well documented with gaps in data being relatively minor.

The quality checks between different reporting mechanisms (PPRS and DUKES, EEMS, EU ETS) and significant overlap of the data reported (DUKES across all years; EEMS all years since 1998 with limited data for 1996 and 1997; periodic industry reports by the trade association, UKOOA; EU ETS all years since 2005) enables the Inventory Agency to deploy gap-filling techniques that are consistent with IPCC GLs and Good Practice Guidance (GPG). For example, the extrapolation of natural gas activity data from 1990 to 2000 (to address a gap in DUKES) is based on analysis of the data reported during 1998 to 2000 ("overlap" years) in EEMS and DUKES, which indicates a systematic under-report in DUKES data of an estimated 14% per year (then used to uplift the reported DUKES data for 1990-1997). There is a higher uncertainty associated with the estimates for earlier years, but the inventory method has been developed to minimise that uncertainty despite the data limitations.

Uncertainties

Uncertainties for both activity and emission factors are based on expert judgement. The uncertainty analysis set out in **Annex 2** provides details of these uncertainty values. Uncertainties in fuel use statistics are typically low. However, we note (as outlined in the section above) that there are known data gaps in national statistics for earlier years of the time series and hence uncertainties for the estimates in 1990 are higher than for recent years where much more extensive and complete operator-reporting of activity and emissions are evident. The carbon emission factors are based on UK specific data. 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. Non-CO_2 emissions are dependent on a greater number of parameters, and are largely based on defaults. As such, the uncertainties are higher, but since the emissions are smaller, this does not have a significant impact on the overall uncertainty of total GHG emissions.

MS 3 Manufacturing industries and construction (excluding iron and steel use of derived fuels, and off road machinery)

Relevant Categories, source names

1A2a – Iron and Steel (combustion) – excluding blast furnace gas, coke oven gas and coke (see **MS 4**)

1A2b - Non-Ferrous Metal (combustion)

1A2c - Chemicals (combustion)

1A2d - Pulp, Paper and Print (combustion)

1A2e - Food & drink, tobacco (combustion)

1A2f - Cement production – combustion, Lime production - non decarbonising

1A2gvii - Other industrial combustion, Autogeneration - exported to grid, Autogenerators

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Biogas, Biomass, Burning oil, Coal, Coke, Coke oven gas, Colliery methane, Fuel oil, Gas oil, LPG, Natural gas, OPG, Petroleum coke, Scrap tyres, Waste, Waste oils, Waste solvent, Wood, SSF

Background

This MS covers the use of fossil fuels for heat and power production in industry. Estimates cover a range of large and small installations. Larger installations are included in the EU ETS, but there are large numbers of small industrial plants which are not. Sectoral emissions for iron and steel, non-ferrous metal, chemical, paper, food and drink, and mineral industries are reported under 1A2a to 1A2f. Emissions for fuel use that cannot be allocated to these industries are reported under 1A2g.

According to the 2006 IPCC GLs, electricity generation by companies primarily for their own use is autogeneration, and the emissions produced should be reported under the industry concerned. However, most National Energy Statistics (including those of the UK) report fuels used by industry for electricity generation as a separate category. The UK statistics for autogeneration covers all industry sectors in a single figure for coal use, and another for natural gas. The UK inventory attempts to report this as far as possible according to the IPCC methodology by placing emission estimates in 1A2g, except for where further information is available to allow the allocation to another source category.

The sectoral estimates reported under 1A2a to 1A2g include fuels reported in the national energy statistics for 'heat generation'. These are fuels that are used by sites that generate heat for other users e.g. many UK paper mills and chemical manufacturers are supplied with steam from a separate combustion plant run on a neighbouring site by a different operator. The re-allocation from the heat generation category to industry sectors is made on the basis of estimates provided by UK energy statisticians.

Key Data sources

Activity Data:	DUKES (BEIS, 2016), cement sector fuel use estimates (MPA, 2016) and, installation-specific activity data from EU ETS e.g. for lime kilns (EA, SEPA, NRW, NIEA, all 2016).
Emission Factors:	Where available, operator-reported EFs from EU ETS are used for high-emitting source sectors. Other UK CS CEFs are taken from the 2004 Carbon Factors Review (Baggott et al., 2004). Defaults for non-CO_2 gases are derived from IPCC (IPCC 2006).

An accompanying document "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references. ***Table 1.6*** *gives additional information for common activity data sources.*

Method approach

For most source estimates, the inventory method uses national energy statistics and applies country-specific factors for CO_2 (Tier 2), and default factors (typically from IPCC) for other gases (Tier 1).

DUKES provides most of the energy activity statistics. The full breakdown is available for all categories under 1A2 for coal, natural gas, fuel oil and gas oil. Other fuels such as LPG, coke and burning oil cannot be split within 1A2 and are therefore allocated solely under 1A2g due to a lack of any data on sectoral use in DUKES. A number of approaches are used to fine tune the allocation of energy use under the different subcategories to ensure consistency with other datasets such as EU ETS, industrial data (e.g. from trade associations) and other estimates in the GHG inventory (e.g. the off-road machinery model). These approaches are listed below:

- Fuel use in cement kilns (1A2f) is collected from process operators, via the Mineral Products Association (MPA). These data are not complete for all of the earlier part of the time series, so some assumptions have to be made to fill these gaps (see assumptions). Reallocations are sometimes made between cement and other subcategories compared with DUKES, to account for known fuel uses;
- Fuel use in lime kilns (1A2f) is estimated based on EU ETS data. All lime kilns are included in the scope of EU ETS from 2008 onwards, so there is a full set of fuel data for 2008-2015, with incomplete data for the years 2005-2007. For the earlier part of the time-series, fuel use is estimated by extrapolation from the EU ETS data using lime production estimates;
- Balancing of energy consumption data between 1A2 and other source categories, to accommodate source-specific AD from other data sources (e.g. operator data, EU ETS) in preference to DUKES data. Key examples of fuel re-allocations in 1A2 are: AD for natural gas for gas network operators (i.e. gas use re-allocation between 1A2 and 1A1c); AD for oils for power stations (i.e. gas and fuel oil re-allocations between 1A2 and 1A1a);
- Analysis of EU ETS indicates that there are a number of installations which use petroleum coke as a fuel, where there is no such allocation of petroleum coke as a fuel for that source in DUKES. The inventory agency therefore re-allocates some petroleum coke from the non-energy use estimate in DUKES to address this reporting

discrepancy and align emission estimates in 1A2f and 1A2g with EU ETS. This re-allocation increases the overall reporting of petroleum coke as an emissive energy use, deviating from DUKES;

- Analysis of EU ETS data has identified several chemical and petrochemical manufacturers that utilise carbon-containing process off-gases and residues as fuel sources. Consultation with industry and with the BEIS energy statistics team has clarified that in DUKES the delivery of feedstock materials to chemical and petrochemical sites are reported as non-energy use, with no subsequent reporting in DUKES of the use of process off-gases as an energy source in these industries. The EU ETS data are therefore used to derive inventory estimates to account for this use of feedstock-derived process gases, which are reported as "other petroleum gas" use within the inventory, in addition to DUKES allocations to fuel use in these sectors. However, in accordance with the 2006 GLs, these emissions are reported under source category 2B8 (see IPPU chapter) rather than 1A2; and,
- Separation of gas oil used for stationary and mobile machinery is based on data on populations of mobile equipment, or train or ship movements etc. The approach developed for allocating gas oil between different source categories is described in **Annex 4**.

Emission factors for carbon are almost exclusively derived from country specific data. Site-specific data, (including both EU ETS data, and data provided by process operators directly or via industrial trade associations) is aggregated up to generate factors for a small number of sectors. Sector-wide factors are derived in other cases based usually on the methods described in Baggott *et al*, 2004. Emission factors for waste oils are based on the analysis of 8 samples of waste oils collected from UK sites in 2003. The factors for coke and other manufactured fuels are based on carbon balance approaches (see **MS 4** for coke). Emission factors for methane and nitrous oxide are largely IPCC defaults. *An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references*[24]

Assumptions & observations

- Breakdown of fuel use for cement from the MPA data are not available for 1991-1999, and so fuel usage for these years must be interpolated between the 1990 and 2000 data, taking into account changes in cement clinker production in each year; and,
- Combined Heat and Power (CHP) systems where all of the electricity is fed into the public supply are classified as power stations and excluded from estimates described here.

Allocation of industrial electricity generation:

- The UK's statistical data for autogenerators relate to fuels used for electricity generation by companies primarily for their own consumption. This includes CHP systems where electricity is used by the generator. The UK methodology allocates gas-fired autogeneration to 1A2g (as no other sub-categorisation is available) while coal use by autogenerators is allocated to 1A2b since almost all of the coal is known to have been used in a power station, operated by an aluminium producer, which supplied electricity to their smelter operation. The smelter closed in 2012 and since then the power station has supplied electricity to the national grid and coal used at the site is now allocated to 1A1a.

Recalculations

The following summarises the recalculations in 1A2:

- DUKES data revisions have affected data in later years;

- Natural gas used in the manufacture of methanol & emissions arising from that use have been transferred to 2B8. Since the UK's only plant closed in 2001, this revision only affects data for 1990-2001;
- DUKES included a new category of fuel oil use in their latest publication (by the oil & gas extraction sector). Data were only available for 2014 and 2015 and it was unclear whether this meant that fuel oil was only used by that sector in the last 2 years, or that separate data were only available for the last 2 years. Until this can be clarified, we have assumed that fuel oil was previously used by the oil & gas extraction sector but that it was reported within the industrial figures. To maintain consistency therefore, we have added this fuel oil use to 1A2gviii;
- Similarly, DUKES has also added new data for propane use by the commercial sector from 2013 onwards only. Pending clarification of whether propane might also have been used before 2013, we have added this propane to our estimates for 1A2gviii;
- A correction has been made to estimates for petroleum coke used in industry in 2014, leading to a small re-allocation of emissions among various emission categories (1A2 & 2D3);
- Emission factors for CH_4 and N_2O have been reviewed and some changes made to the assumptions regarding calorific values of UK fuels. Since the factors are derived from IPCC default factors (expressed on an energy basis) but converted to a mass basis, the revisions to calorific values have an impact on the UK factors. Changes are relatively small, however;
- The method for allocation of gas oil across the various mobile and stationary industrial sub-sectors has been revised following a review of the model used. This results in re-allocations from 1A2b-1A2e to 1A2gviii for the early years of the time series.

Improvements (completed and planned)

Completed: Recalculations and updates completed as described above.

Planned/Ongoing: Emission factors and activity data remain under annual review.

QA/QC

Specific QA/QC and validation exercises relevant to these source categories include:

- the comparison of the reference/sectoral approach; and,
- comparison of EU ETS data with DUKES and data direct from industry

The energy AD used in these estimates that come from DUKES are subject to the UK Statistics Authority's *Official Statistics Code of Practice*[25].

The EU ETS data, is subject to its own QA process, defined and managed by the competent authority and compliant with EU rules.

Time series consistency

Differences in data sources across the time series are noted in the method approach section above. These do not lead to time series consistency issues, since they have been introduced in order to ensure the scope of emissions included remains consistent.

Uncertainties

Uncertainties for both activity and emission factors are based on expert judgement. The uncertainty analysis set out in **Annex 2** provides details of these uncertainty values. Uncertainties in fuel use statistics are typically low. The carbon emission factors are based on UK specific data. 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. Non-CO_2 emissions are dependent on a greater number of parameters, and are largely based on defaults. As such, the uncertainties are higher, but since the emissions are smaller, this does not have a significant impact on the overall uncertainty of total GHG emissions.

MS 4 Iron and steel, and coke manufacture

Relevant Categories, source names

1A1ci: Coke production

1A2a: Blast furnaces, Iron and steel - combustion plant (coke oven gas, blast furnace gas & coke oven coke only)

1B1b: Coke production

Iron and steel - flaring

2C1a: Basic oxygen furnaces

2C1b: Iron and steel - flaring

2C1d: Sinter production

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Blast furnace gas, Coal, Coke, Coke oven gas, Coke produced, Colliery methane, Dolomite, Fuel oil, Gas oil, Limestone, LPG, Natural gas

Background

This MS covers the carbon balance approach used for integrated steelworks and independent coke manufacture. Integrated steelworks use the blast furnace/basic oxygen furnace route to produce steel from iron ore.

Most UK coke is produced at coke ovens associated with the UK's three integrated steelworks, although one independent coke manufacturer also exists. The Teesside steelworks was closed in September 2015 and so at the end of 2015, there were three coke ovens at the steelworks and one independent coke oven. Four other coke ovens were in existence in 1990 but subsequently closed due to closure of two integrated steelworks and the closure of other coke consumers, such as the UK's only lead/zinc smelter in 1999. **Table 3.8** shows how the numbers of coke ovens and steelworks vary over the period covered by the inventory. Coke production emissions are reported under 1A1ci (combustion) and 1B1b (fugitive).

Table 3.8 Number of coke ovens and steelworks in the UK

Year	Coke ovens	Integrated steelworks	Electric arc steelworks
1990	10	5	Unknown
1995	9	4	20
2000	9	4	19
2005	6	3	12
2006	6	3	11

Year	Coke ovens	Integrated steelworks	Electric arc steelworks
2007	6	3	10
2008	6	3	8
2009	6	3	7
2010	6	3	7
2011	6	2	7
2012	6	3	6
2013	6	3	6
2014	6	3	6
2015	4[a]	2[a]	6

[a] Figures at year end, following closure of the Teesside integrated works and its two coke ovens

The carbon balance method described in this method statement covers the use of coke oven coke, blast furnace gas and coke oven gas as fuels throughout the iron and steel industry, whereas the use of primary fossil fuels in boilers and heat treatment or melting furnaces is described in the method statement for 1A2. All fuels used in coke ovens, sinter plant, and blast furnaces are included in the carbon balance.

The key processes and related emission activities covered by this method statement are summarised below.

1. Coke oven coke is produced by heating coking coal in ovens in order to drive off volatiles which are collected as gases (coke oven gas, used as a fuel to heat the ovens) or liquids (coal tars and benzole, recovered for use in chemicals manufacture and other processes). The solid residue is coke oven coke which is used as a fuel for sintering, as a reductant in blast furnaces, or sold for use in other industrial processes. Emissions of greenhouse gases resulting from combustion to heat the coke ovens are reported in 1A1c, whereas fugitive emissions of methane from the coke ovens are reported in 1B1b.
2. Integrated steelworks convert iron ores into steel using the three processes of sintering, pig iron production in blast furnaces and conversion of pig iron to steel in basic oxygen furnaces. Emissions from integrated steelworks are estimated for these three processes, as well as other minor processes such as slag processing.
3. Sintering involves the agglomeration of raw materials for the production of pig iron by mixing these materials with fine coke (coke breeze) and placing it on a travelling grate where it is ignited. The heat produced fuses the raw materials together into a porous material called sinter. Emissions from sintering are reported in 2C1d.
4. Blast furnaces are used to reduce the iron oxides in iron ore to iron. They are continuously charged with a mixture of sinter, fluxing agents such as limestone, and reducing agents such as coke, fuel oil and coal. Hot air is blown into the lower part of the furnace and reacts with the reducing agent, producing carbon monoxide, which reduces the iron ore to iron.
5. Gas leaving the top of the blast furnace has a high heat value because of the residual CO content, and is used as a fuel in the steelworks. Molten iron and liquid slag are withdrawn from the base of the furnace. The most significant greenhouse gas emissions to occur directly from the blast furnace process are the combustion gases from the 'hot stoves' used to heat the blast air.

6. These generally use blast furnace gas, together with coke oven gas and/or natural gas as fuels. These emissions are reported under CRF category 1A2. Gases emitted from the top of the blast furnace are collected and emissions should only occur when this gas is subsequently used as fuel. These emissions are allocated to the process using them. However, some blast furnace gas is lost and the carbon content of this gas is reported under CRF category 2C1.
7. Pig iron has a high carbon content derived from the coke used in the blast furnace. A substantial proportion of this must be removed to make steel and this is done in the basic oxygen furnace. Molten pig iron is charged to the furnace and oxygen is blown through the metal to oxidise carbon and other contaminants. As a result, carbon monoxide and carbon dioxide are emitted from the furnace and are collected for use as a fuel. As with blast furnace gases, some losses occur and these losses are reported with blast furnace gas losses under CRF category 2C1. In DUKES, basic oxygen furnace gas is combined with blast furnace gas and so separate figures for production and use of the two gases are not given.
8. The fuels derived in coke ovens and integrated steelworks are used in boilers and in heat treatment or melting furnaces and CO_2 emissions from these energy uses are calculated using emission factors derived using the carbon balance.

Key Data sources

Activity Data:	Main sources of activity data (fuel use, production data) are DUKES (BEIS, 2016), ISSB annual statistics (ISSB, 2016), installation-specific activity data from EU ETS (EA, NRW, both 2016), operator information for integrated steelworks (Tata Steel and SSI Steel, both 2015)
Emission Factors:	Input parameters for the carbon balance method are derived from EU ETS data or operators of integrated steelworks (reference as for AD). Other UK CS CEFs are derived from the 2004 Carbon Factors Review (Baggott et al., 2004). EFs for non-CO_2 gases are predominantly IPCC defaults (IPCC 2006), Baggott et al., 2004.

*An accompanying spreadsheet “Energy_background_data_uk_2017.xlxs” lists all emission factors used in the energy sector, including a full list of references[24]. **Table 1.6** gives additional information for common activity data sources.*

Method approach

The carbon balance for the combined coke ovens and integrated steelmaking processes is based on tracking the carbon through four successive stages – coke making, sintering, pig iron production, and basic oxygen steel production. At each stage carbon is input as fuels and/or feedstocks; carbon leaves in products; is emitted to air or removed as waste products. The carbon flow description and **Figure 3.1** below presents a simplified version of the model listing main inputs and outputs:

Carbon Flow Description

coal → coke + coke oven gas + benzole & tars + fugitive carbon emission

coke + limestone + iron ore → sinter + carbon emission

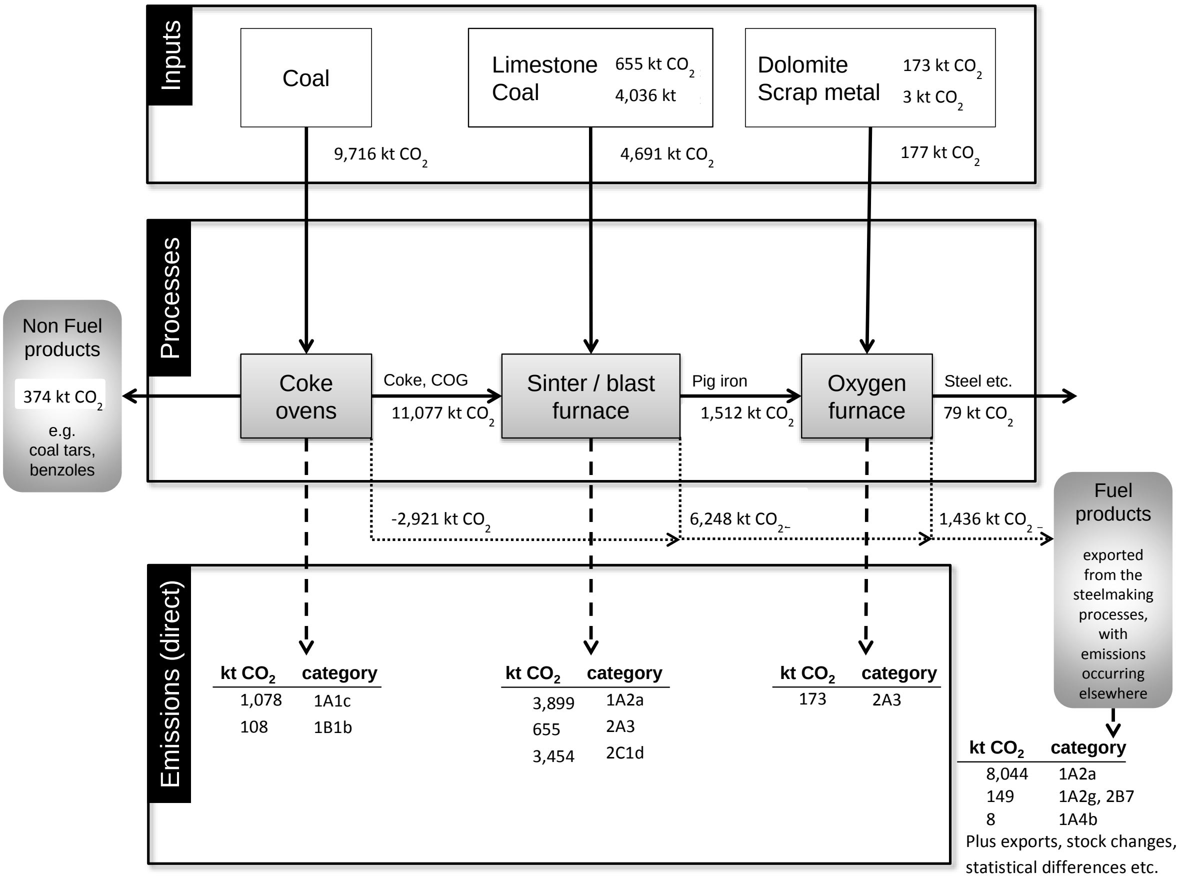
sinter + coke + other reducing agents → pig iron + blast furnace gas

pig iron + scrap + dolomite → steel + slag + basic oxygen furnace gas

The outputs that are allowed to vary, and therefore used to ensure that the overall carbon balances, are coke, blast furnace gas and basic oxygen furnace gas.

The carbon balance model used is shown in a simplified form in **Figure 3.1**, with inputs and outputs of carbon (expressed as CO_2) given for the year 2014 as an example. Note that there is one negative value in the diagram because the figures take into account imports, exports, and stock changes.

Figure 3.1 Carbon balance model for 2015[a]



[a] Other adjustments includes imports (-3415 kt CO_2), exports (276 kt CO_2), stock changes (-188 kt CO_2), fugitive emissions from coke ovens reported as methane (23 kt CO_2) and carbon stored in dusts (9 kt CO_2)

Emission estimates for limestone and dolomite added to sinter plants, blast furnaces, and oxygen furnaces are based on industry consumption data (Iron & Steel Statistics Bureau, 2015) and carbon contents from the operators (Tata Steel, SSI Steel, both 2015), and based on their EU ETS reporting (EA, NRW, both 2016).

Emissions of CH_4 and N_2O are estimated using IPCC 2006 default emission factors.

Assumptions & observations

A detailed description of the carbon balance methodology has been given in Ricardo Energy & Environment, GHG Inventory Research: Use of EU ETS Data - Iron & Steel Sector, Chemical Industry Feedstock Use, April 2014 (available for download on the NAEI website[26]) and so only a brief summary of assumptions is given here.

26 http://uk-air.defra.gov.uk/assets/documents/reports/cat19/1405081135_GHG_Inventory_Research_Report_EU_ETS_final.pdf

The carbon balance method requires the carbon content in input fuels and feedstocks to be estimated using consumption data and carbon contents for each fuel or feedstock. The balance is then used to distribute that carbon amongst the various derived fuels, products and wastes from the coke ovens and steelmaking processes. The total emission of CO_2 is therefore dependent upon the assumptions made about the quantity of carbon in inputs, and in the main input – coking coal – in particular. The carbon content of coking coal and blast furnace coal has, in recent years, been measured by operators as a result of their need to collect data for EU ETS reporting purposes, and operators have also been able to supply high quality measurement-based data for the carbon contents of derived fuels, coal tars, benzole, limestone, dolomite, steel scrap, and steel product. The EU ETS data indicate that the carbon contents of fuels do not vary greatly from one year to another and therefore, for earlier years, where EU ETS data are not available, carbon factors are assumed to be the same as for those years where EU ETS data are available. For each fuel, the average carbon content is calculated for years with EU ETS reporting, and these values then used for the earlier years.

The operators also supply data on the consumption and production of fuels and these data should be consistent with UK energy statistics. This is largely so, but in a couple of instances where the UK statistics seem to underestimate consumption of a particular fuel in a particular year, we have used the operators' data instead. For example, operator data for the consumption of coking coal in coke ovens for the years 2003-2015 is mostly higher than the figures given in DUKES, and the operator data are used in preference. The coal consumption figures for other industrial use are also modified by an equal and opposite amount so that overall coal consumption in the GHGI is the same as in DUKES. DUKES also excludes a small quantity of coke oven gas generated at one steelworks which is then supplied as a fuel to a co-located process, and so we have used operator data on this fuel in the inventory. In this case, it would not be appropriate to maintain consistency with overall UK demand figures in DUKES (since this fuel is missing from DUKES, not classified to a different sector). Finally, some small deviations are made for 2009, where operator data on consumption of coal and coke oven coke in blast furnaces are somewhat higher. The changes to coal are treated as misallocations in DUKES (so UK totals for coal consumption are adhered to), whereas for coke oven coke, it is necessary to increase UK consumption to above the level given in DUKES, since coke consumption by known users exceeds the DUKES figure.

Recalculations

There have only been minor recalculations due to revisions to UK energy statistics and other input data.

Improvements (completed and planned)

There have been no changes to the methodology for this version of the inventory, and no improvement work is planned, though all input data and assumptions are kept under review.

QA/QC

Specific QA/QC and validation exercises relevant to these source categories include:

- the comparison of the reference/sectoral approach;
- comparison of inventory estimates based on the carbon balance, with EU ETS data and detailed emission estimates provided by the operators;
- comparison of DUKES data with industry-reported activity data (e.g. from ISSB);
- comparison of carbon emission factors derived from the carbon balance, with IPCC default emission factors; and,
- checks on the time-series consistency of carbon emission factors generated by the carbon balance method.

The energy AD used in these estimates that come from DUKES are subject to the UK Statistics Authority's *Official Statistics Code of Practice*[25]. EU ETS data is subject to its own QA process. A bilateral exchange was undertaken in May 2015 with the inventory agency from Germany, which included a review of the revisions to the iron and steel sector method in the 2014 submission.

Time series consistency

All activity data used are available for the full time series of the estimates. Carbon factors for key inputs such as coking coal and blast furnace coal are available from operators only for recent years (2005 onwards in the case of coking coal, 2007 onwards for other fuels) so the same values must be assumed to be appropriate in earlier years. Data were not available for 2015, partly due to the Teesside works closing in September of that year, so 2014 values have been assumed to be correct for 2015 as well. While this does introduce some additional uncertainty for parts of the time-series, the assumed factors for coking coal and blast furnace coal, and the derived factors for coke oven coke, coke oven gas and blast furnace gas for these years are all within the ranges suggested in the IPCC 2006 Guidelines.

Uncertainties

Uncertainties for both activity and emission factors are based on expert judgement. The uncertainty analysis set out in **Annex 2** provides details of these uncertainty values. Uncertainties in fuel use statistics are typically low. The carbon emission factors are based on UK specific data. 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.

MS 5 Other stationary combustion

Relevant Categories, source names

1A4ai: Miscellaneous industrial/commercial combustion

Public sector combustion

Railways - stationary combustion

1A4bi: Domestic combustion

1A4ci: Agriculture - stationary combustion

Miscellaneous industrial/commercial combustion

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Anthracite, Burning oil, Charcoal, Coal, Coke, Fuel oil, Gas oil, LPG, Natural gas, Peat, Petroleum coke, Straw, Wood, SSF

Background

This method statement covers emissions from fuel combustion by non-industrial sectors including commercial, agricultural public sector and residential. Most stationary plants are small-scale, apart from a few large installations providing energy for large commercial or public sector buildings (e.g. banks, hospitals, schools, sport centres). Emissions from stationary railway sources are reported under 1A4a where the fuel is used in stationary combustion of burning oil and fuel oil to heat buildings, as well as natural gas combustion. This gas usage may include fuel used for electricity generation for own use by the railway sector. The 'miscellaneous' source includes energy use by a range of other users including the sewage and refuse disposal sector, and fuels used by television and radio broadcasters.

Key Data sources

Activity: DUKES (BEIS, 2016)

Emission factors: Baggott et al., 2004, IPCC, 2006

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]*.* ***Table 1.6*** *gives additional information for common activity data sources.*

Method approach

Emissions for this category are calculated based multiplying activity data by an emission factor. Activity data are taken directly from DUKES, with a few exceptions (see assumptions and observations). A full list of emission factors is included in **Annex 3**. Carbon emission factors are largely UK specific, whereas non-CO_2 emissions use default emission factors.

Assumptions & observations

The NAEI source public service includes emissions from stationary combustion at military installations, which should ideally be reported under 1A5a Stationary. However, we do not have separate data for the military fuel component.

Bottom up estimates are made for a number of categories using gas oil (railways, off road machinery etc.). In order to reconcile the gas oil used in these categories with the total in DUKES, reallocations (subtractions) are made from other categories, including AD used for the estimates of 1A4. These deviations from DUKES are presented in **Annex 4**.

Activity data estimates for domestic sector use of fuels derived from petroleum coke are based on annual estimates provided by industry experts (CPL, 2015).

Recalculations

There have been no changes to methods. The following summarises the recalculations:

- Any revisions to DUKES and other input data have been incorporated into the inventory;
- Emission factors for CH_4 and N_2O have been reviewed and some changes made to the assumptions regarding calorific values of UK fuels. Since the factors are derived from IPCC default factors (expressed on an energy basis) but converted to a mass basis, the revisions to calorifc values have an impact on the UK factors. Changes are relatively small, however;
- Revised estimates have been made for burning oil use in the overseas territories and crown dependencies.

The impact of changes is set out in **Chapter 10.**

Improvements (completed and planned)

No improvements to this method are currently planned. Emission factors and activity data are kept under review.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Fuel combustion estimates are verified through the comparison of the reference and sectoral approaches.

The energy AD used in these estimates that come from DUKES are subject to the UK Statistics Authority's *Official Statistics Code of Practice*[25].

For gas oil, bottom up estimates are made for various sources, which leads to changes in the sectoral allocations within DUKES. There are no official top down statistics to verify the bottom up statistics, however, the totals are reconciled with DUKES. Pet coke and peat data are outside of DUKES, but are small emission sources included for completeness.

Time series consistency

Emission factors and activity data are taken from consistent data sets, there are no time series consistency issues to note.

Uncertainties

Uncertainties for both activity and emission factors are based on expert judgement. The uncertainty analysis set out in **Annex 2** provides details of these uncertainty values. There are no additional official statistics to compare the category specific fuel use for 1A4 with, as such it is difficult to verify the activity data allocations in DUKES. As such the uncertainty for the sources included in this MS will be higher than for power stations, for example. Uncertainties in total fuel use statistics are typically low. The carbon emission factors are based on UK specific data. 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. Non-CO_2 emissions are dependent on a greater number of parameters, and are largely based on defaults. As such, the uncertainties are higher, but since the emissions are smaller, this does not have a significant impact on the overall uncertainty of total GHG emissions.

MS 6 Off road machinery

Relevant Categories, source names

1A2gvii: Industrial off-road mobile machinery

1A3eii: Aircraft - support vehicles

1A4bii: House and garden machinery

1A4cii: Agriculture - mobile machinery

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

DERV, Gas oil, Petrol

Background

This MS includes all emissions from off road machinery. These are compiled in a single model, and the outputs reported in the IPCC categories set out above.

Emissions are estimated for 77 different types of portable or mobile equipment powered by diesel or petrol driven engines. These range from machinery used in agriculture such as tractors and combine harvesters; industry such as portable generators, forklift trucks and air compressors; construction such as cranes, bulldozers and excavators; domestic lawn mowers; aircraft support equipment. In the inventory they are grouped into four main categories:

- Domestic house & garden – reported under 1A4b;
- Agricultural power units (includes forestry) – reported under 1A4c;
- Industrial off-road (includes construction and quarrying) – reported under 1A2gvii; and
- Aircraft support machinery – reported under 1A3e.

Key Data sources

Activity:	Netcen, 2004, ONS, UKMY, BEIS Projections (pers. comm.), CAA
Emission factors:	Baggott et al., 2004, EMEP-EEA Guidebook, EU Non-Road Mobile Machinery Directive.

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]*.* ***Table 1.6*** *gives additional information for common activity data sources.*

Method approach

A Tier 3 methodology is used for calculating emissions from individual types of mobile machinery. Default machinery or engine-specific fuel consumption and emission factors (g/kWh) are taken from EMEP-EEA Guidebook. For methane, emission factors for more modern machinery based on engine or machinery-specific emission limits for total hydrocarbons established in EU Non-Road Mobile Machinery Directive are also included where available. The measures introduced to reduce total hydrocarbon emissions are assumed to effect methane emissions. Activity data are based on bottom-up estimates of equipment numbers and hours of use in 2004 (Netcen, 2004). Various proxy statistics are used as activity drivers for different groups of machinery types to estimate fuel consumption across the full time series.

Emissions are calculated from a bottom-up approach using machinery- or engine-specific emission factors in g/kWh based on the power of the engine and estimates of the UK population and annual hours of use of each type of machinery. The emission estimates are calculated using a modification of the methodology given in EMEP/ EEA (2009).

The population, usage and lifetime of different types of off-road machinery were updated following a study carried out by the Inventory Agency on behalf of the Department for Transport (Netcen, 2004). This study researched the current UK population, annual usage rates, lifetime and average engine power for a range of different types of diesel-powered non-road mobile machinery. Additional information including data for earlier years were based on research by Off Highway Research (2000) and market research polls amongst equipment suppliers and trade associations by Precision Research International on behalf of the former DoE (Department of the Environment) (PRI, 1995, 1998). Usage rates from data published by Samaras *et al* (1993, 1994) were also used. Part of the 2014 Improvement Programme for the air pollutant emissions inventory led to some minor changes in activity data for certain types of construction and airport support machinery, but these had minor effects on GHG emissions.

The population and usage surveys and assessments were only able to provide estimates on activity of off-road machinery for years up to 2004. These are one-off studies requiring intensive resources and are not updated on an annual basis. There are no reliable national statistics on population and usage of off-road machinery nor figures from BEIS on how these fuels, once they are delivered to fuel distribution centres around the country, are ultimately used. Therefore, other activity drivers were used to estimate activity rates for the four main off-road categories from 2005-2015.

Table 3.9 below details the drivers used for each of the equipment categories.

Table 3.9 Activity drivers used for off-road machinery

Category	Driver source	Machinery types
Domestic house and garden	CLG household statistics (number of households)	All types of garden equipment, e.g. lawn mowers, garden tractors, leaf blowers, chain saws, trimmers
Airport machinery	CAA, 2014 terminal passenger statistics	All types of airside machinery and transport, e.g. terminal tractors
Agricultural machinery	DUKES, gas oil consumption in agriculture	All types of agricultural and forestry machinery, e.g. tractors, combines, balers, tillers, fellers, chain saws, shredders
Construction	ONS construction statistics. "Output in the Construction Industry. Supplementary Tables June 2016", Table 2b – Construction output in Great Britain: volume non-seasonally adjusted, by sector.	generator sets <5 kW
		generator sets 5-100 kW
		asphalt pavers
		tampers /rammers
		plate compactors
		concrete pavers
		rollers
		scrapers
		paving equipment
		surfacing equipment
		trenchers
		concrete /industrial saws
		cement & mortar mixers
		cranes
		graders
		rough terrain forklifts
Quarrying	Data on UK production of minerals, taken from UK Minerals Yearbook data, BGS (2016).	bore/drill rigs
		off highway trucks
		crushing/processing equipment
Construction and Quarrying	Growth driver based on the combination of the quarrying and construction drivers detailed above.	excavators
		loaders with pneumatic tyres
		bulldozers
		tracked loaders
		tracked bulldozers
		tractors/loaders
		crawler tractors
		off highway tractors
		dumpers /tenders

Category	Driver source	Machinery types
General Industry	Based on an average of growth indices for all industrial sectors, taken from data supplied by BEIS for use in energy and emissions projections.	generator sets 100-1000KW
		pumps
		air compressors
		gas compressors
		welding equipment
		pressure washers
		aerial lifts
		forklifts
		sweepers/ scrubbers
		other general industrial equipment
		other material handling equipment

Having calculated fuel consumption from a bottom-up method, the figures for diesel engine machinery were allocated between gas oil and road diesel. This was following a survey of fuelling practices of uses of off-road machinery where it was found that, particularly for small, non-commercial and domestic users who may only occasionally need to refuel, engines are filled with road diesel rather than gas oil.

A simple turnover model is used to characterise the population of each machinery type by age (year of manufacture/sale). For older units, the emission factors used came mostly from EMEP-EEA (1996) though a few of the more obscure classes were taken from Samaras & Zierock (1993). The load factors were taken from Samaras (1996). Emission factors for garden machinery, such as lawnmowers and chainsaws were updated following a review by Netcen (2004). For the air pollutants and for those equipment whose emissions are regulated by Directive 2002/88/EC or 2004/26/EC, the emission factors for a given unit were taken to be the maximum permitted by the directive at the year of manufacture. The emission regulations are quite complex in terms of how they apply to different machinery types. Each of the 77 different machinery types was mapped to the relevant regulation in terms of implementation date and limit value. The trends in total hydrocarbon (THC) emissions across the emission regulation stages were applied to the trends in methane emissions as it is assumed that measures to control THC emissions will also impact methane emissions.

Assumptions & observations

The assumptions made to estimate emissions from this source are described in the methods and approach section above. There are no data available on trends in fuel consumption or activities (population x usage) by these specific groups of machinery to corroborate the choice of proxies used as activity drivers. The drivers chosen are considered by expert judgement to be most appropriate among all the statistical data that are available. The Inventory Agency consider that the drivers used for household garden and machinery and airport support equipment are likely to be more robust than the drivers used for general industry.

A fuel reconciliation procedure is followed for gas oil which takes account of consumption from all sources, as described in **Annex 4**. For the industrial and construction machinery, the fuel reconciliation process essentially overrides any changes in estimates of fuel consumption calculated from the bottom-up procedure arising from the 2014 review of activity data for some selected machinery types. However, this review still affects the emissions of methane by leading to changes in implied emission factors for these machinery types, e.g. through revisions to the lifetime and turnover in the machinery fleet.

Recalculations

There have been no changes to the method.

Re-calculations arise from:

- Revision to DUKES gas oil consumed in Agriculture. The 2013 value is 86% of the previous value used and the 2014 value is 78% of the previous value used.
- Revision to DUKES data used for the driver in the off road model, leading to lower activity estimates for gas oil (~1%) and petrol (~14%) in 2013 and 2014.
- Revisions to the drivers for construction, construction/quarrying, and industry (<1.5% change between 2004 and 2014).
- Combination of updates to drivers for industrial off road machinery (UK minerals yearbook, ONS construction statistics), and adjustments made to balance with DUKES based on amount of gas oil available. The changes are from 2004 to 2011 and are <1.5%.

Improvements (completed and planned)

There have been no improvements completed for this submission. It is being considered to develop the model used for how sales and population data are handled for different machinery types.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

An expert judgement quality check has been done to verify that the amount of gas oil used by off-road machinery estimated from the bottom-up approach is neither excessively high or low as a proportion of total UK gas oil available for consumption as given in DUKES.

Time series consistency

Although the bottom up data for machinery population and usage is only available for one year, the proxy statistics used to generate the time series are consistent across the time series.

Uncertainties

Fuel consumption by these off-road machinery sources is not provided in DUKES so is estimated for each machinery type from a bottom-up Tier 3 approach to derive machinery population and usage rates. See **Section 3.2.4** for information. There are no centralised statistics on machinery population and usage so the uncertainties are considered quite high. An overall fuel balance taking account of consumption by other uses of gas oil, diesel and petrol ensures consistency with total consumption figures in DUKES. Various proxy data are used to establish a consistent time-series in activity rates, as explained in this section.

The highest uncertainties are considered to be in the estimates for general industrial machinery as these cover a wide range of machinery types of a fairly diffuse nature, e.g. portable generators. The estimates in the year-to-year trends for this particular off-road source are also influenced by the uncertainties in the other sources using gas oil via the fuel reconciliation step. Uncertainties in the trends for the other off-road sources (domestic house and garden, airport machinery and agricultural machinery) are considered to be smaller and less biased by the choice of proxy data.

MS 7 Aviation

Relevant Categories, source names

1A3a: Aviation

International bunkers - Aviation

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Aviation turbine fuel (jet kerosene), Aviation spirit (aviation gasoline)

Background

In accordance with the agreed guidelines, the UK inventory contains estimates for both domestic and international civil aviation. Emissions from international aviation are recorded as a memo item, and are not included in national totals. Emissions from both the Landing and Take-Off (LTO) phase and the Cruise phase are estimated. Emissions of a range of pollutants are estimated in addition to the reported greenhouse gases. The method reflects differences between airports and the aircraft that use them. In addition to aircraft main engines exhaust, emissions from aircraft auxiliary power units are also included. A full description is given in Watterson *et al.* (2004). The method used to estimate emissions from military aviation can be found in **MS 9**.

Key Data sources

Activity data:	CAA (2016a), CAA (2016b), BEIS (2016), DfT (2016)
Emission Factors:	Baggott et al., 2004 and EMEP/EEA, 2013

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]*. In addition, Annex 3 includes a table to map all aircraft types evident in UK activity data from the CAA to the EMEP-EEA Guidebook aircraft categories.*

***Table 1.6** gives additional information for common activity data sources.*

Method approach

Estimates are based on IPCC Tier 3 and use the number of aircraft movements broken down by aircraft type at each UK airport.

Activity data

The methods used to estimate emissions from aviation require the following activity data:

- **Aircraft movements and distances travelled**

  Detailed activity data has been provided by the UK Civil Aviation Authority (CAA). These data include aircraft movements broken down by: airport; aircraft type; whether the flight is international or domestic; and, the next/last POC (port of call) from which sector lengths (great circle) have been calculated. The data covered all Air Transport Movements (ATMs) excluding air-taxi. The CAA also compiles summary statistics at reporting airports, which include air-taxi and non-ATMs

- **Inland Deliveries of Aviation Turbine Fuel and Aviation Spirit**

  Total inland deliveries of aviation spirit and aviation turbine fuel to air transport are given in DUKES (BEIS, 2016). This is the best approximation of aviation bunker fuel consumption available and is assumed to cover international, domestic and military use.

- **Consumption of Aviation Turbine Fuel and Aviation Spirit by the Military**

  These data are supplied by the MOD. Military aviation estimates are included in **MS 9**. The data for total fuel use for military aviation is used in the normalisation to the DUKES total.

Calendar year activity data are derived from the data sources described above.

Table 3.10 Aircraft Movement Data: LTOs and Cruise distances for Domestic and International Flights from UK Airports, 1990-2015

Year	International LTOs (000s)	Domestic LTOs (000s)	International Aircraft, Gm flown	Domestic Aircraft, Gm flown
1990	460.5	377.0	652.0	116.4
1995	530.9	365.3	849.0	118.3
2000	704.3	407.1	1190.7	145.2
2005	800.5	488.2	1447.6	178.7
2008	840.4	472.0	1557.2	173.4
2009	773.3	420.6	1440.4	157.3
2010	734.0	393.9	1395.	146.4
2011	769.2	381.2	1465.2	141.6
2012	765.7	365.2	1444.6	137.5
2013	786.6	360.9	1471.1	134.4
2014	809.9	347.1	1524.0	130.2
2015	821.7	356.0	1565.8	135.0

Gm Giga metres, or 10^9 metres

Estimated emissions from aviation are based on data provided by the CAA and, for overseas territories, the DfT.

Gm flown calculated from total flight distances for departures from UK and overseas territories airports.

Emission factors used

A combination of national airport specific LTO factors (derived from local airport studies) and EMEP/EEA Eurocontrol cruise factors for generic aircraft are used.

An accompanying spreadsheet “Energy_background_data_uk_2017.xlxs” lists all emission factors used in the energy sector, including aviation, and associated references. Carbon emission factors are country specific, whereas defaults are used for other gases.

Method

The basic approach to estimating emissions from the LTO cycle is as follows. The contribution to aircraft exhaust emissions (in kg) arising from a given mode of aircraft operation (see list below) is given by the product of the duration (seconds) of the operation, the engine fuel flow rate at the appropriate thrust setting (kg fuel per second) and the emission factor for the pollutant of interest (kg pollutant per kg fuel).

The annual emissions total for each mode (kg per year) is obtained by summing contributions over all engines for all aircraft movements in the year. The time in each mode of operation for each type of airport and aircraft has been taken from individual airport studies. The time in mode is multiplied by an emission rate (the product of fuel flow rate and emission factor) at the appropriate engine thrust setting in order to estimate emissions for phase of the aircraft flight. The sum of the emissions from all the modes provides the total emissions for a particular aircraft journey. The modes considered are:

- Taxi-out;
- Hold;
- Take-off Roll (start of roll to wheels-off);
- Initial-climb (wheels-off to 450 m altitude);
- Climb-out (450 m to 1000 m altitude);
- Approach (from 1000 m altitude);
- Landing-roll;
- Taxi-in;
- Auxiliary Power Unit (APU) use after arrival; and
- APU use prior to departure.

Departure movements comprise the following LTO modes: taxi-out, hold, take-off roll, initial-climb, climb-out and APU use prior to departure.

Arrivals comprise: approach, landing-roll, taxi-in and APU use after arrival.

Aircraft often take-off at reduced thrust (i.e. less than 100% thrust). Thrust setting forTake-off Roll; Initial-climb; and Climb-out depend on airport and aircraft type and are derived from local airport studies. Thrust setting during Approach are 15% for the initial phase (above 600 ft) and 30% for the final phase (below 600 ft). Depending on airport and aircraft type, the Landing-roll often includes periods or reverse thrust at either at idle or 30%, the remainder of the time is at idle thrust setting. Other modes (Taxi and Hold) are at idle thrust. Idle thrust is nominally 7%, however an adjustment is made to the idle fuel flow to account engine specific variations.

The approaches to estimating emissions in the cruise are summarised below. Cruise emissions are only calculated for aircraft departures from UK airports (emissions therefore associated with the departure airport), which gives a total fuel consumption compatible with recorded deliveries of aviation fuel to the UK. This procedure prevents double counting of emissions allocated to international aviation.

The EMEP-EEA Emission Inventory Guidebook (EMEP-EEA, 2013) provides fuel consumption and emission factors for non-GHGs (NO_x, HC and CO) for a number of aircraft modes in the cruise. The data are given for a selection of generic aircraft type and for a number of standard flight distances.

The breakdown of the CAA movement by aircraft type contains a more detailed list of aircraft types than in the EMEP-EEA Emission Inventory Guidebook. Therefore, each specific aircraft type in the CAA data has been assigned to a generic type in the Guidebook. Details of this mapping are given in **Table A 3.1.4** in **Annex 3.1.4**.

A linear regression has been applied to these data to give fuel consumption as a function of distance:

$$E_{Cruise_{d,g,p}} = m_{g,p} \times d + c_{g,p}$$

Where:

$E_{Cruise_{d,g,p}}$	is the emissions in cruise of pollutant p for generic aircraft type g and flight distance d (kg)
d	is the flight distance
g	is the generic aircraft type
p	is the pollutant (or fuel consumption)
$m_{g,p}$	is the slope of regression for generic aircraft type g and pollutant p (kg / km)
$c_{g,p}$	is the intercept of regression for generic aircraft type g and pollutant p (kg)

Estimates of CO_2 were derived from estimates of fuel consumed in the cruise (see equation above) and the carbon contents of the aviation fuels. Methane emissions are believed to be negligible at cruise altitudes (IPCC, 2006).

Estimates of N_2O have been derived from an emission factor recommended by the IPCC (IPCC, 1997) and the estimates of fuel consumed in the cruise (see equation above).

The estimates of aviation fuels consumed in the commodity balance table in the BEIS publication DUKES are the national statistics on fuel consumption, and IPCC guidance states that national total emissions must be on the basis of fuel sales. Therefore, the estimates of emissions have been re-normalised based on the results of the comparison between the fuel consumption data in DUKES and the estimate of fuel consumed produced from the civil aviation emissions model, having first scaled up the emissions and fuel consumption to account for air-taxi and non-ATMs. The scaling is done separately for each airport to reflect the different fractions of air-taxi and non-ATMs at each airport and the different impacts on domestic and international emissions. Air-taxi and non-ATM fuel consumption estimates are not documented by Watterson *et al.* (2004), as this revision to methodology occurred after publication of the report. The aviation fuel consumptions presented in BEIS DUKES include the use of both civil and military fuel, and the military fuel use must be subtracted from the DUKES total to provide an estimate of the civil aviation consumption. This estimate of civil aviation fuel consumption has been used in the fuel reconciliation. Emissions from flights originating from the overseas territories have been excluded from the fuel reconciliation process as the fuel associated with these flights is not included in DUKES. Emissions will be re-normalised each time the aircraft movement data are modified or data for another year added.

For aviation turbine fuel reconciliation is quite close; pre-normalised fuel estimates generally agree with DUKES within 5%. However, the reconciliation for aviation spirit is poor due to limited coverage of smaller flights by the CAA dataset.

Assumptions & observations

The following modifications are made to the CAA data in order to ensure complete geographical coverage of the inventory and full compliance with the IPCC definitions of domestic and international:

- Flights between the UK and overseas territories are reclassified from international to domestic;
- International flights with an intermediate stop at a domestic airport are considered international in the CAA aircraft movement data. These are reclassified as having a

domestic leg and an international leg in response to a recommendation from the UNFCCC centralised review in 2013; and
- The CAA data have been supplemented with data from overseas territories, supplied by DfT.

Recalculations

For recalculations, see improvements listed below (for 2017). There have been no method changes.

Improvements (completed and planned)

A number of improvements have been made to the model over recent years, to include findings from UK specific research. The 2017 inventory submission incorporates improvements in the reduced take-off thrust assumptions. Fleet assumptions have also been reviewed, which has led to the minor modification of assumptions regarding the choice of some surrogate aircraft data.

A watching brief is kept on developments in emission factors and activity data for all modes of transport.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 10.**

Time series consistency

Consistent data sets and methods are used across the full time series to ensure time series consistency.

Uncertainties

Uncertainties for both activity and emission factors are based on expert judgement. The uncertainty analysis set out in **Annex 2** provides details of these uncertainty values. Uncertainties in fuel use statistics are typically low. The carbon emission factors are based on UK specific data. 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. Non-CO_2 emissions are dependent on a greater number of parameters, and are largely based on defaults. As such, the uncertainties are higher, but since the emissions are smaller, this does not have a significant impact on the overall uncertainty of total GHG emissions.

MS 8 Road Transport

Relevant Categories, source names

1A3bi: Road transport - cars - cold start

Road transport - cars - motorway driving

Road transport - cars - rural driving

Road transport - cars - urban driving

1A3bii: Road transport - LGVs - cold start

Road transport - LGVs - motorway driving

Road transport - LGVs - rural driving

Road transport - LGVs - urban driving

1A3biii: Road transport - buses and coaches - motorway driving

Road transport - buses and coaches - rural driving

Road transport - buses and coaches - urban driving

Road transport - HGV articulated - motorway driving

Road transport - HGV articulated - rural driving

Road transport - HGV articulated - urban driving

Road transport - HGV rigid - motorway driving

Road transport - HGV rigid - rural driving

Road transport - HGV rigid - urban driving

1A3biv: Road transport - mopeds (<50cc 2st) - urban driving

Road transport - mopeds (<50cc 2st) – lubricants use

Road transport - motorcycle (>50cc 2st) - rural driving

Road transport - motorcycle (>50cc 2st) - urban driving

Road transport - motorcycle (>50cc 4st) - motorway driving

Road transport - motorcycle (>50cc 4st) - rural driving

Road transport - motorcycle (>50cc 4st) - urban driving

1A3bv: Road transport - all vehicles LPG use

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Petrol (gasoline), Diesel (DERV), LPG

Background

This MS includes all fuel related emissions from road transport. Emissions from Urea consumption are reported under IPPU, in **Chapter 4**.

Key Data sources

Activity data:	DfT (traffic data, vehicle licensing statistics, ANPR data), DUKES (total fuel sales)
Emission factors:	COPERT 4v11, EMEP/EEA Emission Inventory Guidebook. Data on petrol and diesel fuels consumed by road transport in the UK are taken from the Digest of UK Energy Statistics (DUKES) published by BEIS and corrected for consumption by off-road vehicles and the very small amount of fuel consumed by the Crown Dependencies included in DUKES (emissions from the Crown Dependencies are calculated elsewhere).

*An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]. **Table 1.6** gives additional information for common activity data sources.*

Method approach

A Tier 3 methodology is used for calculating exhaust emissions from passenger cars (1A3bi), light goods vehicles (1A3bii), and heavy duty vehicles including buses and coaches (1A3biii) and motorcycles (1A3biv).

Petrol and diesel vehicle fuel consumption (and emissions) are estimated from the bottom up data using an array of traffic statistics and exhaust emission and fuel consumption factors representing real-world performance of vehicles. These estimates are reconciled to national energy consumption statistics from DUKES. This approach provides estimates that are consistent with the IPCC and include inherent QA/QC in the comparison of bottom-up traffic activity related estimates and top down fuel sales data.

Emissions from vehicles running on LPG are estimated on the basis of national figures (from DUKES) on the consumption of this fuel by road transport. The CO_2 emissions from LPG consumption cannot be broken down by vehicle type because there are no reliable figures available on the total number of vehicles or types of vehicles running on this fuel. It is believed that many vehicles running on LPG are cars and vans converted by their owners and that these conversions are not necessarily reported to vehicle licensing agencies. Figures from DUKES suggest that the consumption of LPG is only a small percentage (<1%) of the total amount of petrol and diesel consumed by road transport and vehicle licensing data suggest a similar percentage of all light duty vehicles run on LPG.

The UK inventory does not currently estimate emissions from vehicles running on natural gas. The number of such vehicles in the UK is extremely small, with most believed to be running in captive fleets on a trial basis in a few areas. Estimates are not made as there are no separate figures from BEIS on the amount of natural gas used by road transport, nor are there useable data on the total numbers and types of vehicles equipped to run on natural gas from vehicle licensing sources. The small amount of gas that is used in the road transport sector would currently be allocated to other sources in DUKES, and therefore the omission of this source does not represent an underestimate in the UK inventory.

Traffic-based emission calculations: an overview

A Tier 3 method is used to calculate fuel consumption and emissions from different types of petrol and diesel vehicles using detailed traffic information before a final fuel reconciliation is done.

Fuel consumption and emissions of the pollutants CH_4, N_2O, NMVOCs, NO_x, CO and other air pollutants from individual vehicle types are calculated from measured emission factors expressed in g/km and road traffic statistics from the Department for Transport. The emission factors are based on experimental measurements of emissions from in-service vehicles of different types driven under test cycles with different average speeds. The road traffic data used are vehicle kilometre estimates for the different vehicle types and different road classifications on the UK road network. These data have to be further broken down by composition of each vehicle fleet in terms of the fraction of diesel- and petrol-fuelled vehicles on the road and in terms of the fraction of vehicles on the road made to the different emission regulations which applied when the vehicle was first registered. These are related to the age profile of the vehicle fleet in each year. This level of detail is necessary because CH_4 and N_2O emissions are dependent on the types of exhaust technologies used to control the regulated air pollutant emissions.

Activity data for traffic-based emission calculations:

Hot exhaust emissions are emissions from the vehicle exhaust when the engine has warmed up to its normal operating temperature. Emissions depend on the type of vehicle, the type of fuel, the driving style or traffic situation of the vehicle on a journey and the emission regulations which applied when the vehicle was first registered as this defines the type of technology the vehicle is equipped with that affects emissions.

For a particular vehicle, the driving style or traffic situation over a journey is the key factor that determines the amount of pollutant emitted over a given distance. Key parameters affecting emissions are the acceleration, deceleration, steady speed and idling characteristics of the journey, as well as other factors affecting load on the engine such as road gradient and vehicle weight. However, work has shown that for modelling vehicle emissions for an inventory covering a road network on a national scale, it is sufficient to calculate emissions from emission factors in g/km related to the average speed of the vehicle in the drive cycle (Zachariadis and Samaras, 1997). A similar conclusion was reached in the review of emission modelling methodology carried out by TRL on behalf of DfT (Barlow and Boulter, 2009, see https://www.gov.uk/government/publications/road-vehicle-emission-factors-2009). Emission factors for average speeds on the road network are then combined with the national road traffic data.

Cold start emissions are the excess emissions that occur when a vehicle is started with its engine below its normal operating temperature. These are calculated separately from the hot exhaust emissions.

Vehicle and fuel type

Emissions are calculated for vehicles of the following types:

- Petrol cars;
- Diesel cars;
- Petrol Light Goods Vehicles (Gross Vehicle Weight (GVW) ≤ 3.5 tonnes);
- Diesel Light Goods Vehicles (Gross Vehicle Weight (GVW) ≤ 3.5 tonnes);
- Rigid-axle Heavy Goods Vehicles (GVW ≥ 3.5 tonnes);
- Articulated Heavy Goods Vehicles (GVW ≥ 3.5 tonnes);
- Buses and coaches; and
- Motorcycles.

Total emission rates (as well as fuel consumption) are calculated by multiplying emission factors in g/km with annual vehicle kilometre figures for each of these vehicle types on different types of roads. This procedure is followed to derive the initial bottom-up estimate of fuel consumption and implied fuel-based emission factors for CH_4 and N_2O by vehicle category before the normalisation to fuel sales is carried out.

Vehicle kilometres by road type

Hot exhaust emission factors are dependent on average vehicle speed and therefore the type of road the vehicle is travelling on. Average emission factors are combined with the number of vehicle kilometres travelled by each type of vehicle on rural roads and higher speed motorways/dual carriageways and many different types of urban roads with different average speeds. The emission results are combined to yield emissions on each of these main road types:

- Urban;
- Rural single carriageway; and
- Motorway/dual carriageway.

DfT estimates annual vehicle kilometres (vkm) for the road network in Great Britain by vehicle type on roads classified as trunk, principal and minor roads in built-up areas (urban) and non-built-up areas (rural) and motorways (DfT, 2016a). DfT provides a consistent time series of vehicle km data by vehicle and road types going back from 1993 to the latest inventory year, taking into account any revisions to historic data. The vkm data are derived by DfT from analysis of national traffic census data involving automatic and manual traffic counts.

Additional information discussed later was used to provide the breakdown in vkm for cars by fuel type.

Vehicle kilometre data for Northern Ireland by vehicle type and road class were provided by the Department for Regional Development (DRD), Northern Ireland, Road Services (DRDNI, 2015a). This gave a time-series of vehicle km data from 2008 to 2014. To create a time-series of vehicle km data for 1990 to 2007, the vehicle km data from DRDNI (2013) was used. The data was scaled up or down based on the ratio of the data for 2008 between DRDNI (2015) and DRDNI (2013) for the given vehicle type and road type considered. Data for 2015 were not available in time for the current inventory compilation and thus they were extrapolated from 2014 vehicle km data for Northern Ireland based on the traffic growth rates between 2014 and 2015 in Great Britain. Motorcycle vehicle km data were not available from the DRDNI and so they were derived based on the ratio of motorcycles registered in Northern Ireland relative to Great Britain each year. The ratios were then applied to the motorcycle vehicle km activity data for Great Britain. Additional information is provided by DRDNI about the split between cars and LGVs and the petrol/diesel car split for cars and LGVs in the traffic flow based on further interrogation by DRDNI of licensing data (DRDNI, 2015).

The Northern Ireland data have been combined with the DfT data for Great Britain to produce a time-series of total UK vehicle kilometres by vehicle and road type from 1970 to 2015. An extract of the vkm time series is shown in **Table 3.11**.

Table 3.11 UK Vehicle km by Type of Road Vehicle, 1990-2015

Billion vkm		1990	1995	2000	2005	2010	2014	2015
Petrol cars	urban	142.2	137.9	135.1	119.9	99.4	89.8	89.3
	rural	140.9	133.9	134.1	127.2	109.0	95.9	93.5
	m-way	49.3	48.4	53.0	48.9	41.7	35.1	34.3
Diesel cars	urban	5.8	17.2	26.1	40.8	54.0	64.6	65.2
	rural	6.1	17.9	28.3	47.5	65.8	82.7	88.3
	m-way	2.8	8.5	14.7	25.2	33.6	43.8	46.0
Petrol LGVs	urban	11.1	7.5	4.2	1.9	1.3	1.0	1.0
	rural	11.4	8.3	5.0	2.3	1.6	1.3	1.3
	m-way	3.9	3.2	2.0	0.9	0.6	0.6	0.6
Diesel LGVs	urban	5.8	10.2	15.6	21.2	22.7	24.7	25.3
	rural	6.0	11.4	18.8	25.9	29.5	32.1	33.9
	m-way	2.0	4.3	7.4	10.4	11.4	13.9	14.7
Rigid HGVs	urban	4.5	3.7	3.9	4.0	3.2	3.0	2.9
	rural	7.1	6.8	7.2	7.5	6.6	6.1	6.3
	m-way	3.7	3.7	4.2	4.2	4.1	3.6	3.9
Artic HGVs	urban	1.1	1.1	1.1	1.1	0.8	0.8	0.9
	rural	4.4	4.7	5.2	5.4	5.1	5.1	5.3
	m-way	4.7	6.0	7.4	7.9	7.5	8.1	8.4
Buses	urban	2.4	2.9	3.0	3.2	3.1	2.8	2.6
	rural	1.7	1.5	1.7	1.5	1.6	1.4	1.4
	m-way	0.6	0.5	0.5	0.5	0.5	0.4	0.4
M/cycle	urban	3.3	1.9	2.3	2.9	2.5	2.2	2.2
	rural	2.0	1.6	2.0	2.2	1.8	2.0	2.0
	m-way	0.3	0.3	0.4	0.4	0.4	0.4	0.4
Total		**423.3**	**443.8**	**482.9**	**512.9**	**507.9**	**521.4**	**529.9**

Vehicle speeds by road type

Vehicle speed data are used to calculate emission factors from the emission factor-speed relationships available for different pollutants. Average speed data for traffic in a number of different areas were taken from the following main sources: Transport Statistics Great Britain (DfT, 2009a) provided averages of speeds in Central, Inner and Outer London surveyed at different times of day during 1990 to 2008. Speeds data from other DfT's publications such as 'Road Statistics 2006: Traffic, Speeds and Congestion' (DfT, 2007a) and 2008 national road traffic and speed forecasts (DfT, 2008a) were used to define speeds in other urban areas, rural roads and motorways. Where information is not available, assumptions were made or road speed limits used for the vehicles expected to observe these on the type of road concerned. **Table 3.12** shows the speeds used in the inventory for light duty vehicles, HGVs and buses.

Table 3.12 Average Traffic Speeds in Great Britain

		Lights kph	Heavies kph	Buses kph
URBAN ROADS				
Central London	Major principal roads	16	16	16
	Major trunk roads	24	24	16
	Minor roads	16	16	16
Inner London	Major principal roads	21	21	24
	Major trunk roads	32	32	24
	Minor roads	20	20	20
Outer London	Major principal roads	31	31	32
	Major trunk roads	46	46	32
	Minor roads	29	29	29
	Motorways	108	87	87
Connurbation	Major principal roads	31	31	24
	Major trunk roads	38	37	24
	Minor roads	30	30	20
	Motorways	97	82	82
Urban	Major principal roads	36	36	32
	Major trunk roads	53	52	32
	Minor roads	35	34	29
	Motorways	97	82	82
RURAL ROADS				
Rural single carriageway	Major roads	77	72	71
	Minor roads	61	62	62
Rural dual carriageway		111	90	93
Rural motorway		113	90	95

Vehicle fleet composition: by age, size, technology and fuel type

Vehicle kilometre data based on traffic surveys do not distinguish between the type of fuels the vehicles are being run on (petrol and diesel) nor on their age. The inventory uses the Automatic Number Plate Recognition (ANPR) data provided by DfT (2016, personal communication) to define the UK's vehicle fleet composition on the road. The ANPR data has been collected annually (since 2007) at over 256 sites in the UK on different road types (urban and rural major/minor roads, and motorways) and regions. Measurements are made at each site on one weekday (8am-2pm and 3pm-9pm) and one half weekend day (either 8am-2pm or 3pm-9pm) each year in June and are currently available for years 2007 to 2011 and 2013. Since 2011, measurements have been made biennially. There are approximately 1.4-1.7 million observations recorded from all the sites each year, and they cover various vehicle and road characteristics such as fuel type, age of vehicle (which can be associated with its Euro standard), engine sizes, vehicle weight and road types.

The ANPR data are primarily used to define the fleet composition on different road types for the whole of Great Britain (GB), rather than in specific regions. However, Devolved Administration (DA)-country specific vehicle licensing data (hereafter referred as DVLA data) are used to define the variation in some aspects of the vehicle fleet composition between DA country. The ANPR data are used in two aspects to define:

- Petrol and diesel mix in the car fleet on different road types (urban, rural and motorway); and
- Variations in age and Euro standard mix on different road types.

As the ANPR data are only available between 2007 and 2011 and for 2013 and 2015, it was necessary to estimate the road-type variations in the fleet for years before the ANPR became available otherwise a step-change would be introduced in the emission time-series. For the petrol/diesel mix of the GB car fleet as a whole, this was done by extrapolating the 2007 ANPR data back to 1990 based on the rate of change in the proportion of diesel vehicles as indicated by the DfT Vehicle Licensing Statistics. The ANPR data confirmed that there is a preferential use of diesel cars on motorways, as was previously assumed in the inventory, but that preferential usage of diesel cars also extended to urban roads as well, although not to the extent as seen on motorways. For Northern Ireland, there were only four years of ANPR data (2010, 2011, 2013, and 2015) with reasonable number of observations being recorded. However, they did not show consistent trend or major difference in the proportion of diesel cars observed on different road types, and that the proportion was similar to that implied by the licensing data. As a result, it is assumed that there is no preferential use of diesel cars in Northern Ireland and the petrol/diesel mix in car km should follow the proportion as indicated by the licensing statistics provided by DRDNI. This leads to the vehicle km data for petrol and diesel cars on different road types in the UK shown in **Table 3.11**.

The age of a vehicle determines the type of emission regulation that applied when it was first registered. These have entailed the successive introduction of tighter emission control technologies, for example three-way catalysts and better fuel injection and engine management systems to control air pollutant emissions. These technologies can also affect GHG emissions.

Table 3.13 shows the regulations that have come into force up to 2015 for each vehicle type. The date into service is taken to be roughly the mid-point of the Directive's implementation dates for Type-Approval and New Registrations.

Table 3.13 Vehicles types and regulation classes

Vehicle Type	Fuel	Regulation	Approx. date into service in UK
Cars	Petrol	Pre-Euro 1	
		91/441/EEC (Euro 1)	1/7/1992
		94/12/EC (Euro 2)	1/1/1997
		98/69/EC (Euro 3)	1/1/2001
		98/69/EC (Euro 4)	1/1/2006
		EC 715/2007 (Euro 5)	1/7/2010
		EC 715/2007 (Euro 6)	1/10/2015
	Diesel	Pre-Euro 1	
		91/441/EEC (Euro 1)	1/1/1993
		94/12/EC (Euro 2)	1/1/1997
		98/69/EC (Euro 3)	1/1/2001

Vehicle Type	Fuel	Regulation	Approx. date into service in UK
		98/69/EC (Euro 4) EC 715/2007 (Euro 5)	1/1/2006 1/7/2010
		EC 715/2007 (Euro 6)	1/10/2015
LGVs	Petrol	Pre-Euro 1 93/59/EEC (Euro 1) 96/69/EEC (Euro 2) 98/69/EC (Euro 3) 98/69/EC (Euro 4) EC 715/2007 (Euro 5)	 1/7/1994 1/7/1997 1/1/2001 (<1.3t) 1/1/2002 (>1.3t) 1/1/2006 1/7/2011
	Diesel	Pre-Euro 1 93/59/EEC (Euro 1) 96/69/EEC (Euro 2) 98/69/EC (Euro 3) 98/69/EC (Euro 4) EC 715/2007 (Euro 5)	 1/7/1994 1/7/1997 1/1/2001 (<1.3t) 1/1/2002 (>1.3t) 1/1/2006 1/7/2011
HGVs and buses	Diesel (All types)	Pre-1988 88/77/EEC (Pre-Euro I) 91/542/EEC (Euro I) 91/542/EEC (Euro II) 99/96/EC (Euro III) 99/96/EC (Euro IV) 99/96/EC (Euro V) EC 595/2009 (Euro VI)	 1/10/1988 1/10/1993 1/10/1996 1/10/2001 1/10/2006 1/10/2008 1/7/2013
Motorcycles	Petrol	Pre-2000: < 50cc, >50cc (2 st, 4st) 97/24/EC: all sizes (Euro 1) 2002/51/EC (Euro 2) 2002/51/EC (Euro 3)	 1/1/2000 1/7/2004 1/1/2007

In previous years, the inventory was developed using licensing data to define the age mix of the national fleet and data from travel surveys that showed how annual mileage changes with vehicle age. This was used to split the vehicle km figures by age and Euro classification. The ANPR data provided direct evidence on the age mix of vehicles on the road and how this varied on different road types and thus obviated the need to rely on licensing data and assumptions about changing mileage with age. The information tended to show that the diesel car, LGV and HGV fleet observed on the road was rather newer than inferred from the licensing records and mileage surveys. However, this information was only available for 2007-2011, 2013, and 2015, so it was important to consider how the trends observed in these limited years of ANPR data availability could be applied to earlier years. This was done by developing a pollutant and vehicle specific scaling factor for each road type reflecting the relative difference in the fleet mix on each road type defined by the ANPR data compared with that obtained from the licensing and older mileage with age data. The fleet-adjustment scaling factors were averaged over the 2007-2011 period and were extrapolated to a value of 1 in 1990 because in this year all vehicles meet pre-Euro 1 standard, and hence differences in the age of the fleet on different road types have no effect on emissions. An overall year-, vehicle-, road- and pollutant-specific factor is then applied to GB average emission factors calculated from the vehicle fleet turnover model across the whole time-series to account for the variations in fleet profiles according to vehicle usage as evidenced from the ANPR data.

As no ANPR data were available for 2012, the average of the fleet-adjustment scaling factors for 2011 and 2013 was applied to the emission factors derived for the fleet in 2012 according to licensing data. As no ANPR data was available for 2014, the average of the fleet-adjustment scaling factors for 2013 and 2015 was applied to the emission factors derived for the fleet in 2014 according to licensing data.

For some pollutants, the emission factors cover three engine size ranges for cars: <1400cc, 1400-2000cc and >2000cc. The vehicle licensing statistics have shown that there has been a growing trend in the sales of bigger and smaller engine-sized cars in recent years, in particular for diesel cars at the expense of medium-sized cars. The inventory uses the proportion of cars by engine size varying each year from 2000 onwards based on the vehicle licensing data (DfT, 2016c). In addition, the relative mileage done by different size of vehicles was factored into the ratios; to take account of the fact that larger cars do more annual mileage than smaller cars (DfT, 2016c).

For other vehicle categories, additional investigation had to be made in terms of the vehicle sizes in the fleet as the emission factors cover eight different size classes of rigid HGVs, six different weight classes of artic HGVs, five different weight classes of buses and coaches and six different engine types (2-stroke and 4-stroke) and size classes of mopeds and motorcycles. Information on the size fractions of these different vehicle types was obtained from vehicle licensing statistics (DfT, 2016c) and used to break down the vehicle km data. Some data were not available and assumptions were necessary in the case of buses, coaches and motorcycles.

DfT Road Freight Statistics (DfT, 2016d) provided a time series of vehicle km (2000-2014) travelled by different HGV weight classes based on the Continuing Survey of Road Goods Transport (CSRGT). The data show that there has been a gradual reduction in traffic activity for the rigid HGVs below 17 tonnes across the time-series, while there has been an increase in traffic activity for rigid HGVs over 17 tonnes over the period 2000 to 2008, after which there is a slight decrease in activity to 2014. Data for 2015 was not available and so the vehicle size mix for 2014 was applied to 2015. For artic HGVs, the dominant group continues to be those over 33 tonnes, and traffic activity from the below 33 tonnes category have been decreasing over time. This information has been used to allocate HGV vehicle km between different weight classes, although further assumptions have to be made as the inventory uses a more detailed breakdown of weight classes than those defined in the Road Freight Statistics.

Only limited information on the sizes of buses and coaches by weight exists; based on analysis of local bus operator information, it was assumed that 72% of all bus and coach km on urban and rural roads are done by buses, the remaining 28% by coaches, while on motorways all the bus and coach km are done by coaches.

Assumptions on the split in vehicle km for buses outside London by vehicle weight class are based on licensing information and correlations between vehicle weight class and number of seats and whether it is single- or double-decker. It is assumed that 31% of buses are <15t and the remaining are 15-18t. For London buses, the split is defined by the fleet composition provided by Transport for London (TfL, 2016).

For motorcycles, the whole time series of vkm for 2-stroke and 4-stroke motorcycles by different engine sizes are based on a detailed review of motorcycle sales, population and lifetime by engine size. It was also assumed that mopeds (<50cc) operate only in urban areas, while only larger >750cc, 4-stroke motorcycles are used on motorways. Otherwise, the number of vehicle kilometres driven on each road type was disaggregated by motorcycle type according to the proportions estimated to be in the fleet. Research on the motorcycle fleet indicated that 2-stroke motorcycles are confined to the <150cc class.

Voluntary measures and retrofits to reduce emissions

The inventory also takes account of the early introduction of certain emission standards and additional voluntary measures, such as incentives for HGVs to upgrade engines and retrofit with particle traps, to reduce emissions from road vehicles in the UK fleet. This was based on advice from officials in DfT.

Fuel Consumption Factors for Vehicle Types:

The source of fuel consumption factors was changed this year and factors for all vehicle types are derived from the fuel consumption-speed relationships given in COPERT 5 and the

EMEP/EEA Emissions Inventory Guidebook (2013). This included a method for passenger cars which applies a year-dependent ‘real-world’ correction to the average type-approval CO_2 factor weighted by new car sales in the UK from 2005-2015. The new car average type-approval CO_2 factors for cars in different engine size bands were provided by the Society of Motor Manufacturers and Traders (SMMT, 2016). The real-world uplift uses empirically-derived equations in the Guidebook that take account of average engine capacity and vehicle mass.

Using the Guidebook factors with fleet composition data and average speeds on different road types (**Table 3.12**), fleet average fuel consumption factors for each main vehicle category are shown in **Table 3.14** for a selection of years between 1990 and 2015.

Table 3.14 UK Fleet-averaged fuel consumption factors for road vehicles (in g fuel/km)

Billion vkm	1990	1995	2000	2005	2010	2014	2015
Petrol cars	56.3	55.8	54.8	54.9	54.0	51.7	50.9
Diesel cars	55.0	53.4	53.6	53.6	54.1	51.2	51.1
LGVs	77.9	78.7	77.6	74.9	74.7	72.8	72.1
HGVs	210	205	194	207	211	216	215
Buses and coaches	292	293	268	267	262	256	255
Mopeds and motorcycles	36.2	37.0	38.0	36.9	35.9	34.9	34.9

Carbon Factors

CO_2 can be calculated from the carbon content of the fuel and the fuel used (calculated as above). Carbon emission factors for petrol, diesel and LPG are set out in *“Energy_background_data_uk_2017.xlsx”*.

CH_4 and N_2O Emission Factors for Vehicle Types

The emission factors for N_2O and CH_4 for all vehicle types in g/km are based on the recommendation of the Emissions Inventory Guidebook (EMEP, 2013) derived from the COPERT 4v11 model “*Computer Programme to Calculate Emissions from Road Transport*”.

For N_2O emissions from petrol cars and LGVs, emission factors are provided for different Euro standards and driving conditions (urban, rural, highway) with adjustment factors that take into account the vehicle’s accumulated mileage and the fuel sulphur content; both of these tend to increase emission factors. For diesel cars and LGVs, bulk emission factors are provided for different Euro standards and road types, with no fuel and mileage effects. The factors for motorcycles make no distinction between different Euro standards and road types. The factors for HGVs and buses are provided for different Euro standards, weight classes and driving conditions.

Nitrous oxide emissions were a problem with early generation petrol cars fitted with three-way catalysts, being formed as a by-product on the catalyst surface during the NO_x reduction process. Emission factors have been declining with successive Euro standards since the first generation of catalysts for Euro 1, presumably due to better catalyst formulations as well as reductions in fuel sulphur content. The fuel sulphur content of road fuels has been steadily declining since 2000 with the requirements of the European Fuel Quality Directive and is now less than 10ppm since January 2009 according to Directive 2009/30/EC.

Cold start emissions of N_2O were estimated using a method provided by the COPERT 4 methodology for the Emissions Inventory Guidebook (EMEP, 2013). The method uses a mg/km emission factor in combination with the distances travelled with the vehicle not fully warmed up, i.e. under “cold urban” conditions. For petrol cars and LGVs, a correction is made to the cold start factor that takes into account the vehicle’s accumulated mileage and the fuel sulphur content, in the same way as for the hot exhaust emission. There are no cold start factors for HGVs and buses.

Road transport is a relatively unimportant emitter of CH_4, only being produced as a consequence of incomplete combustion, but largely controlled by catalysts on petrol vehicles. Emission factors are based on factors given in the EMEP/EEA guidebook (EMEP, 2013) for urban, rural and motorway speeds. For methane the EMEP/EEA guidebook (EMEP, 2013) provides a separate factor for cold start and hot urban emissions. These are used in conjunction with estimates on the number of urban kilometres travelled with hot and cold engines.

Table 3.15 summarises the N_2O and CH_4 implied emission factors for each vehicle type in mg/km. The age-mileage functions provided by TRL are used to work out the accumulated mileage effects in the calculation of N_2O emission factors. These factors are weightings according to the distances travelled by the mix of Euro classes in the fleet each year as well as the proportions of kilometres travelled at different speeds and therefore with different emission factors. These factors also include the contribution from cold start emissions.

Table 3.15 N_2O and CH_4 Implied Emission Factors for Road Transport (in mg/km) [a]

Pollutant	Source	1990	1995	2000	2005	2010	2014	2015
CH_4	Petrol cars	108.4	84.4	53.2	31.9	17.8	13.6	13.0
	DERV cars	16.5	11.9	7.5	2.7	0.9	0.5	0.5
	LGVs	76.8	52.0	24.8	7.4	2.8	1.6	1.3
	HGVs	73.4	72.1	64.2	63.1	36.6	15.8	12.1
	Buses and coaches	127.2	135.1	108.4	90.3	50.4	25.9	21.4
	Mopeds and motorcycles	201.3	201.0	187.2	152.5	109.8	87.9	82.1
N_2O	Petrol cars	8.0	13.6	11.0	7.2	2.8	1.7	1.6
	DERV cars	-	1.9	3.7	5.7	6.3	6.3	6.2
	LGVs	5.2	4.1	4.9	5.9	6.2	6.2	6.2
	HGVs	30.0	23.9	13.4	8.1	17.2	34.6	37.5
	Buses and coaches	30.0	25.3	15.4	8.8	13.7	23.1	25.5
	Mopeds and motorcycles	1.9	1.9	1.9	1.9	1.9	2.0	2.0

[a] Includes cold start emissions.

Using the CH_4 and N_2O emissions and fuel consumption calculated from the traffic data, it is possible to derive implied fuel-based emission factors of CH_4 and N_2O (in g/kg fuel) for each vehicle type in each year which is used in conjunction with the normalised fuel consumption (see below) to estimate their emissions. This ensures all pollutant emissions are consistent with fuel sales.

Fuel reconciliation with national statistics and normalisation

The "bottom-up" calculated estimates of petrol and diesel consumption described above are compared with BEIS figures for total fuel consumption in the UK published in DUKES. The total amounts in DUKES are adjusted to remove the small amount of consumption by inland waterways, off-road machinery and consumption in the Crown Dependencies. For a valid comparison with DUKES which covers only fossil fuel petrol and diesel, the amount of petrol and diesel displaced by biofuel consumption has been used to correct the calculated consumption of petrol and diesel.

This comparison shows a small difference between the bottom-up estimated fuel consumption and DUKES-based figures. In order to be consistent with the IPCC methodologies and ensure that the fuel consumption data matches national statistics it is necessary to adjust the calculated estimates for individual vehicle types by using a normalisation process to ensure the total calculated consumption of petrol and diesel equals the DUKES-based figures.

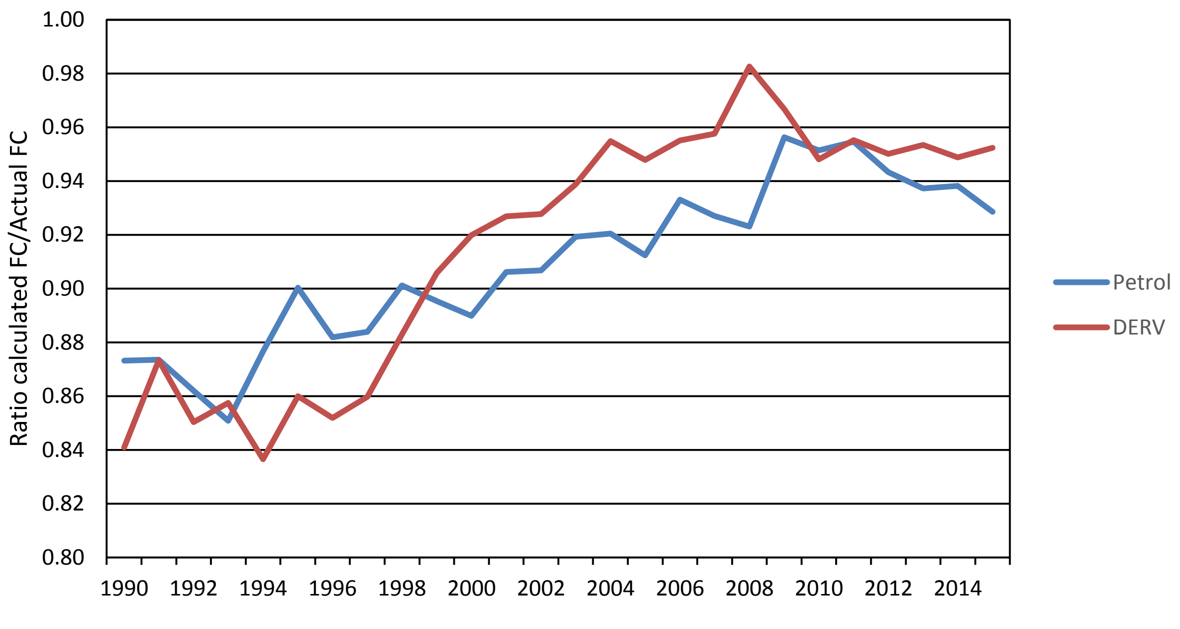
Figure 3.2 shows the ratio of model calculated fuel consumption (corrected for biofuel consumption) to the figures in DUKES based on total fuel sales of petrol and diesel in the UK, allowing for off-road consumption; **Figure 3.3** and **Figure 3.4** compare the ‘bottom up’ estimates for fuel consumption for each vehicle type compared to the ‘top down’ DUKES estimate for petrol and diesel respectively. In all years, the bottom-up method tends to underestimate fuel consumption. The maximum deviation from DUKES is 16% (for DERV, in 1990) however the ratio tends towards 1 up to 2009, indicating better agreement with fuel sales data in recent years than in the earlier part of the time-series. In 2015, the bottom-up method underestimates petrol and diesel consumption by 7.1% and 4.8% respectively.

The normalisation process introduces uncertainties into the fuel consumption estimates for individual vehicle classes even though the totals for road transport are known with high accuracy. Petrol fuel consumption calculated for each vehicle type was scaled up by the same proportions to make the total consumption align with DUKES. The same procedure was used to scale up diesel consumption by each vehicle type. Passenger cars consume the vast majority of petrol, so one would expect that DUKES provides a relatively accurate description of the trends in fuel consumption by petrol cars. This suggests the gap in the early part of the inventory time-series between DUKES and bottom-up estimates is due to inaccuracies in the estimation of fuel consumption by passenger cars during the 1990s.

The fuel consumption, normalised to DUKES in the manner described above, is used to calculate CO_2 emissions for each vehicle type. For CH_4 and N_2O, the implied fuel-based emission factors derived from the traffic data are combined with the normalised fuel consumed by each vehicle type with the amount of displaced biofuel added to the DUKES total. This is so that these non-CO_2 emissions cover all the fuel consumed by the road vehicles, including the biofuel, and not just the fossil-fuel amounts included in DUKES.

Further details on changes to fuel consumption factors and the impacts this has on fuel consumption estimates can be found in Ricardo (2016).

Figure 3.2 Ratio of calculated consumption of petrol and diesel fuel



Note: Calculated petrol and diesel fuel consumption are based on traffic movement and fuel consumption factors summed for different vehicle types. DUKES figures for these fuels are based on fuel sales in the UK.

Figure 3.3 Trend in petrol consumption for UK road transport calculated by bottom-up emissions model using COPERT 4 fuel consumption factors

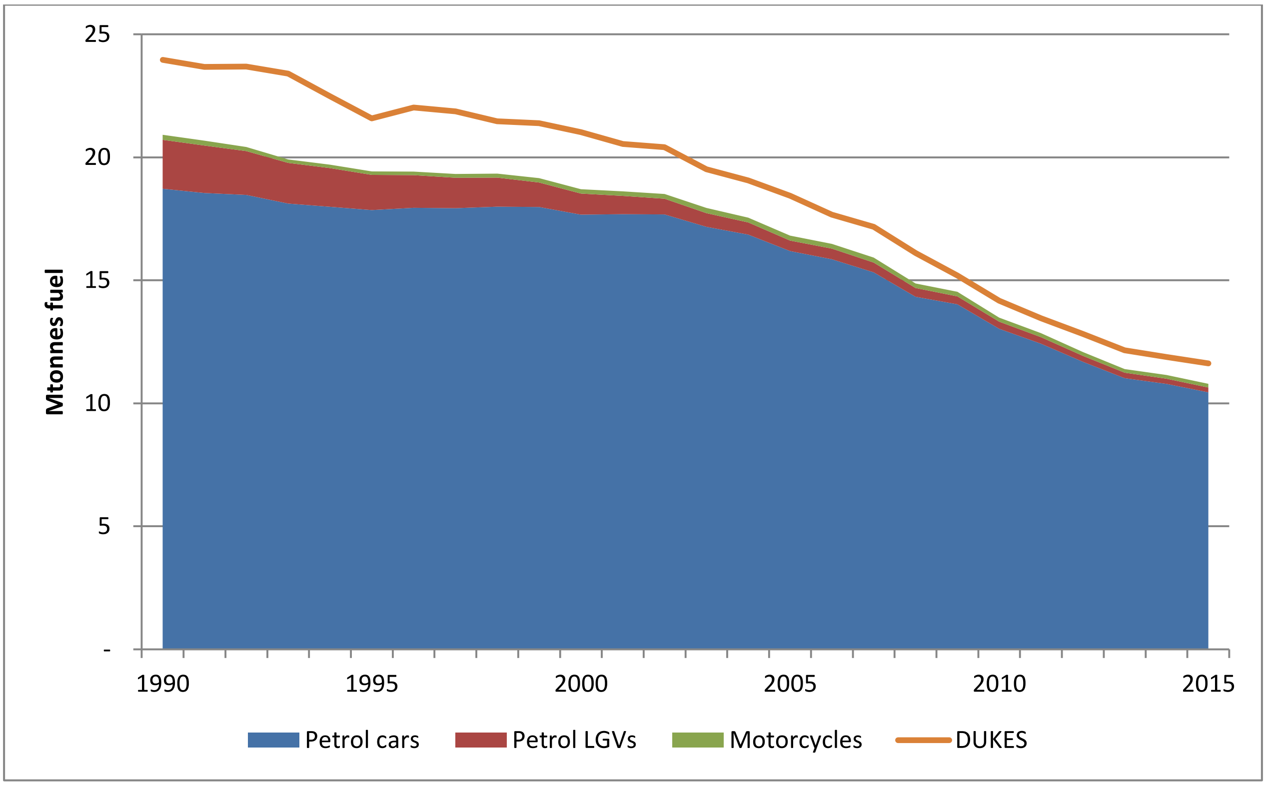
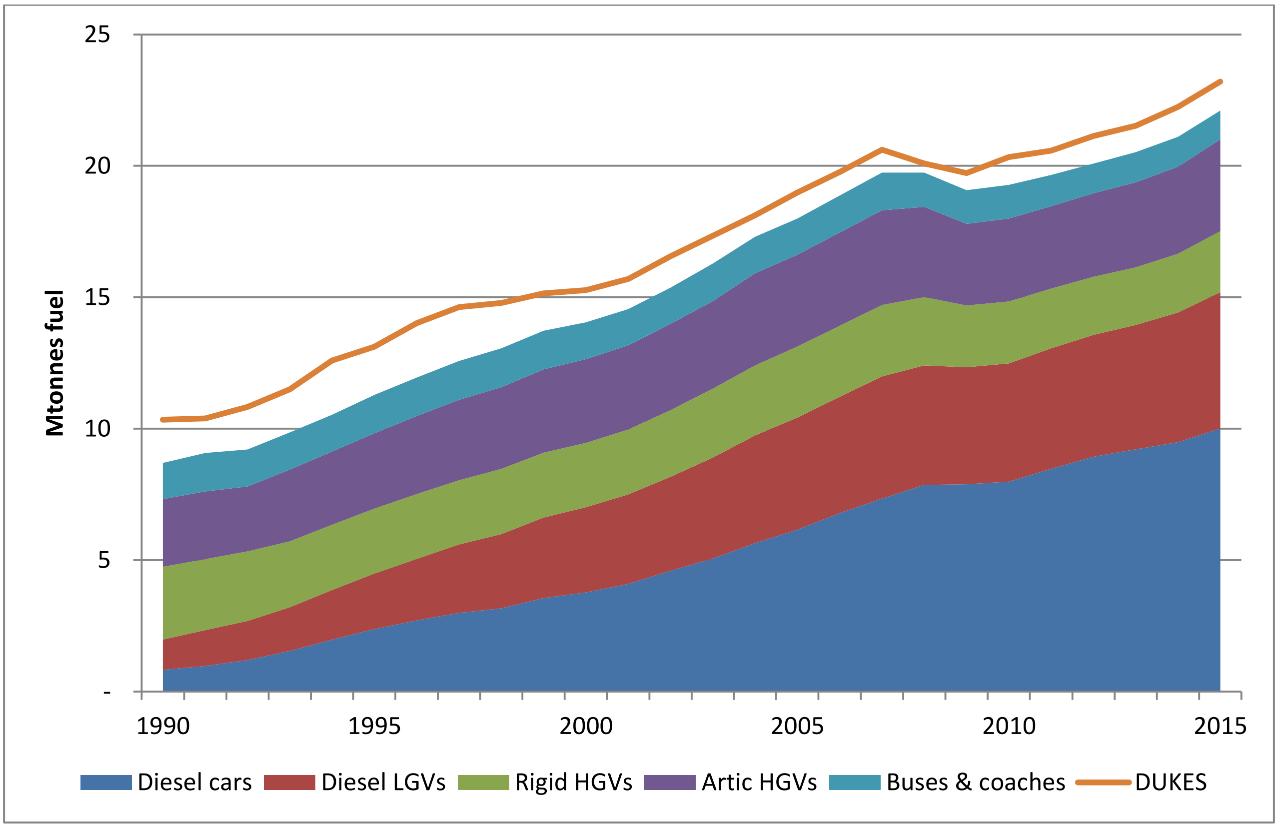


Figure 3.4 Trend in diesel consumption for UK road transport calculated by bottom-up emissions model using COPERT 4 fuel consumption factors



Emission factors for CH_4 and N_2O emissions from LPG consumption

Carbon emissions from LPG consumption are calculated from the total LPG consumption given in DUKES and fuel-based factors set out in *"Energy_background_data_uk_2017.xlsx"*. Emissions of CH_4 and N_2O from consumption of LPG were calculated from vehicle km data and emission factors (expressed as g of pollutant per km) available from COPERT 4 covering all types of light duty vehicles (cars and LGVs).

Reliable vkm statistics for LPG vehicles are not readily available. Consumption of LPG is relatively small in the UK (0.2% of all road fuels in 2015) and there are no reliable data on the number or types of vehicles running on LPG. Licencing statistics suggests that 0.2% of all light duty vehicles ran on LPG in 2015. As information on the type of LPG vehicles travelling in the UK is not available, it has been assumed that all vehicles using LPG are LGVs and this assumption then allows the kilometres travelled by LPG LGVs to be calculated from fuel efficiency factors for vehicles using this fuel taken from DfT/TRL (DfT, 2009c) combined with the total LPG consumption given in DUKES. The LPG kilometres were then combined with the g/km emission factors for CH_4 and N_2O provided in COPERT 4 assuming the fleet composition of LPG vehicles in terms of the mix of Euro standards was the same as for diesel LGVs.

Although the method for calculating CH_4 and N_2O emissions from LPG consumption is based on g/km emission factors, the use of LPG fuel consumption to estimate km travelled means the emissions are in effect based on LPG sales consistent with the method used for petrol and diesel consumption.

Emission from lubricants

Lubricant consumption by the unintended combustion in vehicle engines is estimated using the method from the EMEP/EEA Emissions Inventory Guidebook (2013). These consumption estimates were used to calculate CO_2 emissions from lubricant combustion in road vehicle engines and are reported in IPCC sector 2D1 (**Section 4.22**) except for lubricants use from mopeds, which is deemed to be intentional fuel use and hence reported in IPCC sector 1A3biv.

Emissions of CH_4 and N_2O also arise from lubricant combustion in engines. However, the exhaust emission factors for these gases will include the contribution of lubricants as well as the main fuel to the pollutant emissions when the vehicles were tested. Hence, the emissions of CH_4 and N_2O (and other air pollutants) from lubricants are included implicitly in the hot exhaust emissions calculated for each vehicle and fuel type. Treating emissions of these pollutants separately would lead to a double count.

Overseas Territories and Crown Dependencies

Fuel consumption data for 1A3b were obtained from national statistics for all Overseas Territories and Crown Dependencies. Fleet composition data were available for all territories in this cycle, due to the acquisition of new fleet composition data, for territories that previously were data poor. Detailed fleet data from the UK GHGI were used to disaggregate the fuel consumption data in order to apply UK-specific emission factors.

Assumptions & observations

There are many assumptions made, using expert judgement, in the Tier 3 approach and these are referred to in the Method Approach section.

Emissions of direct greenhouse gases are calculated on the basis of fuel sold (and not vkm travelled) and are consistent with UK energy statistics.

For CO_2, the assumptions have little effect on total road transport emissions as this is based on fuel sales figures in DUKES, but the assumptions used during the normalisation process affect the distribution of emissions between vehicle types. In particular, the procedure used to normalise the diesel consumption calculated for each vehicle type with the total DUKES figure is important as all vehicle types have a similar share of diesel consumption.

For CH_4 and N_2O emissions, the diesel normalisation method assumed has a direct effect on emission estimates as emissions per unit of fuel consumed vary for each vehicle type.

A sensitive parameter in the emission calculations of CH_4 and N_2O for petrol cars is the assumption made about the proportion of the fleet with catalyst systems that have failed, for example due to mechanical damage or failure of the lambda sensor. Following discussions with DfT, it is assumed that the failure rate is 5% per annum for all Euro standards and that up to 2008 only 20% of failed catalysts were rectified properly, but those that were rectified were done so within a year of failing. The assumptions are based on evidence on fitting of replacement catalysts. According to DfT there is evidence that a high proportion of replacement catalysts were not Type Approved and do not restore the emission performance of the vehicle to its original level (DfT 2009b). This is being addressed through the Regulations Controlling Sale and Installation of Replacement Catalytic Converters and Particle Filters for Light Vehicles for Euro 3 (or above) LDVs after June 2009. Therefore, a change in the repair rate is taken into account for Euro 3 and above petrol LDVs from mid-2009 assuming all failed vehicles are rectified properly.

Other key assumptions that affect CH_4 and N_2O emissions include:

- Application of vehicle speeds measured on a sample of roads to cover the whole road network;
- Distances covered by petrol car engines not fully warmed up in calculation of cold start emissions; and
- All LPG is consumed by light goods vehicles.

Recalculations

There have been no major recalculations. Smaller re-calculations have occurred for the following reasons:

- Updates to some of the vehicle km (from DfT) and fleet composition data for London (from TfL).
- Revisions to vehicle km data for Northern Ireland including the split between road types. This affected the whole time-series.

Improvements (completed and planned)

A watching brief is kept on developments in emission factors and activity data for all modes of transport.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

An internationally established Tier 3 method is used consistent with IPCC Guidelines and EMEP/EEA Emissions Inventory Guidebook approaches. The Method Approach section has described a comparison between the bottom-up, traffic-based approach for calculating fuel consumption and the total fuel sales figures provided in DUKES; the agreement is within 16% across the time-series.

The traffic data (vkm) and fleet composition data are provided by DfT and have been assessed by the UK Statistics Authority and confirmed as National Statistics. A Statement on Quality Strategy Principles and Processes for DfT statistics is provided at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/10957/statement-on-quality.pdf

Emission factors and fuel consumption factors are from standard IPCC and EMEP/EEA Inventory Guidebooks and COPERT. These are peer-reviewed sources.

Time series consistency

There are no time-series issues. Time-series consistency is ensured by the use of DUKES fuel consumption and use of continuous, consistent vkm traffic data from DfT. **Chapter 2** describes trends in implied emission factors for CH_4 and N_2O. These are consistent with trends in fleet turnover made using trends in new vehicle sales and constant survival rates combined with ANPR observations showing usage patterns from 2007-present.

Uncertainties

The uncertainty analysis is set out in **Annex 2**. The reconciliation between bottom up and top down approaches gives a high level of confidence in the calculated emissions for road transport. There is greater uncertainty in the division in CO_2 emissions between vehicle types.

There are greater uncertainties in the emission factors for CH_4 and N_2O because of limited emission factor measurements, in particular for more recent vehicle technologies and emission standards entering service. The main sources of uncertainties in the activity data affecting the CH_4 and N_2O inventories are in the division of diesel fuel consumption between vehicle types and the uncertainty in the fuel consumption factors that determine how much CH_4 and N_2O emissions are scaled to be consistent with national fuel consumption. Also in the on-road fleet composition, catalyst failure rates, trip lengths (for estimating cold start emissions).

MS 9 Railways

Relevant Categories, source names

1A3c: Rail - coal

Railways: freight – gas oil

Railways: intercity – gas oil

Railways: regional – gas oil

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Gas oil, coal

Background

This MS includes emissions from gas oil used to power trains and from the consumption of coal used to power steam trains. The methodology for gas oil is based around three categories of railway locomotive: freight, intercity and regional. Stationary combustion in the rail sector is included in **MS 5**. Most of the electricity used by the railways for electric traction is supplied from the public distribution system, so the emissions arising from its generation are reported under 1A1a Public Electricity.

Key Data sources

Activity: DUKES, Office of Rail and Road (ORR) National Rail Trends Yearbook (NRTY), ORR data portal

Emission factors: EMEP/EEA 2013, DfT's Rail Emissions Model (DfT 2012b), AP-42 (USEPA)

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]*.* ***Table*** *gives additional information for common activity data sources.*

Method approach

Emissions are calculated based on AD x EF.

Coal consumption data has been obtained from DUKES. Estimates have been made across the time-series from 1990-2015 and are believed to be due to consumption by heritage trains. For the indirect GHG emissions, US EPA emission factors for hand-stoked coal-fired boilers are used to estimate emissions from coal-fired steam trains.

The UK GHGI reports emissions from trains that run on gas oil in three categories: freight, intercity and regional. Emissions from these are reported under the IPCC category 1A3c Railways. Emission estimates are based on:

- Vehicle kilometres travelled and emission factors in grams per vehicle kilometre for passenger trains; and
- Train kilometres travelled and emission factors in grams per train kilometre for freight trains.

For Great Britain, vehicle kilometre data for intercity and regional trains has been obtained from the UK's Department for Transport's Rail Emissions Model for 2009 to 2011 and then estimated for other years from ORR's National Rail Trends Yearbook (NRTY) and data portal. Train kilometre data for freight trains has been estimated from ORR's National Rail Trends Yearbook (NRTY) and data portal.

Gas oil consumption by passenger and freight trains is obtained from the 2011 NRTY for the period 2005-2009 and from ORR's data portal for the years 2011 - 2014. No data is available for the years 1970 – 2004 and 2010 and data for 2015 was not published at the time of compilation. Therefore, fuel consumption for these years was estimated based on the trend in train kilometres.

For Northern Ireland, train kilometre data and fuel consumption data are provided by Translink, the operator of rail services in the region.

Carbon sulphur dioxide and nitrous oxide emissions are calculated using fuel-based emission factors and the total fuel consumed. The CEF for coal is derived from Fynes & Sage (1994) whilst the CEF for gas oil is taken from Baggott et al. (2004).

Emissions of other pollutants are based on the vehicle / train kilometre estimates, and emission factors for different train classes. The distribution of the train fleet by train class is determined based on:

- For passenger trains:
  Vehicle train kilometres data for different train classes for 2009, 2010 and 2011 are derived from the Department for Transport's Rail Emissions Model. The data for other years is extrapolated based on the year of introduction.
- For freight trains:
  Total billion tonne train kilometre data is taken from the NRTY and ORR. The breakdown by train class was obtained from the Department for Transport's Rail Emissions Model of 2009. Data for other years is extrapolated based on the year of introduction.

The emission factor for SO_2 decreased from 0.76 kt/ Mt fuel in 2011 to 0.02 kt/ Mt fuel in 2012 in line with requirements introduced from the 1st January 2012 in the EU Fuel Quality Directive (2009/30/EC) that limited the sulphur content of gas oil to 10ppm.

For coal-fired steam trains, US EPA emission factors for hand-stoked coal-fired boilers are used to estimate emissions. These are considered most appropriate for the type of coal-fired boilers on heritage trains.

Assumptions & observations

It has been assumed that new passenger trains introduced since 2012 are compliant with the European Non Road Mobile Machinery Stage IIIB regulations.

As with passenger trains, it has been assumed that the new freight trains introduced since 2012 are compliant with the European Non Road Mobile Machinery Stage IIIB regulations.

Recalculations

There have been no method changes or recalculations.

Improvements (completed and planned)

A watching brief is kept on developments in emission factors and activity data for all modes of transport.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

Time series consistency

Coal use in heritage railways is not reported in DUKES for all years. For the years in which no activity data are reported, emissions are reported as “IE.” Consultation with the DUKES team has indicated a high level of confidence in total coal use for the UK. As such although no data are available to allocate emissions to rail for earlier years in the time series, this does not represent an under report in the UK inventory.

Gas oil consumed by the rail sector is estimated based on the change in train / vehicle kilometres prior to 2005, for 2010 and for 2015. However, the total amount of gas oil consumed in the UK is thought to be reliable and therefore this does not represent an under / over report in the UK inventory as a whole.

Uncertainties

The uncertainty analysis is set out in **Annex 2**. The main uncertainties for the rail sector relate to the poor emission factor data across all sources and the lack of detailed train kilometre data by train class.

MS 10 Shipping – coastal and fishing in UK waters

Relevant Categories, source names

1A3d: Shipping – coastal

1A4ciii: Fishing vessels

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Gas oil, fuel oil

Background

This MS includes emissions from coastal shipping and fishing in UK territorial waters. Shipping outside of UK territorial waters is included in **MS 13**, inland waterways in **MS 12**, and shipping between the UK and OTs (classified as domestic) are described in **MS 11**.

Key Data sources

Activity:	DUKES (BEIS 2016), Entec, 2010, DfT Maritime Statistics, MMO Fishing statistics (MMO, 2016).
Emission factors:	Baggott et al., 2004, EMEP/EEA 2006

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]*.* ***Table 1.6*** *gives additional information for common activity data sources.*

Method approach

Emissions from coastal shipping and fishing vessels are based on Entec (2010). This study is described in **Annex 3**. This MS describes how the Entec study is used for inventory reporting. The method is consistent with a Tier 3 approach.

The Entec study produced bottom up estimates of fuel consumption and CO_2 emissions for 2007. The study also produced a method for extrapolating the estimates for the full time series. The Entec data and method is used directly for the GHG inventory data for coastal shipping and fishing. CH_4 and N_2O were not considered by Entec, these are estimated using Entec's fuel consumption estimates and default emission factors from EMEP/EEA 2006.

Using this data leads to a deviation from DUKES national energy statistics for shipping. **Annex 3** describes how fuel use for all of the shipping related sources are reconciled with the DUKES data.

Recalculations

There have been no method changes.

There has been a minor (< 1%) change in the activity in 2014 due to a revision to DfT statistics for waterborne passenger movements.

Improvements (completed and planned)

Improvements have begun and are ongoing on a significant improvement task to apply activity data from Automatic Identification System (AIS) receivers to improve the bottom-up emissions estimate method.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. All fishing and shipping estimates are reconciled with total DUKES fuel use estimates to ensure completeness.

Time series consistency

The fluctuations in the time-series of emissions from navigation partly reflect the fluctuations in the total fuel consumption statistics for marine fuels given in DUKES. The time-series for national navigation is derived from trends in port activity statistics for different vessel types.

Some of these show an increase in activities over time, others a decrease in activities over the time series.

The break in the time-series in national navigation emissions for residual oil and gas oil from 2007 onwards is due to the imposition of the Sulphur Emission Control Area (SECA) around UK waters from this year. It is assumed that the imposition of fuel sulphur content limits resulted in increased use of lower sulphur distillate (gas oil) compared with high sulphur residual oil. It was also assumed that passenger vessels switched from using residual oil to gas oil outside of SECAs from 2007 onwards to comply with the Sulphur Content in Marine Fuel Directive. As a consequence, the sum in emissions and fuel consumption from both fuels does not show a break, but there is an increase in gas oil emissions and a decrease in residual oil emissions from 2007.

These fluctuations and breaks in the time series are not considered to be time series consistency issues.

Uncertainties

The uncertainty analysis is set out in **Annex 2**. The uncertainty in the bottom up calculated estimates are considered to be less than the energy statistics. Additional uncertainty is introduced through the use of proxy statistics to develop the time series. The uncertainty in the carbon emission factor is low since this is UK specific, whereas the uncertainties for non-CO_2 gases are higher.

MS 11 Shipping between UK and OTs

Relevant Categories, source names

1A3d: Shipping between UK and Gibraltar

Shipping between UK and OTs (excl. Gibraltar)

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Fuel oil

Background

This MS includes estimates of emissions from shipping movements between the UK and the Overseas Territories. These were not included in the Entec 2010 study (described in **Annex 3**) and are therefore calculated separately. These are included as domestic emissions for UNFCCC reporting, and reported under 1A3d.

Key Data sources

Activity: DfT (personal communication), OT port authorities (personal communications), EMEP/EEA 2009

Emission factors: Baggott et al., 2004, EMEP/EEA 2009

*An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]. **Table 1.6** gives additional information for common activity data sources.*

Method approach

a) Activity data

The total fuel consumed by vessels moving between the UK and each OT is calculated as the sum of all fuel consumed by freight and passenger vessels. This is calculated separately for movements from the UK to each OT and from each OT to the UK.

There are no published data on the number and types of voyages between the UK and overseas territories (OTs). However, officials at the UK Department for Transport (DfT, Personal communication, 2016) were able to interrogate their ports database which forms the basis of the less detailed information published in DfT's Maritime Statistics. This included information on freight shipping movements and passenger vessel movements. Additional information on passenger vessel movements were gathered from individual OT port authorities.

For freight shipping, the DfT were able to provide the number of trips made between a UK port and an OT port by each unique vessel recorded. The information provided the type of vessel and the departure and arrival port. Figures were provided for all years between 2000 and the latest inventory year.

The information on the type of vessel combined with information from EMEP Emissions Inventory Guidebook 2009[27] was used to define:

- the average cruise speed of the vessel;
- the average main engine power (in kW); and
- the specific fuel consumption factor (g/kWh).

DfT were unable to provide the detailed port data for years before 2000. The individual OT port authorities also did not have this information. The trends in fuel consumption calculated by Entec for all UK international shipping from 1990 to 2000 (based on less detailed UK port statistics) were used to define the trend in fuel consumption for shipping between the UK and OTs over these years.

For passenger vessels, the information held by OT port authorities indicated the only movements were by cruise ships (i.e. not ferries). Data from DfT was used for the years 2013-2015(DfT, 2016). Detailed movement data were held by the port authority of Gibraltar listing all voyages departing to or arriving from the UK from 2003 to 2012[28]. The DfT also held information on the number of UK port arrivals by cruise ships from the OTs, but only between 1999 and 2004. This is unpublished information and was provided via direct communication with DfT officials.

Information held by the other OTs indicated that none had any cruise ship sailings with the UK logged. The data held by DfT showed the majority of sailings were from Gibraltar and the data were consistent with the information provided by the Gibraltar port authority. However, the DfT data also showed a total of 3 arrivals from the Falkland Islands between 1999 and 2004.

No cruise ship information was available before 1999 from either DfT or the individual OT port authorities. Trends in the total number of passengers on cruises beginning or ending at UK ports between 1990 and 1999 published in DfT's Maritime Statistics (from Table 3.1(a) UK international short sea passenger movements, by port and port area: 1950 – 2009) were used to define the trend in fuel consumption by cruise ships between the UK and OTs over these years.

[27] http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009

[28] http://www.gibraltarport.com/cruise/schedules

Distance travelled: Distances for each voyage for freight and passenger were taken from http://www.portworld.com/map/. This has a tool to calculate route distance by specifying the departure and arrival ports. Using the distance, average speed, engine power and fuel consumption factor it was possible to calculate the amount of fuel consumed for every voyage made.

Emission factors

The emission factors used are average factors implied by Entec (2010) for all vessels involved in international voyages supplemented by factors from the EMEP/EEA emissions inventory guidebook (2009) for marine engines.

Assumptions & observations

Total fuel use for these shipping movements is reconciled with DUKES.

All fuel used for voyages between the UK and OTs is assumed to be fuel oil.

Data provided by various data sources are assumed to be complete.

Recalculations

There have been no method changes but there have been recalculations.

Recalculations have occurred to the submission under to Convention (the ‘GBR’ submission) due to the removal of Bermuda from the list of OTs.

Improvements (completed and planned)

This emission source was introduced in response to the UNFCCC ERT in 2012. No improvements to this method are currently planned.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. There are no official statistical data sets available to verify the information provided for the calculation of these estimates. They are considered to be the best available data. Total fuel use for all shipping sources is reconciled with DUKES.

Time series consistency

The method approach section above details which years data were available for. Gaps have been filled for the early part of the time series based on other statistics, to ensure that the inventory is complete for all years.

Uncertainties

The uncertainty analysis is set out in **Annex 2**. The uncertainty in this particular source is high although the contribution to the total inventory is low and as such, it does not warrant further research. Estimates are included for completeness, following a recommendation from the ERT.

MS 12 Inland Waterways

Relevant Categories, source names

1A3d Inland goods-carrying vessels

Motorboats / workboats (e.g. canal boats, dredgers, service boats, tourist boats, river boats)

Personal watercraft e.g. jet ski

Sailing boats with auxiliary engines

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

DERV, Gas oil, Petrol

Background

The category 1A3dii Waterborne Navigation includes emissions from fuel used for passenger vessels, ferries, recreational watercraft, other inland watercraft, and other gasoline-fuelled watercraft. Methods for estimating emissions for these small vessels are presented separately here as they are calculated using different approaches to other marine emissions in the UK inventory.

Key Data sources

Activity:	Walker et al (2011), ONS Social Trends, OECD Stat, Visit England, DfT Maritime Statistics (elaborated under Method approach, below).
Emission factors:	EMEP/EEA 2007 and 2009

*An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]. **Table 1.6** gives additional information for common activity data sources.*

Method approach

The Guidelines recommend national energy statistics be used to calculate emissions, but if these are unavailable then emissions should be estimated from surveys of fuel suppliers, vessel movement data or equipment (engine) counts and passenger and cargo tonnage counts. The UK has no separate national fuel consumption statistics on the amount of fuel used by inland waterways in DUKES. However, they are included in the overall marine fuel statistics. A Tier 3 bottom-up approach based on estimates of population and usage of different types of inland waterway vessels is used to estimate their emissions. In the UK, all emissions from inland waterways are included in domestic shipping totals.

The methodology applied to derive emissions from the inland waterways sector uses the 2007 and 2009 EMEP/EEA Emissions Inventory Guidebooks (EMEP, 2009b) approach.

Emissions from individual vessel types are calculated using the following equation:

$$E = \sum_i N \times HRS \times HP \times LF \times EF_i$$

where:

E = mass of emissions of pollutant i or fuel consumed during inventory period,
N = source population (units),
HRS = annual hours of use,
HP = average rated horsepower,
LF = typical load factor,
EF_i = average emissions of pollutant i or fuel consumed per unit of use (e.g. g/kWh).

The method requires:

- a categorisation of the types of vessels and the fuel that they use (petrol, DERV or gas oil);
- numbers for each type of vessel, together with the number of hours that each type of vessel is used;
- data on the average rated engine power for each type of vessel, and the fraction of this (the load factor) that is used on average to propel the boat; and
- g/kWh fuel consumption factors and fuel-based emission factors.

The inland waterways class is divided into four categories and sub-categories (Walker et al, 2011):

- Sailing Boats with auxiliary engines;
- Motorboats / Workboats (e.g. dredgers, canal, service, tourist, river boats);
    - recreational craft operating on inland waterways;
    - recreational craft operating on coastal waterways;
    - workboats;
- Personal watercraft i.e. jet ski; and
- Inland goods carrying vessels.

Activity data for 2008

A bottom-up approach was used based on estimates of the population and usage of different types of craft and the amounts of different types of fuels consumed. Estimates of both population and usage were made for the baseline year of 2008 for each type of vessel used on canals, rivers and lakes and small commercial, service and recreational craft operating in estuaries / occasionally going to sea. For this, data were collected from stakeholders, including the British Waterways, DfT, Environment Agency, Maritime and Coastguard Agency (MCGA), and Waterways Ireland.

As it was only possible to estimate population and activities for one year (2008), proxy statistics were used to estimate activities for different groups of vessels for other years in the time series:

- Private leisure craft – ONS Social Trends 41: Expenditure, Table 1, Volume of household expenditure on "Recreation and culture"; http://www.ons.gov.uk/ons/rel/social-trends-rd/social-trends/social-trends-41/social-trends-41---expenditure.pdf. No data were available for this dataset after 2009, therefore a second dataset was used to estimate the activity from 2010: OECD.Stat data: http://stats.oecd.org/Index.aspx?DataSetCode=SNA_TABLE5 - 'Final consumption expenditure of household, UK, P31CP090: Recreation and culture);
- Commercial passenger/tourist craft – Visit England, Visitor Attraction Trends in England 20145, Full Report: http://www.visitengland.org/insight-statistics/major-tourism-surveys/attractions/Annual_Survey/ : "Total England Attractions"
- Service craft (tugs etc.) – DfT Maritime Statistics, Port traffic trends. Table PORT0102 - All UK port freight traffic, foreign, coastwise and one-port by direction; https://www.gov.uk/government/statistical-data-sets/port01-uk-ports-and-traffic and
- Freight – DfT Waterborne Freight in the United Kingdom, Table DWF0101: Waterborne transport within the United Kingdom (Goods lifted - UK inland waters traffic - Non-seagoing traffic – Internal) https://www.gov.uk/government/statistical-data-sets/dwf01-waterborne-transport

One of these four proxy data sets was assigned to each of the detailed vessel types covered in the inventory and used to define the trends in their fuel consumption from the 2008 base year estimate to all other years in the inventory.

Emission factors

The fuel-based emission factors used for all inland waterway vessels for CH_4 and N_2O were taken from the EMEP/EEA 2009. Emission factors for carbon are from Baggott et al, 2004.

Assumptions & observations

A key assumption made is that privately owned vessels with diesel engines used for recreational purposes use DERV while only commercial and service craft and canal boats use gas oil (Walker et al., 2011). Some smaller vessels also run on petrol engines. As a result, around 90 kt of DERV and 90 kt of petrol previously assigned to the road transport sector for 2009 in the 2009 inventory are now allocated to inland waterways.

Walker at al. (2011) and Murrells et al. (2011) draw attention to the potential overlap between the larger vessels using the inland waterways and the smaller vessels in the shipping sectors (namely tugboats and chartered and commercial fishing vessels), and the judgement and assumptions made to try to avoid such an overlap.

Recalculations

There have been no method changes. The have been recalculations; as follows;

- 5.6% decrease in the estimated activity in 2014 in the proxy statistics used to estimate the activity from freight vessels within the inland waterways sector.
- Minor recalculation in the proxy statistics used to estimate the activity from private leisure craft within the inland waterways sector. This includes a <1% decrease in 2010-2011, a 0.1% increase in 2012, and a 1-2% decrease in 2013-2014.

Improvements (completed and planned)

No improvements to this method are currently planned. Emission factors and activity data are kept under review.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

Time series consistency

The bottom up analysis for this source category was carried out for one year, and the time series is generated using proxy statistics, as set out in the method approach section, above. Consistent time series of proxy statistics, where available, have been used to estimate the time series. For private water craft, two data sets have been combined. Where the two data sets overlap, there is a correlation in the trend. The combination of these data sets does not introduce any time consistency issues.

Uncertainties

The uncertainty analysis is set out in **Annex 2**. There are no official statistics for the population of vessels, the total fuel consumption or the annual usage of the vessels. There may also be some overlap in definitions between coastal shipping and inland waterways. Total fuel use for shipping is reconciled with the DUKES total to ensure completeness.

MS 13 Fishing outside of UK territorial waters

Relevant Categories, source names

1A4ciii: Fishing vessels (outside UK waters)

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Gas oil, fuel oil

Background

A separate method as required for fishing vessels outside UK waters as the approach used for calculating shipping (Entec, 2010) is based on geographical boundary and covers only domestic emissions from fishing vessels that stay within UK waters (covering a sea area up to 200 nautical miles from the UK coast), leaving from and returning to UK ports. It is therefore assumed that this study does not include the full fuel consumption from fishing vessel operations. In response to comments from reviewers during the In-Country review of the UK's Greenhouse Gas Inventory in 2012, emissions have been estimated from commercial fishing activities occurring in waters outside the Entec study area. These emissions are included in the UK national totals and reported under 1A4ciii.

Key Data sources

Activity: MMO, 2016. Borges et al., 2008

Emission factors: Baggott et al., 2004, EMEP/EEA 2009, Entec 2010

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]*.* ***Table 1.6*** *gives additional information for common activity data sources.*

Method approach

A Tier 2 approach is used to estimate emissions from deep sea trawlers heading out of the UK waters, fishing and then returning to the UK.

Activity data

The Marine Management Organisation (MMO) produces a report annually on the UK fishing industry[29] entitled "*UK Sea Fisheries Statistics*[30]". This is classed as a National Statistics Publication. This report gives the tonnes of fish landing into the UK and abroad by UK vessels by **area of capture**. The areas of capture are listed in terms of the ICES[31] sea area classification system. The sea areas covered by Entec (2010) are broadly the ICES areas IV, V, VI and VII and these are included in calculation for fishing within UK waters (see **MS 10**). The method statement considered activities outside these areas only. According to the MMO reports, these other areas where the UK actively fishes are listed below:

- Barents Sea/Murman Coast (I);
- Norwegian Coast (IIa);
- Bear Island & Spitzbergen (IIb);
- Bay of Biscay (VIII);

[29] The MMO is an executive non-departmental public body (NDPB) incorporating the work of the Marine and Fisheries Agency (MFA) and marine-related powers and specific functions previously associated with DECC and the Department for Transport (DfT)

[30] http://www.marinemanagement.org.uk/fisheries/statistics/annual.htm#chapter3

[31] ICES is the International Council for the Exploration of the Sea. See for example http://www.fao.org/docrep/009/a0210e/a0210e12.jpg

- East Coast of Greenland (XIV);
- North Azores (XII); and
- Other Areas.

The MMO reports give tonnes of fish landed in the UK from each of these areas from 1994-the latest year.

The approach involved in calculating the fuel used by the fleet to reach and return from these “non-UK” sea areas and the fuel consumed whilst fishing in the areas.

To calculate the fuel used to reach and return from these non-UK ICES sea areas it is necessary to know:

- the number of vessel trips to non-UK ICES areas, based on average tonnes fish landed per trip;
- the distance from a UK port to a point in the ICES sea area;
- the average vessel speed in order to estimate the time taken to reach the sea area;
- the typical engine power of the types of vessels used; and
- time spent fishing in the sea areas.

i) Number of vessel trips

According to the MMO Landings report, the fish catches in the non-UK ICES areas are mainly of pelagic fish such as mackerel and herring. These are also mainly caught by the largest vessels, over 24m.

A publication by Borges et al[32] on Dutch commercial fishing operations by pelagic trawlers indicated that a small number of very large-sized trawlers (factory trawlers) catch on average **155 tonnes** pelagic fish per vessel per trip based on data for 2005. These are vessels that are over 100m in length with an engine size close to 6,000kW making them similar in size to a bulk carrier ship.

The MMO Landings data for 2011 indicates that 39,500 tonnes fish were caught in the non-UK ICES areas in 2011. Assuming the UK vessels have the same trawling capacity as the Dutch fleet, then this would require **255 vessel trips** per year in 2011.

The Borges et al study stated that the Netherlands has some of the largest fishing vessels in the world. If the UK vessels are generally smaller then they will require more than the 255 trips to the non-UK ICES areas estimated above to make the total catch reported. However, this will be offset by the fact that their engine sizes and hence fuel consumption rates would be lower.

According to Table 3 in the MMO Structure and Activity 2011 report, the average engine size of the >24m fleet of vessels in the UK was 1,206 kW which is considerably less than the engine size of the factory trawlers in the Dutch fleet. The largest vessels in the UK fleet are in Scotland (142 vessels >24m, with an average engine size of 1,350 kW). It is possible that very large vessels make up a sub-set of these figures.

For the purpose of these estimates, 255 vessel round-trips was assumed to the non-UK ICES areas in 2011 in conjunction with an assumed engine power for these vessels of 5,800kW. Fish landings for these non-UK ICES areas in other years from the MMO reports were used to calculate number of round-trips in other years.

[32] L Borges et al, “What do pelagic freezer-trawlers discard?”, ICES Journal of Marine Science, 65: 605–611(2008), http://icesjms.oxfordjournals.org/content/65/4/605.full.pdf

For 2015, the landings of fish increased to 34,100 tonnes, which following the method applied above implies 227 round trips.

ii) Distances covered to/from the non-UK ICES sea areas

The MMO information was used to split the tonnes of fish landings from the non-UK ICES areas between each area in each year. The tables in the 2011 MMO Landing reports indicate that the major areas of capture by UK fishing vessels in the non-UK ICES areas are the north Norwegian coast and ‘other areas’. The MMO reports do not specify what ‘other areas’ refer to, but the MMO Landings report indicates that Spain and Morocco are major areas outside UK waters receiving landings of pelagic fish from UK vessels. It was therefore assumed that the landings to the UK from ‘other areas’ are from off the coast of Morocco which is known to be an important fishing area.

Further detailed landings data in the 2011 MMO Landings report indicate that 81% of landings of pelagic fish are to major ports in Scotland (Peterhead, Lerwick and Fraserburgh) with 11% to major ports in the south-west of England (mainly Plymouth, Newlyn and Brixham) and the rest to other ports.

It was assumed that all 11% of the landings to the south-west of England were captured in the ‘other areas’ (designated as Morocco). Peterhead and Lerwick were assumed to take the remaining landings captured from Morocco and all the landings captured off the coast of Norway and the other minor areas. The Peterhead/Lerwick split was taken to be 65%/35% for all the areas of capture based on MMO data.

This information on landings was used to split the total number of vessel trips from the UK (calculated above) to each of the non-UK ICES sea areas between the “representative” UK ports of Peterhead, Lerwick and Plymouth.

To calculate trip distances, certain central positions were allocated to each area of capture. Distances from the relevant UK port to these positions are shown below:

Table 3.16 Approximate distances to points in each sea area in km

	Peterhead	Lerwick	Plymouth
Barents Sea/Murman Coast (I)	1923	1730	
Norwegian Coast (IIa)	1000	750	
Bear Island & Spitzbergen (IIb)	2600	2300	
Bay of Biscay (VIII)	2000	1875	660
East Coast of Greenland (XIV)	1800	1700	
North Azores (XII)	3000	3000	
Other Areas [(a)]	2900	2900	1700

Using the return port-sea area distances and the number of return trips made, split between each combination of UK port-to-sea area, the total distances travelled per year by all UK fishing trips to the non-UK ICES areas were calculated for each year.

iii) Average vessel speed

An average cruise speed of 25 kph was used for the fishing vessels travelling between the UK port and area of fish capture. This is taken from the EMEP Inventory Guidebook section on marine navigation.

Using this speed with the trip distances calculated above, the total time taken to travel the distances calculated above was derived for each year.

iv) Rated engine power

A rated engine power of 5,800 kW was used for all vessels, consistent with the calculation of number of vessel trips above.

A weighted average engine load factor of 0.8 is used for the calculation of fuel consumption during fishing operations. This is based on an assumption that the vessel would be operating under different loads for different parts of a day. The assumptions were: 5 hrs/day at 80% load, 11 hrs day at 50% load, 8 hrs/day at 20% load.

v) Fuel consumption

A specific fuel consumption factor of 203 g/kWh was used to calculate total fuel consumption by UK vessels travelling to and returning from the non-UK ICES sea area in conjunction with rated engine power, load factor and total travel time. The fuel consumption factor was taken from Table 3-4 in the EMEP/EEA Emissions Inventory Guidebook 2009 for a medium- and high-speed diesel engine using Marine Diesel/Gas Oil (MDO/ MGO).

The fuel used whilst actively fishing in the non-UK areas was calculated by assuming each vessel spends 4 days actively fishing once it has reached its sea area. This was used in conjunction with the same engine power, load information and fuel consumption factor as above to calculate total fuel consumption for all UK vessels whilst actively fishing in these sea areas.

Note that using other information in the MMO reports on total fishing effort in combination with the vessel trip information and landings used here implies that the average time spent fishing is around 3-4 days, consistent with this assumption.

The total fuel consumption for fishing by UK vessels in non-UK ICES areas is the sum of the total fuel consumed during the fishing activity and the total fuel consumed travelling to and from the area of capture.

Emission factors

The emission factors are those used by Entec for fishing vessels in UK waters supplemented by factors from the EMEP/EEA emissions inventory guidebook (2009) for marine engines and Baggott et al., 2004 for carbon factors.

Assumptions & observations

All the fuel used for deep sea fishing in non-UK waters is assumed to be gas oil sourced in the UK. All other assumptions are documented in the Method Approach, above.

Recalculations

There have been no recalculations.

Improvements (completed and planned)

No improvements to this method are currently planned. Emission factors and activity data are kept under review.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

Time series consistency

No data are available to estimate emissions for years prior to 1994. Emissions for 1990 to 1993 are assumed to be the same as 1994.

Uncertainties

The estimates of fuel consumption are very uncertain, owing to the number of assumptions used, limited data availability and reliance on Dutch data. There is no top down number available to verify the estimates or constrain to. However, where possible, other data sources have been considered to validate some of the assumptions (see method approach section). The uncertainty in the carbon emission factor is low, since this is based on UK specific data. The emission factors for CH_4 and N_2O are higher since these are based on defaults, however, these make up a small proportion of the total emission. These estimates are included in the UK inventory for completeness. The uncertainty analysis for the UK inventory is set out in **Annex 2**.

MS 14 International shipping

Relevant Categories, source names

Marine bunkers: Shipping - international IPCC definition

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Gas oil, fuel oil

Background

This method statement covers estimates of international marine bunkers which are reported as a Memo item and not included in the UK totals.

Key Data sources

Activity:	DUKES (BEIS, 2016); other shipping source AD
Emission factors:	Entec, 2010, EMEP/EEA 2009, Baggott et al., 2004

*An accompanying spreadsheet “Energy_background_data_uk_2017.xlxs” lists all emission factors used in the energy sector, including a full list of references[24]. **Table 1.6** gives additional information for common activity data sources.*

Method approach

Activity data

Fuel consumption for international shipping is calculated as the difference between total shipping fuel use in DUKES and all other shipping uses:

International shipping fuel consumption = (total DUKES fuel consumption – Entec domestic shipping fuel consumption – naval fuel consumption – inland waterways fuel consumption – fishing vessels outside UK waters fuel consumption – shipping vessels travelling from the UK to overseas territories fuel consumption)

Emission factors

Emission factors for CH_4 and N_2O were taken from EMEP/EEA 2009, and emission factors for carbon are from Baggott et al., 2004. Emissions of other gases from international shipping (1A3di) were calculated by multiplying the residual fuel consumption calculated above with an implied emission factor for international vessel movements. The implied emission factors were derived from the Entec study by dividing the Entec emission estimates for international vessel movement by their associated fuel consumption for each fuel type. This effectively means the inventory does capture the types of vessels, engines, speeds and activities used for international movements in Entec's inventory even though the overall movements, fuel consumption and hence emissions are different. The same factors were used for voyages between the UK and OTs (see above).

Assumptions & observations

Calculation of international emissions as the residual

The method implies that the total marine fuel consumption by all marine activities covered in the inventory is considered a "closed" system, in other words, the sum of consumption across all the different marine activities (international shipping, domestic coastal shipping, fishing, naval and inland waterways, voyages to overseas territories, fishing outside UK waters) is consistent with the total amount of gas oil and fuel oil used for consumption as given in DUKES for marine bunkers and national navigation. The approach also implies a different domestic/international split to that implied by DUKES. The proportion of fuel consumption (hence emissions) allocated to domestic shipping is considerably smaller than that implied in DUKES.

Process for agreeing changes to shipping inventory approach and reasons behind deviation from DUKES

Following the results of the Entec (2010), the approach to deriving the estimates for the UK domestic and international shipping fuel use totals has been subject to periodic review through consultation across all stakeholders. These consultations and method developments have been necessary to analyse the data discrepancies between the "bottom-up" fuel use estimates derived from the Entec study, and the "top-down" estimates of fuel sales and ultimate fate by sector that are presented in the UK energy statistics, DUKES.

Periodic meetings are held to bring together the key parties: BEIS, Defra, DfT, the UK Petroleum Industry Association (UKPIA), Entec and the Inventory Agency. The analysis of the different datasets has led to a revision in the derivation of the shipping fuel allocations, to use more data that are derived from the bottom-up data on vessel movements. The new method was then adopted for the 2009 version of the inventory published in early 2011 and was described in the UK's 2011 National Inventory Report methodology annex.

The inventory team now maintains regular contact with the DUKES team, and the outputs from DUKES and other data collection systems are considered in order to determine the best available estimates for fuel use for domestic and international shipping.

Consistency with marine fuels data submitted to IEA/EUROSTAT

In response to feedback from the Expert Review Team, the Inventory Agency has confirmed with the UK national energy statistics team at BEIS that the UK allocations of marine bunker fuels reported within DUKES are consistent with the data submitted to EUROSTAT and the IEA across the full time-series. Note, however, that the UK inventory memo item estimates for international shipping deviate from the reported DUKES (and IEA/EUROSTAT) data due to reallocation of some of the bunker fuels to military shipping based on data from the Defence Fuels Group of the MoD; these emissions are included in national inventory estimates and not in the Memo Item (International bunkers) estimate.

Furthermore, the shipping methodology described above leads to a different domestic/international split in fuel use allocation for marine fuels compared with the allocations in the national energy statistics (DUKES) and submissions to IEA/EUROSTAT.

Recalculations

Fuel use is calculated as a residual and as such will change following any recalculations to

- Domestic coastal shipping (**MS 10**);
- Fishing vessels (**MS 10**);
- Inland waterways (**MS 12**);
- Naval shipping (**MS 15**); and
- Shipping between the UK and OTs (**MS 11**).

Activity data are also recalculated based on DUKES revisions.

Improvements (completed and planned)

No improvements to this method are currently planned. Emission factors and activity data are kept under review.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

Time series consistency

The fluctuations in the time-series of emissions from navigation partly reflect the fluctuations in the total fuel consumption statistics for marine fuels given in DUKES. The time-series for national navigation is derived from trends in port activity statistics for different vessel types. Some of these show an increase in activities over time, others a decrease in activities over the time series. Further erratic behaviour in the time-series for bunker fuels results from the method used to introduce consistency with consumption data in DUKES. Further details in the methodology are given in the previous sections on navigation.

Uncertainties

The uncertainty analysis is set out in **Annex 2**. Uncertainty for international bunkers is not estimated.

MS 15 Naval shipping

Relevant Categories, source names

1A5b: Shipping - naval

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Gas oil

Background

Emissions from military shipping are reported separately under IPCC code 1A5b.

Key Data sources

Activity: MoD, 2016

Emission factors: Baggott et al., 2004, EMEP/EEA 2009

*An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]. **Table 1.6** gives additional information for common activity data sources.*

Method approach

Emissions are calculated using a time-series of naval fuel consumption data (naval diesel and marine gas oil) provided directly by the Sustainable Development and Continuity Division of the Defence Fuels Group of the MoD (MoD, 2016). Data are provided on a financial year basis and are amended to derive figures on a calendar year basis.

Carbon emission factors are based on Baggott et al., 2004 and CH_4 and N_2O use emission factors from EMEP/EEA 2009. For other pollutants, implied emission factors derived for international shipping vessels running on marine distillate (MGO and MDO) from the Entec (2010) study, where available, were assumed to apply for military shipping vessels.

Assumptions & observations

Fuel use for military shipping is included in the DUKES totals. Naval fuel consumption data (naval diesel and marine gas oil) provided directly by the Sustainable Development and Continuity Division of the Defence Fuels Group of the MoD (MoD, 2016) is subtracted from DUKES to ensure there is no double counting (see **Annex 4**).

Recalculations

There have been no method changes or recalculations.

Improvements (completed and planned)

No improvements to this method are currently planned. Emission factors and activity data are kept under review.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Total fuel use is verified through the comparison of the reference and sectoral approaches.

Time series consistency

The time series is generated from consistent data sets for all years, there are no known issues to raise.

Uncertainties

The uncertainty in the fuel use estimates is low since these are taken from a reliable source. Carbon emission factors are based on country specific data, whereas the non-CO_2 gases are reliant on defaults, which can lead to higher uncertainties. Total fuel use for all shipping categories are reconciled with the DUKES total, and total uncertainties for all users of a given fuel are constrained to the total uncertainty for the fuel.

MS 16 Military aircraft

Relevant Categories, source names

1A5b: Aircraft - military

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Aviation spirit, aviation turbine fuel

Background

Emissions from military aviation are reported separately under IPCC code 1A5b.

Key Data sources

Activity: MoD, 2016

Emission factors: Baggott et al., 2004, EMEP/EEA 1999, IPCC, 1997.

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]*.* ***Table 1.6*** *gives additional information for common activity data sources.*

Method approach

LTO data are not available for military aircraft movements, so a simple, Tier 1 approach is used to estimate emissions from military aviation. The estimate of military emissions is made using military fuel consumption data (MoD, 2016) and IPCC (1997) and EMEP-EEA (1999) cruise defaults shown in Table 1 of EMEP-EEA (1999). The military fuel data include fuel consumption by all military services in the UK. It also includes fuel shipped to overseas garrisons and casual uplift at civilian airports.

Assumptions & observations

Fuel use for military aviation is included in the DUKES totals. Military aircraft consumption data provided directly by the Sustainable Development and Continuity Division of the Defence Fuels Group of the MoD (MoD, 2015) is subtracted from DUKES to ensure there is no double counting (see **Annex 4**). Fuel use for casual uplift is considered to be outside of DUKES.

The EMEP-EEA (1999) factors used are considered appropriate for military aircraft.

Recalculations

There have been no method changes and revised fuel use statistics from the MoD.

Improvements (completed and planned)

No improvements to this method are currently planned. Emission factors and activity data are kept under review.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

Time series consistency

The time series is generated from consistent data sets for all years, there are no known issues to raise.

Uncertainties

The uncertainty in the fuel use estimates is low since these are taken from a reliable source. Carbon emission factors are based on country specific data, whereas the non-CO_2 gases are reliant on defaults, which can lead to higher uncertainties.

MS 17 Coal mining and handling

Relevant Categories, source names

1B1a1i: Deep-mined coal

1B1a1ii: Coal storage and transport

1B1a2i:Open-cast coal

Relevant Gases

CH_4

Relevant fuels, activities

Coal produced

Background

In 2015 there were 5 deep-mining collieries operational, of which 3 have methane drainage and recovery systems used to collect and burn mine gas to raise power. A further 17 open cast coal mines were also operating in the UK in 2015. This is compared with 188 deep mining collieries and 126 open cast mines operating in 1990[33]. The UK coal industry is undergoing considerable restructuring with mine closures continuing under difficult economic circumstances, and this is evidenced by the 53% reduction in UK deep mined coal production between 2012 and 2015.

Key Data sources

Activity Data: All activity data on coal production at open cast and deep mines is from DUKES (BEIS, 2016), except for production at licensed mines during 1990-1995 (only) which are from an industry reference (Barty, 1995).

Emission Factors: Operator reported data on methane emissions from deep mines are used to derive CS EFs (UK Coal, 2015; Coal Authority, 2015), in conjunction with UK energy statistics from DUKES when site-specific emissions are not known (BEIS, 2016). Data for emissions in 2015 is not available, and so estimates are based on mine-specific production between 2014 and 2015, and mine-specific methane production in 2014 (UK Coal, 2015; Coal Authority, 2015). Methane EFs from mining operations from UK research are used to estimate emissions from open cast mines and

33 http://webarchive.nationalarchives.gov.uk/20140721140515/http://coal.decc.gov.uk/assets/coal/DyGgJafg_pdf_part.pdf

licensed mines (both from Williams, 1993), and emissions from coal storage and transport (Bennett et al, 1995).

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]. ***Table 1.6*** *gives additional information for common activity data sources.*

Method approach

Emissions are calculated from saleable coal production statistics for open cast and deep mined coal, taken from DUKES (BEIS, 2016). For all sources, UK-specific emission factors are applied, which in the early part of the time series are derived from periodic industry publications, and for later years (1998 onwards) are primarily derived from company-specific or mine-specific reporting of methane emissions by mine operators. Industry-wide colliery methane utilisation data are taken from DUKES (BEIS, 2016).

From 1990-1995, a small number of privately-owned mines classified as "deep mines" operating in the UK were shallower and smaller than Government-owned deep mines. These mines were licensed by the UK Government and in all years produced less than 3% of total UK deep-mined coal, whilst the majority of deep mines were Government-owned and operated. The Watt Committee Report #28 (Williams, 1993) indicates that these smaller licensed mines emitted less methane than the nationalised deeper mines, and therefore the aggregate emission factor for the early part of the time series is slightly lower. Activity data for production at licensed mines is taken from Barty (1995), with the activity data for non-licensed mines calculated by difference from the UK deep-mine coal production total in UK energy statistics.

Emission factors for methane from **deep-mined coal** production are taken from:

1990-1992 Bennett et al (1995) was a study on deep mines which produced estimates of emissions for the period 1990-93. This was a period over which significant numbers of mines were being closed, hence the range in emission factors from 10 to 13.1 kg CH_4 per tonne coal extracted.

1990-1995 The methane emission factor of 1.36 kg CH_4/tonne coal produced at licensed, shallow mines is from Williams (1993).

1993-1997 No time series of emissions data or industry research for deep-mined mines are available for 1993-97, and therefore the 1998 factor from operator reporting at deep mines (see below) is used. The combination of this 1998 factor for deep-mined coal and the lower factor for licensed, shallow mines operating to 1995 leads to a variable aggregate factor during 1993-1995.

1998-2014 The emission factors for UK mines in 1998-2014 are based on operator measurements of the methane extracted by the mine ventilation systems for all collieries operated by UK Coal (UK Coal, 2015) and for collieries owned by other operators that report methane utilisation and venting data (Coal Authority, 2015). Not all UK collieries provide data on methane utilisation and venting. The emission factor derived from the sites that provide data is applied across all UK production at deep mined sites. The proportion of UK production that is covered by the reporting collieries ranges from 77% in 1998 to 96% in 2004 and 2007, and was around 90% from 2008 to 2012. However, due to recent closures of larger mines the proportion of UK production covered by mines that report their methane emissions to the inventory agency has fallen to only 78% in 2014. In 2015, only data on the production of coal is available, and as such mine-specific methane emissions from production and utilisation are estimated on the basis of the ratio of mine-specific production reported between 2014 and 2015.

Methane extracted at deep mines is either emitted into the atmosphere or utilised for energy production; the gas is not flared for safety reasons. Data provided by colliery operators provides mine-specific annual data on the mass of methane:

- vented to atmosphere, fan drift (A);
- drainage to surface (B); and
- utilisation of methane in electricity generation (C).

The total methane vented to atmosphere from these sites that report the methane vented drained and utilised is therefore calculated as "A + B – C".

For the non-reporting sites that are typically smaller sites with no methane utilisation, the EF derived from the reporting sites (from the vented and drained methane) is applied. Annual data (methane generation, methane utilisation, coal production) are obtained from mine operators. In 2005 there were 7 mines that reported methane emissions, then 6 in 2006, 5 in 2007 to 2010, 4 in 2011-12 and only three in 2013 and 2014. For these mines the aggregate emissions of methane (before any utilisation in gas engines) has been used together with the annual production data to derive an "unabated" methane IEF that is regarded as the most representative factor to apply to the production data from the smaller non-reporting (of emissions) UK deep coal mines.

Therefore, total methane emission estimates for **deep-mined coal** in the UK from 1998 onwards are calculated as follows:

UK Emissions = D + (E*F)

Where:

D = the sum of methane emissions reported (after any utilisation in gas engines) by the (typically larger) UK deep coal mines that can provide annual methane emission estimates;

E = UK total deep mined coal production from DUKES – Annual coal production at all sites included in D; and

F = IEF for unabated methane emissions, based on reported methane emissions data from sites included in D (i.e. methane elution before any utilisation) / production at the sites included in D.

The decline in methane emissions in recent years in the UK reflects both the decline in UK deep-mined coal production and the increase in uptake of technology to utilise coal mine methane to generate electricity.

The emission factor for methane from **coal storage and transport** factor of 1.16 kg CH_4 per tonne of coal produced is only applied to deep mined coal production and is taken from industry research, Bennett et al (1995).

The emission factor for methane emissions from **open cast coal production** of 0.34 kg CH_4 per tonne of coal production is taken from industry research, Williams (1993). The total production of saleable coal is derived from the DUKES statistics. Where coal is upgraded to saleable form, some coal is rejected in the form of coarse discards containing high mineral matter and also in the form of unrecoverable fines. Typically, around 20% of the weight of the raw coal feed is lost through these preparation processes, as per the 2006 IPCC guidelines. Raw coal production is therefore estimated by increasing the amount of 'saleable coal' by the fraction lost through washing. The total emissions from open-cast mining are based on measurements of the total methane content of freshly sampled coal cores from open-cast sites from the three main producing regions in the UK. These data are used to generate the total emission factor for all open-cast coal production, regardless of the stage at which this emission takes place.

Assumptions & observations

- **Open cast coal emission factor:** As noted in the method section, the CS EF for CH_4 emissions from open cast coal production are based on analysis of the total methane content of freshly sampled coal cores and these EFs reflect the total methane emissions for all open-cast coal produced, regardless of the stage at which this emission takes place. i.e. it is assumed in the UK GHGI estimation method that all of the measured methane content of the coal is released prior to combustion, and these emissions are all allocated within 1B1a2i open-cast coal mining (Mining activities). This is consistent with the 1996 IPCC GLs method where country-specific data are used, in section 1.7.2.4, Equation 5 and the text on page 1.111: "In most cases, if the Tier 2 approach is used to estimate methane emissions from surface mines, post-mining emissions from surface-mined coals are assumed to be zero." Furthermore, the UK approach is consistent with the general equation for estimating fugitive emissions from surface coal mining presented in section 4.1.4 of the 2006 GLs, as the UK EF comprises all methane in the coal produced that could be released at any stage post-mining. As a result, the UK estimate for open-cast coal mining activities is likely to be an over-estimate, as some methane will be retained within the coal up to the point of combustion, especially for lump coal used in domestic grates, where desorption of the methane is much slower than for fine coal processed for use in other sources such as power stations. The basis for this open-cast coal production factor also explains why the EF on methane from coal storage and transport (see paragraph above) is only applied to the activity of deep-mined coal in the UK, rather than to the total UK coal production data; to apply it to open-cast production also would introduce a double-count;
- **Other coal:** In the UK energy balance, there is an additional line for coal production which is for “other” sources of coal into the UK economy, which are typically very small numbers (95 kt in 2013 and zero in 2015) and represent coal obtained from slurries, ponds and rivers. We therefore include the activity data for "other" sources of coal within the UK energy balance, as part of the overall supply of coal as reported in the CRF table 1. Ab, but we do not derive any estimates of fugitive emissions from this production source, as it is not coal that has been abstracted from open cast or deep mines.

Recalculations

In previous submissions, coal lost during washing and preparation processes at open-cast mines was not considered. However, the data reported by DUKES specifies that the production data are for ‘saleable coal’, whilst the IPCC 2006 guidelines indicate that typically a 20% loss is incurred from raw coal production in the form of coarse discards containing high mineral matter and in the form of unrecoverable fines. To account for this loss, the methodology was adapted to include this factor. As a result, there have been recalculations to the entire open-cast mining production time-series.

Improvements (completed and planned)

No improvements to this method are currently planned. Emission factors and activity data are kept under review. As the UK deep mined coal market continues to undergo restructuring and closures due to economic constraints, we anticipate that the number of mines that will remain operating and reporting may continue to reduce and therefore the data availability and method options may be further impacted.

QA/QC

Activity data for coal production in deep-mined and open-cast mines in the UK are quality-checked through comparison of data reported within DUKES and data reported directly by the

UK Coal Authority, which provides regional and UK totals of coal production. The information provided directly by colliery operators regarding their methane recovery systems are also checked against the data published by BEIS on coal mine methane projects in the UK (which encompasses both operating and closed / abandoned mines with coal mine methane recovery systems).

Time series consistency

The factors for coal mining are all based on UK industry research. Emission factors from coal storage and transport, licensed mines and from open cast mines do not vary through the time series; in each case the same factor is applied to the UK activity in every year. For deep-mined coal emissions there is a variable emission factor across the time series, derived from operator reporting and reflecting the changing methane management practices within UK collieries, especially to increase methane capture and oxidation for power-raising in recent years, leading to a gradually declining methane emission factor per unit coal produced since the early 2000s. The variability in the factor also reflects the changes in production from different mines that have different methane management practices, as for some UK collieries the capture and use of methane has not proved cost-effective and therefore the technology is not uniformly implemented. The variability of the time series of emission factors represents changes in UK coal mining, and not time series consistency issues.

Uncertainties

The uncertainty in the coal production statistics is low, since these are based on national statistics. The emission factors applied are country specific, and in some cases based on mine specific data, and therefore the uncertainty is lower than using default literature values. Additional uncertainty is introduced through the application of emission factors based on a sub-set of mines to represent full UK coal production, but we note that the total UK deep mined production where a methane elution factor is applied based on data from other sites is typically smaller sites that together produce (for many years in the time series) only around 10% of UK coal. However, we also note that the proportion of UK production at non-reporting deep mines has grown due to recent closures to 28%, 22% and 15% in 2013, 2014, and 2015 respectively, and therefore the overall uncertainty of deep-mined coal methane emissions is higher for these years.

MS 18 Closed coal mines

Relevant Categories, source names

1B1a1iii: Closed Coal Mines

Relevant Gases

CH_4

Relevant fuels, activities

Modelled emissions

Background

Methane emissions from **closed coal mines** are accounted for within category 1B1a1iii (reallocated from 1B1c) of the UK inventory. Emission estimates are based on a study funded by DECC (WSP, 2011) which updated research from 2005 (White Young Green, 2005) to:

- reflect the UK trend in mine closures and re-openings driven by fluctuations in energy prices since the 2005 research; and

- improve the representation of methane recovery and utilisation at closed collieries (Colliery methane combustion emissions are reported in the energy sector, 1A).

Methane emissions from closed mines reach the surface through many possible flow paths: vents, old mine entries, diffuse emission through fractured and permeable strata. Direct measurement of the total quantity of gas released from abandoned mines is not practical.

Data for 32 mines closed between 1990 and 2015, and 121 mines closed before 1990 are included in the model. The model also includes projections, which can be changed to account for mine closures occurring earlier or later than predicted. Methane utilisation has increased significantly across the time series, up to a maximum of 94% in 2004.

Key Data sources

WSP, 2011 and White Young Green, 2005

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]*.* ***Table 1.6*** *gives additional information for common activity data sources.*

Method approach

The UK model was developed in 2005 (White Young Green, 2005) and revised in 2011 (WSP, 2011). The 2011 study used the same method, updating data for mine closures during 2005-2010.

The model generates both historic and projected methane emission estimates from closed UK coal mines, combining two separate sets of calculations to estimate emissions from:

- coal mines that were closed before 2005 and included in the 2005 update; and
- mines that were not included in the 2005 update, including mines closing or predicted to close between 2004 and 2028.

The model uses a relationship between emissions and the quantity of the underlying methane gas within the abandoned mine workings, including site-specific considerations of the most appropriate decay model for the recently closed mines.

The model calculates methane reserves for all UK coalfields that are not totally flooded from 1990 with projections to 2050. The gas reserves are calculated by totalling all the gas quantities in individual coal seams likely to have been disturbed by mining activity. To enable calculation of the reserves over time, the rise in water levels in the abandoned mines due to water inflow has been calculated based on industry consultation, with a date estimated for each of the mines to be fully flooded; as mine workings become flooded they cease to release significant amounts of methane to the surface.

The development of the model has drawn on industry monitoring to measure methane emission from vents and more diffuse sources, including measurement of the flow rate and methane concentrations of vented mine gases. The industry knowledge of these methane sources has increased greatly in the UK over the last 10 years as the technology to capture and utilise the methane for power generation has developed alongside new economic incentives to utilise the mine methane in this way. Monitoring of more diffuse sources involves the collection of long-term gas samples to measure any increases in background atmospheric methane level in the locality.

Methane flows measured by both methods showed a general increase with the size of the underlying gas reserve. The data indicate an emission of 0.74% of the reserve per year as a suitable factor to apply to the methane reserve data in order to derive methane emission estimates for abandoned UK coalfields for 1990 to 2050, and this factor is applied within the model to derive the UK emission estimates.

Estimates have been made for both deep mined and open cast coal.

WSP (2011) derived estimates for historic methane emissions from closed coal mines and also generated projections to 2050, based on forecasts for UK coal mining activity. The 2015 emission estimates in this 2017 UK GHGI submission are therefore taken from the projections of emissions within the 2011 WSP report.

Assumptions & observations

Recalculations

There were no recalculations or method changes to the closed coal mines source category in this submission. The WSP model uses mine-specific projected dates of closure for all mines that were still operating in 2011. However, early closure of these mines compared to these projections therefore requires the model to be updated to reflect this. Three mines closed between 2014 and 2015, and the model has been modified to integrate this accordingly.

All deep-mines in the UK have now closed, and therefore this source category will decline in significance in future years

Improvements (completed and planned)

No improvements to this method are currently planned. The model is periodically reviewed and updated.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5.** WSP (2011) was subject to review by a steering committee, and final sign off by DECC. The research also includes benchmarking of UK specific estimates with other inventories to ensure that the method used remains appropriate for the UK.

Time series consistency

No time series consistency issues have been identified.

Uncertainties

The uncertainty in the emissions from this source was assessed as part of WSP (2011). The uncertainty assessment indicated a range of ±17% to ±41% over the period 1990-2050. This level of uncertainty is in line with IPCC guidance on Tier 2 and Tier 3 methodologies. This considered the uncertainty in the future mine closure dates, gas reserve estimates, the annual methane emissions rate as % of gas reserve, the open cast mine methane emissions factor and the methane utilisation factor.

MS 19 1B2 excluding: Oil refining, storage and distribution (1B2aiv to v) and natural gas distribution (1B2biii to v)

Relevant Categories, source names

1B2a1: Upstream Oil Production - Offshore Well Testing

1B2a2: Petroleum processes

Upstream Oil Production - process emissions

1B2a3: Upstream Oil Production - offshore oil loading

Upstream Oil Production - onshore oil loading

1B2a4: Upstream Oil Production - oil terminal storage

1B2b1: Upstream Gas Production - offshore well testing

1B2b3: Upstream Gas Production - process emissions

1B2b4: Upstream Gas Production - gas terminal storage

1B2c1i: Upstream Oil Production - venting

1B2c1ii:Upstream Gas Production - venting

1B2c2i: Upstream Oil Production - flaring

1B2c2ii:Upstream Gas Production - flaring

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

All fugitive releases from oil and gas production, excluding leakage from gas transmission and distribution. Distribution of oil products is not described since there are no direct GHG emissions.

Background

This source category covers emissions which occur during the production, transportation, or use of liquid and gaseous fuels. It excludes combustion of those fuels used by the industry during the production, transportation, or use of liquid and gaseous fuels. Fuel combustion emissions associated with upstream oil and gas exploration and production are reported within 1A1cii Oil and Gas Extraction, the method for which is presented in **MS 2**. Emissions from leakage during gas transmission and distribution, and the point of use are included in **MS 20**.

UK upstream oil and gas exploration and production is almost entirely offshore, with a very small number of onshore oil wells. No onshore gas production occurs in the UK. Shale gas reserves have been identified and some preliminary research into prospective shale gas extraction is on-going, but there is no active exploration or production currently in the UK.

Offshore oil and gas is transported to processing plants via pipelines and marine tankers; emissions of CH_4 and VOC occur during loading of oil into the ship's tanks (including from the onshore terminal when oil is transferred to tankers for export or transfer to UK refineries), and then subsequently at the unloading stage to onshore storage vessels. Emissions of CH_4 and VOC also occur from storage tanks at oil terminals.

Key Data sources

Activity data:	EEMS (BEIS, 2016), DUKES (BEIS, 2016), IPPC/EPR-reported data (EA and SEPA, 2016) EU ETS data (BEIS, 2016), UKOOA (2005), UKPIA (2016)
Emission factors:	EEMS (BEIS, 2016), EU ETS (BEIS, 2016), UKOOA (2005)

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]. ***Table 1.6** gives additional information for common activity data sources.*

Method approach

An overview of the data sources and methods used to derive estimates for the categories included in this MS is below.

The key methodology for 1B2 source categories is based around a number of data sources/studies.

- Oil and gas operators submit annual source-specific emission estimates to the **Environmental and Emissions Reporting System (EEMS)**, regulated by the BEIS Offshore Inspectorate and developed in conjunction with the trade association Oil & Gas UK. For further details see **Annex 3**. UK GHGI estimates are based on EEMS (activity data and emission factors derived from operator-reported emissions) from 1998 to the latest inventory year for all offshore installations. Industry studies from the trade association **(UKOOA, 2005)** are used to inform estimates prior to the EEMS system, 1990-1997;
- Annual reporting of emissions by pollutant aggregated across all emission sources under the **IPPC/EPR reporting system** to the UK environmental regulatory agencies (i.e. EA, NRW, SEPA) are available for onshore sites only (i.e. including oil and gas terminals, but excluding all offshore oil and gas installations). These data are available from 1998 in England and Wales and for 2002 and 2004 onwards in Scotland and include emission estimates for a suite of GHG and air quality pollutants including CO_2, CH_4 and N_2O;
- For 1995 to 2009, all terminals also reported source-specific emission estimates to the **EEMS system**, but from 2010 this was determined to be on a voluntary basis only, and therefore from 2010 onwards the EEMS dataset is incomplete for terminals. For combustion and flaring sources, the EEMS dataset includes mass-based activity data, and emission estimates for a suite of GHG and air quality pollutants including CO_2, CH_4 and N_2O;
- From 2005 onwards, **combustion CO_2** emissions from upstream oil and gas facilities have been reported under **EU ETS**, and from 2008 onwards **combustion and flaring CO_2** emissions from upstream oil and gas facilities has been reported under EU ETS. The scope is not as comprehensive as EEMS or IPPC, but the data are useful to check carbon emission factors and to inform a de-minimis emission value for each site. For oil and gas **terminals** the EU ETS data provides useful additional detail, where facilities may not report to EEMS but do report facility-wide (i.e. aggregated across all sources) emission estimates under IPPC/EPR. The EU ETS data provides emission estimates that can be broken down by fuel and between combustion and flaring sources, to augment the IPPC emissions data, enabling more accurate source-specific emission reporting;
- The EEMS data are only comprehensive post 1998, as such further data sets are used to compile the time series: To do this the **Petroleum Processing Reporting System (PPRS) is used** to provide data on **gas flaring volumes** at offshore and onshore installations, as well as **oil and gas production data** to extrapolate the activity data back to 1990. PPRS is the mechanism by which upstream oil and gas operators are required to report energy and other activity data to the BEIS Energy Statistics team as part of the wider system of regulation of the oil & gas extraction and production sector, and to inform upstream energy market trends;
- The UK GHG inventory estimates for categories during 1990-1997 inclusive are based on industry estimates provided within periodic reports in the 1990s, with a comprehensive review and update by the trade association provided in 2005 **(UKOOA, 2005).** This 2005 update was based on a UKOOA report from 1998, updated to use latest emission factors and activity data from across the sector. The 1998 UKOOA report presents data from detailed industry studies in 1991 and 1995 to derive emission estimates for 1990 from available operator estimates. Emission estimates for 1991-1994 were then calculated using production-weighted interpolations. Only limited data were available from operators in 1990-1994, and emission totals were only presented in broadly aggregated sectors of: drilling (offshore), production (offshore), loading (offshore) and total emissions onshore. Emission estimates for the more detailed oil &

gas processing sources (well testing, fuel combustion, flaring, venting, process and fugitive, oil loading / unloading and oil storage) were then based on applying the fraction of total emissions derived from the 1997 data from EEMS; and

- The inventory agency continues to investigate ways in which methane emissions from **oil and gas well blow outs** can be estimated, however no data are currently available with which to make a time series. The inventory agency will continue to explore the possibility of data with other countries, by reviewing published research or through engagement with experts.

A summary of how the data sources above are applied to the detailed categories and subcategories under 1B2 are presented in **Table 3.17** below.

Table 3.17 Summary of Data Sources and Estimation methods for 1B2 source categories in the UK GHG Inventory

<table>
<tr><th colspan="2">Categories and subcategories</th><th>Methodology</th></tr>
<tr><td rowspan="5">Onshore terminals, Offshore oil and gas platforms & Offshore floating production and storage vessels, well testing rigs</td><td>1B2aii, 1B2bii Oil, Gas Production: Upstream facility process and fugitive releases</td><td>1990-1997 (UKOOA 2005): 1998-Latest year (EEMS): For onshore terminals and wells, missing sites from EEMS are estimated based on IPPC/EPR-reported data (EA and SEPA, 2016).</td></tr>
<tr><td>1B2aiii Transport: Offshore loading of oil, 1B2avi Other: Onshore loading of oil</td><td>1990-1997 (UKOOA 2005): 1998-Latest year (EEMS): Assumes CH_4 IEF from 1998 applies to all years 1990-1997. For onshore terminals and wells, missing sites from EEMS are estimated based on IPPC/EPR-reported data (EA and SEPA, 2016).</td></tr>
<tr><td>1B2ci,ii Venting at upstream oil, gas facilities</td><td>1990-1997 (UKOOA 2005): 1998-Latest year (EEMS): For onshore terminals and wells, missing sites from EEMS are estimated based on IPPC/EPR-reported data (EA and SEPA, 2016).</td></tr>
<tr><td>1B2ci,ii Flaring at upstream oil, gas facilities</td><td>1990-1996 (UKOOA 2005): 1997-Latest year (EEMS): Assuming the same oil:gas split as in EEMS 1997, and aggregate oil and gas flaring volumes 1990-Latest year (BEIS, 2016). For onshore terminals and wells, where terminals do not report to EEMS (since 2010) EU ETS data on flaring are used if available. Where no EEMS or EU ETS data are available, an estimate of the total reported emissions in IPPC are allocated to flaring.</td></tr>
<tr><td>1B2ai, 1B2bi Oil, Gas Exploration: well testing</td><td>1990-1996 (UKOOA 2005): 1997-Latest year (EEMS): AD estimated assuming CO_2 IEF from 1998 is valid for earlier years.</td></tr>
<tr><td>Refineries</td><td>1B2aiv Refining / Storage: Petroleum processes, Oil Terminal storage</td><td>All years - Fugitive emissions from oil storage and refinery processes are derived from aggregate industry estimates provided by the refinery trade association (UKPIA, 2016).</td></tr>
</table>

Assumptions & observations

The EEMS data set allows for emissions to be accurately allocated between oil and gas production between 1998 and the latest year. Prior to 1998, in order to present a plausible trend in overall emissions for the oil and gas sectors back to 1990, a relatively simplistic approach has been adopted to divide the industry estimates between oil and gas back to 1990.

For flaring, gas consumption and well testing emissions, the oil:gas ratio of activity data in 1998 has been used to extrapolate back the activities to 1990, retaining the previous emission factors for the “oil and gas” sources. For process and fugitive sources, oil storage and venting emissions, where the EEMS data are simply presented as emissions data without any underlying activity and emission factor information, the estimates for the early part of the time series are simply based on the oil:gas ratio (for each pollutant) from 1998.

Recalculations

There have been no method changes. There have been some minor revisions to UK estimates for sources from the upstream oil and gas sector and downstream petroleum processes, where QC and stakeholder consultation with regulators and operators has enabled the Inventory Agency to address any identified reporting gaps or inconsistencies. Other revisions include the re-allocation of two sites from oil-producing to gas-producing, and one from gas-producing to oil-producing. Overall, the emissions from these re-allocated sites remains unchanged however. In addition, the identification of one site as a downstream site, and associated re-allocation of emissions contributes to recalculations. Quantitative data presented in **Section 10**.

Improvements (completed and planned)

No improvements to this method are currently planned. Emission factors and activity data are kept under review.

QA/QC

The EEMS dataset quality system is managed by the regulatory agency (BEIS) and developed in conjunction with the trade association (UK Oil & Gas). EEMS uses an online reporting system with controls over data entry, together with guidance notes provided to operators to provide estimation methodology options and emission factors for specific processes.

The Inventory Agency combines UK energy statistics, the EEMS data, EU ETS and IPPC data to derive the oil and gas sector estimates. The data reported from the EEMS system must be reconciled with the UK Energy Statistics and integrated into the NAEI without double-counting emissions. Where the EU ETS or IPPC data are inconsistent with the EEMS data, the Inventory Agency works with the BEIS Offshore Inspectorate and facility operators to determine the best available data for each source. The Inventory Agency also conducts time-series consistency checks to identify missing sites or sources, and for those sources where the EEMS data includes emissions and activity data the Inventory Agency reviews the time series of implied emission factors to identify outliers. Any sites or sources where the quality checks identify gaps, outliers or inconsistent reporting between different regulatory systems are resolved in consultation with the BEIS Offshore Inspectorate.

Time series consistency

The emission estimates for the offshore industry are based on the EEMS dataset for 1998-2015, whilst emission estimates for 1990-1997 are based on trade association data (UKOOA, 2005) to update earlier industry studies (UKOOA, 1998) that had used production data as a basis for generating sector-wide estimates from 1990. The EEMS dataset (BEIS, 2016) provides a consistent time-series of emission estimates for many facilities and sources, but since 2010 the reporting by onshore terminals is voluntary and the completeness of the dataset is variable for recent years. Furthermore, whilst the EEMS data quality appears to be improving over recent years, the completeness of EEMS data for specific facilities and sources is still subject to uncertainty; reporting gaps appear to be systematic for some facilities, such as frequent non-reporting of oil loading / unloading emissions at some terminals. The Inventory Agency continues to work with the regulatory agency, BEIS, in the continued development of emission estimates from this sector.

The time-series of the IEF of CO_2 emissions in sector 1.B.2.a.2 (Oil Production) show a significant drop between 2011-2012 and a sharp rise between 2013 and 2015. Whilst oil production activity data is comparatively steady between 2011 and 2015, CO_2 emissions from this source are highly variable. This is because CO_2 emissions for this source are dominated by one installation which processes sour gas in the UK. This site was offline for most of 2012, 2013, and part of 2014, explaining the large variation in IEF over this period of the time-series.

Uncertainties

Uncertainties are presented in **Annex 2**. Emissions data taken from the EEMS reporting system 1998 onwards are considered to be high quality, emissions data for other years are subject to greater uncertainties.

MS 20 Gas leakage

Relevant Categories, source names

1B2b4: Natural Gas (transmission leakage)

1B2b5: Natural gas (distribution leakage)

Natural Gas (leakage at point of use)

Relevant Gases

CO_2, CH_4

Relevant fuels, activities

Leakage from gas transmission and distribution, leakage at the point of use

Background

The UK GHG inventory includes estimates of methane and carbon dioxide emissions from natural gas leakage from the downstream gas supply network, including releases from: high pressure transmission network; distribution network; gas leaks at point of use. Annual activity data and gas compositional analysis are provided by National Grid, four companies (formed in 2005) that operate the low-pressure gas distribution networks within Great Britain, and Airtricity in Northern Ireland.

Key Data sources

Activity data:	Natural gas leakage data in energy and mass units, from the UK downstream natural gas network operators: National Grid, Scotia Gas, Northern Gas Networks, Wales & West, and Airtricity (NI). AD for gas use in domestic and commercial sectors from DUKES (BEIS, 2016) are used to generate leakage at point of use estimates.
Emission factors:	Natural gas compositional data (mass % data for: nitrogen, carbon dioxide, methane, ethane, propane, i-butane, n-butane, neo-pentane, i-

pentane, n-pentane, hexanes+) supplied by the gas network operators as listed above. UK estimates of natural gas consumption within each Local Distribution Zone (LDZ) are used to generate a weighted-average UK compositional analysis of natural gas consumed annually. From 2007 these data are available from Long Term Development Plans published by each of the gas network operators; earlier data by LDZ are based on Local Authority-level consumption estimates aggregated into LDZs (CLARE database, 2012).

EFs for the gas leakage at point of use are derived from UK data on gas fitting performance and assumptions regarding unit operational cycles, ignition times.

An accompanying spreadsheet "Energy_background_data_uk_2017.xlxs" lists all emission factors used in the energy sector, including a full list of references[24]*.*

Method approach

The leakage estimates are calculated using separate methodologies to cover:

1. Natural gas leaks from the high-pressure transmission mains (National Grid Gas); (reported under **1B2b4 Transmission**)
2. Natural gas leaks from the low pressure distribution network, medium pressure gas mains, Above Ground Installations (AGIs), AGI working losses and interference (National Grid Gas, Scotia Gas, Northern Gas Networks, Wales & West, Airtricity); (Reported under **1B2b5 Distribution**)
3. Other losses of natural gas at the point of use (BEIS DUKES, UK research); (Reported under **1B2b5 Distribution**)

For methods 1 and 2 above, from 2004 onwards the gas network operators provide annual gas leakage estimates on a mass basis, providing a breakdown of emissions across all 14 regional gas networks in the UK, which are called Local Distribution Zones (LDZs). National Grid Gas operates the high-pressure natural gas transmission network and 5 of the LDZs; Northern Gas Networks operates 2 LDZs; Scotia Gas operates 3 LDZs; Wales and West Utilities operates 3 LDZs; Airtricity operates 1 LDZ. In addition, each of the gas network operators provides annual natural gas compositional analysis for their networks. Prior to 2004, the data on gas leakage (activity data and compositional analysis) was all provided by British Gas, which operated all of the UK networks before the industry was privatised.

The information on methane losses from the high pressure transmission system (1B2b4) are estimated by National Grid based on (i) periodic fugitive emission surveys for the NTS, compressor stations and LNG terminals, and (ii) NG records of intentional venting actions on the network. These data have not been available for every year across the time series, with only two data points in the 1990s, annual data from 2000-2004, then data for 2011 and 2012. Data for other years are estimated using interpolation (2005-2010) and extrapolation (early time series and for 2013 and 2015).

The UK GHG inventory estimates for 1B2b5 (distribution leakage) are based on the aggregate of mass of gas leaked across all networks (low pressure mains and other losses), with the methane content of the natural gas based on compositional analysis from all of the gas network operators.

The activity data reported in the CRF for these sources are the final UK annual gas demand data. These data are not used within the GHG inventory estimation method, but are presented to enable IEFs to be derived, to aid comparability of the UK estimates with those of other countries.

UK Gas Network Leakage Model

The UK gas network operators use a common industry leakage model to derive their annual estimates of gas leakage from the low and medium pressure distribution systems. The UK gas network leakage model was developed by British Gas and uses factors and assumptions on leakage rates for different types of gas mains and installations, based on measurements and surveys conducted in 1992 and 2002, with annual updates to maintain the representation of the UK gas network infrastructure (such as length and type of pipelines and other units) and reflect the rolling programme of network replacement. Historical data for the leakage from the low-pressure distribution network and other losses is based on studies from British Gas in the early 1990s (British Gas, 1993; Williams, 1993).

Natural Gas Compositional Data

Data on the methane and NMVOC content of natural gas have been provided by contacts within British Gas Research for 1990-1996 and by UK Transco from 1997 to 2005 (Personal Communication: Dave Lander, 2008), and from the gas network operators from 2006 onwards. NMVOC content for 2001-2003 has been estimated by interpolation due to a lack of data; CO_2 compositional data from 2004 onwards are derived from annual compositional analysis by gas network operators, whilst the 1990-2003 data have been extrapolated back from the 2004 figure. No gas composition data have been provided by Airtricity and hence the UK average gas composition is assumed for Northern Ireland.

Each of the gas network operators obtain their compositional analysis from a central system of data logging from the automated sampling and analysis network that was operated previously under the Transco ownership, prior to the network being opened up to greater market competition. The Inventory Agency has direct contacts within the organisation (GL-Advantica) that manages the compositional data from across the UK gas network, and works directly with their gas analysis team to ensure that gas compositional data provided to the Inventory Agency by network operators is representative of the gas quality year-round, rather than a snap-shot from a limited number of analyses.

The calculation of the reported UK average gas composition is derived from the sum-product of the annual Local Distribution Zone (LDZ) compositional data and the estimated gas consumption through each of the LDZs, to provide an average gas composition for Great Britain which is then applied across the UK. The estimates of gas consumption within each LDZ are based, from 2007 onwards, on LDZ throughput data presented within Long Term Development Statements by each of the gas network operators; prior to 2007 these data are unavailable, and the best available data to inform the UK weighted average composition are sub-national gas use statistics at local authority level (then aggregated to LDZs) which are published by BEIS annually and processed for UK Local Authority CO_2 emission estimates via the CLARE database.

Northern Ireland Gas Network

The gas infrastructure in Northern Ireland is much newer than in the rest of the UK, as the gas pipeline (from Scotland) was only commissioned in 1999. Since then, the gas network has continued to develop across Northern Ireland. Annual estimates of gas leakage from 2005 onwards have been provided by the main gas operator (Airtricity, 2016), and the data for 1999 to 2004 have been extrapolated back from the 2005 figure.

The third inventory estimation methodology is used to determine estimates of natural gas leakage at the point of use, and these estimates are also reported in 1B2b5. Leakages are estimated for a range of different appliances that use gas, combined with national statistics on natural gas consumption in the domestic and commercial sectors (BEIS, 2016).

Industrial Heating Boilers

Methane releases are assumed to be "**Not Occurring**" from these appliances, based on consultation with technical experts that advise the UK Government for the CHP QA scheme (Personal Communication: R Stewart, 2011). Larger boilers typically operate almost permanently once ignited (particularly if used for steam-raising) with little or no cycling from on to off states. Furthermore, releases of un-burnt natural gas are strictly controlled in industrial locations for safety reasons.

Domestic Heating, Water Heating Boilers and cooking

Methane emissions from pre-ignition losses of gas appliances domestic properties are based on activity data from Energy Consumption in the UK (DECC, 2014) which provides a time-series of gas use for heating, water heating and cooking in the domestic sector to 2013, using a series of assumptions regarding the size of units, number of units, age of units, gas flow rates, air flow rates, delays to ignition, operation times from used to determine the percentage of gas that is not burned. Since 2013, this data has not been available, and so extrapolations have been used, normalised by domestic consumption reported in DUKES (BEIS, 2016). The estimates of UK appliance stock, by capacity and design and estimated average gas consumption per appliance per day are all derived from Ecodesign studies (energy efficiency analysis) through the UK Government Market Transformation Programme (Ecodesign Lot 22 and Lot 23, 2011). The estimates of appliance cycle operation times and estimated delays to ignition for different appliances are based on expert judgement of UK combustion technology experts (Personal communication, Stewart, 2012).

Commercial Gas Appliances: Catering and other uses

Methane emissions from pre-ignition losses of gas appliances used in commercial catering and other uses are based on activity data from ECUK (DECC, 2014) which provides a time series of gas use for catering and other uses in the commercial sector to 2013. For 2014 and 2015, consumption has been derived from reported figures in DUKES (BEIS, 2016). The method then applies a series of assumptions regarding the operational cycles and delays to ignition, to derive a simple percentage non-combusted estimate for each gas appliance type using references and expert judgements as noted above for domestic appliances.

An overview of the time series of gas leak at point of use estimates in the UK, together with overall gas use by economic sector and appliance type is presented in **Annex 3**.

Assumptions & observations

Assumptions used to estimate the leakage at point of use for domestic heating and water heating boilers are as follows:

- average boiler size in the UK of 30kW;
- a burn chamber size, natural gas flow rate taken from a typical combination boiler;
- estimated delay to ignition: 0.25 seconds for automatic ignition, 2 seconds for manual ignition;
- an air flow rate based on 25% excess oxygen in the combustion chamber when compared to stoichiometric ratio;
- an equation for a mixed reactor ($1-e^x$) that when integrated will provide an estimate of the concentration of un-burnt air/fuel mixture released; and
- assumptions relating to the boiler yearly operation and cycling frequency, between heating and water heating applications
    - On average in the UK domestic properties have heating systems operating for half of the year and on average the heating is on for 5 hours per day. It is also assumed that during each hour that the boiler providing heating cycles on and off 4 times.

- All UK domestic properties that have hot water heating systems also have gas heated hot water.
- Average water heating is on for 4 hours per day every day of the year.
- During each hour that a boiler is heating water, the boiler cycles on and off 5 times.

The number of boilers from 1990 to 2014 is thought to have increased (ca. 22 million in 2008) due to the increasing use of gas central heating for space heating, and the increase in the number of houses. However, it is assumed that pre-ignition gas loss in boilers installed in houses in 1990 were greater than in the current boilers installed, as technology has improved. Therefore, it is assumed that the proportion of gas leaked (i.e. % of the total gas use) from domestic heating and water heating appliances per annum is steady across the time series, with the rationale that the sum of greater pre-ignition losses from fewer older-technology boilers in the early part of the time series will be roughly equivalent to the sum of lower pre ignition losses per unit from the greater number of newer-technology boilers in recent years.

Assumptions used to estimate the leakage at point of use for domestic cooking appliances (manual and automatic ignition) and gas fires are as follows:

- gas fires use an estimated 2.5% of total gas used for space heating in the domestic sector, with the remainder used in (automatic ignition) boilers;
- gas use in cooking hobs is estimated to be 73.6% of the total domestic gas use in cooking, with the remainder in gas ovens. This is based on data of average annual gas oven fuel use in kWh/yr and average domestic gas hob fuel use in kWh/yr, combined with data on UK stock of gas ovens and hobs, taken from a series of 2011 European Commission Eco-design studies (Bio IS / ERA Technology, 2011);
- for manual ignition devices, a conservative estimate of the delay prior to ignition of 2 seconds has been assumed (expert judgement), whilst the average operational cycle times for different types of appliance have been estimated at 900 seconds for a domestic hob (expert judgement) and 5400 seconds for a gas fire (EC Eco-design Lot 20 Task 5, gas stove base case, 2011); and
- for automatic ignition appliances, a conservative estimate of the delay prior to ignition of 0.25 seconds has been assumed (expert judgement), whilst the average operational cycle times of domestic ovens has been estimated at 900 seconds (expert judgement).

Assumptions used to estimate the leakage at point of use for commercial gas appliances (catering and other uses) are as follows:

- for commercial catering gas use, a conservative estimate of the delay prior to ignition of 0.5 seconds has been assumed (expert judgement, to reflect a mixture of hobs and oven use), whilst the average operational cycle has been estimated at 900 seconds (expert judgement); and
- for other commercial gas appliances, assumed to be predominantly gas-fired boilers of automatic ignition design, a conservative estimate of the delay prior to ignition of 0.25 seconds has been assumed (expert judgement), whilst the average operational cycle time has been estimated at 1800 seconds (expert judgement).

Recalculations

There have been method changes. The following recalculations have been made.

1B2b4 Natural Gas (transmission leakage)

New information was provided by National Grid estimates leakage emissions from the National Transmission System and LNG Storage sites as notably lower, especially as LNG storage has now been decommissioned. This has caused recalculations to the time-series since 2012.

Minor updates to LTDS data has made a small difference to overall activity data and emission factors.

1B2b5 Natural gas (distribution leakage)

Minor updates to LTDS data has made a small difference to overall activity data and emission factors.

1B2b5 Natural Gas (leakage at point of use)

Updates to activity data using DUKES long term trends (BEIS, 2016) have caused major revisions to emission factors for all pollutants in 2014. In 2013, minor changes to DUKES activity data cases a small difference in calculated emission factors (BEIS, 2016). Finally, a minor change of emission factors for all pollutants from gas leakage at point of use from 1990 cause minor recalculations from this source.

Improvements (completed and planned)

No improvements to this method are currently planned. Emission factors and activity data are kept under review.

QA/QC

The sector estimates are subject to the same Tier 1 QA/QC routines as all other source categories in the UK GHGI.

Checks on data reported by gas network operators are conducted to check consistency across the time series and also between operators; for example, in compiling the 2015 submission data, through quality checks between gas network operators it was noted that the gas compositional data for 2013 from Wales and West Utilities was an outlier. The Inventory Agency identified that estimated mass percentage calculations were incorrect, and the values were subsequently revised and then used in the UK GHGI compilation.

As recommended during the September 2014 centralised review of the UK inventory, the UK Inventory Agency has also conducted verification checks on the UK GHGI estimates, by deriving separate emission estimates for methane using the Tier 1 default methods outlined in both the 1996 GLs and the 2006 GLs. The method in the 1996 GLs uses max and min default factors based on the pipeline length of the transmission and distribution network, whilst the 2006 GLs Tier 1 method uses max and min default factors based on the total volume of delivered natural gas. The results are summarised below for 1990 and 2013 data:

1990 UK GHGI total (transmission plus distribution) = 378.8 kt CH_4

> Using IPCC 1996 GLs Tier 1 method, the range for emissions is derived as 155 to 215 kt CH_4
>
> Using IPCC 2006 GLs Tier 1 method, the range for emissions is derived as 67 to 105 kt CH_4

Therefore, compared to both Tier 1 methods, <u>the 1990 UK GHGI estimate is higher than the range of values</u>.

2013 UK GHGI total (transmission plus distribution) = 168.5 kt CH_4

> Using IPCC 1996 GLs Tier 1 method, the range for emissions is derived as 155 to 215 kt CH_4
>
> Using IPCC 2006 GLs Tier 1 method, the range for emissions is derived as 95 to 148 kt CH_4

Therefore, compared to the Tier 1 methods, the 2013 UK GHGI estimate is within the range of values for the 1996 GLs method and higher than the range of values for the 2006 GLs method.

The comparison against the IPCC Tier 1 methods indicates that the UK GHGI estimates are of a similar order of magnitude as the Tier 1 defaults. The 1990 UK GHGI value appears to be high, as it is above the range of values derived from the IPCC Tier 1 methods, whilst the 2013 UK GHGI value is also higher than the range for the 2006 GLs Tier 1 method. However, the UK estimates are derived from a country-specific method and we note that the uncertainty estimates provided in the 2006 GLs for the default EFs provided for gas network distribution (which is by far the greatest contributor to overall methane leakage) are cited as -20 % to +500% for factors for developed countries. Therefore, given the large uncertainty range, the UK data are consistent with the IPCC Tier 1 estimates.

Time series consistency

As far as possible, consistent source data and methods are used across the time series. However, we note the following limitations of the current methods:

- The available data on methane leakage from the high pressure gas transmission system is limited. Data are not available for all years of the time series and therefore gap-filling techniques (extrapolation and interpolation) are used;
- The calibration of the UK gas leakage model used by all natural gas network operators in based on two in-depth studies of the leakage rates from different constituent elements of the UK gas network – one in 1992, another in 2002. These studies have been used to establish estimated leakage rates in the UK model that are then applied to activity data gathered annually through surveys and from gas network renewal projects; and
- The derivation of the UK average natural gas composition uses the best available data for every year of the time series, as the factors are critical for the UK GHGI estimates as a whole (not just for the leakage estimates, but also for natural gas combustion estimates). Since 2007 the weighted average has been calculated using actual data available on gas throughout for each LDZ; prior to 2007 these data are not available and the LDZ gas throughput estimates used in the calculation of the UK average gas composition use Local Authority level gas use estimates, aggregated up to LDZs. These earlier data at Local Authority level were regarded as “experimental statistics” by DECC until the 2005 dataset were published as national statistics, and as such are regarded as more uncertain than the more recent data.

Uncertainties

Uncertainties are presented in **Annex 2**. Uncertainties in the emission estimates from leakage from the gas transmission and distribution network stem predominantly from the assumptions within the industry model that derives mass leakage estimates based on input data such as network pipe replacement (plastic replacing old metal pipelines) and activities/incidents at Above Ground Installations; for these sources the methane content of the gas released is known to a high degree of accuracy, but the mass emitted is based on industry calculations.

As noted in the section above, the uncertainties for the estimates of gas leakage at point of use are high due to the lack of source data, an IPCC method and the need to use a series of assumptions and expert judgement to estimate the leakage from different gas appliance types. The Inventory Agency considers that the assumptions provide a conservative estimate of gas leakage at point of use across the time series.

4 Industrial Processes (CRF Sector 2)

4.1 OVERVIEW OF SECTOR

IPCC Categories Included	2A: Mineral Products 2B: Chemical Industry 2C: Metal Production 2D: Non-energy Products from Fuels and Solvent Use 2E: Electronics Industry 2F: Product Uses as Substitutes for ODS 2G: Other Product Manufacture and Use 2H: Other
Gases Reported	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3, NO_x, CO, NMVOC, SO_2
Key Categories ('T' or 'L' indicates whether it has been identified in the trend or level assessment respectively and the number indicates which KCA approach it was identified in)	2A1: Cement production - CO_2 (L1) 2B: Chemical industry - HFCs (L2, T2) 2B: Chemical industry – CO_2 (L2) 2B2: Nitric acid production - N_2O (L1, L2, T1, T2) 2B3: Adipic acid production - N_2O (L1, L2, T1, T2) 2B8: Petrochemical and carbon black production - CO_2 (L1) 2B9: Fluorochemical production - HFCs, PFCs, SF_6 and NF_3 (L1, T1) 2C1: Iron and steel production - CO_2 (L1, T1) 2C6: Zinc production - CO_2 (T1) 2F: Product Uses as Substitutes for ODS - HFCs (L2, T2) 2F1: Refrigeration and air conditioning - HFCs, PFCs, SF_6 and NF_3 (L1, T1) 2F4: Aerosols - HFCs, PFCs, SF_6 and NF_3 (T1) 2G: Other product manufacture and use – N_2O (L2, T2)
Key Categories (Qualitative)	None identified
Overseas Territories and Crown Dependencies Reporting	For most sectors emissions are reported as not occurring. Estimates for use of F-gases based on scaled UK estimates are reported in the relevant categories under 2F and 2G.
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.

Major improvements since last submission	2E2, 2E3, 2E4 - Market investigation in 2015 to confirm zero activity level 2F1 - Review of RAC Emissions Model carried out in 2015 and improvements made. Further review in 2016. 2F2a - The model used to estimate emissions from this sector has been overhauled during 2015 to account for the impacts of the global recession, recent f-gas regulations and calibrated in light of stakeholder consultation. The resulting model allows us to comment in much more detail on the underlying assumptions. 2F6 - New to the 2015 submission 2G4 - Addition of further process to the estimates

The industrial processes and other product use sector (IPCC Sector 2) contributes 6.7% to total greenhouse gas emissions. Emissions from this sector include non-energy related emissions from mineral products, chemical industry and metal production and product use, including emissions of F-gases. Since 1990, this category has seen a 50% decline in emissions, mostly due to changes in the emissions from the chemical production and halocarbon and SF_6 production industries. The step-change in emissions between 1998 and 1999 evident in **Figure 4.2** is due predominantly to the fitting of nitrous oxide abatement equipment at the UK's only adipic acid production plant (this plant has since closed).

Table 4.1 Number of industrial processes in the UK by type

Year	Cement	Lime – merchant[a]	Lime – captive[a]	Power stations with FGD[b]	Glass-Works[c]	Fletton brick works	Ammonia
1990	23[d]	11[d]	10	0	35[d]	8	4
1995	23	9	9	1	35[d]	5	4
2000	21	9	9	2	35	3	4
2005	16	9	6	5	33	3	4
2006	16	9	6	5	30	3	4
2007	15	9	6	5	28	3	4
2008	15	9	6	7	26	3	3
2009	13	9	4	8	24	3	3
2010	12	9	4	8	24	2	3
2011	12	9	4	8	24	1	3
2012	12	9	4	8	24	1	3
2013	11	9	4	8	24	1	3
2014	11[f]	9	4	8	23	1	3
2015	11	8	4	8	23	1	3
Year	**Nitric acid**	**Adipic acid**	**Steel-works**	**Electric arc furnaces**	**Primary aluminium**	**Other non-ferrous**	**Soda ash**
1990	8	1	4	20	4	5	2
1995	6	1	4	20	4	4	2

2000	6	1	4	19	4	3	2
2005	4	1	3	12	3	2	2
2006	4	1	3	11	3	2	2
2007	4	1	3	10	3	2	2
2008	4	1	3	8	3	2	2
2009	2	1	3	7	3	2	2
2010	2	0	2	7	2	2	2
2011	2	0	2	7	2	2	2
2012	2	0	3	6	1	2	2
2013	2	0	3	6	1	2	2
2014	2	0	3	6	1	2	2
2015	2	0	3[g]	6	1	2	1

[a] merchant refers to site selling lime and emitting CO_2, captive refers to sites using lime and CO_2 in-situ so in theory no emissions result.

[b] Flue Gas Desulphurisation

[c] excludes very small glassworks producing lead crystal glass, frits etc.

[d] approximate figures only

[e] large-scale primary production or secondary refining operations only

[f] one of these sites was out of operation during almost the whole of 2014 following a flood which damaged the kiln

[g] Teesside steelworks closed in September 2015 so only 2 sites in operation by the end of the year

The figures in **Table 4.1** show that the numbers of industrial processes in the UK have been declining since 1990. While this is partly due to the closure of some smaller sites, perhaps with growth in capacity at remaining sites, it is predominantly a reflection of decreasing production of many industrial materials in the UK. A large number of closures in the period 2007-2009 were due to decreased demand for many products as a result of the general economic situation in the UK and elsewhere, with falling demand for steel, cement, bricks and aluminium, for example, leading to plant closures.

Figure 4.1 Breakdown of total GHG emissions in Industrial Processes sector

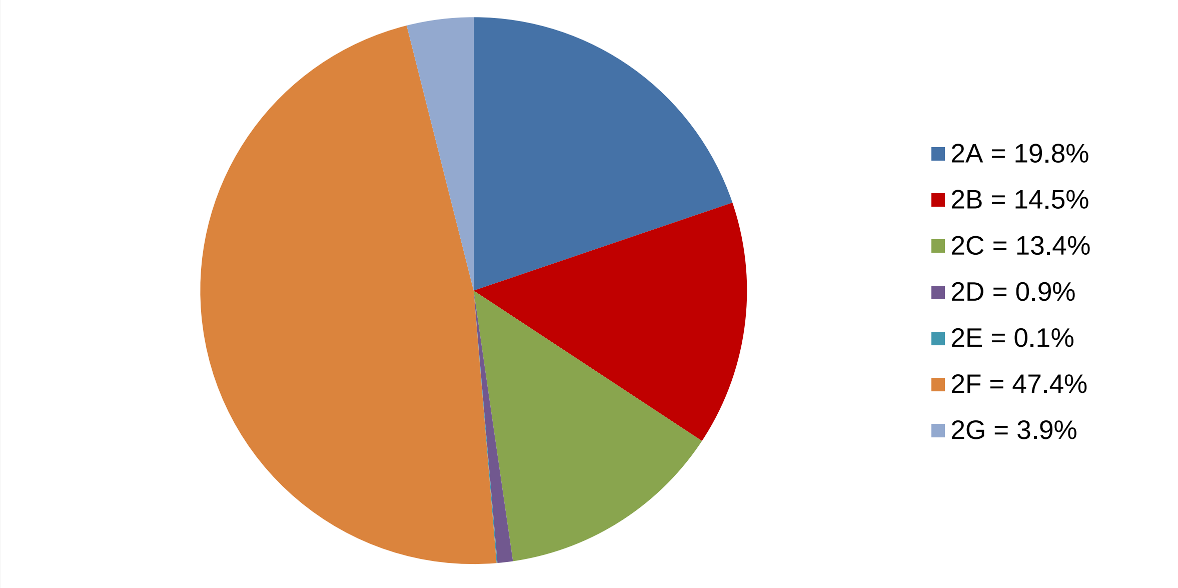
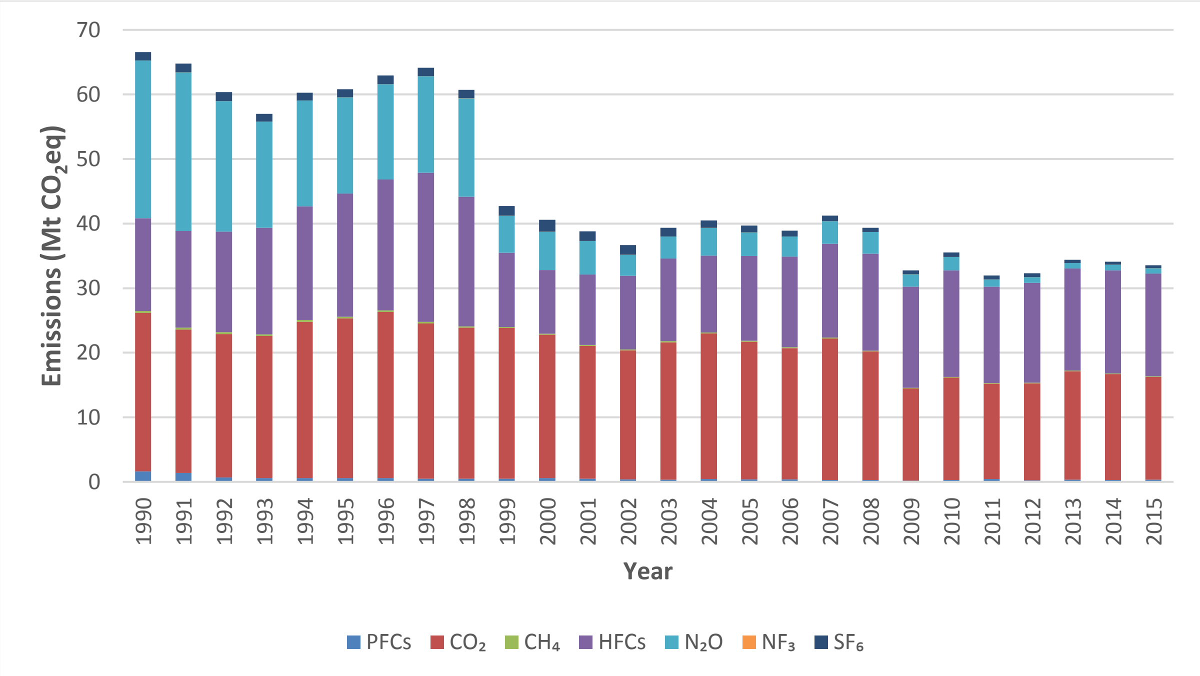


Figure 4.2 Trend in total GHG emissions in Industrial Processes sector



4.2 SOURCE CATEGORY 2A1 – CEMENT PRODUCTION

4.2.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2A1: Cement (Decarbonising)	T3, T2	CS
Gases Reported	CO_2		
Key Categories	2A1: Cement production - CO_2 (L1)		
Key Categories (Qualitative)	2A1: Cement Production - CO_2		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

Emissions of CO_2 from fuel combustion in cement kilns are reported under CRF source category 1A2f, whilst emissions from calcination of non-fuel feedstock to cement kilns are reported under category 2A1.

Fuel combustion also gives rise to emissions of NO_x and N_2O which are reported under 1A2f. Finally, emissions of methane, NMVOC, SO_2 and CO also occur, both due to fuel combustion but also due to the evaporation of organic or sulphurous components present in the raw materials. The current GHGI methodology for estimating emissions of these pollutants does not allow emissions from fuels and emissions from raw materials to be quantified separately and so all emissions of these four pollutants are reported under 1A2f.

The UK had 11 sites producing cement clinker during 2015, an increase on the previous year since one of the 11 sites only produced clinker for a few weeks at the end of 2014, following a 12-month shutdown when flooding in December 2013 damaged the kiln.

4.2.2 Methodological Issues

Emission estimates for 2005-2015 are available from the annual UK production of clinker and emission factors provided by the Mineral Products Association (MPA), formerly the British Cement Association (BCA). This in turn is based on data generated by UK cement clinker producers for the purposes of reporting to the EU Emission Trading Scheme. Data received from the MPA have been cross-checked against the EU ETS data set supplied directly by regulators for use in the inventory. Since 2011, the emissions reported in the EU ETS have mostly been slightly higher. As a conservative approach, we have therefore used the higher of the two figures each year i.e. MPA data for 2005-2010 & 2015, and EU ETS for 2011-2014. The EU ETS and MPA/BCA data include emissions associated with cement kiln dust.

EU ETS and MPA data are available for 2005 to 2015 only, and so the emission factor value for 2005 has been applied to earlier years as well.

The methodology used for estimating CO_2 from calcination is summarised in **Table 4.2**.

Table 4.2 Methods used to estimate emissions of CO_2 from this category

Period	Activity data	Emission factor, kt C / kt carbonate	Emission
1990-2000	British Geological Survey – UK Minerals Yearbook, figure for UK	Use of 2005 factor from BCA	AD x EF
2001	British Geological Survey – UK Minerals Yearbook, figure for Great Britain only	Use of 2005 factor from BCA	AD x EF
2002-2004	British Cement Association, clinker production data for UK	Use of 2005 factor from BCA	AD x EF
2005-2010, 2015	Mineral Products Association, clinker production data for UK	Factor derived from annual, site-specific data compiled from EU ETS data by Mineral Products Association (since higher than EU ETS-based CEF for that year)	AD x EF
2011-2014	Mineral Products Association, clinker production data for UK	Factor derived from site-specific EU ETS returns for all UK sites (since higher than MPA-based CEF for that year).	AD x EF

4.2.3 Uncertainties and Time Series Consistency

The time-series consistency of the MPA (formerly called BCA) data is very good due to its continuity. Cross-checks with the EU ETS data received directly from UK regulators indicates only very small differences. Data originally supplied for 2013 was significantly different, but dialogue with MPA established that this was due to an error, since data for one site had been omitted. Subsequently, a corrected dataset was received which was closely consistent with EU ETS data for that year.

Table 4.3 summarises activity data and implied emission factors over the time series. The activity data for 2001 onwards **are for Great Britain only** due to confidentiality issues surrounding data for the few sites located in Northern Ireland. The CO_2 emissions data in the table are for the whole of the UK. The CO_2 emission factors are therefore a mixture of those based entirely on UK data (for 1990-2000) and those that mix UK emissions and GB activity data (2001 onwards), but are presented to give an indication of the trend in the factor over time.

Table 4.3 Time series of activity data and CEF for cement production.

Year	Cement Clinker production (kt)[a]	CO_2 emitted (kt)	CO_2 emission factor, (t / t clinker)
1990	13,199	7,295	0.553
1991	10,845	5,994	0.553
1992	9,872	5,456	0.553
1993	9,996	5,525	0.553

Year	Cement Clinker production (kt)[a]	CO_2 emitted (kt)	CO_2 emission factor, (t / t clinker)
1994	11,521	6,368	0.553
1995	11,371	6,285	0.553
1996	11,609	6,416	0.553
1997	12,141	6,710	0.553
1998	12,372	6,838	0.553
1999	11,816	6,531	0.553
2000	11,456	6,332	0.553
2001	*10,183*	5,844	0.574
2002	*10,327*	5,988	0.580
2003	*10,146*	5,868	0.578
2004	*10,402*	5,977	0.575
2005	*10,074*	5.941	0.590
2006	*10,069*	5,893	0.585
2007	*10,227*	6,117	0.598
2008	*8,700*	5,203	0.598
2009	*6,421*	3,720	0.579
2010	*6,598*	3,792	0.575
2011	*7,096*	4,096	0.577
2012	*6,555*	3,724	0.568
2013	*6,712*	4,029	0.600
2014	*7,197*	4,215	0.586
2015	*7,617*	4,461	0.568

[a] Figures in italics exclude production in Northern Ireland

[b] Estimated – no production figures have been published for 2015

An initial large drop in clinker production over the period 1990-1993 can be explained by a sharp drop in construction activity and hence a decline in the need for cement (confirmed by statistics available for the construction industry). This initial large drop and a less pronounced downward trend in production over the period 1994-2007 may, in part, also be due to increased use of slag cement, the production of which is likely to have risen sharply over the same period – we estimate that capacity for slag cement production increased from 0.75 Mtonnes at the start of 1990 to 1.5 Mtonnes by 2004, with a further increase to 2 Mtonnes by 2007. The drop in activity data between 2000 and 2001 is at least partially due to the change in the scope of the data, with data for 2001 onwards excluding Northern Ireland. A sharp decrease in clinker production between 2007 and 2009 is linked to the recession, which caused a decline in construction and therefore demand for cement. A number of cement kilns were closed or mothballed during 2008 and 2009, and none of these have subsequently been re-opened. Clinker production then increased again by 2011 and production thereafter has been relatively constant. Our estimate for 2015 suggests a modest increase in 2015 but this figure is uncertain being based on MPA estimates of CO_2 emissions, assuming that the CEF would have been the same in 2015 as in 2014.

The country-specific emission factors for cement clinker production are constant for the period 1990-2000 because no data are available, and so a default UK factor is applied. Factors presented in **Table 4.2** for the period 2001-2015 are all higher than the factor for 1990-2000, because of the change in the activity data from UK to GB in 2001. Since the later activity data exclude a small number of sites in Northern Ireland, the activity data are lower, and the CO_2 emission factors are therefore higher. The factors in the period 2001-2015 do vary from year to year, from a minimum value of 0.568 t CO_2 / t in 2012 and a maximum value of 0.600 t CO_2 / t in 2013. The reason for the large increase in the IEF in 2013 compared with the previous year is not known, although the inconsistency between the activity data (excluding

Northern Ireland) and emissions (including Northern Ireland) may be at least partially responsible.

4.2.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. Emissions reported to the Inventory Agency by the Mineral Products Association are cross checked with plant specific data reported in the EU ETS to ensure complete coverage of all emissions.

4.2.5 Source Specific Recalculations

No recalculations have been made in this category.

4.2.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.3 SOURCE CATEGORY 2A2 – LIME PRODUCTION

4.3.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2A2: Lime Production (Decarbonising)	T1, T3	D, CS
Gases Reported	CO_2		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

Lime (CaO) is manufactured by the calcination of limestone ($CaCO_3$) and dolomite ($CaCO_3MgCO_3$) in kilns fired by coal, coke or gas. The calcination results in the evolution of carbon dioxide. However, for the inventory it is necessary to distinguish between merchant lime processes where the purpose is to produce lime for use off-site and where carbon dioxide is an unwanted by-product emitted to atmosphere, and those captive lime processes where lime is produced so that both the carbon dioxide and lime can be used on-site in the process. In these latter processes, which include sugar refining, none of the carbon dioxide is emitted to atmosphere, apart from the exception listed in the next section. Lime production related to the manufacture of sodium carbonate was previously included in emissions reported under 2A2, but these emissions, in line with IPCC Guidelines, are now reported in 2B7.

Lime was produced at 12 UK sites during 2014. Four of these produce lime for use on-site in sugar manufacturing.

4.3.2 Methodological Issues

The UK method uses EU ETS data to determine emissions from 2005 onwards, Pollution Inventory (PI) data from 1994 to 2004 and British Geological Survey (BGS) data from 1990 to 1993. The EU ETS data consist of CO_2 emission estimates (including emissions associated with lime kiln dust) and activity data. The activity data takes various forms e.g. feedstock or product, depending upon site, and so the emissions data have been adopted, with the lime activity data then being back-calculated using a default emission factor of 121.5 t carbon/ kt limestone or dolomite. This emission factor is derived by assuming that 85% of UK lime production is from limestone and the remaining 15% is from dolomite (based on a recommendation from the EU's UNFCCC review). For limestone, an emission factor of 120 t carbon/kt limestone is then assumed, based on the stoichiometry of the chemical reaction, and for dolomite, the corresponding emission factor of 130 t carbon/kt dolomite is used.

Prior to 2005 there are no EU ETS data, and data are also missing for 2005-2006 for some lime kilns because of UK exemptions from the EU ETS for some sites in those years. Therefore, between 1994 and 2004, CO_2 emission estimates for lime production are based on emissions data published for each site in the Pollution Inventory (PI). The PI data are mostly for total CO_2 i.e. include emissions from both decarbonisation and fuel combustion on a site, but estimates of the CO_2 from decarbonisation only are made using EU ETS data and PI data for 2006-2008, both of which give fuel combustion emissions separately from decarbonisation. For the period 1994-1997, there is less reporting of CO_2 in the PI and so site-specific CO_2 emissions are estimated based on other site-specific data such as emissions data for particulate matter from those sites in the relevant years. The PI data are assumed to cover the same scope as the later EU ETS data i.e. to include emissions from lime kiln dust as well as lime product. We have no PI data for the period 1990-1993 so BGS activity data are the only data available to calculate emissions. As emissions estimates based on BGS data are consistently lower than emissions from PI and EU ETS sources for the period from 1994 onwards, we have assumed that BGS data for 1990-1993 would also underestimate emissions and have therefore applied a 'correction' factor of 1.08 to the BGS data for those years. The methods used for each part of the time series are summarised below.

Table 4.4 Methods used to estimate emissions from this category for merchant lime plants

Period	Activity data	Emission factor, kt C / kt carbonate	Emission
1990-1993	BGS x 1.08	121.5	AD x EF
1994-1997	(back-calculated)	121.5	PI CO_2 + estimates extrapolated from later PI data on basis of other data such as emissions data for other pollutants
1998-2004	(back-calculated)	121.5	PI CO_2
2005-2006	(back-calculated)	121.5	EU ETS & PI CO_2
2007-2015	(back-calculated)	121.5	EU ETS

The calculated emissions and activity data exclude carbonates calcined in the chemical industry since this is all used in the Solvay process, for which emissions are reported in 2B7.

The EU ETS data used for merchant lime production do not report any emissions from calcination at sugar plant, although these sites are covered by EU ETS. However, the UNFCCC centralised review of the 2013 submission of the UK GHG Inventory recommended that CO_2 emission estimates were needed for lime production associated with sugar production. Based on consultation with the UK sugar industry, the UK inventory estimates have previously assumed that all of the lime used in the carbonatation process (whereby lime and carbon dioxide are used to remove impurities in sugar solutions) was converted to calcium carbonate, meaning no net emission in CO_2. The ERT recommended instead that this conversion was assumed not to be complete and that instead some unreacted lime was present in waste sludges at the end of the carbonatation process. Emission estimates were therefore included for the 2014 submission onwards, using a default percentage of unreacted lime as advised by the ERT, this ERT default is based on data from other countries since UK-specific data are not available and EU ETS returns from UK sugar producers do not include any emissions associated with unreacted lime. Due to the confidentiality of the lime production data at the sugar production sites, further details of the methodology cannot be given here.

The calcium carbonate produced by the sugar industry is marketed as a soil liming agent and is assumed to be wholly used by UK agriculture. Emissions associated with this usage are included in the estimates for agriculture as described in **Section 5**.

Emission factors for indirect gases from the production of lime are calculated from emissions reported in the PI in the case of CO and NO_x, and for VOC based on literature factors.

4.3.3 Uncertainties and Time Series Consistency

Uncertainty in the emission estimates for merchant lime plants is low for recent years but higher for earlier years in the time series. EU ETS data provides a comprehensive dataset for UK facilities from 2008 onwards, and the uncertainties associated with these verified data are low; the EU ETS data from 2005 provide partial coverage of the sector and are used in conjunction with other data sources to derive inventory estimates, and hence the data for 2005-2007 are also regarded to be associated with low uncertainty. Uncertainty is higher for the estimates before 2005, because of the need for assumptions to be made in deriving the estimates (for example, assumptions regarding the split between combustion and process emissions in the PI data used between 1994 and 2004). Estimates for the years 1990 to 1993 are the most uncertain, because no reported CO_2 emissions data are available, and emissions have therefore to be based on the BGS data that are known to be inaccurate for later years. An adjustment is made to the BGS data to try to deal with the expected underestimating of activity by BGS, but a comparison of BGS and other data for later years indicates that the BGS underestimates are not consistent and so the scale of any underestimation in 1990-1993 is difficult to predict with any confidence.

The estimates for lime kilns at facilities producing sugar are regarded as highly uncertain since EU ETS data for those sites do not provide any evidence that any CO_2 is emitted at those sites from this source. In addition, a study for the European Commission on EU ETS emission allowances for the lime sector (Ecofys, 2009b) states that it can be assumed that “there are no process-dependent CO_2 emissions released from the limestone that is used”. The UK producer has also indicated that they consider the conversion of lime back to calcium carbonate as being complete (Personal Communication: British Sugar, 2013).

4.3.4 Source-specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. Cross comparison of the BGS data with the EU ETS data as a means of verification has indicated a potential under report in the BGS data. This has led to a change in the methodology to ensure completeness of the inventory reporting.

4.3.5 Source Specific Recalculations

There have been no significant changes to this category.

4.3.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review. EU ETS Phase III data will be reviewed to seek any new information on sources of emissions from lime-related process sources that may be added to the scope of EU ETS from 2013 data onwards.

4.4 SOURCE CATEGORY 2A3 – GLASS PRODUCTION

4.4.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	Glass Production Glass (continuous filament glass fibre) Glass (glass wool)	T3, T2	CS
Gases Reported	CO_2, NMVOC		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

Emissions from glass manufacture include those emissions of carbon dioxide that result from the use of limestone, dolomite and soda ash as sources of CaO, MgO and Na_2O respectively in soda-lime and other glasses. Emissions from fuels used in glass furnaces are reported in 1A2g.

The UK had 23 large sites making glass at the end of 2014, for the production of container glass (12 sites), flat glass (4 sites), continuous filament glass fibre (1 site), glass wool (4 sites), and stone wool (2 sites). A fifth site producing flat glass by the float process closed in November 2013. There are also single small sites producing ceramic fibres and glass frit respectively. Ballotini are produced at three sites, but production is small - output was less than 1% of UK glass production in 2015. Special and domestic glasses are no longer manufactured in the UK, and production of lead glass are only on a very small scale. It is assumed that limestone and dolomite are used in the production of container, flat, and special glass, and in glass and stone wool. Any use of carbonates in frits and lead glass is assumed to be trivial because of the small-scale production of these in the UK (together, both sectors account for about 0.1% of UK glass production). EU ETS data for the sole UK site making ceramic fibres indicate that this process does not involve the use of the three carbonate minerals. The ballotini processes are not covered by EU ETS but are based almost exclusively on the use of recycled glass (cullet) and so carbonates are not used in significant quantities. Since the production of ballotini is a trivial fraction of UK glass production and the use of carbonates for ballotini is also trivial, emissions are not estimated.

Due to the very small number of sites involved, and the confidential nature of the EU ETS data used to generate the emissions data, reporting the emissions from stone wool separately would be problematic. The UK therefore combines the data with emissions for other glass industry sites.

As well as carbon dioxide emissions resulting from the decomposition of carbonate feedstocks, certain types of glass manufacture will give rise to emissions of other pollutants including VOC emissions from the use of coating materials for glass fibres. Both continuous filament glass fibre and glass/stone wool manufacture involve the attenuation of molten product into fine fibres, which are then cooled and coated with organic materials.

Process emissions of N_2O are not estimated for production of glass because suitable methods or data have not been found. Operators of UK plant regulated under the Industrial Emissions Directive do not report any emissions data to the regulators and so any releases of N_2O from each of these sites must be below the reporting threshold of 10 tonnes and therefore any emissions will be very low for the UK as a whole.

4.4.2 Methodological Issues

Emissions from the use of carbonates in glass production are calculated using data from two sources:

- A detailed, site by site survey of raw material usage in the glass industry, carried out in 2006 (GTS, 2008). This report covered the flat, container, and fibre sectors;
- Data reporting under the EU Emissions Trading System (EU ETS) from 2008 onwards.

In the case of the survey of raw material usage, data are available on the quantities of each type of carbonate used by each sub-sector of the industry during 2006. Emissions must be estimated, and this is done based on the stoichiometric relationship between carbon and the related carbonate i.e.

120 t carbon/kt limestone;

130 t carbon/kt dolomite;

113 t carbon/kt soda ash.

These factors assume that all of the carbon in the carbonates is released to atmosphere.

The data from the EU ETS are for emissions of CO_2, but disaggregated by the source of the emission (e.g. use of natural gas, or use of limestone etc.) The data have first to be analysed so that the emissions can be separated into those that occur due to use of various fuels, and those that are due to use of the three carbonates. Data are available for all significant glassmaking sites for the period 2008-2015 i.e. all sites manufacturing flat, container, continuous filament glass fibre, glass wool and stone wool. Consumption of carbonates can be back-calculated, using the same stoichiometric relationships as given above. Since ETS data are available on a site by site basis, the emissions data and the derived activity data can be agglomerated to give estimates for each sub-sector of the glass industry. The EU ETS data set also includes details of extremely small CO_2 emissions (less than 1 tonne) occurring due to the use of barium carbonate or potassium carbonate by the UK glass sector, but these have been ignored from the UK inventory due to their trivial nature.

The two data sources can be used to derive estimates of carbonate use / CO_2 emissions for each sub-sector of the glass industry as follows:

2008-2015:flat, container, glass fibre, glass wool, stone wool;

2006: flat, container, glass fibre/glass wool (combined in the survey).

The two data sets indicate some changes over time in rates of carbonate use for flat, container and glass wool, and partial EU ETS data for 2005-2007 also support this. Therefore, the 2006 survey, rather than the later EU ETS data, is assumed to be more reliable as a guide to the rates of carbonate usage in the three sectors in the years 1990-2005. Carbonate usage for that period is therefore extrapolated from the 2006 figures on the basis of production in each sub-sector in each year. For stone wool, we only have data from the EU ETS for 2008-2015, and so the average consumption rate calculated for those years is then applied to the period 1990-2007 using stone wool production estimates for each year. The data indicate that some glass industry sub-sectors in the UK do not use all three carbonate minerals, or only use small quantities of some.

Neither of the two data sources described above contains information on special or domestic glasses because the only significant UK sites producing either type of glass closed before 2006. Therefore, carbonate consumption rates for both types of glass have been assumed to be equal to the average rate for container, flat and glass wool in 2006, as given in the raw material usage study.

Glass production data are available on an annual basis for container glass only (British Glass, 2015), and a full time-series of production for other types of glass has therefore to be estimated based on the partial time series of production data covering a limited number of years (e.g. data for late 1990s from EIPPCB, 2000, flat glass data for 2003 onwards from British Glass). These are then extrapolated to other years on the basis of estimated plant capacity. In the case of flat and container glass, the glass production data used to estimate carbonate usage are corrected for the amount of cullet used in each year, so the estimates do take into account changes over time in recycling rates and use of cullet. This is not possible for other types of glass, and so the calculation of carbonate usage for these glass types is based on total production. Therefore, the estimates for glass wool, special glasses and domestic glass implicitly assume that the rate of recycling in these sectors remains constant over the time series.

Table 4.5 Summary details for the UK glass industry and the scope of estimates for CO_2 emissions from carbonate use

Glass Sector	1990 production, kt	2015 production, kt	Estimates included for emissions from use of:		
			Limestone	Dolomite	Soda Ash
Container	[a]	[a]	Yes	Yes	Yes
Flat	[a]	[a]	Yes	Yes	Yes
Special	226	-	Yes	Yes	Yes
Domestic, including lead	76	0.1	Yes	Yes	Yes
Continuous filament glass fibre	82	37	Yes	Yes	Yes
Glass wool	104	328	Yes	Yes	Yes
Stone wool	83	93	No	Yes	Yes

Glass Sector	1990 production, kt	2015 production, kt	Estimates included for emissions from use of:		
			Limestone	Dolomite	Soda Ash
Ceramic fibres	14	14	No	No	No
Frits	13	7	No	No	No
Ballotini	20	35	No	No	No

a - confidential

Emissions of NMVOC in recent years from glass fibre and glass wool processes located in England are available from the Pollution Inventory. These data are used to calculate emission factors, based on estimates of glass production at these sites. Emissions can then be calculated both to include all processes throughout the UK and, by extrapolation, to include other years.

4.4.3 Uncertainties and Time Series Consistency

For the years 2008-2015, the methodology is based on the use of highly accurate emissions data reported under the EU ETS for all significant UK glass producers.

The emission estimates for 2006 are based on activity data given in a detailed industry study. These emission estimates should be assumed to be slightly more uncertain than the EU ETS data of 2008-2015 since the source gives carbonate usage figures only, and emissions have to be calculated assuming that the carbonate usage figures refer to pure carbonates and that all carbon in the minerals is released to atmosphere. While the emissions data are therefore conservative, we think that the uncertainty is still likely to be relatively low since fairly pure carbonate minerals are readily available.

For the remaining years in the time-series, the methodology relies upon the extrapolation of highly accurate activity/emissions data for one year to all other years based on glass production. The glass production data are, however, a mixture of actual production data from the glass industry, and Ricardo Energy & Environment estimates, which are far more uncertain. The emission estimates for 2A3 are therefore subject to far greater uncertainty for the earlier part of the time-series than for recent years, because of the greater reliance on extrapolation, and the lower quality of the glass production estimates for the earlier part of the time-series.

4.4.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5.**

4.4.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10**.

4.4.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.5 SOURCE CATEGORY 2A4 – OTHER PROCESS USES OF CARBONATES

4.5.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2A4a Fletton Bricks 2A4a Brick manufacture 2A4d Power stations - FGD	T3, CS T3, CS T3, CS	CS CS CS, D
Gases Reported	CO_2, CH_4, CO, SO_2, NMVOC		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

The UK has a large number of sites involved in the production of heavy clay goods – bricks and roofing tiles, and similar items. These sites range from the smallest operations where bricks are hand-made, to bigger sites where bricks are manufactured on a large scale, using automatic production methods. The brick industry can also be divided into fletton and non-fletton types. Fletton bricks are manufactured using the Lower Oxford Clay, found in South-East England only. This clay has an exceptionally high content of carbonaceous material which acts as an additional fuel when the bricks are fired, but also produces a characteristic appearance in the finished bricks. The Lower Oxford clay also contains sulphurous material, which results in SO_2 emissions during firing. Non-fletton bricks are made from other clays and shales and these have much lower carbon contents. For all bricks, firing leads to emissions of CO_2 from the carbonaceous material in the clay. Limestone, dolomite and barium carbonate can also be used in brickmaking and also release CO_2 when fired. Finally, many brick manufacturers add crushed coke ("colourant") to some bricks to change the final appearance of the bricks. Coke oven coke is known to be used in this manner, and we have assumed that petroleum coke is as well. Colourant is added at rates of up to 15% of the raw material weight. A high proportion of the carbon in the colourant is known not to be oxidised during firing and remains in the brick: for EU ETS reporting purposes, all UK brick makers use a figure of 50% oxidation. Although 2A4 explicitly covers use of carbonates, we have included carbon emissions from the use of colourants in bricks here as well, in the absence of anywhere more appropriate to report them.

The 2006 GLs draws attention to other sources of CO_2 emissions from use of soda ash and other carbonates. These other uses include flue gas desulphurisation (FGD), magnesia production, and use of soda ash in soaps & detergents, and other applications.

Limestone is used in FGD systems for abatement of SO_2 emissions at most remaining UK coal-fired power stations and emissions are reported under 2A4. The power stations at Drax and Ratcliffe were the first to get FGD (in 1997), followed by West Burton A in 2004, Eggborough and Cottam in 2005, then Ferrybridge C, Fiddlers Ferry and Rugeley B in 2008/2009. Various small, predominantly waste and/or biomass-fired stations also report CO_2

emissions from limestone scrubbing in the EU ETS. In all of these processes, limestone reacts with the SO_2 present in flue gases, being converted to gypsum, with CO_2 being evolved. Uskmouth B has a dry lime-injection system, so there is no potential for CO_2 emissions at this site. Seawater scrubbing systems are used at Aberthaw, Kilroot, and Longannet power stations but CO_2 emission estimates are not included in the GHGI for this type of FGD system; there is no estimation method for this process. Some MSW incinerators are believed to use the dry lime injection process to remove SO_2 emissions: as with Uskmouth B, there will be no CO_2 emissions from this type of FGD technology.

Magnesia production in the UK is thought to be limited to a single plant that closed in 2005. This site produced magnesia from seawater, with magnesium salts in the seawater precipitated as magnesium hydroxide, followed by conversion to magnesia in kilns. No process emissions of CO_2 occurred at this site. We have no information on any use of soda ash in the UK outside of the glass industry, and so no emission estimates are made.

4.5.2 Methodological Issues

CO_2 emissions from production of bricks and tiles are based on data reported in the EU ETS. The EU ETS data set provides site by site emissions, broken down by the source of emission (e.g. from clays, fuels, colourants etc.) and begins in 2005, although the data are only representative of the sector from 2008 onwards, when all significant manufacturing sites were included in EU ETS. The data can easily be divided into emissions from fuels and emissions from non-fuels (i.e. process emissions). It is slightly more difficult to divide the non-fuel data into sub-types such as emissions from clays, colourants, or 'pure' carbonates like limestone, dolomite and barium carbonate, since some of the information within the ETS data set on the source of the CO_2 is ambiguous. So although it is possible to make a crude split, we have instead reported the process emissions as a group. Note that this does mean that emissions from the colourant (coke oven or petroleum coke) are included here, but we think this is justified both because of the slight ambiguity in some of the ETS data, but also because there is no other category which would be more appropriate.

The ETS data are calculated by each brick and tile producer using site-specific activity data, and industry-wide emission factors, compiled by the industry trade association each year (British Ceramics Confederation, 2014). These factors include factors for simple carbonates based on the stoichiometric relationship of carbon to the carbonate, as well as measured emission factors for different types of clay e.g. Keuper Marl, Weald Clay, and Lower Oxford Clay. The industry factors also include an estimate for colourants which is based on the assumption that 50% of carbon in the colourant is oxidised during firing.

Consultation with the brick industry indicates that the ETS data for 2008-2010 represents 93% of sector production, and that has been taken into account in the UK GHGI approach. In 2013, a single further site reported in EU ETS, bringing coverage to 95%. The emissions data for 2008-2015 are therefore increased slightly to reflect non-reporting brickworks, assuming that emission rates at non-reporting sites will be the same as on average at reporting sites. With the exception of the large site that joined EU ETS in 2013, the non-reporting sites over the period 2008-2015 are all the smaller producers and it is not known how representative the industry factors will be for these atypical sites. In the absence of better data, however, we have assumed that emission rates are the same.

ETS data is very limited before 2008, and therefore is not used to derive a national total. Instead, we have used annual brick production data, available in Government Statistics (Monthly Statistics of Building Materials and Components, July 2016, available from www.gov.uk) to extrapolate back from the ETS data. These data are for total numbers of bricks produced, and it is necessary to consider what proportion of these bricks are of the fletton type, since this type of brick is associated with higher process emissions. Fletton bricks have had a declining share of the UK brick market for many years and fletton bricks are no longer used in the construction of new buildings. Information on the market share is, however limited: Ove Arup (1990) puts it at 25%, Blythe (1995) states it is 20%, and by 2011, following the announcement that the last but one fletton brickworks was being closed, local media reports all stated that fletton bricks now accounted for less than 10% of the UK market. We have therefore assumed a 25% share in 1990, falling to 20% in 1995, then falling to 10% by 2010 and remaining at 10% thereafter. Using these assumptions, it is possible to then generate estimates of the numbers of fletton bricks and non-fletton bricks produced each year.

For non-fletton bricks, a figure of 152 grams CO_2 per brick can be calculated from the ETS-based emission estimates for 2008-2013, and then the estimates of non-fletton bricks produced can be used to generate emission estimates for the period 1990-2007 using this emission factor.

In the case of fletton bricks, the PI provides additional data to supplement the information in the EU ETS for 2008 onwards. Total emissions of CO_2 are reported at the Stewartby site, and at the combined Saxon/Kings Dyke works for each year between 1998 and 2007. The later ETS data at these sites is used to separate the PI data for 1998-2007 into a fuel component and a process component. This gives a time series of process emission estimates back to 1998, and this is further extrapolated back to 1990 on the basis of the estimates of fletton brick production.

Table 4.6 gives a timeline for the brick sector, summarising what is known about the sites operating and the data available for emission estimates over the time series.

Table 4.6 Timeline for the brick sector in the UK: production sites and data availability

Years	Number of sites and fuels	Availability of data
1990-1997	6 fletton works in operation in 1990; only 5 still in operation by 1993. Those in 1993 burnt coal, or a mixture of coal and natural gas. Unknown number of non-fletton works.	No emissions data available, annual production (numbers) of all bricks available and fletton and non-fletton brick production estimated from this. Emission estimates require use of emission factors generated from later PI and ETS data.
1998-2007	Two of the 5 fletton works in operation since 1993 close in 1998/1999. Both used coal only as a fuel so by the end of 1999, 3 works remain: Stewartby burns coal, the other two (Saxon/Kings Dyke), both in the same area in England, now burn natural gas only. Approximately 100 non-fletton brickworks in early 2000s.	Annual emissions of CO_2 and methane available in the Pollution Inventory for each fletton site until 2004, when emissions for the two gas-burning sites, which are located about 1.5 km apart start to be reported as combined totals. Reported emissions have to be split between energy-related and process-related emission. Annual production (numbers) of all bricks available, so fletton and non-fletton brick production has to be estimated. Emission estimates for non-fletton bricks have to be generated using emission factors from later EU ETS data.

Years	Number of sites and fuels	Availability of data
2008	Closure of coal-burning fletton works at end of 2008, leaving only the 2 gas-burning works remaining. 63 non-fletton brickworks report in EU ETS in 2008.	Annual emissions of CO_2 and methane available in the Pollution Inventory for Stewartby, and for Saxon/Kings Dyke. EU ETS data for the same two fletton brickmaking units, and also for non-fletton brickworks. These data are detailed, allowing fuel-related and process-related emissions to be separated. Emission estimates can be based directly on EU ETS data.
2009-2014	Saxon works closed in 2011, leaving only the Kings Dyke fletton brickworks remaining. Many closures of non-fletton brickworks, with 49 reporting in EU ETS by 2011. In 2013, final large site joins EU ETS, with total of 46 non-fletton sites then reporting.	Annual emission of CO_2 and methane available in the Pollution Inventory for the Saxon/Kings Dyke works. EU ETS data for all significant fletton and non-fletton works for all years except for one site that joins ETS in 2013. Emission estimates can be based directly on EU ETS data.

Other types of ceramics are manufactured in the UK, including wall and floor tiles, refractories, sanitaryware, household ceramics etc. We do not have reliable data on either the levels of production or suitable emission factors for these types of ceramic goods, so no emission estimates can be made. However, the following simple calculations have been made, which indicate that emissions are insignificant.

The UK Minerals Yearbook (BGS, 2014) gives production, imports and exports for 4 types of clay (ball clay, china clay, fireclay, other clays & shales). This reference also gives a breakdown of the uses to which the 'other clays & shales' are put – mostly bricks, cement production, and construction, with very little used for other ceramics. Fireclay is assumed to be used solely for ceramics, and the EU ETS data shows that fireclay is used by many brickmakers. It will also likely be used for refractories and sanitaryware and, in the absence of any data, we have assumed a 50/50 split of fireclay usage between bricks and other ceramics. The Kaolin and Ball Clay Association (KABCA) give estimates of the markets for both ball clay and china clay on their website[34]. Neither type of clay will be used in any significant quantity in bricks but KABCA indicate figures of 22% of china clay and 'over 80%' of ball clay used in ceramics. Based on BGS figures for 2008, 2009, 2011, and 2012 (data are not available for 2010), we can then derive some approximate figures for clays used in bricks and in other ceramics:

Table 4.7 Consumption of Clays in Brickmaking and Other Ceramics Manufacture (Mtonnes)

Product		2008	2009	2011	2012	Average
Bricks	Ball clay	0	0	0	0	

[34] See http://www.kabca.org/what-is-kaolin.php and http://www.kabca.org/what-is-ball-clay-.php

Product		2008	2009	2011	2012	Average
	China clay	0	0	0	0	
	Fire clay	0.092	0.066	0.082	0.049	
	Other clay & shales	4.993	2.839	4.022	3.591	
	Total	5.085	2.904	4.104	3.640	3.933
Other ceramics	Ball clay	0.224	0.196	0.199	0.161	
	China clay	0.052	0.053	0.051	0.044	
	Fire clay	0.092	0.066	0.082	0.049	
	Other clay & shales	0.160	0.120	0.137	0.023	
	Total	0.527	0.434	0.470	0.277	0.427

The consumption of clays for other ceramics is therefore estimated as approximately a tenth (11%) of the consumption of clays in bricks. The carbon content of fire clay and other clays and shales could be obtained from EU ETS data for bricks, and the carbon content of ball clay is known to be very low since the British Ceramics Confederation produce carbon emission factors for ball clay in their guidance for EU ETS reporting. No data are available for china clay, and, at the current time, we do not have data to generate a full time-series of activity data. For the purposes of determining the significance of the source, if we generate a time-series based on 11% of the clay usage in bricks, and then assume the same average carbon content in clay for ceramics as in the common clays used in brickmaking (which would be a worst case because of the very low carbon content of ball clay), this would yield emission estimates that were well below 0.05% of the national total (0.0064% in 1990 and 0.0037% in 2013) and therefore insignificant.

Emissions from Flue Gas Desulphurisation (FGD) are either calculated using an emission factor of 69 t carbon/kt gypsum produced, or based on EU ETS emissions data. The factor is based on the stoichiometric relationship between gypsum and carbon dioxide formed in the FGD plant. Data on gypsum produced in FGD plant has previously been taken from the British Geological Survey (2012), but these data are not always consistent with site-specific emissions data available from EU ETS, and so a composite series of emissions data is used with BGS activity data and the emission factor used for 1994-2004, and EU ETS emissions data for 2005-2014. BGS data for 2005 are in very good agreement with EU ETS data for that year, and so it has been assumed that BGS data for 1994-2004 are also comparable with the later EU ETS data.

4.5.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

In the case of FGD plant there is a change in methodology between 2004 and 2005. However, BGS and EU ETS-based emission estimates for 2005 are very close, and for 2006-2014 are within 6% of each other (with the EU ETS numbers usually higher). We have no data from BGS for 2015 and so no comparison can be made with the EU ETS based figures.

Estimates for bricks are considered to be highly reliable for the period 2008-2015 where EU ETS data are available for almost all sites. For earlier years, the emission estimates rely upon extrapolation of the 2008 emissions data using brick production estimates and this will introduce uncertainty within the earlier part of the time series. Emission estimates for methane from fletton brickworks are, similarly, based on reported data in later years and extrapolation using brick production for the early part of the time-series, so the uncertainty will again be greatest in the earlier part of the time series.

4.5.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5.**

4.5.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10**.

4.5.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.6 SOURCE CATEGORY 2B1 – AMMONIA PRODUCTION

4.6.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2B1: Ammonia Feedstock 2B1: Ammonia Fuel	T3, T1 T3, T1	CS, D CS, D
Gases Reported	CO_2, CH_4, N_2O, NO_X		
Key Categories	2B: Chemical industry – CO_2 (L2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

Ammonia is typically produced using the Haber process, which starts with the steam reforming of natural gas to make hydrogen. The simplified reactions are:

$$CH_4 + H_2O \Leftrightarrow CO + 3H_2$$

$$CO + H_2O \Leftrightarrow CO_2 + H_2$$

The hydrogen is then reacted with nitrogen to form ammonia.

$$N_2 + 3H_2 \Leftrightarrow 2NH_3$$

If the by-products CO and CO_2 are not captured and used, then these are emitted to atmosphere. Ammonia plants can be integrated with methanol manufacture for greater efficiency, since the carbon oxides can be used to manufacture methanol:

$$CO + 2H_2 \Leftrightarrow CH_3OH$$

$$CO_2 + 3H_2 \Leftrightarrow CH_3OH + H_2O$$

Over the time period covered by the UK greenhouse gas inventory, ammonia has been manufactured at four locations in the UK. CO_2 emissions are reported from three of those sites: at the remaining site (Hull), the ammonia is produced with hydrogen supplied as a by-product from another chemical process operated on a neighbouring site. At one of the remaining three sites where CO_2 is reported, some carbon from the steam reformer was, until 2001, exported for use in the manufacture of methanol.

At least one ammonia plant sells CO_2 to the food industry and nuclear industry. Because this CO_2 is still ultimately emitted to atmosphere, it is included in the emissions reported here. This is considered more reliable than trying to identify carbon emissions at the point of final use since CO_2 will also be emitted from other processes such as fermentation.

Methane emissions from the steam reforming processes and the associated ammonia production facilities are reported under 2B10, together with methane emissions from other types of chemical manufacturing sites. Nitrous oxide emissions are not estimated: manufacturers do not report any emissions of this pollutant and they are therefore assumed to be negligible.

Urea production was occurring in the UK at one site as recently as 1986, but this facility closed soon after. No other urea production facilities have been commissioned in the UK, and throughout the records from UK environment regulation and permitting of production plant (whereby individual plants operate under agreed permits, which in England was implemented from 1993 onwards) there is no mention of urea production in any IPC/IPPC/IED permits. We're also aware that the main company that currently manufactures ammonia in the UK has three urea production facilities (one in each of France, Germany and Netherlands) that they use to supply the UK market. Therefore we are confident that there has been no production of urea in the UK since 1990, and hence our ammonia production estimates throughout the time series take no account of urea production.

4.6.2 Methodological Issues

Ammonia production processes require natural gas both as a feedstock and as a fuel to produce heat required by the steam reforming stage of the ammonia process. The emissions from both feedstock **and** fuel use of natural gas are both reported under 2B1, in line with the requirements of the 2006 Guidelines.

Emissions of CO_2 from both fuel and feedstock use of natural gas are calculated by combining reported data on CO_2 produced, emitted and sold by the various ammonia processes. Where data are not available, they have been calculated from other data such as plant capacity or total natural gas consumption. The ammonia plant utilising hydrogen by-product from chemical manufacture does not need to be included as there are no process emissions of CO_2.

Table 4.8 summarises the details of the UK ammonia plants and **Table 4.9** gives details of production and emissions etc. by the sector.

Table 4.8 Details of UK ammonia plants

Plant	Feedstock	Carbon emissions	Notes
Billingham	Natural gas	Yes	Some production of methanol using by-product carbon until 2001
Severnside	Natural gas	Yes	Closed in 2007
Ince	Natural gas	Yes	
Hull	Hydrogen	No	

Table 4.9 UK ammonia production and emission factors

Year	Ammonia production (kt)	CO_2 emitted (kt)	CO_2 emission factor, (t / t NH_3) (all UK production plant)*
1990	1328	2004	1.51
1995	1388	2054	1.48
2000	1213	2007	1.65
2005	1172	1780	1.52
2006	949	1385	1.46
2007	1251	1865	1.49
2008	1082	1683	1.56
2009	889	1296	1.46
2010	1084	1488	1.37
2011	687	1043	1.52
2012	1017	1574	1.55
2013	957	1383	1.45
2014	987	1482	1.50
2015	1022	1590	1.56

*As reported within the CRF table 2(I).A-Gs1

CRF table 2(I).A-Gs1 presents the ammonia production data for all UK sites (including Hull where there are no CO_2 emissions).

Due to the limited market for ammonia production in the UK, to present detailed technology-specific data on production and emissions would be disclosive. Full details of the installation-specific production, fuel use and emissions will be provided upon request to a UNFCCC Expert Review Team. The data in the table above summarises the estimated overall UK production of ammonia (which is partly based on operator data and partly on inventory agency estimates based on plant capacity), total estimated 2B1 CO_2 emissions and ammonia IEF on a production basis, as presented in the CRF.

The operator of the Ince and Billingham UK ammonia plants has provided information on reasons underlying the year on year variation in emission factors. Firstly, plants are typically shut down for routine maintenance every two years, and start-up and shut-down procedures increase the emission factors overall. Secondly plant production rates are varied by the operator during times of high gas prices or low demand, which reduce efficiency and increase emission factors.

In addition to these operational variables, each plant will have a different intrinsic efficiency, which will in part reflect the age of the plant and the technology used. The IPCC 2006 Guidelines suggests a Tier 1 default emission factor of 1.694 tonnes CO_2 / tonne NH_3 for 'modern' European plant, but a higher Tier 1 default of 2.104 tonnes CO_2 / tonne NH_3 for a 'typical' plant i.e. based on a mix of modern and old plant. The overall UK IEF presented in the table above are below the IPCC default, but this is due to the production at the UK plant where there are no CO_2 emissions; UK factors for the three sites with CO_2 emissions show an average of 1.83 tonnes CO_2 / tonne NH_3 for production across 1990-2015, and would mainly be within the range suggested by the two IPCC defaults, the exceptions being 1990-1993 & 1998 when the factors were marginally below 1.694 tonnes CO_2 / tonne NH_3, and 2002 when the emission factor was slightly higher than 2.1 tonnes CO_2 / tonne NH_3. *[Note that these data are not presented in the table above due to commercial confidentiality, but full details are available to an ERT.]* All of the UK plants have been in operation since before 1990; the fact that the average UK factor lies between the 2006 IPCC Guideline defaults for modern plant and mixed modern/old plant indicates that the performance of the UK ammonia plants is broadly typical of European plant.

4.6.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type. The uncertainty associated with this source is low, since the carbon content of natural gas is well known and plant specific data are received from the operators annually.

A consistent time series of activity data has been reported from the manufacturers of ammonia, and this results in good time series consistency of emissions.

4.6.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5** and the source emissions data from plant operators is subject to the QA/QC procedures of the Environment Agency's Pollution Inventory.

4.6.5 Source Specific Recalculations

There have been no significant recalculations to this category.

4.6.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.7 SOURCE CATEGORY 2B2 – NITRIC ACID PRODUCTION

4.7.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2B2: Nitric Acid Production	T3, T2	CS
Gases Reported	N_2O, NO_x		
Key Categories	2B2: Nitric acid production - N_2O (L1, L2, T1, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

Nitric acid is produced by the catalytic oxidation of ammonia:

$$4NH_3 + 5O_2 \Rightarrow 4NO + 6H_2O$$

$$2NO + O_2 \Leftrightarrow 2NO_2$$

$$3NO_2 + H_2O \Leftrightarrow 2HNO_3 + NO$$

Nitrous oxide is also formed by oxidation of ammonia:

$$4NH_3 + 3O_2 \Rightarrow 2N_2O + 6H_2O$$

Nitrous oxide is emitted from the process, as well as a small percentage of the NO_x that cannot be recovered for conversion into nitric acid. At the end of 2014 nitric acid was being manufactured at 2 UK sites with a total of 4 production plants. At one site, the nitric acid production plant has had NO_x/N_2O abatement fitted to all units since commissioning (pre-1990), whilst at the other UK production site, all three production lines have had nitrous oxide abatement retrospectively fitted during 2011 Quarter 1. This has led to a notable reduction in the UK IEF for nitrous oxide emissions from nitric acid production in the UK between 2010 and 2011 (see **Table 4.12** below).

4.7.2 Methodological Issues

Across the 1990-2015 time-series the availability of emissions and production data for UK nitric acid plant is inconsistent, and hence a range of methodologies have had to be used to provide estimates and derive emission factors for this sector. Where possible, emission estimates are based on site-specific data provided by process operators.

Site-specific production estimates are largely based on production capacity reported directly by the plant operators. This approach may overestimate actual production. No data are available for three sites operating between 1990 and 1993, and production at these sites is calculated based on the difference between estimates of total production and the sum of production at the other sites.

Emission estimates for N_2O are derived for each nitric acid site using one of the following:

a) Emissions data provided by the process operators directly or via the Pollution Inventory (1998 onwards for plant in England, 2001 onwards for plant in N Ireland);
b) Site-specific emission factors derived from reported emissions data for the same site for another year (1990-1997 for some plant in England, 1994-1997 for other plant in England, 1990-2000 for plant in N Ireland); and
c) A default emission factor of 7 kt N_2O /Mt 100% acid produced in cases where no emissions data are available for the site (some sites in England, Scotland, 1990-1993). This default factor is the default factor provided in the 2006 IPCC Guidelines (IPCC, 2006) for medium pressure plant.

Table 4.10 gives a summary of the approaches used across the time series to estimate production and N_2O emissions for the UK inventory and **Table 4.11** summarises the methods used by operators to derive the emissions data they report to regulators and the inventory team. The emissions monitoring at the two sites still in operation was originally based on periodic (at least quarterly, if not more frequent) sampling, but from 2010 onwards has been continuous, using on-line infra-red monitoring systems. The monitors at both sites are certified to MCERTS, installed and maintained to EN14181, and subject to EU ETS Permit. The details of monitoring at the closed sites are not known, but it is assumed to have been the same as the sites that remain in operation i.e. periodic prior to 2010. The closed sites were shut before the fitting of continuous monitoring devices was required for EU ETS reporting purposes.

Inventory emission estimates for NO_X are derived for each nitric acid site using emissions data provided by the process operators directly or via the Pollution Inventory. No emissions data are available before 1994. Emissions between 1990 and 1993 are estimated by interpolating between the 1994 emission based on plant-specific data, and an estimate for emissions in 1988 based on nitric acid production data (CIS, 1991) and a default NO_x emission factor of 3.98 tonne NO_x / kt of 100% acid produced.

This default NO_X emission factor is a weighted aggregate of CORINAIR (1989) emission factors for the different types of nitric acid processes ranging from 3-12 t/kt of 100% acid produced. The weighting is based on data on the types of UK manufacturing plant in the year 1985, provided by the Nitric Acid Association (Munday, 1990).

Some nitric acid capacity is co-located with a process that manufactures adipic acid. For the years 1990-1993, its emissions are reported combined with those from the adipic acid plant (see **Section 4.8**) but emissions from 1994 onwards are reported separately. This causes some inconsistency in between reporting categories, although total emissions are not affected.

Table 4.10 Methods used to estimate emissions from this category

Period	Site specific production data		Site Specific emissions data, kt N_2O		
	Estimated	Operator data	As reported by operator	Estimated using site-specific EF	Estimated using IPCC default EF
1990-1993	7 sites	1 site		5 sites	3 sites
1994	5 sites	1 site		6 sites	
1995-1997	4 sites	2 sites		6 sites	
1998-1999		6 sites	5 sites	1 site	
2000	1 site	5 sites	5 sites	1 site	
2001		5 sites	4 sites	1 site	
2002-2008		4 sites	4 sites		
2009-2015		2 sites	2 sites		

Table 4.11 Methods used by operators to quantify site emissions

Period	Site emissions based on:	
	Emission Factors	Monitoring
1998-2000	4 sites	1 site
2001-2004	3 sites	1 site
2005	2 sites	2 sites
2006-2007	1 site	3 sites
2008	2 sites[a]	2 sites
2009	1 site	2 sites
2009-2015	None	2 sites

[a] One site closed at end of January 2008 which submitted emissions data for that month based on emission factors having used monitoring to quantify emissions the previous year.

Table 4.12 Summary of Nitric Acid Production in the UK, 1990-2014

Year	No of sites	Production (Mt 100% Nitric Acid)	Aggregate EF (kt N_2O / Mt Acid)	Aggregate EF (kt NO_X / Mt Acid)
1990	8	2.41	5. 38	3.36
1994	6	2.49	3.89	1.93
1995	6	2.40	3.82	0.808
1996	6	2.44	3.83	0.743
1997	6	2.35	3.78	0.902
1998	6	2.61	3.99	0.732
1999	6	2.44	6.29	0.913
2000	6	2.03	6.94	0.992
2001	5	1.65	6.62	0.662
2002	4	1.64	4.20	0.392
2003	4	1.71	4.38	0.431
2004	4	1.71	5.00	0.438
2005	4	1.71	3.80	0.379
2006	4	1.47	3.87	0.424
2007	4	1.61	3.54	0.380
2008	4	1.29	3.89	0.234
2009	2	0.93	3.89	0.270
2010	2	1.21	3.51	0.221
2011	2	1.08	0.616	0.118
2012	2	1.13	0.115	0.127
2013	2	1.01	0.142	0.107
2014	2	1.10	0.124	0.099
2015	2	1.13	0.130	0.108

The larger of the two remaining UK plants fitted control equipment to reduce N_2O emissions in early 2011, and this will also have decreased NO_X emissions from that plant as well, leading to the large decreases in the aggregate EFs for both pollutants in 2011 compared with the previous year. The large increase in N_2O emissions between 1998 and 1999 resulted from a change in the NO_X abatement system at one plant from NSCR to SCR. NSCR reduces emissions of N_2O as well as NO_X, whereas SCR only abates NO_X and can actually increase N_2O emissions.

4.7.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

Emissions from nitric acid production are estimated based on a combination of emission factors and reported emissions data. The methodology used to estimate N_2O for this sector does vary through the time-series depending upon the availability of data. The calculated N_2O EF for UK nitric acid production facilities varies quite significantly across the time series, which is a reflection of nitric acid production patterns across UK sites that utilise different process conditions. Successive closures have changed the average N_2O EF, as plants with generally above-average emission rates cease production. Abatement of N_2O at two plants has also played a part in reducing the UK emission factors over time. The changes in EF may also partially reflect the lack of availability of a consistent time-series of emissions data.

The nitric acid plant emissions data reported by operators since 1998 are considered to be reliable since they are subject to internal QA/QC checks by the plant operators and the Environment Agency before being reported in the Pollution Inventory. More details have been obtained regarding the abatement plant and the N_2O monitoring methodologies at UK plant, and this has clarified some previous uncertainties regarding their process emissions.

4.7.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

4.7.5 Source Specific Recalculations

There have been no significant recalculations to this category.

4.7.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.8 SOURCE CATEGORY 2B3 – ADIPIC ACID PRODUCTION

4.8.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2B3: Adipic Acid Production	T2, T3	CS
Gases Reported	N_2O		
Key Categories	2B3: Adipic acid production - N_2O (L1, L2, T1, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

Adipic acid is manufactured in a multi-stage process from cyclohexane via oxidation with nitric acid. Nitrous oxide is produced as a breakdown product from the nitric acid.

4.8.2 Methodological issues

There was only one company manufacturing adipic acid in the UK, but this closed in early 2009. Production data are not provided in the NIR because of commercial confidentiality concerns.

Production data and emission estimates have been provided by the process operator (Invista, 2010). The emission estimates are based on the use of plant-specific emission factors for unabated flue gases, which were determined through a series of measurements on the plant, combined with plant production data and data on the proportion of flue gases that are unabated.

In 1998 an N_2O abatement system was fitted to the plant. The abatement system was a thermal oxidation unit and was reported by the operators to be 99.99% efficient at N_2O destruction. The abatement unit was not available 100% of the time, and typically achieved 90-95% availability during adipic acid production.

A small nitric acid plant was associated with the adipic acid plant, and this also emitted N_2O. From 1994 until the plant's closure in 2009, the emission from the nitric acid production is reported under 2B2, but prior to 1994 it is included under adipic acid production because separate emissions data for the different processes on that site were not available for those years. This discrepancy in reporting will cause a variation in the reported effective emission factor for these years for 2B2 and 2B3 but overall emission estimates are not affected.

4.8.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

Emissions data for N_2O from adipic acid production are provided by the process operator, but can be cross-checked against emissions reported in the Pollution Inventory.

The level of uncertainty associated with reported emissions of N_2O is not known, but the data are considered to be reliable as they are subject to QA/QC checks by the operator, and the related Pollution Inventory data are also checked by the Environment Agency. A higher uncertainty is assumed for 1990 than for later years. Emissions no longer occur from this source since the plant has now closed.

Fluctuations in the N_2O EF from this plant are apparent since the installation of the abatement plant. Following direct consultation with the plant operators, it has been determined that the variability of emissions is due to the varying level of availability of the abatement plant. A small change in the availability of the abatement system can have a very significant impact upon overall plant emissions and hence upon the annual IEF calculated.

4.8.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. During summer 2005, consultation between Defra, AEA, plant operators and the UK Meteorological Office was conducted to discuss factors affecting emissions from the adipic acid plant, including: plant design, abatement design, abatement efficiency and availability, emission measurement techniques, historic stack emission datasets and data to support periodic fluctuations in reported emissions. The meeting prompted exchange of detailed plant emissions data and recalculation of back-trajectory emission models.

4.8.5 Source Specific Recalculations

There have been no significant recalculations in this category.

4.8.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.9 SOURCE CATEGORY 2B4 – CAPROLACTAM, GLYOXAL AND GLYOXYLIC ACID PRODUCTION

Caprolactam was made at one site in the UK in the early 1970s. The site was destroyed in a serious explosion in 1974, and no other production sites have been built since. Glyoxal and glyoxylic acid have not been produced on an industrial scale in the UK at any time. A literature search of documents from the last 25 years on chemical production in Europe as well as consultation with the Chemical Industries Association has confirmed that these sources should be reported as not occurring.

4.10 SOURCE CATEGORY 2B5 – CARBIDE PRODUCTION

This source category includes silicon carbide and calcium carbide. Neither chemical is known to have been manufactured on an industrial scale in the UK since the 1960s, when calcium carbide plants at Kenfig and Runcorn closed. As above for 2B4, literature searches and consultations with UK chemical industry representatives have confirmed that this source should be reported as not occurring in the UK.

4.11 SOURCE CATEGORY 2B6 – TITANIUM DIOXIDE PRODUCTION

4.11.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2B6 Titanium dioxide	CS	CS
Gases Reported	CO_2		
Key Categories	2B: Chemical industry – CO_2 (L2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements.		

Titanium dioxide has been produced in the UK by two methods: i) from ilmenite, using the sulphate process; and ii) from rutile, using the chloride process. Only the chloride process leads to process emissions of greenhouse gases. In 1990, there were two sites each using the chloride and the sulphate process, but the two sulphate processes closed in 1997 and 2009, so all titanium dioxide in the UK is now produced using the chloride process at the two sites at Stallingborough and Greatham. The chloride process involves the chlorination of rutile ore in a reducing atmosphere to produce titanium tetrachloride ($TiCl_4$), followed by oxidation of the $TiCl_4$ to titanium dioxide. The reducing atmosphere is produced by combustion of petroleum coke or coke oven coke.

4.11.2 Methodological Issues

The 2006 GLs recommend the use of either a Tier 1 method involving a default emission factor and national activity data, or a Tier 2 method using installation-specific data on reducing agent usage. For the UK, neither of these methods are feasible options due to limited data; there are no UK activity data (i.e. annual production statistics) for any individual chemical product, and the only site-specific data for the UK plant is in the form of CO_2 emissions data. These emissions data are available from two regulatory reporting sources:

- From the PI, covering CO_2 from reducing agents and fuel use in plant utilities; and
- From the EU ETS, covering fuel use for energy production only until 2012, and coke use in addition from 2013 onwards.

Operator reporting has been variable over the years, in line with the evolving scope and detail required for EU ETS and PI data returns.

- During Phase II of the EU ETS (2008-2012), the titanium dioxide plants only reported CO_2 from fuels burnt in the site boilers in their EU ETS returns;
- For Phase III (2013 onwards), coverage of EU ETS reporting was extended to cover fuels burnt in furnaces, driers etc. as well as use of reducing agents; and
- For three years (2006-2008), the process operators were required to report thermal CO_2 and chemical CO_2 separately to the PI.

From these data it is possible to obtain the emissions from the chemical process for 4 years: 2006-2008 (using the PI data for chemical CO_2 emissions), and 2013-2015 (by difference between the PI/EU ETS totals covering all CO_2 emissions and the detailed EU ETS data covering all energy-related emissions. The fuel/process split in emissions for these 5 years can be calculated, and the PI provides total CO_2 emissions at each site back to 1998. Prior to 1998, there is no data on either emissions or production, and therefore it is assumed that emissions in 1990-1997 are at the same level as in later years (the production capacity at all UK sites producing TiO_2 by the chloride route is the same for all years).

In order to avoid a potential double-count in emissions in the UK GHGI, it is necessary to ensure that the reductant used in the processes is not included as a fuel and emissions reported in 1.A. The method adopted by the inventory team addresses this issue by back-calculating the coke oven coke/petroleum coke activity data (used as a reductant) from the emissions data using UK carbon emission factors for the feedstock, and discounting this amount from the Energy sector estimates.

4.11.3 Uncertainties and Time Series Consistency

The country-specific method used is regarded as the best available method for the UK GHGI estimates, given the lack of any production activity data. The use of site-specific EU ETS and PI data, even if not relating to input materials as required by the Tier 2 method in the GLs, ensures that emissions data are quite certain for the period from 1998 onwards. Estimates for 1990-1997 are more uncertain due to the need to extrapolate 1998 data backwards in the absence of any specific information on production, materials usage or emissions in those years.

4.11.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

4.11.5 Source Specific Recalculations

There has been a revision to activity data used to derive the EF from reported emissions for petroleum coke in the Chemical industry - titanium dioxide.

For information on the magnitude of recalculations, see **Section 10**.

4.11.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.12 SOURCE CATEGORY 2B7 – SODA ASH PRODUCTION & USE

4.12.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2B7 Soda Ash Production	CS	CS
Gases Reported	CO_2		
Key Categories	2B: Chemical industry – CO_2 (L2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**		
Major improvements since last submission	No major improvements.		

Soda ash has been produced in the UK using the Solvay process at two sites both of which have been operating since the start of the time period covered by the inventory. The Solvay process involves the conversion of limestone (calcium carbonate) and brine (sodium chloride) to soda ash (sodium carbonate) and calcium chloride. The initial stage in the process is the calcination of limestone in a kiln to produce lime and CO_2 gas, both of which are used in the process. Coke oven coke is used to fire the lime kilns and CO_2 from the coke is included in the gases used in the soda ash plant. In theory, if limestone and brine are converted completely to soda ash and calcium chloride, then that part of the soda ash process is carbon-neutral and the CO_2 emitted should be equal just to those emissions occurring from the coke. In practice, the process is not 100% efficient, so emissions of CO_2 are actually somewhat higher than would just be due to the coke use. Soda ash production at one of the two UK sites (Winnington) ceased in February 2014, although the site is still being used to make sodium bicarbonate from sodium carbonate solution & CO_2, which we assume is sourced from the neighbouring Lostock plant. EU ETS data suggest this sodium bicarbonate process does emit some CO_2 – presumably unreacted CO_2 that passes through the process, and since this CO_2 probably originates with the soda ash process at Lostock, it is included in the emission estimates for 2B7.

Emissions from soda ash (sodium carbonate, Na_2CO_3) used in the manufacture of soda-lime glasses is reported under source category 2A4.

4.12.2 Methodological Issues

The 2006 GLs suggests that emissions should be based "on an overall balance of CO_2 around the whole chemical process”. In the UK, soda ash is produced at two sites and both began to report under the EU ETS in 2013. The EU ETS emissions data for the two sites is calculated using a carbon balance approach with inputs in coke and limestone balanced against soda ash and waste products. The 2013-2015 EU ETS data therefore meets the requirements for the method suggested in the GLs.

Prior to 2013, no data for the UK plant were reported in EU ETS, but CO_2 emissions were reported in the PI between 1998 and 2014. Comparison of the PI and EU ETS data for 2013-2015 shows that EU ETS data were 38% higher than emissions in the PI in 2013, 68% higher in 2014, and 80% higher in 2015. The reason for this is not known, but since the PI data for 1998-2013 are fairly consistent, it is assumed that there is a systematic underestimate in the PI data (possibly they represent CO_2 releases from just part of the process, rather than the whole-process balance used in the EU ETS), and that this underestimate is at the same level as in 2013. We have therefore used the PI data for 1998-2012 but multiplied by a factor of 1.38 to give estimates of emissions in those years. The difference in 2014 and 2015 was higher and so a more conservative approach would be to use the average difference (62%). However, the Winnington plant was closed in 2014 and so both 2014 & 2015 are atypical compared with the 1990-2013 period of full operation of both processes. For 1990-1997, no data of any type are available, but since the same two sites have been in operation in the UK across the entire time-series, emissions in 1990-1997 are assumed to be at the same level as in later years.

4.12.3 Uncertainties and Time Series Consistency

The method used is regarded as the best available given the lack of any production activity data, or a time-series of coke consumption. The use of site-specific EU ETS data for 2013-2015 should ensure that the emission estimates for those years are quite certain. The poor agreement between the PI and EU ETS data in 2013-2015 means that the emission estimates for 1998-2012, based on PI data, are far more uncertain. The difference between EU ETS and PI data is even greater (in percentage terms) in 2014-2015 than in 2013, however both sites only operated fully throughout 2013, Winnington having closed in February 2014. We have therefore treated the 2013 EU ETS/PI ratio of 1.38 (based on both plant operating throughout the year) as a more reliable guide to the potential underestimation in the PI data in earlier years. Estimates for 1990-1997 are more uncertain still due to the need to extrapolate 1998 data backwards in the absence of any specific information on production, materials usage or emissions in those years.

4.12.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5.**

4.12.5 Source Specific Recalculations

There have been no significant recalculations in this category.

4.12.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.13 SOURCE CATEGORY 2B8 – PETROCHEMICAL AND CARBON BLACK PRODUCTION

4.13.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2B8a Methanol 2B8b Ethylene 2B8c Ethylene Dichloride 2B8d Ethylene Oxide 2B8e Acrylonitrile 2B8f Carbon Black 2B8g Chemicals: OPG	T3, CS T3, CS T1 T1, CS T1, CS T1, CS T1, CS	CS CS D D, CS D, CS D, CS D, CS
Gases Reported	CO_2, CH_4, N_2O		
Key Categories	2B: Chemical industry – CO_2 (L2) 2B8: Petrochemical and carbon black production - CO_2 (L1)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**		
Major improvements since last submission	No major improvements.		

The UK has a large petrochemical industry, with manufacture of all of the chemicals explicitly mentioned in the 2006 IPCC Guidelines for at least part of the period 1990-2015, although a series of site closures in recent years has reduced the number of products manufactured in the UK.

Methanol was manufactured in the UK until 2001, at a site where the process was integrated with ammonia production. Ethylene was produced at five sites in 1990, although the closure of the Baglan Bay works in 1993, and then the Fawley works in 2010 have reduced this to three by the end of 2015. The UK ethylene crackers use either naphtha or natural gas liquids as feedstocks, and off-gases from the ethylene crackers are used as fuels on-site. Ethylene dichloride (EDC) has been produced at 4 sites over the period covered by the GHGI, although only 1 is still in operation, and only 2 of those processes used the oxychlorination route that causes process emissions of CO_2.

Ethylene oxide (EO) was produced at a single UK plant between 1990 and closure in January 2010. There is also a single site producing acrylonitrile (ACN): this has operated since 1990 and is still in operation. Two sites produced carbon black, until their closure at the very start, and in the middle of 2009 respectively. Most of the production was of furnace black.

A number of other chemical sites also emit CO_2 due to the use of off-gases as fuels. Emissions of CO_2 at these sites are very small relative to the emissions from ethylene production. All emissions of CO_2 from use of off-gases as fuels is reported under 2B8g, including the emissions from ethylene production.

Many chemical processes emit small quantities of methane, either as a result of fugitive releases from equipment, or as a component of tail gases released from vents. The inventory includes separate emissions data for production of ethylene, methanol, ACN, EO, and carbon black. Emissions of methane from other chemical processes are reported under 2B10.

4.13.2 Methodological Issues

Details of the methodologies used for petrochemical and related processes are shown in **Table 4.13**.

Table 4.13 Methodologies for petrochemical and related processes

Chemical product	Reporting for		Methodology
	CO_2	CH_4	
Ethylene	2B8g	2B8a	Site specific emissions data from EU ETS (CO_2 only), PI and from process operators. Where no emissions data are available, these are estimated by extrapolation from data available for later years, taking into account changes in plant capacity.
Methanol	2B8b	2B8b	See below for CO_2 methodology. Emission estimates for methane are based on operator-reported data from the PI.
Ethylene Dichloride	2B8c	-	Emissions estimated using IPCC Tier 1 emission factor for process CO_2 assuming production is 500,000 tonnes per year[b].
Ethylene Oxide	2B8d	2B8d	CO_2 emission estimates for 1995-2009 from the PI, emissions in 1990-1994 assumed same as in 1995. CH_4 estimates for 2004-2009 from the PI. No emissions data are available for 1990-2003, so the Tier 1 IPCC default is used, combined with estimates of EO production at the plant derived from the CO_2 emitted, and assuming a CO_2 emission factor of 0.663 t CO_2 / t EO (IPCC default for oxygen process, default catalyst sensitivity).
Acrylonitrile	2B8g	2B8e	CO_2 emission estimates for 2008-2014 from EU ETS. No data on emissions for earlier years, but the capacity of the plant is thought to have been unchanged since 1990, so the average emission for the 5-year period 2008-2012 is used for 1990-2007. The operator reports methane emissions to be below the 10 tonne threshold for reporting in the PI, so an emission of 5 tonnes/annum is assumed in the UK inventory.

Chemical product	Reporting for		Methodology
	CO_2	CH_4	
Carbon black	2B8f	2B8f	CO_2 emissions are reported in the PI for 1998-2009 for one site, and 2003-2008 for the other (this site closed at the start of 2009, so emissions in 2009 are assumed zero). The emissions reported in the PI are assumed to be 100% from process sources, and emissions in earlier years are assumed to be the same as in the earliest year for which data exist. Emission estimates for methane are also based on PI data for later years, but no data are available for the period 1990-2003, and so the IPCC Tier 1 default is used instead.
Other petrochemicals	2B8g	2B10	Emissions data for other petrochemical processes is taken from EU ETS (CO_2 only), and the PI (English/Welsh sites) or SPRI (Scottish sites). For those years where operator-reported emissions data are not available, then emissions are assumed to be the same as for later years where data are available. There are no petrochemical processes located in Northern Ireland which would emit GHGs

a – this process is integrated with an ammonia production process and all emissions of CO_2 are reported in 2B1.

b – production is not known but capacity of two plant in 1987 was 500,000 tonnes and one subsequently closed so 500,000 tonnes is considered a conservative estimate.

Emissions of CO_2 from methanol production were reported in 2B8b for the first time in the current inventory. Methanol production, like ammonia, requires hydrocarbon fuels both as a source of raw materials and as a fuel. The UK methanol process used natural gas. Whereas in ammonia processes, natural gas is reformed to produce hydrogen for the process and carbon dioxide as a waste by-product, in the methanol process reforming of natural gas generates carbon dioxide for the process with hydrogen as the waste product. The UK's only methanol plant was integrated with one of the ammonia plants, so that carbon dioxide produced by the ammonia plant could be exported and used to synthesise methanol. This CO_2, and additional CO_2 produced in the methanol plant's own reforming process is now assumed stored – in previous versions of the inventory, all of this CO_2 was assumed emitted and either reported in 2B1 (for the CO_2 from the ammonia plant) or 1A2c (for the CO_2 generated by steam reformation of natural gas on the methanol plant). The plant closed in 2001 and there is very limited information on emissions and none at all on natural gas consumption at the plant. The nominal capacity of the plant was 500 ktonnes but analysis of European production data for the 1997-2001 period indicate that the UK plant production fell sharply between 1997 and 1998 as new capacity came on stream elsewhere in Europe, and the plant was closed as uneconomic in 2001. For the period 1990-1996, it has been assumed that the UK plant was running at 98% of capacity, as in 1997. The various estimates of production have then been combined with the IPCC Tier 1 emission factor for methanol using conventional steam reforming of natural gas with integrated ammonia plant (1.02 t CO_2 / t methanol) to give the emission reported in 2B8b. The production estimates are also used to calculate the CO_2 stored, and finally, both emitted CO_2 and stored CO_2 are also converted into estimates of natural gas consumed so that we can ensure there is no double-counting of that natural gas either in 2B1 or in 1A2c. **Table 4.14** summarises the data for methanol production.

Table 4.14 Estimates for methanol production

Year	Estimated methanol production (kt)	CO_2 emitted (kt)	CO_2 stored (kt)
1990	488	498	671
1995	488	498	671
1996	488	498	671
1997	488	498	671
1998	232	237	319
1999	215	219	295
2000	257	262	353
2001	130	133	179
2002 onwards	0	0	0

The methodology for CO_2 estimates for 2B8g were developed through an inventory improvement research project in 2013-14 (Ricardo-AEA, 2014b), with a review conducted of available data on industrial use of process off-gases and waste residues as fuels, including consultation with operators of several of the installations that were known to use process off-gases as a fuel. The research included a review of data within the EU ETS. In addition, installation-specific (but anonymised) data from the chemical industry Climate Change Agreement (CCA) data reported for 2008 and 2010 were also reviewed. CCA data was used primarily to quality check the number of sites in the chemicals sector that reported the use of waste-derived fuels, and this dataset confirmed that there were a very small number of sites reporting waste-derived fuel use. It is not possible with the current data available to distinguish between feedstock-derived off-gases that are used directly as a fuel and those used in other process-related activities that result in emissions, such as flaring, and therefore the total emissions reported for those sites are allocated to 2B8g.

4.13.3 Uncertainties and Time Series Consistency

For the use of waste residues and process off-gases as fuel in the chemical industry, the emissions estimates are somewhat uncertain as the completeness of the data over the whole time-series are very hard to verify; the 2014 inventory improvement study, however, has confirmed that the inventory covers all high-emitting sites in the UK that have been in operation in recent years, and therefore the overall uncertainty on the UK inventory estimates, at least for the period covered by EU ETS data, is not regarded as significant. Energy and environmental experts within the UK trade association for the chemical sector, the Chemical Industries Association, also confirmed that they were not aware of any other sites in the UK that used process off-gases, over and above the sites identified included in the UK GHGI (Personal communication, Chemical Industries Association, 2014). These are dominated by the four ethylene production sites and a handful of other sites producing organic chemicals, typically co-located with refineries.

Emission estimates for other sources are mostly based on a mixture of PI and/or EU ETS data with estimates for earlier years then based on the assumption that emissions are as in later years. Tier 1 IPCC default emission factors are used for the minor sources 2B8c (for CO_2), 2B8d and 2B8f (both CH_4, part of time-series only). No UK-wide activity data (production data) are available with which to generate a better time series for any of the sub-sectors within 2B8, so the earlier part of the time-series for all of the chemical industry sectors is particularly uncertain. EU ETS-based emissions are considered the most reliable basis for estimates in the GHGI and the uncertainty is estimated to be +- 5%. PI data are more uncertain, because it is not clear what methods are used and the emission sources (combustion, process, other) are not transparent. Uncertainty for GHGI estimates based on the PI data is estimated to be +- 15%. Emissions data for methane are likely to be more uncertain than those for CO_2 since the former are often fugitive in nature, or minor components in stack emissions (thus requiring stack monitoring to quantify).

4.13.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

4.13.5 Source Specific Recalculations

There have been no significant recalculations to this category.

4.13.6 Source Specific Planned Improvements

It is noted that this sector has been identified as a key category, and that not all of the estimates within this sector use a tier 2 or higher approach. The UK has recently reviewed this sector and included some additional sources using what is believed to be the best currently available data. The UK will review this position should further information come to light.

4.14 SOURCE CATEGORY 2B9 – FLUOROCHEMICAL PRODUCTION

4.14.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2B9a and 2B9b: Halocarbons Production (By-Product and Fugitive respectively)	T2	PS
Gases Reported	HFCs, PFCs		
Key Categories	2B: Chemical industry - HFCs (L2, T2) 2B9: Fluorochemical production - HFCs, PFCs, SF_6 and NF_3 (L1, T1)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

Emissions arise from the UK manufacture of HFCs, PFCs and HCFC-22. HFC-23 is a by-product of HCFC-22 manufacture. There are two single manufacturers of HFCs and PFCs respectively in the UK, and two companies were operating HCFC-22 plants, both of which closed in 2008/9; one reopened in 2013.

There is no UK production of SF_6.

4.14.2 Methodological Issues

A full description of the emission model and associated methodology used for this sector is contained in AEA (2008). Within the model, manufacturing emissions from UK production of HFCs, PFCs and HFC-23 (by-product of HCFC-22 manufacture) are estimated from reported data from the respective manufacturers. Manufacturers have reported both production and emissions data, but only for certain years, and for a different range of years for different manufacturers. Therefore, the emissions model is based on implied emission factors, and production estimates are used to calculate emissions in those years for which reported data are not available. Two of the three manufacturers were members of the UK greenhouse gas Emissions Trading Scheme. As a requirement of participation in the scheme, their reported emissions were verified annually via external and independent auditors. For PFC production, emissions are now reported to the Environment Agency's Pollution Inventory, and these emissions are directly used within the GHG inventory. The operator of the HFC and (now closed) HCFC-22 plant provides speciated emissions data directly to the Inventory Agency, based on vent analysis and flowmeter readings, or on weighbridge differences. The other HCFC-22 plant, which closed in 2008, also reported to the Pollution Inventory and these emissions were used within the GHG inventory.

4.14.3 Uncertainties and Time-Series Consistency

The uncertainty analysis in **Annex 2**, provides estimates of uncertainty according to IPCC source category and fuel type. The uncertainty estimate for emissions from HFC manufacture has been revised for this submission, based on information from the plant operator. The uncertainty is now estimated at 10%.

There is a significant decrease in HFC emissions in 1998/1999. This step-change in emissions is due to the installation of thermal oxidiser pollution abatement equipment at one of the UK manufacturing sites. Fugitive HFC emissions from both an HCFC-22 plant and HFC manufacturing plant (run by the same operator) are treated using the same thermal oxidiser unit. Emissions also decrease in 2004, reflecting the installation of a thermal oxidiser at the second of the UK's HCFC-22 manufacturing sites. This was installed in late 2003, and became fully operational in 2004. HFC-23 emissions decreased in 2009 and 2010 following the closure of both HCFC-22 manufacturing sites. A small emission of HFC-23 remains, which arises from the production of HFC-125, most likely due to impurities in the feedstock. HCFC-22 manufacture restarted in 2013.

A significant increase in PFC emissions from the production of halocarbons is observed from 1992 to 1996 (with the trend changing after 1996). The increase in emissions was due to increasing production levels at the single UK manufacturing plant during this period. Since 1996, the level of emissions has changed each year which broadly reflects the demand (and hence production levels) for PFCs. In 2004 and 2005, emissions reported by the company increased compared with the preceding 3 years of fairly stable emission levels 2001-2003. Emissions declined sharply in 2007-2009, before increasing again in 2010 and 2011 and then declining again.

4.14.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 10**, and details of verification of emissions are given in **Annex 6**. Data reported via the Pollution Inventory are also further checked by the Environment Agency.

4.14.5 Source Specific Recalculations

No recalculations have been made to emissions from this sector.

4.14.6 Source Specific Planned Improvements

There are currently no planned improvements for this sector, however data sources will be kept under review.

4.15 SOURCE CATEGORY 2B10 – OTHER

4.15.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2B10 Sulphuric Acid Production Chemical Industry Chemical Industry (Nitric Acid Use) Chemical Industry (Pigment Manufacture) Chemical Industry (Reforming) Chemical Industry (Sulphuric Acid Use) Coal, tar and bitumen processes	CS CS CS CS CS CS CS	CS CS CS CS CS CS CS
Gases Reported	CH_4, CO, NO_x, SO_2, VOC		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

The UK has a large chemical manufacturing sector and emissions of methane, carbon monoxide, NO_x, SO_2, and NMVOC in the inventory are treated in some detail to reflect the many different types of process. Emissions from processes not covered elsewhere in 2B, are reported under 2B10.

Chemical manufacturing processes are a significant source of NMVOC emissions. Due to the complexity of the sector and the difficulty of separating emissions from different chemical processes, almost all emissions are reported using a single, general, category.

Emissions of the remaining pollutants are less significant compared with national totals but are reported in more detail.

Methane emissions are reported elsewhere in 2B for emissions from specific chemical processes, but also reported in 2B10 in the case of emissions from other, general petrochemical processes. Methane emissions from ammonia production sites have historically been included in the latter, and reported under 2B10, rather than being reported separately in 2B1.

Emissions of other pollutants are reported under the following source categories:

- Chemical industry - CO, SO_2, NMVOC;
- Chemical industry (nitric acid use) - NO_x;
- Chemical industry (pigment manufacture) - SO_2;
- Chemical industry (reforming) – CO;
- Chemical industry (sulphuric acid use) - SO_2;
- Coal, tar and bitumen processes – NMVOC; and
- Sulphuric acid production - SO_2.

The first source listed is the general category used where emissions occur from processes which do not fit elsewhere. The remaining categories are specific and often relate to small numbers of sites. The categories 'chemical industry (nitric acid use) and 'chemical industry (sulphuric acid use) refer to processes using these acids and emitting NO_X and SO_2 respectively. Manufacture of nitric acid (see **Section 4.7**) and sulphuric acid are treated separately from use. Sulphuric acid was being produced at one site at the end of 2014. Pigment manufacture relates to a single plant where sulphur was burnt as part of the manufacturing process – this site closed in 2008. The sulphur oxides produced were largely consumed in the process, although some emissions did occur.

Reforming processes convert natural gas or other light hydrocarbons into hydrogen and carbon monoxide for use in further chemical processes, and can result in emissions of CO. The remaining source category is reserved for minor sources of NMVOC from processes involving coal-based and bitumen-based chemicals.

4.15.2 Methodological Issues

Site-specific emissions data for chemical processes located in England and Wales are available in the Pollution Inventory (Environment Agency, 2016) and Welsh Emission Inventory (NRW, 2016) respectively. Reporting generally started in 1994 or 1995, and few data exist for the years prior to 1994. Site specific emissions data for processes in Scotland have been obtained from the Scottish Pollutant Release Inventory (SEPA, 2016). The Scottish Environment Protection Agency has also, on previous occasions, supplied some data on emissions of NMVOC from individual Scottish chemical processes and additional NMVOC data for processes located in both Scotland and Northern Ireland have been obtained from process operators. Additional data on Northern Ireland's only major chemical works is provided by NIEA (2016).

The National Sulphuric Acid Association (NSAA, 2003) has provided historical emissions data for sulphuric acid production processes. Emissions from ship purging are based on a single estimate given by Rudd *et al* (1996), which is applied to all years.

All of the data available are in the form of emission estimates, usually generated by the process operators and based on measurements or calculated based on process chemistry. Emission factors and activity data are not available, but emission factors are estimated using the best available 'surrogate' activity data that are available across the time series; this approach then enables estimates of emissions to be made for the years prior to operator-reported emission estimates (typically pre-1994). For most commodities, the extrapolation is linked to changes in the level of output from the chemicals manufacturing sector as measured by the 'index of output' figures published by the Office for National Statistics (2016). In the case of SO_2 from sulphuric acid production, emissions data are available from operators across the whole time-series.

4.15.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

Estimates for 1994 onwards are mostly based on data reported by process operators through the regulatory agency data management and checking systems that govern UK industrial emissions data within the PI, WEI, SPRI and NIPI. The dataset is evidently incomplete in some years, due to the variations through time in the reporting thresholds for different pollutants. The Inventory Agency has used good practice techniques to address these reporting inconsistencies, and therefore the completeness of the data is good through the time series.

Unfortunately, UK production data are not readily available for chemicals and other products from the sites reported under 2B8. This inhibits the Inventory Agency's ability to conduct data validation tests on the reported emissions data against a reliable time-series of production estimates.

Emission estimates for NMVOC in the early part of the time series are more uncertain than the estimates for other pollutants due to inconsistencies in operator reporting to the Pollution Inventory until the late 1990s. For the first few years of the Pollution Inventory, operators reported NMVOCs using a range of different approaches (e.g. "as toluene", "as carbon", reporting several individual compounds and then also a total NMVOC figure – but not sufficiently transparent to unambiguously identify double-counts). As a result, the data have to be interpreted using expert judgement in order to derive as consistent a time series as possible.

Emission estimates for the period prior to 1994 are also more uncertain, with the exception of sulphuric acid production. This is due to the need for extrapolation of emissions data for 1994 or some other year backwards, using general indicators of chemical industry output.

The uncertainty of some emission estimates from 2002 onwards is higher for some of the sources included in this sector. This is due to changes in the reporting requirements for the Pollution Inventory and other regulator's inventories, with the *de minimis* limits for reporting of emissions of some pollutants being raised, and a greater need to extrapolate data to fill reporting gaps.

4.15.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Emissions data taken from the Pollution Inventory are subject to additional QA/QC by the Environment Agency before being used in the inventory.

4.15.5 Source Specific Recalculations

There have been no significant recalculations in this category.

4.15.6 Source Specific Planned Improvements

Minor revisions to emission estimates may be required periodically in order to deal with changes in the data available e.g. revisions to emissions reported to UK regulators. The Inventory Agency will continue to review the available operator-reported data and seek to derive a consistent time series of emissions.

4.16 SOURCE CATEGORY 2C1 – IRON AND STEEL PRODUCTION

4.16.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2C1: Sinter plant – coke Iron & steel flaring (BFG) Electric arc furnaces Ladle arc furnaces Sinter plant – limestone Sinter plant - dolomite Basic oxygen furnaces - dolomite Following for indirect gases only: Blast furnaces Basic oxygen furnaces Iron and Steel (other) Rolling Mills (Hot & Cold Rolling)	T1, T2 T1, T2 T1, T2 T2 T2 T2 T2 T2 T2 T2 T2	CS D, CS CR, CS CS CS CS CS CS CS CS CS
Gases Reported	CO_2, CH_4, N_2O, CO, NO_x, SO_2, VOC		
Key Categories	2C1: Iron and steel production - CO_2 (L1, T1)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	None		

UK iron and steel production may be divided into integrated steelworks, electric arc steelworks, downstream processes such as continuous casting and rolling of steel, and iron & steel foundries.

Integrated steelworks convert iron ores into steel using the three processes of sintering, pig iron production in blast furnaces and conversion of pig iron to steel in basic oxygen furnaces. For the purposes of the inventory, emissions from integrated steelworks are estimated for these three processes, as well as other minor processes such as slag processing.

Sintering involves the agglomeration of raw materials for the production of pig iron by mixing these materials with fine coke (coke breeze) and placing it on a travelling grate where it is ignited. The heat produced fuses the raw materials together into a porous material called sinter.

Blast furnaces are used to reduce the iron oxides in iron ore to iron. They are continuously charged with a mixture of sinter, fluxing agents such as limestone, and reducing agents such as coke. Hot air is blown into the lower part of the furnace and reacts with the coke, producing carbon monoxide, which reduces the iron ore to iron.

Gas leaving the top of the blast furnace has a high heat value because of the residual CO content, and is used as a fuel in the steelworks. Molten iron and liquid slag are withdrawn from the base of the furnace. Subsequent cooling of the slag with water can cause emissions of

SO_2. The most significant greenhouse gas emissions to occur directly from the blast furnace process are the combustion gases from the 'hot stoves' used to heat the blast air. These generally use blast furnace gas, together with coke oven gas and/or natural gas as fuels. Emissions are reported under CRF category 1A2a. Gases emitted from the top of the blast furnace are collected and emissions should only occur when this blast furnace gas (BFG) is subsequently used as fuel. These emissions from BFG combustion are reported in the UK inventory according to the process using them, rather than all being reported in 2C1. However, some blast furnace gas is lost and the carbon content of this gas is reported under CRF category 2C1.

Pig iron has a high carbon content derived from the coke used in the blast furnace. A substantial proportion of this must be removed to make steel and this is done in the basic oxygen furnace. Molten pig iron is charged to the furnace and oxygen is blown through the metal to oxidise carbon and other contaminants. As a result, carbon monoxide and carbon dioxide are emitted from the furnace and are collected for use as a fuel. As with blast furnace gases, some losses occur and these losses are reported with blast furnace gas losses under CRF category 2C1.

Limestone and dolomite are used in steelmaking, typically being added to sinter where they are calcined, releasing CO_2 which is emitted to atmosphere, while the other products subsequently act as slag formers in blast furnaces. In practice, some of the limestone or dolomite used may be added directly to blast furnaces without being sintered first, which would mean that the CO_2 released would be emitted from the blast furnace stage of steelmaking rather than the sintering stage. However, this distinction is not important for GHG reporting and the practice is ignored for the GHGI with all additions and, therefore, emissions being reported as from sintering. Dolomite is also an important addition as a fluxing agent in basic oxygen furnaces and CO_2 evolved from the dolomite is reported as a separate category under 2C1.

Electric arc furnaces produce steel from ferrous scrap, using electricity to provide the high temperatures necessary to melt the scrap. Emissions of carbon dioxide occur due to the breakdown of the graphite electrodes used in the furnace and NO_x is formed due to oxidation of nitrogen in air at the high temperatures within the furnace. Emissions of NMVOC and CO occur due to the presence of organic contaminants in the scrap, which are evaporated and partially oxidised. Emissions from electric arc furnaces are reported under CRF category 2C1.

The inventory contains estimates of NMVOC emissions from rolling mills. Lubricants are needed and contain organic material, some of which evaporates. These emissions are reported under 2C1. A more significant emission from rolling mills and other downstream processing of steel are those emissions from use of fuels to heat the metal. These emissions are reported under 1A2a.

The UK had 2 integrated steelworks (at Port Talbot & Scunthorpe) in operation at the end of 2015, following the closure of the Teesside works in September 2015. In 1990, five sites had been in operation, with the steelworks at Ravenscraig in Scotland closing in 1992, followed by the closure of Llanwern in Wales in 2001. Teesside was mothballed between January 2010 and April 2012, due to the loss in demand for its steel products.

Electric steel is manufactured in 2 large steelworks, in Rotherham and Tremorfa, and a few smaller works. Other large steelworks once operated in Sheffield, Sheerness, and Newport but have closed.

4.16.2 Methodological Issues

The methodology for the prediction of carbon dioxide emissions from fuel combustion, fuel transformation, and related processes at integrated steelworks is based on a detailed carbon balance (this methodology is described in more detail within the section on CRF sector 1A2a).

Carbon emissions from integrated steelworks are reported under 1A1c, 1B1b, 1A2a, 2A3 and 2C1, depending upon the emission source. Emissions from sintering (from use of both coke breeze and limestone & dolomite), flaring of blast furnace gas and basic oxygen furnace gas, use of dolomite in oxygen furnaces, and emissions from electric arc and ladle arc furnaces are all reported under 2C1.

Flared losses of blast furnace gas (including basic oxygen furnace gas) are given in DUKES and carbon factors are derived using the carbon balance described previously.

Data on the usage of limestone and dolomite for steel production are available from the Iron & Steel Statistics Bureau (2016). The carbon content of limestone and dolomite used at steelworks is available from operators, based on EU ETS data (Tata Steel, 2014). Separate values are available for the years 2007-2015. These data show close consistency across the EU ETS reported time series and therefore the 2007 value has been extrapolated back across the time series as the best estimate for the limestone and dolomite quality back to 1990.

Carbon emissions from electrodes in electric arc furnaces and ladle arc furnaces are calculated using emission factors provided by Corus (2005). Emissions from the addition of petroleum coke to electric arc furnaces at one steelworks are based on EU ETS data for the period 2005-2015, with estimates for the period 1990-2004 being extrapolated from the 2005 data on the basis of our estimates of steel production at that site. Emissions from the use of coke oven coke in foundries and other iron & steel industry processes are included in category 1A2a but any process emissions from foundries of direct GHGs are likely to be very small and are not estimated. **Table 4.15** summarises the methods used for direct gas emissions reported under 2C1.

Table 4.15 Summary of Emission Estimation Methods for Source Categories in CRF Category 2C1

Source Category	Method	Activity Data	Emission Factors
Sintering – coke breeze	AD x EF	BEIS energy statistics	Carbon: UK-specific factor from carbon balance CH_4: UK-specific based on reported emissions N_2O: Fynes & Sage (1994)
Sintering – carbonates	AD x EF	ISSB	Carbon: UK-specific from EU ETS
Iron & steel - flaring	AD x EF	BEIS energy statistics	Carbon: UK-specific factor from carbon balance CH_4, N_2O: IPCC (2006)
Electric arc furnaces	AD x EF	ISSB	Carbon: UK-specific factor CH_4, N_2O:EMEP/EEA
Ladle arc furnaces	AD x EF	ISSB	Carbon: UK-specific factors

Emissions of indirect gases are generally based on emissions data reported by process operators either directly to the Inventory Agency, or via the Environment Agency Pollution Inventory. In a few instances where emissions data are not available, literature factors are used.

4.16.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

Much of the activity data used to estimate emissions from this source category come from the Iron and Steel Statistics Bureau (ISSB) and BEIS publication DUKES. Time-series consistency of these activity data are very good due to the continuity in data provided in these two publications.

4.16.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5.**

The UK inventory carbon balance method uses the best available industry data across the time series, including EU ETS data from integrated steelworks from 2005 onwards. The comparison in recent years between the UK GHGI method and the EU ETS data for individual installations indicates that the GHGI method is somewhat conservative, as the GHGI data are generally slightly higher than installation data. The inventory agency will continue to keep the method and input data under review to ensure that the carbon balance model delivers estimates that are as accurate as possible for the UK.

4.16.5 Source Specific Recalculations

There have been a few small updates to the AD and EFs used in this category. The largest change is due to a revision to using the IPCC 2006 default N_2O factor for 2C1d. The CEF for sinter plant limestone has also been recalculated using site-specific ETS figures for 2007-2013.

For information on the magnitude of recalculations, see **Section 10**.

4.16.6 Source Specific planned Improvements

It is noted that this sector has been identified as a key category, and that not all of the estimates within this sector use a tier 2 or higher approach. The UK uses what is believed to be the best currently available data, and that tier 1 methods are only used for very limited parts of this sector. The UK will review this position should further information some to light. Emission factors and activity data will be kept under review. Where appropriate, fuel characterisation data from verified Emission Trading Scheme datasets will be considered in future GHGI cycles.

4.17 SOURCE CATEGORY 2C2 – FERROALLOYS PRODUCTION

The term ferroalloy covers a wide range of products, manufactured by various means, only some of which lead to industrial process emissions of greenhouse gases. Potential sources of CO_2 emissions include:

- Use of reductants such as coke oven coke;
- Consumption of carbon electrodes in furnaces used for melting raw materials;
- Decarbonisation of limestone or dolomite used as a fluxing agents;
- Decarbonisation of any carbonate ores used.

The UK has been a minor producer of ferroalloys. The current version of the BREF note (Best Available Techniques Reference document) for the non-ferrous metals industry, produced by the European IPPC Bureau[35] estimates UK production in 1993 as 55 ktonnes out of a European total production of 2,620 ktonnes while the updated draft of that document, currently in final draft form (October 2014), does not identify any production of ferroalloys at all in the UK in the period 2005-2012.

Other than the estimate for 1993 given in the BREF note, the inventory agency has not found any data on UK production of ferroalloys. The absence of the UK as a European producer in the recent update of the BREF note suggests that UK production is either zero or insignificant; through consultation with trade associations and industry statistics experts (ISSB) the inventory agency has only been able to identify a few small-scale manufacturers of specialist ferroalloys such as ferro-molybdenum and ferro-vanadium. The production data for 1993 lists 45,000 tonnes of ferromanganese production in a blast furnace (where emissions would arise from use of reductants), and 10,000 tonnes of other ferroalloys in electric furnaces. The ferroalloy producers identified as in operation in recent years either carry out exothermic processes only (for ferro-molybdenum alloys) or use electric induction furnaces for melting. None of the processes report any CO_2 emissions in the Pollution Inventory, or are included in the EU ETS; the inventory agency has not identified any process currently in operation that would cause any industrial process emissions. The estimated production of 45,000 tonnes of ferromanganese in 1993 would use coke oven coke or coal as a reductant, and therefore the emissions are already included in the inventory (*Included Elsewhere*), as all UK consumption of these fuels is assumed to lead to emissions of CO_2. Any emissions associated with ferroalloy production would therefore already be included in 1A2a or 1A2b for coal, or 1A2g for coke oven coke. Given the lack of a time-series of production data, or information on the type or quantities of any reductant used in the ferromanganese production, the inventory agency has not made any re-allocation of emissions from 1A to 2C2.

There is no evidence of any use of electric arc furnaces, or the use of limestone or dolomite fluxes or carbonate ores. Therefore, UK emissions from ferroalloys are i) **Included Elsewhere** in the case of any emissions from use of reductants; ii) **Not Occurring** in the case of emissions from other sources.

[35] downloadable from http://eippcb.jrc.ec.europa.eu/reference/

4.18 SOURCE CATEGORY 2C3 – ALUMINIUM PRODUCTION

4.18.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2C3: Non-Ferrous Metals (Aluminium Production)	T2, T1	CS, PS
Gases Reported	CO_2, PFCs, CO, NO_x, SO_2, VOC		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

Aluminium was produced by the electrolytic reduction of alumina at two sites in the UK at the end of 2011, although the larger of these two sites subsequently closed in early 2012, leaving just one small smelter operating in the UK. A third site had closed during 2009, and a fourth process closed in mid-2000. The operational site and the recently-closed processes all use or used the pre-baked anode process, whereas the plant that closed in 2000 used the Soderberg Cell process. This distinction is important because of large differences in emission rates for some pollutants.

Both process types make use of carbon anodes and these anodes are consumed as the process proceeds, resulting in emissions of CO_2, CO, NMVOC and SO_2. The high temperatures necessary in the process mean that NO_x is also emitted. Finally, the PFC species tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6) are formed if the alumina content of the electrolyte falls too low. Computerised control of alumina addition to the cells is a feature of modern plant and has helped to reduce PFC emissions from aluminium production.

Emissions of methane are not estimated as there is no methodology available and emissions are considered to be negligible.

4.18.2 Methodological Issues

Emissions of carbon are estimated using statistics on the production of aluminium by each type of process and suitable emission factors. The carbon emission factors reflect current practice, and higher emission factors were used for earlier years, due to the production of some aluminium using the Soderberg process.

During the 1990s, there were two aluminium smelting operators in the UK, operating at four sites. One of these sites closed in 2000, another in 2009, and a third in 2012 leaving just one small site now open. All emissions of PFCs (CF_4 and C_2F_6) occur during the aluminium smelting process during anode effects. The estimates were based on estimates of emissions provided by the plant operators. These estimates were derived from records of the number and duration of anode effects.

Both operators use (or used) a Tier 2 methodology of a smelter-specific relationship between emissions and operating parameters based on default technology-based slope and over-voltage coefficients. This method uses (or used) default factors for the CWPB (Centre Worked Prebaked) plant for three of the plants, and, default factors for VSS (Vertical Stud Soderberg) for the plant which closed in 2000. The remaining operational plant uses CWPB. One of the operators used the North West American Calculation assuming 3lbs PFC for every minute the cell was "on anode effect", for the early part of the time series. The time series does not show any discontinuity as a result of the change in method.

Parameters for the calculation of emissions from the plant in 2015 are set out below.

Table 4.16 Parameters for calculation of PFC emissions from Aluminium production in 2015

	Units	
CF_4 Produced	kg	1271
C_2F_6 Produced	kg	154

The type of smelter design has a large effect on the rate of PFC emissions. The UK industry has previously made major investment to improve their technology and all UK plants now use point feeder prebake. Large reductions in emissions of PFCs have occurred over the time series through the switch to point feeder technology. Point feeder technology is regarded as the best technology for feeding aluminium oxide into the electrolytic cells. This technology allows more regulated feeding at controlled intervals, ensuring an operating process with fewer anode effects. The move to point feeder technology not only reduces PFC emissions but improves the efficiency of the production process.

For other pollutants, emissions data are available from regulators (i.e. the Environment Agency's Pollution Inventory for the two largest processes in England & Wales, and the Scottish Pollutant Release Inventory, produced by the Scottish Environment Protection Agency, for the Scottish sites) and also, more recently, direct from plant operators.

Activity data are taken from BGS data sets for all years except 2005, 2007 and 2008 where production data available directly from the operators of each site did not agree with the BGS figure, the sum of the site-specific data being slightly higher. The BGS data was therefore replaced by the site-specific data for these years.

Methodologies used for direct gases from 2C3 are summarised in **Table 4.17**.

Table 4.17 Summary of Emission Estimation Methods for Source Categories in CRF Category 2C3

Source Category	Method	Activity Data	Emission Factors
Primary aluminium	AD x EF	BGS, operators	Carbon: UK-specific factors (defaults for Soderberg and pre-bake processes) PFC: Operator reported data, based on IPCC T2 method

Emissions of indirect gases are based on emissions data reported by process operators either directly to the Inventory Agency, or via the Environment Agency Pollution Inventory or the Scottish Pollutant Release Inventory.

The time series of emission factors and activity data used are reported in **Table 4.18** below. The drop in the CO & NO_x emission factors from 2012 onwards is due to the closure of the

Lynemouth plant in early 2012, leaving just the much smaller Lochaber plant in operation. Emissions data for CO & NO_x supplied by the operator indicated higher emission factors for the Lynemouth plant than at Lochaber, so the closure of the former has a marked impact on the sectoral emission factors, with a step change in 2012 due to the operation of Lynemouth for only part of the year, and another step change from 2013 onwards following the closure of that site.

Table 4.18 Time series of activity data and emission factors for aluminium production

Year	Activity data	Emission factors - kt/Mt					
	Mt Al Produced	Carbon	CF_4	C_2F_6	CO	NO_X	SO_2
1990	0.290	423.8	0.60	0.075	72.43	1.02	13.53
1995	0.238	423.2	0.16	0.019	72.43	1.02	13.53
2000	0.306	420.0	0.11	0.014	79.12	0.76	14.60
2005	0.370	420.0	0.04	0.004	77.17	0.77	15.76
2008	0.327	420.0	0.05	0.006	95.93	0.91	15.08
2009	0.254	420.0	0.03	0.004	94.87	0.63	11.71
2010	0.186	420.0	0.08	0.010	96.13	1.05	12.84
2011	0.214	420.0	0.10	0.013	78.64	1.06	15.80
2012	0.060	420.0	0.03	0.004	25.07	0.59	15.98
2013	0.044	420.0	0.02	0.002	1.13	0.05	13.93
2014	0.042	420.0	0.11	0.014	1.19	0.05	13.77
2015	0.048	420.0	0.03	0.003	1.05	0.05	13.78

4.18.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

The source of activity data is almost always from data compiled by the British Geological Survey (production of primary aluminium). This is a long running publication and the compilers of the activity data strive to use consistent methods to produce the activity data. This helps to ensure good time series consistency of the emission estimates. The alternative data used for 2005 and 2007 is only slightly higher (<0.4%) than the BGS number and supports the view that the BGS data are reliable, although the discrepancy in the 2008 data is larger (3.4%).

A large increase in emissions of PFCs between 2010 and 2011 was observed for one of the operating plants, this has been discussed with the plant operator. The increase in emissions can be explained by the pot restart programme, which is further elaborated below:

1. PFC emissions are influenced by the number of pots re-started in a given period. Stopping and starting electrolytic cells is a normal process activity, however the

rate of increase in operating pots did have an effect on the emissions (62 during 2011). To restart pots requires power outages and liquid (bath and aluminium) to be transferred from 'donor' pots. The electrolysis process benefits from stability and this is impossible during a restart programme with frequent power interruptions and liquid level changes.

2. Significant effort has been put into the metal flow process from the potrooms to the casting plant to smooth out the liquid level changes and improve stability; however this was an ongoing challenge during 2011.
3. The drive to improve energy efficiency through pot voltage reduction and increased amperage minimises the functional operating window of the pot and puts more emphasis on the definitive control of liquid levels. When increasing amperage the process becomes much more sensitive to change and the acceptable operating window much smaller. Low anode effect rates can be achieved, however much more attention to detail is required and the pot liquid levels (metal and bath) need to be well controlled. Whilst the operator's efforts to improve energy efficiency for every tonne of aluminium produced have been successful, an increase in instability on the potlines could be attributable to these efforts. A point to note is that the energy efficiency improvements have reduced carbon dioxide emissions which will offset some of the increased PFC emission.
4. Unavoidable rectiformer maintenance work throughout 2011 resulted in power interruptions contributing to the potline instability.

There was a large decline in emissions in 2012 as aluminium smelting activities came to an end in March 2012 at one of the plants. In 2014 there was a significant increase in the implied emission factor (and emissions, the activity data are similar to 2013) because of process issues during 2014, in particular an 'anode crisis'. Aluminium manufacture has to be kept under specific conditions to maintain low PFC emissions.

Aluminium alloy production

No emissions of SF_6 are reported by any of the aluminium foundries in the Pollution Inventory or SPRI. Emissions from the use of SF_6 in the UK aluminium sector are therefore reported as Not Occurring.

4.18.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Emissions data taken from the Pollution Inventory are subject to additional QA/QC from the Inventory Agency.

4.18.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10**.

4.18.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.19 SOURCE CATEGORY 2C4 – MAGNESIUM PRODUCTION

4.19.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2C4: SF_6 Cover Gas HFC Cover Gas	T2 T2	PS PS
Gases Reported	HFCs, SF_6		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

In the UK, SF_6 and an HFC act as cover gases to prevent molten magnesium from burning during the production of magnesium.

4.19.2 Methodological Issues

SF_6 is used in the magnesium alloy and casting industry as a cover gas, to prevent molten magnesium oxidising when exposed to air. It is estimated that 95% of SF_6 (Gluckman, 2013) used in this way is released to the atmosphere unless capture/recycle technologies are employed. SF_6 is non-flammable and non-toxic, and is therefore a safe gas to use. In the UK, SF_6 has been used as an alternative cover gas to SO_2 in magnesium alloy production and sand and die-casting since the early 1990s. Since 2006, EU magnesium producers have looked for alternatives to SF_6 in response to bans in the EU F-Gas regulation. Some die casters have gone back to using SO_2. Others have used HFC-134a and a fluoro-ketone (FK 5-1-12) with the trade name Novec 612.

The UK magnesium casting industry is very small. There are three significant manufacturers (one alloy producer, one die-caster and one sand-caster) plus two very small operations (both sand-casters). Alloy production involves the use of primary magnesium ingots, recycled scrap material and second-generation magnesium materials (i.e. material already made into alloys) for the production of different alloys. Both die and sand casters use these magnesium alloys to produce specific components for a wide range of industries. For the casting industry, SF_6 is used for casting specific magnesium alloys where other cover gases, such as HFC-134a, are currently considered not suitable.

A review of the data sources and methodology used to estimate emissions from F-gases used as cover gases in magnesium foundries was carried out in 2013 (Gluckman, 2013). In all cases UK magnesium companies were able to report consumption, but had no actual measured data on emissions. The assumptions about the fraction of SF_6 and HFCs that are emitted from the consumption of these F-gases were reviewed through discussion with industry experts and in some cases amended. It is estimated that 95% of SF_6 consumption is emitted but that only 20% of HFC-134a consumption is emitted (as a much greater proportion reacts with the magnesium). These figures are based on expert estimates by Gluckman (2013). The estimates of emissions in the 2015 inventory are similar to those reported in the previous inventory until approximately 2005.

For magnesium alloy production, SF_6 emissions from 1998 onwards are estimated based on the data reported to the Environment Agency Pollution Inventory (EA, 2015), whilst emissions prior to 1998 are estimated based on consultations with the plant operators.

From 2004, one of the main industry users of SF_6 as a cover gas has implemented a cover gas system using HFC-134a for some of its production capacity. There has not been a complete switch to HFC-134a, although the operator is considering this on an ongoing basis depending on suitability for the different alloys produced. In addition to having a significantly lower GWP than SF_6 (and thus reducing emissions on a CO_2 equivalent basis), use of HFC-134a is further advantageous in that a significant fraction of it is destroyed by the high process temperatures (80%) thus reducing the fraction of gas emitted as a fugitive emission.

From 2008, emissions of HFCs have been reported in the Pollution Inventory, and therefore the reported data are used directly.

As part of a recent study to update the F-gas inventory (Gluckman, 2013), castings operators were re-contacted to provide activity data for recent years (the previous survey was conducted in 2004). The two largest users of SF_6 and HFC-134a (that represent 99% of UK emissions from magnesium) are now contacted annually for their activity data (consumption of SF_6 and HFC-134a).

4.19.3 Uncertainties and Time Series Consistency

The main area of uncertainty is regarding emissions of SF_6 from casting based on discussions with the sector Trade Association for the period prior to 1998. Data from the main magnesium alloy producer is also uncertain for this period.

For the period 1998-2014, the uncertainty of the time-series emissions is estimated to be significantly lower. Data received from the main magnesium alloy producer and the other 4 casting operations are associated with low uncertainty and show good consistency across the time series.

SF_6 emissions from UK magnesium producers peaked in 2000 at approximately 1,000 kt CO_2 equivalent. The use has fallen steadily, particularly from 2006 onwards, being approximately 80 kt CO_2 equivalent in 2015. HFC-134a emissions were zero until 2008 and are approximately 2 kt CO_2 equivalent in 2015.

4.19.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Emissions data taken from the Pollution Inventory are subject to additional QA/QC from the Inventory Agency.

4.19.5 Source Specific Recalculations

For information on the magnitude of recalculations to this Source Category, see **Section 10**.

4.19.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.20 SOURCE CATEGORY 2C5 – LEAD PRODUCTION

Primary lead production is limited in the UK to a single site, which produced zinc and lead from imported ore concentrates. Emissions are reported under 2C6 and so this process is described in the following section. Emissions of CO from a number of small secondary lead producers are estimated based on data reported by the process operators.

Emissions of CO_2 can, in theory, occur from the use of reductants such as coal, coke oven coke, or natural gas during secondary lead processes, however none of the UK's secondary lead processes are known to involve the use of reductants. If any use of reductant does occur, however, it would be included in UK fuel statistics as an energy use, and thus emissions of CO_2 would already be included in the UK inventory, reported under 1A2.

4.21 SOURCE CATEGORY 2C6 – ZINC PRODUCTION

4.21.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2C6 Non-ferrous metal processes Non-Ferrous Metals (primary lead/zinc)	CS CS	CS CS
Gases Reported	CO_2, CO, SO_2		
Key Categories	2C6: Zinc production - CO_2 (T1)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements.		

Zinc was produced in the UK until early 2003, using the Imperial Smelting Process (ISP) at a smelter operated by Britannia Zinc at Avonmouth. The site processed imported ore concentrates, and had a capacity to produce approximately 150,000 tonnes of zinc, as well as 65,000 tonnes of lead and small quantities of other metals such as cadmium. The ISP involves the use of a blast furnace to reduce zinc and lead oxides to the metal using coke as a reductant. Limestone could also be added to act as a slag-forming agent.

The UK also had two other non-ferrous metal production facilities that would have emitted CO_2 from processes. These were:

- the Capper Pass Tin Smelter at Melton, Humberside (closed in 1991)
- IMI Refiners' secondary copper smelter at Walsall (closed in 1997)

There is very little data specific to these installations available to the inventory agency as their closure pre-dates most of the routine annual emissions reporting regulations in the UK. Both processes used coke oven coke as a reductant that would lead to process emissions of CO_2, and emission estimates from these two sites are also reported under 2C6.

4.21.2 Methodological Issues

Britannia Zinc reported CO_2 emissions in the Pollution Inventory from 1998 until 2002, at which point the site ceased operation. Emissions of CO_2 would have occurred from the use of coke in the ISP, but also from decarbonisation of any limestone used, and from the other fuels used on site e.g. gas/oil burners used on the sinter plant and oil-fired furnaces used in the zinc refinery. We have not been able to discover any data on the quantities of coke and other fuels used, or the quantities of limestone that might have been used. The operator-reported CO_2 emissions in the Pollution Inventory are totals only, and no conclusions can be drawn regarding the split between coke, other fuels and limestone. The reported emissions are, however, much higher than would be implied by the Tier 1 factors given in the 2006 GLs for the ISP at Avonmouth. There is insufficient data to determine whether this is due to a high level of fuel combustion emissions on site, or that the process-related emissions at this site were higher than is typical for this type of process.

The Digest of UK Energy Statistics (DUKES) does give a full time-series of data on the consumption of coke oven coke by the non-ferrous metal industry. The consumption shown in this source is zero after 2003, confirming that after the closure of Britannia Zinc, no other non-ferrous metal processes in the UK used coke oven coke. We also believe that very few, other than Britannia Zinc, Capper Pass and IMI Refiners have used coke oven coke at any point in the period covered by the UK inventory.

Because all three sites have been closed for many years, there is no information on the consumption of coke oven coke at each site. Of the three, it is likely that IMI Refiners used relatively small amounts of coke, whereas the Capper Pass smelter was the largest of its kind in the world, and its closure in 1991 coincides with a big reduction in the non-ferrous metal industry's consumption of coke as shown in DUKES. There is insufficient data to split the coke consumption data between the three sites, and instead all of the coke use in DUKES is reported in 2C6. This will ensure completeness and reduce the uncertainty in the reported emissions, since only the total coke use figure is known to a high level of certainty. Carbon factors for the coke oven coke are derived from the carbon balance approach previously described for 1A2a.

As previously described, limestone may have been used at Britannia Zinc (and probably in the blast furnaces at Capper Pass as well) but we do not have any evidence on which to base emission estimates. Since all of these plants closed more than 10 years ago, there is no scope to access new information to improve this situation, and therefore we recommend that no emission estimates for these source categories be reported. Further, we note that the UK GHGI already includes emissions from all reported limestone and dolomite activity based on data from the British Geological Survey on UK supply and demand of these materials, and hence there is no gap in the UK GHGI, but possibly a small mis-allocation with higher estimates in another sector to counter the possible under-report here.

Emissions of CO from the lead/zinc smelter and the copper refinery are reported in 2C6 and 2C7 respectively and estimates are based on emissions data reported by the process operators in the Pollution Inventory (EA, 2015). No CO emissions data exist for Capper Pass and so no estimate has been made.

4.21.3 Uncertainties and Time Series Consistency

The use of DUKES data for coke consumption by non-ferrous metal processes ensures time series consistency and completeness, which is important since it is impossible to now determine how much coke oven coke was used in each of the 3 three non-ferrous metal processes that once existed in the UK. Any limestone used in the blast furnaces at Brittania Zinc and Capper Pass cannot be estimated, but emissions data for 2C1 cover all use of limestone and dolomite for blast furnaces and so overall completeness is assured.

4.21.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5.**

4.21.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10**.

4.21.6 Source Specific Planned Improvements

It is noted that this sector has been identified as a key category this year, and that a tier 1 method is used. The UK has recently reviewed this sector and included some additional sources using what is believed to be the best currently available data. Unfortunately as the only site for this sector has now been closed for a number of years it is highly unlikely that new data will mean a better estimate will be possible; incidentally the reason it is identified as a key category is due to the fact that this one large site closed since the base year.

4.22 SOURCE CATEGORY 2D1 – LUBRICANT USE

4.22.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2D1: Industrial engines – lubricants Agricultural engines – lubricants Marine engines – lubricants Road vehicle engines – lubricants	T1 T1 T1 T1	D, CS D, CS D, CS D, CS
Gases Reported	CO_2		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Emissions from overseas territories and crown dependencies are included, and are scaled from UK estimates.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	None.		

Lubricant consumption by the unintended combustion in vehicle engines is estimated using the method from the EMEP/EEA Emissions Inventory Guidebook (2013). These consumption estimates were used to calculate CO_2 emissions from lubricant combustion in road vehicle engines and are reported in IPCC sector 2D1, except for lubricants use from mopeds, which are deemed to be intentional fuel use and hence is reported in IPCC sector 1A3biv.

Emissions of CH_4 and N_2O also arise from lubricant combustion in engines. However, the exhaust emission factors for these gases will include the contribution of lubricants as well as the main fuel to the pollutant emissions when the vehicles were tested. Hence, the emissions of CH_4 and N_2O (and other air pollutants estimated on a vkm-travelled basis) from lubricants are included implicitly in the hot exhaust emissions (IPCC Sector 1A3b) calculated for each vehicle and fuel type. Treating emissions of these pollutants separately would lead to a double count.

Lubricant use in the remaining sectors is calculated from the difference between the UK demand figure in DUKES & the COPERT-based road transport lubricant figures.

4.22.2 Methodological Issues

Detailed activity data on lubricants are not available in the UK; DUKES does include data on sector-specific lubricant use (e.g. use by industry, agricultural sector, shipping etc.) in addition to the total lubricant demand time-series, but this falls short of what is required for the Tier 2 method. Therefore we have used the 2006 GLs Tier 1 method, with UK lubricant activity data from DUKES and the IPCC default ODU factor of 0.2, together with the UK-specific carbon emission factor for lubricants which is based on analysis of UK waste oil samples.

4.22.3 Uncertainties and Time Series Consistency

DUKES gives a full time series of lubricant consumption data so consistency of the emission estimates is good. The use of the Tier 1 methodology means that estimates are quite uncertain.

4.22.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

4.22.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10**.

4.22.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.23 SOURCE CATEGORY 2D2 – PARAFFIN WAX USE

4.23.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2D2:Petroleum waxes	T1	D
Gases Reported	CO_2		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Emissions from overseas territories and crown dependencies are included, and are scaled from UK estimates.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	None		

4.23.2 Methodological Issues

DUKES gives total consumption of petroleum waxes for the years 1990-2009 only. For 2010 onwards, petroleum wax consumption is only available as part of the much larger consumption of 'miscellaneous petroleum products'. In 2009, the consumption of petroleum waxes was equal to 5.9% of the total consumption of waxes plus other miscellaneous products, so this figure of 5.9% is then applied to the DUKES figures for miscellaneous product use in 2010-2015 to obtain an estimate of petroleum wax use in those years.

Emissions are estimated using the Tier 1 ODU factor of 0.2, and the IPCC default carbon content of 20 kg C/ GJ (net basis).

4.23.3 Uncertainties and Time Series Consistency

Emission estimates for this sector are highly uncertain because of the use of a Tier 1 methodology. In addition, the activity data for 2010-2015 are especially uncertain due to the loss of detail in DUKES meaning that the consumption of petroleum waxes has to be estimated by the Inventory Agency based on trends in consumption of a much wider group of petroleum products.

4.23.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

4.23.5 Source Specific Recalculations

There have been no significant recalculations in this category.

4.23.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.24 SOURCE CATEGORY 2D3 – OTHER NON-ENERGY PRODUCTS FROM FUELS AND SOLVENT USE

4.24.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2D3 Road transport – urea 2D3 Non-energy use of petreoleum coke 2D3 NMVOC sources listed in **Table 4.19**	T3 T2 CS	CR, D D CS
Gases Reported	CO_2, NMVOC		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Emissions from overseas territories and crown dependencies are included, and are scaled from UK estimates.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements since last submission.		

Emissions of CO_2 are estimated from consumption of urea by road vehicles with relevant types of catalytic converters for control of pollutant emissions and are reported under 2D3. Urea has the chemical formula $(NH_2)_2CO$ and is injected into the exhaust stream of certain types of diesel vehicles (currently Euro IV and V HGVs and buses) as a 32.5% (by weight) aqueous solution. The catalytic process of converting NO_x to nitrogen in the exhaust leads to the release of CO_2 from the urea in the tailpipe.

Petroleum coke is known to be used by various sectors either as a fuel (e.g. at power stations and in cement kilns), or in various processes (e.g. in brickmaking, titanium dioxide manufacture, aluminium smelting, or electric arc steelmaking). The consumption of petroleum coke for each sector is either available directly from DUKES or estimated, based on EU ETS and other data. For most years, there is more petroleum coke listed in the UK energy statistics than can be accounted for by these known users. In other years, the known users require more petroleum coke than is available in the energy statistics. But, since there is excess petroleum coke for most years (18 out of 26) between 1990 and 2015, it is assumed that there are additional, unknown uses of petroleum coke in those years. The excess petroleum coke in the energy statistics is reported as being for non-energy uses but this will include both fuel grade and anode grade coke, so it is possible that the coke could be used as a fuel, or in processes, or both. In the absence of any data, and because the coke appears in UK energy statistics as 'non-energy use', it has been assumed that it is used for an unknown non-energy use. Such uses could be emissive or the carbon could be stored, but we have taken the conservative approach and assumed that all of the carbon in this petroleum coke is emitted, and reported it in 2D3.

Emissions of NMVOC from numerous uses of solvents and other volatile petroleum products are reported under 2D3. These NMVOC sources include the manufacture and use of paints, printing inks, adhesives and other types of coatings (both in industry and in households), degreasing and dry cleaning, manufacture of tyres, vegetable oil, and agrochemicals, and the use of consumer products such as aerosols, fragrances and automotive products such as screenwash. Also included is the use of kerosene as a viscosity-reducer in 'cutback' asphalt grades.

4.24.2 Methodological Issues

The 2006 IPCC Guidelines specify two approaches for estimating CO_2 emissions from urea consumption. This is either from statistics on total urea sales or by estimating urea consumption as a proportion of the amount of fuel consumed. There are no statistics on urea sales in the UK, so the approach based on fuel consumption is used. Not all diesel vehicles use urea so it is necessary to know the amount of fuel consumed specifically from those vehicles with the relevant exhaust after treatment technology that require urea injection.

Urea is used by HGVs and buses in the UK manufactured to Euro IV and V standards. These came into effect from 2006. The EMEP/EEA Emissions Inventory Guidebook (2013) provides the means for estimating urea consumption as a proportion of fuel consumed by these specific types of vehicles. Fuel consumption by Euro IV and V HGVs and buses was estimated using a bottom-up method described in **MS 8**. The estimations involve the use of vehicle km activity and fleet composition data from DfT and g/km fuel consumption factors, with total fuel consumption calculated for road transport by this method normalised to national fuel sales in DUKES.

Following figures given in the EMEP/EEA Guidebook for estimating other pollutant emissions, an assumption was made that 75% of Euro V HGVs and buses are equipped with SCR – the catalyst system that uses urea. The same assumption was also applied to Euro IV vehicles. Fuel consumption was calculated for these types of vehicles using SCR technology. Following the EMEP/EEA Guidebook, urea consumption is assumed to be 4% of fuel consumption for a Euro IV HGV and bus and 6% for a Euro V HGV and bus. Independent assessment in the UK from suppliers of urea and vehicle manufacturers supports these assumptions. These assumptions allowed the time-series for consumption of urea by UK road transport to be estimated. No urea was consumed before 2006.

A constant emission factor of 0.238 $kgCO_2$/kg urea solution, as given in the EMEP/EEA Guidebook was used. This is consistent with the factor and emission equation given in the 2006 IPCC Guidelines, assuming urea is used as a 32.5% aqueous solution which is the norm in the UK.

The emissive non-energy use of petroleum coke is assumed to result in 100% of the carbon content of this fuel being emitted. The 2006 IPCC default factor for petroleum coke has been used in conjuction with calorific values for petroleum coke used in sectors other than electricity generation, taken from UK energy statistics. The relatively high calorific value given for this type of petroleum coke means that the IPCC default factor implies that this petroleum coke is over 90% carbon, which is higher than the carbon content of coke oven coke or anthracite.

Solvents are used by a wide range of industrial sectors as well as being used by the general public. Many applications for industrial solvent use require that the solvent is evaporated at some stage, for example solvent in the numerous types of paints, inks, adhesives and other industrial coatings must evaporate in order for the coating to cure. The solvent contained in many consumer products such as fragrances, polishes and aerosols is also expected to be released to atmosphere when the product is used.

Emissions of NMVOC from use of these solvents can therefore be assumed to be equal to solvent consumed in these products, less any solvent that is recovered or destroyed. In the case of consumer products and smaller industrial processes, such as vehicle refinishing processes, the use of arrestment devices such as thermal oxidisers would be prohibitively expensive and abatement strategies therefore concentrate on minimising the solvent consumption. Solvent recovery and destruction can be ignored for these processes.

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In comparison, larger industrial solvent users such as flexible packaging print works, car manufacturing plants and specialist coating processes such as the manufacture of hot stamping foils are generally carried out using thermal oxidisers or other devices to capture and destroy solvent emissions. In these cases, NMVOC emissions will still occur, partly due to incomplete destruction of solvent by the arrestment device, but also because some 'fugitive' emissions will avoid being captured and treated by that device. The level of fugitive emissions will vary from process to process, and will depend upon the extent to which the process is enclosed. For these sectors, it is still possible to estimate emissions based on solvent consumed, but allowance must be made for solvent destroyed or recovered. This can only be done accurately if the extent of abatement can be reliably estimated for each site. In most cases this means that detailed information at individual plant level must be gathered.

Other uses of solvents do not rely upon the solvent being evaporated at some stage and, in contrast, losses of solvent in this way are prevented as far as possible. Processes such as seed oil extraction, and dry cleaning include recovery and re-use of solvent, although new solvent must be introduced to balance any losses. Emission estimates for these sectors can be made using solvent consumption data (i.e. assuming that purchases of new solvent is equal to emissions of solvent) or by using solvent mass balance data at a site by site level.

Manufacturers of paints, inks and other coatings also wish to minimise losses of solvent but in these cases, the solvent is not recovered and re-used, but is instead contained in products which are then used elsewhere. Emission estimates for these sectors can be made using emission factors (i.e. assuming some percentage loss of solvent).

Finally there are some applications where solvent is used in products but is not entirely released to atmosphere. Solvent used in wood treatments and certain grades of asphalt can be retained in treated timber and in road dressings respectively. In these cases, emission estimates are based on solvent consumption data but include an allowance for solvent not released. **Table 4.19** shows how estimates have been derived for each inventory source category.

Table 4.19 Methods for Estimating Emissions from Solvent and Other Product Use.

Source Category	General method
Aerosols (car care, cosmetics & toiletries, household products) Agrochemicals use Decorative paint - retail decorative Decorative paint - trade decorative Dry cleaning Industrial adhesives (general) Industrial coatings - agricultural and construction Industrial coatings - aircraft Industrial coatings - commercial vehicles Industrial coatings - high performance Industrial coatings – marine Industrial coatings - metal & plastic Industrial coatings - vehicle refinishing Industrial coatings – wood Non Aerosol Products (household, automotive, cosmetics & toiletries, domestic adhesives, paint thinner) Other rubber products Other solvent use Printing – newspapers Printing - other flexography Printing - other inks Printing - other offset Printing - overprint varnishes Printing - print chemicals Printing - screen printing Surface cleaning - hydrocarbons Surface cleaning - oxygenated solvents Leather degreasing	Solvent consumption data for the sector, assumption that little or no solvent is recovered or destroyed.
Industrial coatings – automotive Printing - heatset web offset Printing - metal decorating Surface cleaning - 111-trichloroethane Surface cleaning – dichloromethane Surface cleaning - tetrachloroethylene Surface cleaning – trichloroethylene	Solvent consumption data for the sector, with adjustments to take account of likely abatement of solvent.
Industrial coatings - coil coating Industrial coatings – drum Industrial coatings - metal packaging Printing - flexible packaging Film coating Industrial adhesives (pressure sensitive tapes) Leather coating Paper coating Textile coating Tyre manufacture	Solvent consumption data at individual site level with adjustments to take account of abatement at each site.
Printing - publication gravure Seed oil extraction	Mass balance data at individual site level
Coating manufacture – adhesives Coating manufacture - inks Coating manufacture - other coatings Wood Impregnation, Creosote use Road dressings	Emission factor (assumed percentage loss of solvent)

All overseas territories and crown dependencies emissions arising from solvents are reported under 2D3. Emission estimates from the UK GHGI were scaled by a territory-specific indicator. Relevant indicators include territory population, GDP, number of cars and number of households. The indicators for each activity were chosen using expert judgement and were dependent on the information available for each territory.

4.24.3 Uncertainties and Time Series Consistency

The main uncertainty on estimates of emissions from urea consumption comes from the uncertainty in the amount of urea consumed by the categories of vehicles equipped with SCR exhaust after treatment technologies in the UK fleet. This is linked with uncertainties in the estimates of fuel consumed by these vehicles and uncertainty in the amount of urea consumed per kg of fuel consumed. Uncertainties in the CO_2 emission factor from urea consumption are very low because the carbon content of urea is known with high accuracy.

The end uses of the petroleum coke reported in 2D3 are unknown, and could actually include some use of coke as a fuel and/or some non-energy uses that result in storage of carbon, as well as emissive non-energy uses. The approach taken is conservative since we assume all of the carbon is emitted, but emissions may be wrongly allocated if some of the petroleum coke is actually used as a fuel. The uncertainty in emissions for this source is very high. Because of the use of this source as a balance against energy statistics, the time series is very erratic. There are eight years where zero emissions are reported due to the UK Inventory Agency estimates for known uses for petroleum coke exceeding the UK demand figure for petroleum coke in the UK energy statistics.

Emission estimates for NMVOC from solvent use are moderately uncertain: emission estimates generally rely upon a number of assumptions and extrapolations which introduce uncertainty, and the overall uncertainty in the NMVOC emissions from 2D3 is judged to be perhaps as much as +/- 30%.

4.24.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5.**

4.24.5 Source Specific Recalculations

Because the estimate of Urea emissions is dependent on the fraction of specific HDVs' fuel use the revision to the fuel consumption factors and fuel normalisation methodologies in 1A3b means that there is a significant revision to Urea emissions.

For information on the magnitude of recalculations, see **Section 10**.

4.24.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.25 SOURCE CATEGORY 2E1 – INTEGRATED CIRCUIT OR SEMICONDUCTOR

Emissions of SF_6 from semiconductor manufacturing are combined with emissions from training shoes and electrical insulation in source category 2G2e for reasons of commercial confidentiality. This source category is described in **Section 4.39**.

4.26 SOURCE CATEGORY 2E2 – TFT FLAT PANEL DISPLAY

4.26.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	None		
Gases Reported	None (gases possible are PFCs, NF_3 or SF_6)		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	Potentially a small amount of emissions from small scale flat panel manufacturing in the 90s and early 2000s.		
Major improvements since last submission	Market investigation in 2015 to confirm zero activity level		

4.26.2 Methodological Issues

ICF (2014) determined that the UK does not have volume Flat Panel manufacturing. ICF reached this conclusion after contacting the National Microelectronics Institute (NMI) who represent flat panel display manufacturers in the UK.

Further market analysis by Ricardo (2016) confirmed that there are no UK emissions from this sector. This included discussions with representatives of the flat panel supply sector and PFC supply sector – all those contacted confirmed that all flat panel displays used in the UK are imported. It was noted that in the 2006 IPCC guidelines that there was activity data given[36] for the UK in 2003-5. When using this activity data and the default methodology the resulting emission was well below the threshold to be considered insignificant, so is reported by the UK as 'NE' for years before 2014.

4.26.3 Source Specific Planned Improvements

Any emergence of volume manufacturing capacity of TFT flat panel display is kept under review.

[36] Table 6.7 of Volume 3 of the IPCC 2006 Guidelines

4.27 SOURCE CATEGORY 2E3 – PHOTOVOLTAICS

4.27.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	None		
Gases Reported	None (gases possible are PFCs)		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	Potentially a small amount of emissions from small scale photovoltaics manufacturing in the 90s and early 2000s.		
Major improvements since last submission	Market investigation in 2015 to confirm zero activity level		

4.27.2 Methodological Issues

ICF (2014) determined that the UK does not have volume photovoltaics (PV) manufacturing. ICF reached this conclusion after contacting the British Photovoltaic Association (BPA) to gather data from PV manufacturing in the UK. The BPA also confirmed that statistics on F-gas use in the PV manufacturing in the UK are not available.

Further market analysis by Ricardo (2016) confirmed that there are no UK emissions from this sector. This included discussions with representatives of the PV supply sector and PFC supply sector – all those contacted confirmed that all PV cells used in the UK are currently imported or manufactured in the UK using emerging technology that does not require F-gases in the process. It was noted that in the 2006 IPCC guidelines that there was activity data given[37] for the UK in 2003. When using this activity data and the default methodology the resulting emission was well below the threshold to be considered insignificant, so is reported by the UK as 'NE' for years before 2014.

4.27.3 Source Specific Planned Improvements

Any emergence of volume manufacturing capacity of photovoltaics is kept under review.

[37] Table 6.8 of Volume 3 of the IPCC 2006 Guidelines

4.28 SOURCE CATEGORY 2E4 – ELECTRONICS INDUSTRY – HEAT TRANSFER FLUID

4.28.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	None		
Gases Reported	None (gases possible PFCs)		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	Under active review.		
Major improvements since last submission	Market investigation in 2015 to confirm zero activity level		

PFCs are used as heat transfer fluids (HTFs) in commercial and consumer electronic applications. The various applications of PFC as HTFs use much smaller volumes of liquid PFCs than electronics manufacturing. Some examples of consumer applications include cooling kits for desktop computers and commercial applications include cooling supercomputers, telecommunication, and radar systems, as well as drive units on high-speed trains.

4.28.2 Methodological Issues

Market analysis by Ricardo (2016) confirmed that there are no UK emissions from this sector. Discussions were held with the only 2 companies that supply the relevant PFC to the EU market (C_6H_{14}), including one company that manufactures this PFC in the UK. These discussions indicated that there is a small use of PFCs for HTF applications in some EU countries and in non-EU export markets. However, there were no known end uses in the UK.

4.28.3 Source Specific Planned Improvements

Any emergence of volume manufacturing capacity of heat transfer applications using F-gases is kept under review.

4.29 SOURCE CATEGORY 2F1 – REFRIGERATION AND AIR CONDITIONING EQUIPMENT

4.29.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2F1: Commercial Refrigeration Domestic Refrigeration Industrial Refrigeration Mobile Air Conditioning Refrigerated Transport Stationary Air Conditioning	T3 T3 T3 T3 T3 T3	CS CS CS CS CS CS
Gases Reported	HFCs		
Key Categories	2F: Product Uses as Substitutes for ODS - HFCs (L2, T2) 2F1: Refrigeration and air conditioning - HFCs, PFCs, SF_6 and NF_3 (L1, T1)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	All emissions from OTs and CDs are included within the UK totals for this sector. Emissions are calculated by scaling emissions from the UK model using a suitable scaling factor (population, GDP etc.).		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	Review of RAC Emissions Model carried out in 2015 and improvements made. Further review in 2016.		

HFCs and HFC blends have been widely used as replacement refrigerants for ozone depleting substances across virtually all refrigeration end-uses. They generally share many of the properties of CFC and HCFC refrigerants, namely low toxicity, zero and/or low flammability and acceptable materials compatibility. Emissions of HFCs can occur at various stages of the refrigeration/air-conditioning product life-cycle:

- During the refrigeration equipment manufacturing process;
- Over the operational lifetime of the refrigeration or air-conditioning unit; and
- At disposal of the refrigeration or air-conditioning unit.

This emission category contains aggregated emission estimates from the end-uses summarized in the table below. As shown, the UK inventory uses a code (RAC-1 to RAC-13) to refer to these sector sub-divisions.

Table 4.20 Model End-Uses and Definitions

Revised Model End-Use		Description
RAC-1	Domestic Refrigeration	Refrigerated appliances including refrigerators, chest freezers, upright freezers, and fridge freezers.
RAC-2	Small Commercial Stand-Alone Refrigeration Units	Small, hermetic, stand-alone refrigeration units including ice cream cabinets and drinking water coolers. These systems are commonly used in retail food stores but are also found in pubs, restaurants, and other hospitality and catering outlets such as hotels, hospitals, and schools.

Revised Model End-Use		Description
RAC-3	Condensing Units for commercial refrigeration applications	Refrigeration systems composed of one (or two) compressor(s) and one condenser, assembled into a unit, which is located external to the sales area. The condensing unit is connected by refrigerant pipework to an evaporator located in the retail sales area (e.g. in a chilled retail display). These units are typically installed in small shops, beer cellars and small walk-in cold rooms and have refrigeration capacities ranging from 1 kW to 20 kW.
RAC-4	Centralised Refrigeration Systems for commercial refrigeration applications	Refrigeration systems that are comprised of racks of compressors installed in a machinery room. These systems are commonly used in supermarket applications, with many refrigerated displays connected to a central system. Each system typically has a cooling capacity in the 30 kW to 150 kW range.
RAC-5	Industrial Systems	Refrigeration systems including industrial process refrigeration and cold storage. Industrial refrigeration systems vary widely in cooling capacity. Many industrial systems are above 1,000 kW. However, the majority that use HFC refrigerants are relatively small, in the 50 kW to 200 kW range.
RAC-6	Small Stationary Air Conditioning	Includes small self-contained air-conditioning (including window units) and non-ducted single split air-conditioning. Units are used primarily in commercial applications, but there is some use in the residential sector. System cooling capacities typically range from 3 to 12 kW. The majority of modern systems are reversible – they can operate either as an air-conditioning unit or an air-source heat pump.
RAC-7	Medium Stationary Air Conditioning	Includes non-ducted multi-split, variable refrigerant flow (VRF) non-ducted split, ducted split, and packaged air-conditioning. Units are used in the commercial UK sector. System cooling capacities typically range from 12 to 200 kW.
RAC-8	Large Stationary Air Conditioning (Chillers)	Large water chillers used for commercial comfort air conditioning. Cooling capacity is typically in the range 100 kW to 500 kW.
RAC-9	Heat Pumps	Residential and small commercial heating only heat pumps, including air-source heat pumps (ASHP) (air-to-air and air-to-water systems) and ground-source heat pumps (GSHP).
RAC-10	Land Transport Refrigeration	Refrigerated road vehicles (i.e., light commercial vehicles, trucks, trailers) and intermodal containers.
RAC-11	Marine Transport Refrigeration	Refrigerated general cargo ships, container ships and fishing vessels (1,000 GT and above).
RAC-12	Light Duty Mobile Air Conditioning	Air-conditioning systems for passenger cars and light commercial vehicles (up to 3.5 tonnes). Both of these vehicle types are covered under Directive 2006/40/EC (the MAC Directive).
RAC-13	Other Mobile Air Conditioning	Air-conditioning systems for trucks (over 3.5 tonnes), buses/coaches, semi-trailers, trailers, and railcars.

4.29.2 Methodological Issues

The previous version of the refrigeration/air conditioning inventory model developed by AEA (2010) was updated by ICF International in the summer/autumn of 2011 based on revised industry input and a more transparent, robust Tier 2 modelling approach. Specifically, the model was reorganized from 9 to 13 end-use sub-sectors (as listed in **Table 4.21**), for which detailed assumptions were developed to utilise a fully bottom-up approach. Both the new model and the previous version make use of a bottom up approach with assumptions made about emission factors and stock levels. The new model is more comprehensive and allows for updating of the assumptions made. Both bottom up models are verified by comparing the predicted HFC consumption for the whole RAC sector with top-down data for the sales of HFCs in the UK. In 2015 the ICF model was reviewed (Gluckman, 2015). A key aspect of the review was to revise input assumptions due to the impact of the revised EU F-Gas Regulation (517/2014). The review process also identified some other input assumptions and stock calculations that required updating. See the end of this section for details of the 2015 RAC model updates.

For each of the 13 end-use sub-sectors, market data and other country-specific information were considered in the development of assumptions on equipment stocks, market growth, equipment lifetimes, refrigerant market penetrations, charge sizes, manufacturing loss rates, operational loss rates, and disposal loss rates across the 1990-2050 time series. To revise and develop new input assumptions, an extensive literature review was conducted and key industry stakeholders were contacted. Priority industry stakeholders were selected across all end-uses and initially contacted to fill data gaps and corroborate information found in the literature. Following the development of preliminary assumptions for all end-uses, draft assumptions were then shared with a broader range of stakeholders to solicit additional industry input and vet assumptions.

In developing modelling input assumptions by end-use, expert judgment was applied to select appropriate values when more than one estimate was provided by literature and/or stakeholders. In general, more weight was given to estimates that are UK- or regional specific and/or more recent. In cases of equal data quality where numerous data points were available, values were selected based on the mid-point of the data range. Where no UK- or EU-specific information was available, the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines default assumptions were relied on to estimate emissions.

The various input assumptions used by the model can be varied on an annual basis. This allows changes in response to market growth or regulatory constraint to be reflected in the bottom-up estimates of HFC emissions made by the model. For example the 2006 EU F-Gas Regulation has led to significant reductions in the levels of leakage from some RAC sub-sectors and improvements in the level of refrigerant recovery during servicing and at end-of-life. This is reflected in the model by changes to the annual operating emission factors and end-of-life recovery factors.

In the process of finalising the input assumptions, an analysis was conducted to compare estimated refrigerant consumption (calculated as the amount of refrigerant used to manufacture new equipment produced in the UK plus the amount used to service leaking equipment) with annual refrigerant sales data from the British Refrigeration Association (BRA). A summary table of the 2015 input assumptions is provided below. A full description of the methodology, sources, and input assumptions used to update emission estimates by end-use is contained in ICF (2011) and Gluckman (2015).

A key input assumption is the split of different refrigerants used in new and existing equipment in each of the 13 sub-sectors. The accuracy of the input assumptions is checked by comparisons with top-down BRA data for the whole RAC market. The model then generates a detailed speciated split of total emissions. This is available split either by the type of refrigerant used (e.g. a blend such as R-404A) or by the individual HFC components within such blends (e.g. R-404A is a mixture of HFC-143a, HFC-125 and HFC-134a).

4.29.2.1 2015 RAC Model Update

The RAC Model (ICF, 2011) was reviewed and updated in 2015 (Gluckman, 2015). The revised model has much improved matching of historical data with BRA data and fits better with Bristol University/Met Office atmospheric modelling of GHG emissions (see **Annex 6** for more information about the Met Office inventory verification work).

The peak emissions in the revised model are 2.3 Mt CO_2 higher than the ICF model due to a greater use of R-404A.

The totals for emissions and bank size for the whole RACHP sector in the revised model are relatively close to the original ICF model. However, many of the sub-sectors show significant differences. The kt CO_2 emissions from sectors such as RAC-4 and RAC-5 were significantly under-estimated in the original ICF model whereas sectors like RAC-7 and RAC-12 were over-estimated. The forecasted emissions post-2020 fall more quickly in the revised model due to the expected impact of the 2014 EU F-Gas Regulation.

Figure 4.3 compares the emissions estimates of the original and revised models. The 2010 spike in the revised model is caused by retrofit activity for R22. There is a bank of R22 in 4 sectors (RAC-3, RAC-4, RAC-5 and RAC-8) with a significant retrofit activity that starts in 2010. R22 is retrofilled with R422D in these sectors. R22 is zero rated for GWP in the ICF model. R422D has a GWP of 2749 The model output for metric tonnes of emissions shows no spike around 2010 – that is because it includes all gases, including R22. The overall bank does not change in size during retrofits, so it is reasonable that leakage emissions are approximately the same for R22 (in 2009) and for the R422D that has replaced it in 2010. However, when calculating GWP-weighted emissions, the 2009 R22 emissions are multiplied by zero. In 2010 the R22 has been replaced with a significant amount of R422D – which leaks at the same physical rate and is multiplied by quite a high GWP. Hence the sudden jump in emissions.

There have been no major updates to the RAC model for this inventory.

Figure 4.3 Comparison of original and revised RAC models

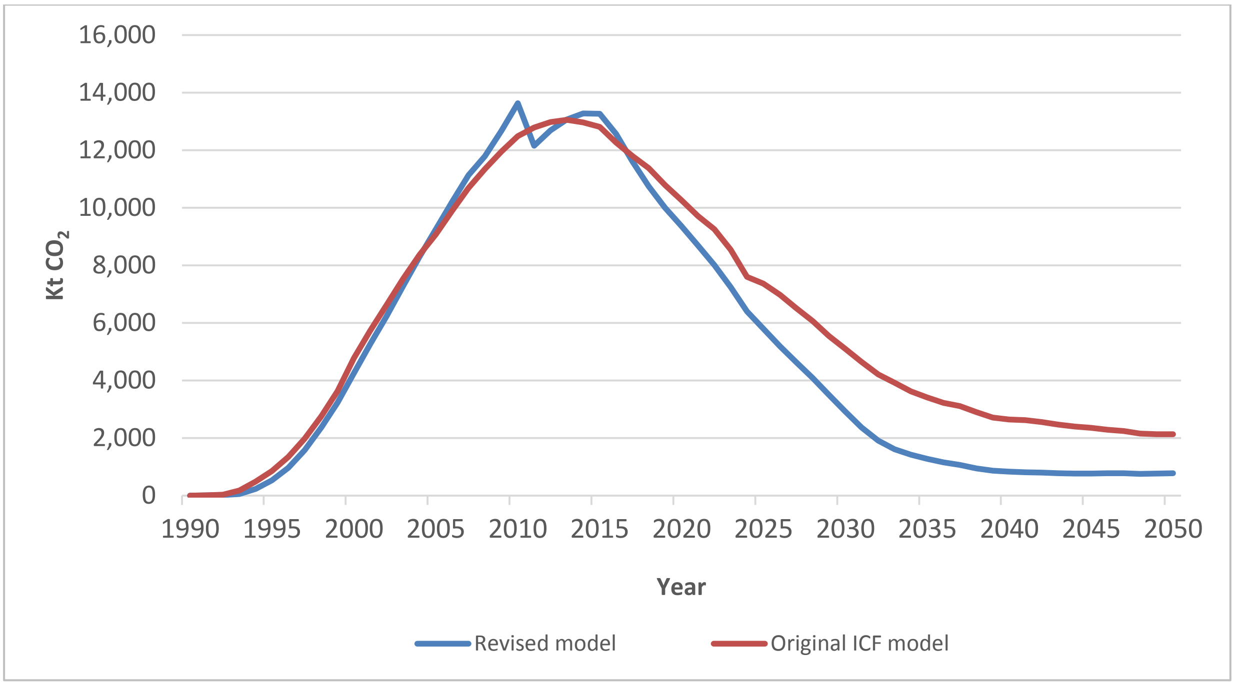


Table 4.21 Summary of 2015 Input Assumptions by End-Use[b]

Application		2015 Parameters[b]							
CRF Sector	UK Category	Total Stock (units)[a]	Total Sales (units)[a]	Lifetime (years)	Charge (kg)[a]	Refrigerants in New Equipment	Manufacturing Loss Rate	Operational Loss Rate	Disposal Loss Rate
Domestic Refrigeration	Domestic Refrigeration	42,282,344	2,928,242	15	0.10	HFC-134a, HCs	0.6%	0.3%	30%[b]
Commercial Refrigeration	Small Hermetic Stand-Alone Refrigeration Units	2,782,258	330,595	10	0.5	HFC-134a, R-404A, R-407C, HCs	1%	1.3%	30%[b]
	Condensing Units	646,370	55,309	14	6	HFC-134a, R-404A, R-407A, R-407F,R-410A, R-507, HCs	2%	7%	12.5%[b]
	Centralised Supermarket Refrigeration Systems	11,750,079 (m^2)	904,048 (m^2)	18[b]	0.56 (kg/m^2)	HFC-134a, R-404A, R-407A, HCs, R-717, R-744	2%	10.5%	6%[b]
Transport Refrigeration	Land Transport Refrigeration	96,287	14,305	7	3.6	HFC-134a, R-404A	0.2%	10.0%[b]	13%[b]
	Marine Transport Refrigeration	527	32	25[b]	1,500[b]	R-404A, R-407C, R-717	1%	16%	13%[b]
Industrial Refrigeration	Industrial Systems	44,163	1,880	25	108	HFC-134a, R-404A, R-407C, R-410A, R-507, HCs, R-717, R-744	1%	10%	10%
Stationary Air-Conditioning	Small Stationary Air Conditioning	6,142,726	565,913	13	1.8	R-407C, R-410A	0.5%	5%	25%
	Medium Stationary Air Conditioning	339,422	29,016	15	15	R-407C, R-410A	1%	6%	17.5%[b]
	Large Stationary Air Conditioning (Chillers)	44,163	2,982	18	180	HFC-134a, R-407C, R-410A, R-717	0.5%	3.5%	7.5%
	Heat Pumps	111,388	25,705	15	3.5	HFC-134a, R-404A, R-407C, R-410A	1%	6%[b]	28%[b]
Mobile Air-Conditioning	Light Duty Mobile Air Conditioning	27,217,672	2,248,830	15	0.7	HFC-134a	0.5%	8%[b]	25%[b]
	Other Mobile Air Conditioning	532,469	59,108	10	4[b]	HFC-134a, R-407C	0.5%	9%[b]	20%[b]

[a] Except where otherwise noted.

[b] Estimates fall outside of the IPCC (2006) range but are in line with UK- and/or EU-specific estimates provided by industry or in the published literature.

Speciated emissions are reported for the OTs and CDs under 2F1. Emission estimates from the UK GHGI were scaled by a territory-specific indicator. Relevant indicators include territory population, GDP and number of cars. The indicators for each activity were chosen based on expert judgement and were dependent on the information available for each territory.

4.29.3 Uncertainties and Time-Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

4.29.4 Source Specific QA/QC and Verification

End-use input assumptions used to generate the refrigeration and air conditioning emissions were developed based on industry consultation and were peer-reviewed. Further, to verify the emissions estimates generated by the revised model, the results were compared with the sales data provided by BRA. The results of the comparison reveal that the data sets align closely, with the 2015 revised model output for UK refrigerant consumption being within 1% of the collective annual BRA data for HFCs from 2006-2010.

Historic emissions estimates generated by the revised model were also compared with concentration observations captured by the dispersion model NAME (Numerical Atmospheric dispersion Modelling Environment) for the years 1995 through to 2008. Results of this comparison show that the revised model output aligns significantly more closely to the NAME observations than historic inventory estimates. More information relating to atmospheric measurements and verification of UK emissions estimates is provided in **Annex 6**.

A list of industry stakeholders consulted on the input assumptions, as well as detailed results from the BRA and emission observation comparisons are discussed in more detail in ICF (2011).

4.29.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10**.

4.29.6 Source Specific Planned Improvements

Emission factors, model parameters, and activity data will be kept under review. A number of potential updates have been identified to further improve upon the emission estimates from this source, including additional stakeholder consultation in the (non-food) industrial refrigeration and marine transport refrigeration sectors. These tasks will be added to the improvement programme; although they are currently not considered a high priority, they will be considered if resources are available.

4.30 SOURCE CATEGORY 2F2A – CLOSED CELLS (FOAM BLOWING AGENTS)

4.30.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2F2a: Foam blowing agents	T2b	CS, D
Gases Reported	HFCs		
Key Categories	2F: Product Uses as Substitutes for ODS - HFCs (L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	All relevant emissions from OTs and CDs are included within the UK totals for this sector. Emissions are calculated by scaling emissions from the UK model using GDP.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	The model used to estimate emissions from this sector has been overhauled during 2015 to account for the impacts of the global recession, recent f-gas regulations and calibrated in light of stakeholder consultation. The resulting model allows us to comment in much more detail on the underlying assumptions.		

Emissions of HFCs from foams can occur as follows:

- During the manufacturing process;
- Over the lifetime of the foam; most rigid foams are closed cell foams and the blowing agent is designed to remain in the foam and contributes to its performance. Loss of HFCs is undesirable as it may affect the performance of the foam but is estimated to occur, albeit at a low rate through diffusion;
- At disposal of the foam; and
- In the waste stream, if the blowing agent is not destroyed following decommissioning

Emissions at each point vary significantly according to the type of foam and the type of application. For the bulk of product types, of the HFC used in the product, less than 10% is emitted during manufacture (although emissions may be as high as 40 to 45% for some types of foam), less than 1% per year over the useful lifetime of the product and the remainder on decommissioning and through the waste cycle[38].

4.30.2 Methodological Issues

The methodology used to estimate emissions corresponds to the IPCC Tier 2b 'bottom-up' approach. The emission factors from the sector have been summarised below.

Emissions are considered separately from the following categories of foams:

[38] Any building insulation that goes into landfill degrades slowly and gives off the remaining gas over many years. This is not well documented and there is little data available on rate of degradation / emission, which is believed to vary depending on the conditions in the landfill.

PU Appliances (F1); PU, PIR Flexibly faced laminate (or boardstock) (F2); PU Discontinuous Panel (F3); PU Continuous Panel (F4); PU, PIR, Phenolic block (F5); Phenolic flexibly faced laminate (F6); PU Spray/injected/pipe-in-pipe (F7); Extruded polystyrene (XPS) (F8); Polyethylene Foam (F9); Integral Skin Foam (F10).

A full description of the emissions and associated methodology used for this sector is set out in Ricardo (2016), which built upon previous work (AEA, 2010). The emissions for the years 1990 to 2002 were based originally on data from March (1999). However, these and emissions data for more recent years (2003 onward) have been obtained from UK industry experts supported by market information from reputable market sources. The methodology is based on a bottom-up assessment of Activity Data which requires information on five elements to complete it:

- Overall dynamics of the thermal insulation market in the UK (including imports and exports);
- The market share changes on-going in the sector which determine the demand for closed cell insulation foams;
- The segregation of the insulation foam sector by manufacturing process and product type;
- The adoption of HFCs as one of the blowing agent options in any chosen process/product combination leading to market penetration assessments against other blowing agent types; and
- The formulation levels at which HFCs have been and will be used in the identified products and processes.

The application of the relevant emission factors to this Activity Data delivers information not only on annual emissions, but also on how banks of blowing agents can develop in products and latterly in waste streams. These banks too will emit steadily, and because of the long-lifetime of many foam applications, the emissions can take place over long periods of time, leading to a number of potential legacy issues. That said, the derived average annual emission rates are relatively low because the products rely for their performance on the retention of the blowing agents in the foam.

Emission factors are determined based on a combination of country-specific data on the HFCs contained in the foam and the time dependent rate of loss of HFCs. The model has been refined to allow the lifecycle of products to be adjusted in 5 yearly intervals. The outputs also give transparency on the source of emissions both by product type and lifecycle stage.

The model provides insight to the manufacturing and trade aspects of each product type in order to determine the amount of product placed on the market in the UK each year. This adds to the existing bank of blowing agent contained in installed products. In parallel, the blowing agent lost from product through annual emission and the decommissioning of product at end-of-life are subtracted from the bank.

The waste stream (not to be confused with decommissioning) is considered as a source of emission in its own right on the basis that a bank of blowing agent is established following decommissioning; while this source is mentioned in the 2006 IPCC guidelines, a method for estimating this source is not given. Although this reduces annual emissions when compared with the previous default assumption of full emission on decommissioning, the impact is mitigated by the long lifecycles of most products being considered. In practice, there is only limited product decommissioning taking place involving HFC-based foams in the period until 2035. Emissions from this source are estimated using a similar approach to product lifetime emissions, i.e. estimated HFCs remaining in the product after decommissioning is added to a bank of gas expected to be in landfill, and a fraction of this is emitted annually. The main difference between this stage and the product lifetime stage is that gas can only escape the bank via emissions, so eventually all of the bank is assumed to be emitted.

The species used for foam blowing are given below.

Table 4.22 Species according to application for foam blowing[a]

Application		HFC-245fa	HFC-365mfc	HFC-227ea	HFC-134a	HFC-152a
Polyurethane (PU)	Boardstock	X[b]	X[b]	X[b]		
	Cont. Panel	X	X	X		
	Disc. Panel	X	X	X		
	Spray	X	X	X		
	Pipe-in-Pipe	X	X	X	X[b]	
	Appliance	X[b]	X[b]	X[b]		
	Reefer	X	X	X		
	Block - Slab	X	X	X		
	Block - Pipe	X	X	X		
Extruded Polystyrene					X	X
Phenolic (PF)	Boardstock	X[b]	X[b]	X[b]		
	Disc. Panel	X	X	X		
	Block - Slab	X	X	X		
	Block - Pipe	X[b]	X[b]	X[b]		

[a] No emissions are occurring for this source in 1990 or in 1995. The bank also includes HFC species not previously reported in the UK GHG inventory (i.e. HFC-365mfc and HFC-245fa), since no GWP was available in the IPCC Second Assessment Report (SAR), but they are included in the 4th Assessment Report (AR4).

[b] These are potentially used, but not known to be used

In the 2015 improvement programme extensive stakeholder consultation was done to determine where parameters of the model should be revised to be most representative of UK emissions. **Table 4.23** summarisies the more significant deviations from 2006 IPCC default parameters and the reason for the deviation. A summary of the factors used in the foams model is provided in **Table 4.24**.

Table 4.23 Significant Deviations from 2006 IPCC GL default parameters[a]

Application	EF Source	Product Lifetime (years)	Manufacturing Factor	Product Lifetime Factor	Notes
Domestic Refrigerators	IPCC 2006 GLs		4%		All HFC-containing units imported
	UK GHGI Model		0%		
Other Appliances	IPCC 2006 GLs		4%	0.5%	Wider range of products included, but lower in use losses because of better designs and thicker foams
	UK GHGI Model		6%	0.25%	

Application	EF Source	Product Lifetime (years)	Manufacturing Factor	Product Lifetime Factor	Notes
PU Boardstock	IPCC 2006 GLs	25			IPCC uses global figure influenced by timber-framed housing
	UK GHGI Model	50			
PU Cont. Panel	IPCC 2006 GLs	50			Information from major panel manufacturers suggests 30 years is a better figure although some guarantee for 40 years
	UK GHGI Model	30			
PU Disc Panel	IPCC 2006 GLs	50	12%		Better manufacturing practices. Information from major panel manufacturers suggests 30 years is a better figure although some guarantee for 40 years
	UK GHGI Model	30	6%		
PU Spray	IPCC 2006 GLs		15%		Recognises pre-2006 status of industry and improvements made
	UK GHGI Model		15-25%		
PF Block Pipe	IPCC 2006 GLs		45%		Recognises new process introduction
	UK GHGI Model		45%/7.5%		
PU/PF Block Slab	IPCC 2006 GLs	15	20%	1%	Recognises better foam structure and fabrication processes. Most slab now used for panel purposes so lifetime should be aligned.
	UK GHGI Model	30	15%	0.75%	
XPS Board	IPCC 2006 GLs		25%	0.75%	Annual cell losses greater but decreases with greater thickness
	UK GHGI Model		12-25%	2.5%	

[a] Decommissioning and waste factors are not compered here as they are not comparable to the maximum potent end of life emission factors given in the 2006 IPCC guidelines.

Table 4.24 Parameters used in the foams model

Application	Product Lifetime (years)	Manufacture	Product Lifetime Factor	Decommissioning	Waste
Dom. Refr-Freezers	15	0.00%	0.25%	2.50%	0.00%
Other Appliances	15	6.00%	0.25%	5.00%	0.00%
PU Reefers-Marine	15	6.00%	0.50%	10.00%	1.00%
PU Boardstock	50	6.00%	1.00%	7.50%	2.00%
PU Continuous Panel	30	5.00%	0.50%	5.00%	0.75%
PU Disc. Panel	30	6.00%	0.50%	5.00%	0.75%
PU Spray	50	15-25%[a]	1.50%	10.00%	2.00%

Application	Product Lifetime (years)	Manufacture	Product Lifetime Factor	Decommissioning	Waste
PU Pipe-in-Pipe	30	6.00%	0.25%	2.00%	0.50%
PU Block-Pipe	15	45.00%	0.75%	2.50%	1.50%
PU Block-Slab	30	15.00%	0.75%	2.50%	1.50%
XPS - Board	50	12-25%[a]	2.50%	7.50%	4.00%
PF - Boardstock	50	6.00%	1.00%	7.50%	2.00%
PF - Panels	30	10.00%	0.50%	5.00%	0.75%
PF - Pipe	15	7.5-45%[a]	0.75%	2.50%	1.50%
PF - Block Slab	30	15.00%	0.75%	2.50%	1.50%

[a] The factor varies depending on the year to reflect the impact of regulation and UK industry practice

Speciated emissions for the OTs and CDs are reported under 2F2. Emission estimates from the UK GHGI were scaled using the GDP of each territory.

4.30.3 Uncertainties and Time-Series Consistency

There are a number of parameters that feed into the modelled estimate of emissions and hence the uncertainty. Between data on foam manufacturing capacity/utilisation, the blowing agent consumption and the overall tracking of thermal insulation demand through publications such as IAL studies we can have a fairly high level of confidence in the estimate. This is despite some high uncertainties in some of the individual assumptions in the model; manufacturers were cautious in providing comment on the HFC market penetration which is the assumption that has greatest cause for uncertainty. Regulatory pressures to label products containing HFCs may help in future to hone the estimates and reduce uncertainties in Activity Data.

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

4.30.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Details of verification of emissions are given in **Annex 6**.

4.30.5 Source Specific Recalculations

As part of the GHGI improvement programme the model underlying the estimates of UK F-gas emissions from closed foams has been updated. Detailed information on the work done can be found in the improvement project report (Ricardo, 2016). The main changes made to the model are as follows:

- Consideration of ongoing emissions due to decommissioned product being disposed to landfill, previously all decommissioning emissions were assumed to occur in the year of decommissioning;
- Revision of underlying assumptions in light of stakeholder consultation, the impact of recent global economic events and the impact of evolving EU F-gas regulations; and
- Increased transparency; emissions can now be reported by lifecycle stage and underlying assumptions of the model can be published and scrutinised.

For information on the magnitude of recalculations, see **Section 10**.

4.30.6 Source Specific Planned improvements

This source has recently been updated so there are no immediate plans for improvement. However, we will be recommending that this sector is revisited when we have a few years' data on the impact of recent F-gas regulations.

4.31 SOURCE CATEGORY 2F2B – OPEN CELLS (ONE COMPONENT FOAMS)

4.31.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2F2b: One Component Foams	T2	CS
Gases Reported	HFCs		
Key Categories	2F: Product Uses as Substitutes for ODS - HFCs (L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	All relevant emissions from OTs and CDs are included within the UK totals for this sector. Emissions are calculated by scaling emissions from the UK model using GDP.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

One Component Foams (OCFs) are used by building tradesmen (and in the DIY home improvement sector, to a lesser extent) to mount doors and windows and to insulate different types of open joints and gaps. When used as an OCF propellant, HFC (134a, 152a) is blended with various flammable gases. HFC escapes from the foam on application, leaving small residues, which remain in the hardened foam for up to a year. These products are not manufactured in the UK, although they are imported. The use of HFCs in OCFs has been banned under the EC Regulation on fluorinated greenhouse gases (EC 842/2006) from July 4th 2008, except for where their use is safety critical.

4.31.2 Methodological Issues

The method of calculation is an IPCC Tier 2 method.

UK estimates of emissions from this source were based on a European evaluation of emissions from this sector (Harnisch and Schwarz, 2003), subsequently disaggregated by GDP to provide a top-down UK estimate.

It has been very difficult to establish the exact size of the UK import market and, therefore, hard to generate an accurate estimate of emissions from the use of this product.

Harnisch and Schwarz (2003) estimated EU emissions from OCFs as follows:

- 1996: 4,000 kt CO_2 equivalent per annum (3100 tonnes of HFC-134a); and
- 2000: 1,700 kt CO_2 equivalent per annum (1200 tonnes of HFC-134a; 1000 tonnes of HFC-152a)

Emissions in tonnes of CO_2 equivalent have reduced between 1996 and 2000 due to the use of HFCs with lower GWP values, and the manufacture of cans containing less HFC. In 2000, 23 million OCF cans that contained HFCs were sold in Germany while 7 million where sold to the rest of the EU market. Research indicated that Germany accounted for 77% of the total EU emission, and that out of the remaining 23%, the UK accounts for 24%, based on a percentage of total EU GDP (excluding Germany). This is equivalent to 1.68 million cans (AEA, 2008).

The estimates of HFCs assume that the ban on F-gas use in one component foams (banned from July 2008 under the F-Gas regulations) has been successful, and this success has been confirmed with the UK Defra F-Gas Regulation team. Therefore no emissions occur from 2009 onwards.

4.31.3 Uncertainties and Time-Series Consistency

Estimates of the uncertainties associated with time-series data for this sector were made in AEA (2004), based on an understanding of the uncertainties within the sector and from discussion with industry. Emissions from this sector are estimated to fall within an uncertainty range of 10-25%. Uncertainty data from this study have been used in the uncertainty analysis presented in **Annex 2**.

4.31.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Details of verification of emissions are given in **Annex 6**.

4.31.5 Source Specific Recalculations

There have been no recalculations to the mass based estimates from this source.

4.31.6 Source Specific Planned improvements

Emission factors and activity data will be kept under review.

4.32 SOURCE CATEGORY 2F3 – FIRE EXTINGUISHERS

4.32.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2F3: Fire Fighting	T2	CS
Gases Reported	HFCs, PFCs		
Key Categories	2F: Product Uses as Substitutes for ODS - HFCs (L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	All relevant emissions from OTs and CDs are included within the UK totals for this sector. Emissions are calculated by scaling emissions from the UK model using GDP.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	None.		

In the UK, manufacturers of fixed suppression systems for firefighting have been using HFCs as an alternative to Halons for many years. HFC-based systems are used for the protection of electronic and telecommunications equipment, and in military applications, records offices, bank vaults and oil production facilities.

The main HFC used in UK fixed systems is HFC-227ea.

4.32.2 Methodological Issues

The IPCC 2006 GLs state that, because F-gases in fire extinguishers are emitted over a period longer than one year, countries must represent emissions from equipment charged during previous years. As such, the revised emission estimation equation (Equation 7.17) requires a modified approach to the one used in 2014 NIR (2012 inventory) to consider the time dependence of the emissions. Effectively, this requires disaggregating the annual bank estimates into ‘new’ versus ‘existing’ systems and then applying emission factors accordingly (i.e., applying a lifetime loss rate to banks from both new and existing systems, a servicing loss rate to the bank of existing systems, and a disposal loss rate to the bank of existing systems reaching disposal in any given year, based on an assumed average lifetime). Further, additional research was required to ensure that a manufacture loss rate should not be applied by confirming whether there is any production of F-gas fire protection agents in the UK. These updates apply the IPCC Tier 2 methodology.

ICF reviewed available literature to confirm/update key assumptions—notably, EEA (2014)—and then refined and finalized the estimates based on consultation with ASSURE (European Association for Responsible Use of HFCs in Fire Fighting) and the UK Fire Industry Association (FIA). The sections below outline the updates implemented by key area.

4.32.2.1 Stock

Annual stock estimates from the years 1990 – 2005 (from the 2012 GHG inventory) were maintained, since they were based on historical data and input from industry experts. However, these annual stock figures were disaggregated into new versus existing systems by subtracting the current year’s bank from the previous year’s bank to estimate consumption in new systems, and then allocating the remainder of the bank to existing systems.

To determine the equipment stock in years beyond 2005, EEA (2014) estimates for net supply of F-gases in the fire protection sector from 2007-2012 (metric tonnes) in the EU, 85% of which is HFC-227ea, were scaled to the UK using a time-dependent GDP ratio. This annual net supply was assumed to equal annual UK consumption of fire protection agent in new and existing systems. The bank estimate for 2006 was interpolated based on the existing 2005 estimate and the new 2007 estimate. The methodology and resulting stock estimates were reviewed and approved by ASSURE (2013) and FIA (2013). ASSURE confirmed that the estimates looked reasonable; FIA noted that the estimates looked reasonable for recent years, but that the 2000 estimates are slightly high. Additional information to refine these historical estimates was not available but this is a conservative bias as it will slightly overestimate emissions.

4.32.2.2 Chemicals in use

According to FIA (2013) and ASSURE (2013), HFC-227ea accounts for virtually 100% of F-gas consumption in this sector in the UK; consumption of other HFCs (e.g., HFC-23, HFC-125, and HFC-236fa) in the UK are statistically insignificant. Therefore, is it assumed that HFC-227ea accounts for 100% of F-gas consumption in this sector (over the full time period).

4.32.2.3 Equipment lifetime

According to FIA (2013) and ASSURE (2013), the average equipment lifetime of fire protection systems is 20 years.

4.32.2.4 Emission factors

The emission factors used in the current inventory were reviewed by FIA (2013) and ASSURE (2013); they confirmed that no updates were required. A summary of the emission factors is provided in the table below. ASSURE emphasised that the high cost of specialty HFC fire protection systems creates a strong incentive for recovery and recycling, minimising leaks during servicing and decommissioning. Further, ASSURE confirmed that there is no F-gas production in the UK in this sector, which is also supported by Defra (2008). Thus, no manufacturing loss factors are applied.

Lifetime emission factors were applied to the entire bank, while servicing emission factors—which decrease over time as more efficient servicing techniques are assumed to be implemented—were applied to the bank of existing systems (not to new or decommissioned systems). The disposal loss rate is applied to the bank of existing systems assumed to reach disposal; because the equipment lifetime is assumed to be 20 years, the disposal emissions will not be modelled until 2015—i.e., 20 years following the initial installation of F-gases in 1995.

The UK has reported emissions of PFC C_4F_{10} from 1995 to 2007. Emissions of this PFC were estimated using the methodology set out in the 2014 NIR. The research set out below has indicated that only HFC-227ea is used in this sector. These PFC emissions will be removed from the time series in the next inventory.

Table 4.25 Key assumptions used to estimate HFC emissions from fire extinguishers

Parameter		1990	1995	2015
Activity data	HFC species and ratio HFC-227ea	100%	100%	100%
	Size of bank (t)	0	20	3353
	Consumption in new systems (t)	0	20	187
	Equipment lifetime (yrs)	0	20	20

Parameter		1990	1995	2015
Emission factors	% released through fire (lifetime)	1.5	1.5	1.5
	% released through servicing	3.4	3.4	1.0
	% released during recovery (disposal)	0.1	0.1	0.1

Speciated emissions for the OTs and CDs are reported under 2F3. Emission estimates from the UK GHGI were scaled by the GDP of each territory.

4.32.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

4.32.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Details of verification of emissions are given in **Annex 6**.

4.32.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10**.

4.32.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.33 SOURCE CATEGORY 2F4 – AEROSOLS

4.33.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2F4: Metered Dose Inhalers Aerosols (Halocarbons)	T2	CS
Gases Reported	HFCs		
Key Categories	2F: Product Uses as Substitutes for ODS - HFCs (L2, T2) 2F4: Aerosols - HFCs, PFCs, SF_6 and NF_3 (T1)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	All relevant emissions from OTs and CDs are included within the UK totals for this sector. Emissions are calculated by scaling emissions from the UK model using population data.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

Most aerosols use hydrocarbon propellants, with a relatively small proportion of the market favouring other volatile liquids including dimethyl ether (DME) and HFCs. Compressed gases are used in very few aerosols since they suffer from a number of disadvantages compared with liquefied gas propellants such as DME and hydrocarbons. HFCs are used only in a few applications where the use of a more expensive propellant is required to provide a non-flammable material. The most important industrial applications in volume terms are air dusters and pipe freezing products; other applications include specialised lubricants and surface treatments, and specialised insecticides. The use of HFCs for novelty applications, such as 'silly string' was banned from July 2009, under the EC Regulation on fluorinated greenhouse gases (EC 842/2006).

Metered dose inhalers (MDIs) are used to deliver certain pharmaceutical products as an aerosol. For patients with respiratory illnesses, such as asthma and chronic obstructive pulmonary disease (COPD), medication needs to be delivered directly to the lungs. MDIs are one of the preferred means of delivering inhaled medication to patients with these illnesses. MDIs originally used CFC propellants but, as with industrial aerosols, concern over ozone destruction led to replacement of CFCs with HFCs.

4.33.2 Methodological Issues

4.33.2.1 Aerosols

The methodology used to estimates emissions corresponds to an IPCC Tier 2 method. Aerosol HFC emission estimates have been derived on the basis of fluid consumption data provided by the British Aerosol Manufacturers' Association (BAMA). An average product lifetime of one year for all aerosols containing HFC has been assumed, based on discussions with BAMA, although this may be shorter or longer depending on the specific aerosol application. It is estimated that 1% of HFC emissions from aerosols occur during manufacture. The majority is released during the product lifetime (97%), with end of life emissions accounting for the other 2%. These emission factors are the same as those estimated in previous work by March (1999). The lifetime and end of life emissions are calculated after import and exports have been taken into account.

Discussions with BAMA in 2016 indicate that the split of HFC use use between HFC-134a and HFC-152a and the total quantity consumed was incorrect during the period from 2008 to 2015. During that time the aerosol sector has made increasing use of HFC-152a which has a considerably lower GWP. **Table 4.26** shows the changes made to the aerosol HFC consumption data during the last 10 years.

Table 4.26 Changes made to aerosol HFC usage and emissions

	HFC-134a consumption, tonnes		HFC-152a consumption, tonnes	
Year	2014 inventory	2015 inventory	2014 inventory	2015 inventory
2006	1097	1097	27	27
2007	951	951	20	20
2008	991	989	22	22
2009	920	851	22	0
2010	849	744	22	1
2011	849	681	22	113
2012	849	659	22	115

2013	849	650	22	120
2014	849	600	22	150
2015	n/a	550	n/a	200

4.33.2.2 Metered Dose Inhalers (MDIs)

The methodology used to estimate emissions corresponds to an IPCC Tier 2 method. The current approach is essentially a “UK consumption model”. The number of MDIs used each year in the UK is derived from the UK National Health Service (NHS) prescription data. HFC emissions have been calculated with estimates of the species and volumes of HFCs used as MDI propellants. Detailed data from the UK NHS are used for estimates between 1998 and 2014. Estimates for 1990-1997 are based on extrapolated data from 1998. This method ensures time series consistency. The NHS data are available for England, Wales, Scotland and Northern Ireland, allowing an accurate split to be made of the UK totals.

The NHS data gives good estimates of the number of MDIs of each drug type that have been prescribed. However, the data gives no information about the amount of HFC propellant per MDI prescribed. The estimates assume an average figure of 12g/MDI (Gluckman, 2013).

The table below shows the way in which emissions are estimated from NHS data on total number of MDIs used in the UK each year. The majority of MDIs use HFC-134a. A small number (4%) have been formulated using HFC-227ea. The table shows the estimated number of MDIs consumed each year in the UK, together with the CO_2 emissions for this level of MDI consumption (assuming 96% HFC-134a and 4% HFC-227ea).

Table 4.27 Key assumptions used to estimate HFC emissions from MDIs

Year	MDI Number (thousands)	Average Propellant (g per MDI)	Emissions (kt CO_2e)
2006	40,146	14	844
2007	41,874	13	817
2008	45,353	12	817
2009	48,413	12	872
2010	50,190	12	904
2011	50,644	12	913
2012	52,009	12	937
2013	51,518	12	928
2014	53,317	12	961
2015	53,612	12	966

Speciated emissions for the OTs and CDs are reported under 2F4. Emission estimates from the UK GHGI were scaled by the population of each territory.

4.33.3 Uncertainties and Time Series Consistency

Uncertainty data from this study have been used in the uncertainty analysis presented in **Annex 2**.

4.33.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Details of verification of emissions are given in **Annex 6**.

4.33.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10**

4.33.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

4.34 SOURCE CATEGORY 2F5 – SOLVENTS

4.34.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2F5: Precision Cleaning	T1a	OTH
Gases Reported	HFCs		
Key Categories	2F: Product Uses as Substitutes for ODS - HFCs (L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

HFCs can be used as solvents in a range of applications such as precision cleaning to replace CFCs, HCFCs or 1,1,1-trichloroethane. HFCs have been developed that are used for precision cleaning in sectors such as aerospace and electronics.

4.34.2 Methodological Issues

Emissions from solvent applications are considered to be prompt emissions because 100% of the chemical is typically emitted within two years of initial use (IPCC 2006). To calculate HFC emissions from the solvent sector using a Tier 1a method, the 2006 IPCC Guidelines specify that activity data should be the quantity of solvent sold in a given year. Therefore, obtaining annual sales of solvents in the UK is required. Using sales data, emissions of HFCs from solvent use in year t are calculated using the following equation, as provided in the 2006 GLs:

$$Emissions_t = S_t \times EF + S_{t-1} \times (1\text{-EF}) - D_{t-1}$$

Where:

$Emissions_t$ = emissions in year t, tonnes

S_t = quantity of solvents sold in year t, tonnes

S_{t-1} = quantity of solvents sold in year t-1, tonnes

EF = emission factor (= fraction of chemical emitted from solvents in the year of initial use), fraction

D_{t-1} = quantity of solvents destroyed in year t-1, tonnes

Because of the diverse industrial and commercial applications in which solvents are used, there is no UK or EU trade association for the solvents industry from which to solicit activity data. Therefore, ICF reviewed available literature to confirm/update key assumptions - notably, Harnish & Schwarz (2003), and EEA (2013). The sections below outline the updates implemented by key area.

4.34.2.1 Stock

Annual sales data of HFCs in the UK solvent sector were not available. Therefore, consumption of HFCs in this sector was estimated using the same estimates as in the previous inventory for 2001 and 2002 (i.e., based on Harnish & Schwarz 2003) in additional to historical F-gas supply data in the EU. Because the consumption estimates in Harnish & Schwarz (2003) in years beyond 2002 were projections, EEA (2013) data on intended F-gas supply data in the EU in the solvents sector was used to estimate HFC consumption from 2007-2012. To estimate the amount of HFCs placed on the market in the UK, the EU estimates from EEA (2013) were scaled down using a time-dependent UK to EU GDP ratio from EuroStat (2013). Using GDP as a scaling factor to estimate the UK F-gas supply in the solvent sector was deemed appropriate, given the wide variety of industrial and commercial industries that use solvents.

4.34.2.2 Chemicals in use

Given the lack of data available on the extent of use of HFC-134a in the UK solvent sector, it is assumed that HFC-43-10mee accounts for 100% of UK F-gas consumption in this sector.

4.34.2.3 Product lifetime

According to the 2006 IPCC GLs, the lifetime of all solvents is assumed to be two years. Therefore, any amount not emitted during the first year is assumed to be emitted in the second, final year (IPCC 2006).

4.34.2.4 Emission factors

A lifetime emission factor is applied to the total amount of solvents placed on the market. Because the 2006 IPCC GLs provide that HFCs are emitted over a two-year period, an annual emission factor of 50%[39] was applied in this analysis using the IPCC (2006) equation above. Recovery and recycling is not considered in emission estimates, per the 2006 IPCC GLs.

[39] Note the ICF report (ICF,2013) states 45%, but the spreadsheet indicates 50% was used.

Table 4.28 Key assumptions used to estimate emissions from the use of solvents

	Parameter	1990	2005	2015
Activity data	EU Estimate (tonnes of HFC placed on market)	0	145	185
	UK Estimate (tonnes of HFC placed on market)	0	26	32
	Product lifetime (yrs)	2	2	2
Emission factors	PM %	n/a	n/a	n/a
	PL %	50	50	50
	D %	n/a	n/a	n/a

4.34.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

4.34.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Details of verification of emissions are given in **Annex 6**.

4.34.5 Source Specific Recalculations

There have been no recalculations to emissions from this sector.

4.34.6 Source Specific Planned Improvements

It is noted that this sector is part of an identified key category this year, and that this sector uses a tier 1 method. This sector has been reviewed recently, and is only a minor part of the key category, so the UK doesn't currently consider this to be a priority item for improvement, but obviously this position will change if new data were to come to light and activity data and emission factors will be kept under review.

4.35 SOURCE CATEGORY 2F6 – OTHER (INCLUDING TRANSPORT OF REFRIGERANTS)

4.35.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2F6b: Refrigerant Containers	CS	CS
Gases Reported	HFCs		
Key Categories	2F: Product Uses as Substitutes for ODS - HFCs (L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	All relevant emissions from OTs and CDs are included within the UK totals for this sector. Emissions are calculated by scaling emissions from the UK model using GDP as a scaling factor.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	New to the 2015 submission		

4.35.2 Methodological Issues

Under the 2006 GLs, a new term in the IPCC Tier 2a method emissions equation for the Refrigeration and Air Conditioning sector is introduced to include emissions from the management of refrigerant containers used to service existing refrigeration/air-conditioning equipment, including refrigerant cylinders used by professional service technicians and small cans used by Do-It-Yourselfers (DIYers). No Tier 1 methodology is provided for this source.

Emissions from refrigerant containers occur when refrigerant is transferred from bulk containers (e.g., 20-tonne isotanks) to smaller capacity containers, typically ranging from approximately 300-500 grams (small cans) to 60 - 70 kg (cylinders). Emissions also occur at time of cylinder reprocessing (for reusable cylinders) or cylinder disposal (for non-returnable cylinders) if the refrigerant “heel” is not fully recovered. IPCC 2006 GLs require that emissions from each type of refrigerant container be calculated separately for refrigerant sold in small cans and in cylinders, including both disposables and reusables. The IPCC 2006 GLs default disposal emissions factors are 20% for small cans and 2% for disposable cylinders. Although the GLs do not specify a default emission rate for losses during the transfer of refrigerant into smaller containers, they do specify a default loss rate of 0.5 during the charging of refrigeration/air-conditioning equipment.

ICF (2014) provides a review of available literature to develop key assumptions on stock and emission factors—notably, Enviros (2008), Defra (2008), BRA (2010). ICF also contacted the five largest refrigerant Fillers & Packers in the UK that reported sales data to BRA in order to confirm/refine the estimates. Further work was carried out and is reported in Ricardo (2016) to refine a refrigerant containers model that is now used for the UK emissions estimate. The sections below outline the assumptions and methodology applied based on this process.

4.35.2.1 Package Sizes and Types

Refrigerants are used by four different types of end users who each use different sizes of refrigerant packaging:

a) Original equipment manufacturers that manufacture pre-charged RACHP equipment. They purchase the majority of refrigerant in large volumes e.g. 20 tonne iso-containers or 1 tonne drums.

b) RACHP system installers that charge new systems after construction at an end user site. For larger sized systems (e.g. supermarket refrigeration systems or air-conditioning water chillers) the majority of refrigerant is supplied in large cylinders (e.g. 60 kg). For small systems (e.g. split air-conditioning) small cylinders (e.g. 15 kg) may also be used.

c) RACHP maintenance companies that carry out regular maintenance of equipment. The majority of refrigerant used for maintenance is supplied in small cylinders.

d) DIY activities for mobile air-conditioning – refrigerant is supplied in small cans (e.g. 0.3 to 0.5 kg) for use in the DIY market.

All large package sizes (e.g. 20 tonne iso-containers, 1 tonne drums, 60 kg cylinders) have been sold as re-usable containers since before 1990.

A small proportion of smaller cylinders (e.g. 15 kg) were sold as non-returnable containers from 1990 to 2008. From 2008 the supply of non-returnable cylinders was banned under the 2006 EU F-Gas Regulation.

The majority of small cans for mobile air-conditioning were sold as non-returnable containers from 1990 to 2008. From 2008 the supply of non-returnable small cans was banned under the 2006 EU F-Gas Regulation.

4.35.2.2 Sources of emission from refrigerant containers

The refrigerant containers emissions model takes into account 4 sources of HFC emission:

a) During package filling at a specialist company that transfers refrigerant from bulk storage into the package sizes described above.

b) During the re-processing of re-usable packages, at the specialist packer-filler companies

c) From non-returnable cylinders in the waste stream (only until 2008 when they were banned)

d) From the use of cylinders in the field by installers and maintenance companies.

All emissions are assumed to occur when cylinders are connected or disconnected to other equipment. There are small losses each time a cylinder is filled, used in the field or reprocessed. The emissions are on a “per event” basis. For example each time a cylinder is filled there is a small emission – the filling emission is the same for filling a large 60 kg cylinder as for filling a small 15 kg cylinder. There are no emissions from cylinders in storage.

4.35.2.3 Number of cylinders filled, used and reprocessed

Annual estimates of cylinder use were developed using data on the sales of refrigerant into the UK market from British Refrigeration Association (2015) for the years 2006 – 2014. The total quantity of refrigerant sold is available for each of the main refrigerant types (e.g. R-404A, HFC-134a etc.). The split of cylinder sizes for each refrigerant type was estimated through discussions with packer-fillers as summarised in the table below. Quantities sold prior to 2006 were extrapolated back to the dates when each refrigerant type was first introduced into the UK market (around 1992 for HFC-134a, 1995 for R-404A and 1998 for R-410A).

Table 4.29 Estimated split of UK refrigerant sales by cylinder size

	Bulk (1 tonne / 15 tonne)	Large cylinder (60 kg)	Small cylinder (13 kg)
R-134a	15%	25%	60%
R-404A / R-507	5%	25%	70%
R-407A / R-407C / R-407F	5%	25%	70%
R-410A	5%	5%	90%
R-410A	15%	25%	60%

4.35.2.4 Emission Factors

Emission factors for each type of emission have been assessed in discussion with industry experts.

4.35.2.4.1 Cylinder filling

Emissions during cylinder filling are very low. Packer-fillers use sophisticated automatic filling equipment and have taken steps to minimise losses of refrigerant when a cylinder is connected / disconnected to filling equipment, including use of “gas drawback” systems to suck gas out of connecting pipework before they disconnect a cylinder after it has been filled. Packer-fillers estimate that the loss per charging operation is under 1 gram of gas in the most sophisticated facilities. Prior to 2006 it is likely that the emission rates were higher. An emissions factor of 10 grams per charging operation has been used in the period 1990 to 2000, tapering to 2 grams after 2008 (a conservatively high estimate).

4.35.2.4.2 Returned cylinder re-processing

All used cylinders have a heel of gas left in them. This is usually a small amount (e.g. well under 5% of full cylinder quantity) although in a few cases partially filled cylinders are returned with over 50% of the original quantity. Packer-fillers treat returned cylinders with great care, partly for environmental reasons and also because of the potential value of the returned gas. Packer-fillers use one of two methods to re-process returned cylinders:

a) They “de-heel” each cylinder by transferring any remaining refrigerant into a large storage drum. When this drum is full it is tested for quality and then added to the main refrigerant bulk tank for use in filling new cylinders
b) They “top-fill” a cylinder with the appropriate refrigerant, filling to the required total weight.

Packer-fillers indicate negligible losses from these processes (e.g. for top fill there is no emission other than that for cylinder filling). Conservatively the model uses 10 grams per de-heeling operation in the period 1990 to 2000, tapering to 2 grams after 2008.

4.35.2.4.3 Non-returnable cylinders

Any heel left in a non-returnable cylinder will be emitted e.g. from a landfill site or a waste metal reprocessing site. There is no data on the average heel size for non-returnable cylinders or small cans. Only a small proportion of UK refrigerant was sold in non-returnable packages in the period 1990 to 2008 and none after that date (due to the ban in the 2006 EU F-Gas Regulation). The model assumes a 2% heel in small cylinders (approx. 0.25 kg) and a 10% heel in small cans (approx. 30 grams).

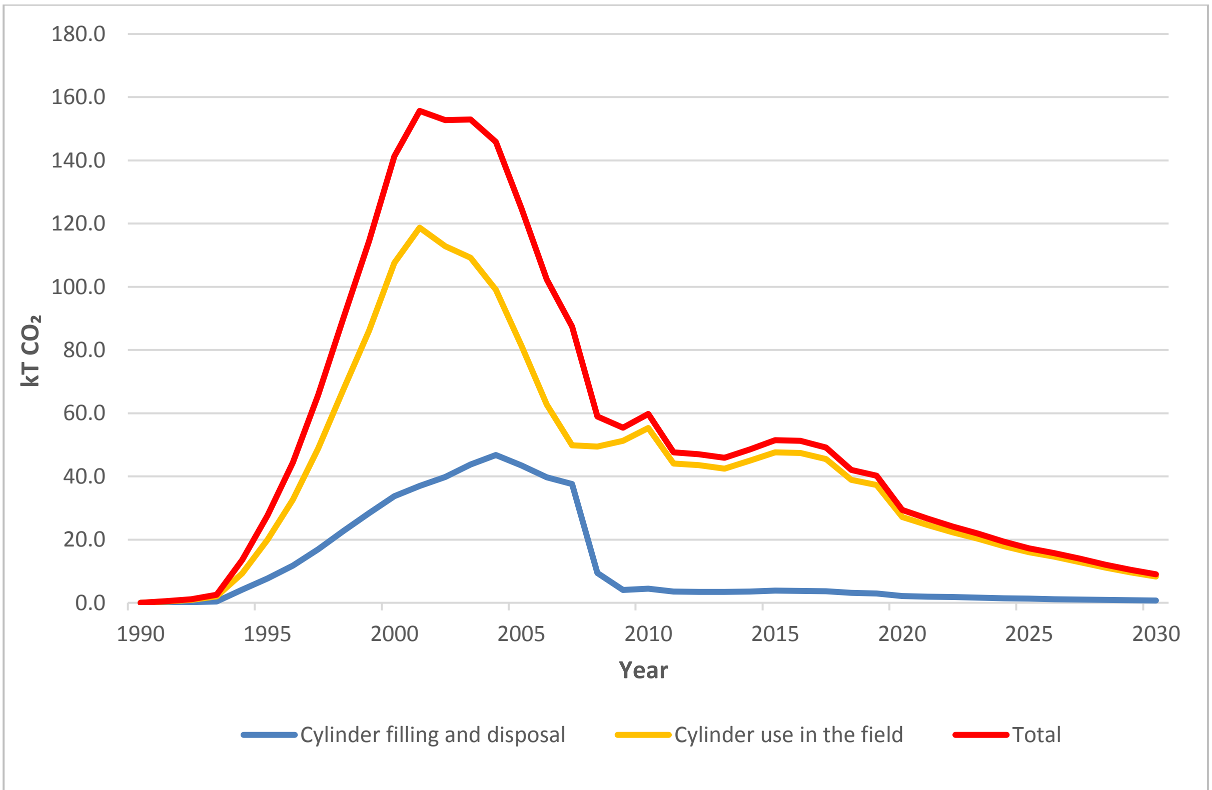
4.35.2.4.4 Cylinder use in the field

There are losses each time a cylinder is connected / disconnected to RACHP equipment during field installation or maintenance. The loss will depend on the care taken by the technician carrying out the filling operation. Refrigerant is lost from the connection hoses when a cylinder is disconnected. Technicians are trained how to use cylinders correctly (it is part of the mandatory F-Gas handling training specified in the 2006 EU F-Gas Regulation and part of the training specified by the EU Ozone Regulation). With best practice the losses are estimated to be in the range of 0.5 to 3 grams of refrigerant per filling event, assuming only refrigerant vapour is emitted. However, with poor practice some liquid refrigerant could be emitted – this could result in an emission of 50 to 100 grams per event. Discussion with experts has established that an average loss of 10 grams per event is reasonable for properly trained technicians (allowing for one in ten filling events to be poor practice). Prior to the introduction of mandatory training loss rates were higher – the model assumes 40 grams per filling event prior to 2001, tapering to 10 grams in 2008.

Some cylinders are used multiple times in the field e.g. a 15 kg cylinder could be used to add, say 5 kg to plant A, 1 kg to plant B etc. There is no detailed data available on average cylinder use patterns. Based on discussion with experts the model assumes 5 filling events per cylinder.

The emissions estimates from refrigerant containers are summarised in the graph below. A high proportion of the emissions are from cylinder use in the field. The drop of field emissions in the period 2000 to 2008 is due to the introduction of better training. The drop in filling / disposal emissions in 2008 is due to the ban on non-returnable cylinders and cans.

Figure 4.4 Trends in refrigerant container emissions



4.35.3 Uncertainties and Time Series Consistency

As discussed above, emissions in the field dominate the total. From 2009 the emissions from filling / disposal of cylinders are well under 10% of the total. The estimates for filling / disposal post-2009 have the best accuracy, estimated at +-10%. Prior to 2008 the filling / disposal estimates are less accurate because of uncertainties regarding the quantity of refrigerant left in non-returnable cylinders/cans on disposal – the overall accuracy is estimated as -10% to +25%. There are significant uncertainties regarding cylinder use in the field. In particular there is no data on the proportion of “poor practice” filling events or on the average number of filling events per cylinder. The accuracy of the use in field emissions is estimated to be -10% to +30%. We believe that a skewed confidence interval best represents the uncertainty of emissions from this source. This is because there is much more space for emissions to be higher due to less good practice than we anticipated than the amount that emissions could be lower if bad practice is less prevalent that we estimated.

As the emissions from use in the field are the dominant source and have the highest uncertainty we would conservatively say that the overall uncertainty for the sector is -10 to +30%.

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

4.35.4 QA/QC and Verification

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

4.35.5 Source Specific Recalculations

Not applicable.

4.35.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

4.36 SOURCE CATEGORY 2G1 – ELECTRICAL EQUIPMENT

4.36.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2G1 – Electrical Equipment	T3	CS
Gases Reported	SF_6		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

SF_6 is released from activities in this source sector.

Sulphur hexafluoride has been used in high and medium voltage switch gear and transformers since the mid-1960s. The physical properties of the gas make it uniquely effective as an arc-quenching medium and as an insulator. Consequently it has gradually replaced equipment using older technologies, namely oil filled and air blast equipment. Currently, there are no alternative fluids that have the same properties as SF_6.

4.36.2 Methodological Issues

A review of the data sources and methodology used to estimate emissions from electrical switchgear was carried out in 2013. Data was collected from all the key UK users of Gas Insulated Switchgear (GIS), including National Grid and the UK electricity distribution companies. Data was also obtained from ENA (Electrical Networks Association) and from the electricity industry Regulator, Ofgem. Since the introduction of the EU F-Gas Regulation in 2006, the UK electricity industry has made significant efforts to monitor and reduce consumption of SF_6. The Regulator collects annual data from each electricity company. These data were used to estimate the size of the SF_6 bank in GIS and emissions for 2008-2012. Emissions from earlier years were estimated by extrapolating the data backwards, using the previously reported bank size in 1995 and 2000 and previously reported leakage rates. This approach ensured time series consistency, whilst making best use of good quality available data. Being based on reported consumption and emission data, this methodology is a considerable improvement on previous estimates.

4.36.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

4.36.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 10.** Details of verification of emissions are given in **Annex 6**.

4.36.5 Source Specific Recalculations

There have been no recalculations to emissions from this sector.

4.36.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

4.37 SOURCE CATEGORY 2G2A – MILITARY APPLICATIONS – AWACS

4.37.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2G2a – Military applications - AWACS	T1	D
Gases Reported	SF_6		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

Military applications include Airborne Warning and Control System (AWACS), which are military reconnaissance planes. In AWACS, the SF_6 is used as an insulating gas in the radar system.

4.37.2 Methodological Issues

A Tier 1 method, country specific activity data, and an IPCC default emission factor of 740 kg SF_6 per plane per year is used to estimate emissions.

The method use the total number of planes carrying AWACs as the activity data. ICF's research of the UK Royal Air Force (RAF) website confirmed that the RAF carries the same number of AWACS (seven) in 2012 as reported in the 2006 GLs (RAF, 2013). ICF further confirmed that RAF has had seven AWACS since 1990. Indeed, AWACS are a part of the Number 8 squadron of the RAF and they were acquired in 1985 (8 Squadron 2012). However, of the seven AWACS present in UK Fleet, not all are designated as forward available fleets. During times of low activity, some AWACS are placed as depth fleet, i.e., not operational, and therefore do not contribute to emissions. In 2012, only four AWACs were classified as forward available fields (MOD 2012), as we do not have data on how many are are in the forward fleet at any one date (with the exception of 2012) all 7 are conservatively assumed to be active in all years.

4.37.3 Uncertainties and Time Series Consistency

The Tier 1 method relies on a constant emission factor, but actual emissions will vary based on the number of sorties (missions), with emissions higher during periods of high military operations and lower during times of low military operations.

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

4.37.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Details of verification of emissions are given in **Annex 6**.

4.37.5 Source Specific Recalculations

There have been no recalculations to emissions from this sector.

4.37.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

4.38 SOURCE CATEGORY 2G2B – PARTICLE ACCELERATORS

4.38.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2G2b – Particle Accelerators	T2	D
Gases Reported	SF_6		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

Particle accelerators are used for research purposes (at universities and research institutions), for industrial applications (in cross-linking polymers for cable insulation and for rubber parts and hoses), and in medical (radiotherapy) applications.

Estimates of emissions in the UK are confined to those from research and university accelerators particle accelerators.

4.38.2 Methodological Issues

The emissions from industrial particle accelerators are a result of leakage during operation and repair. Research and industrial high voltage systems usually need to be opened more frequently than industrial low voltage accelerators. Hence the emission factor of low voltage industrial accelerators is comparably lower. In the case of radiotherapy applications, industrially pre-set particle accelerators with hollow conductors filled with SF_6 are used. The emissions of SF_6 are planned releases. Radiotherapy accelerators are typically opened two times a year when being serviced and the SF_6 contained is not captured but completely released. (Schwartz, 2005).

SF_6 emissions from research and university accelerators are estimated using an IPCC Tier 2 method – an accelerator-level emission-factor approach. This required information on the individual charge of the various research and university accelerators operating in the UK. This information is used in the following equation along with default emission factors (IPCC 2006):

Total emissions = University and research particle accelerator Emission Factor x Σ Individual Accelerator Charges

Where:

SF_6 university and research particle accelerator Emission Factor = 0.07 kg SF_6 per kg SF_6 charge, the average annual university and research particle accelerator emission rate as a fraction of the total charge.

Individual Accelerator Charges = SF_6 contained within each university and research accelerator.

The SF_6 emissions from medical and industrial accelerators are estimated using a Tier 1 method – country-level method. Given the scale of the number of medical and industrial particle accelerators, it was not feasible to collect individual charge information of each accelerator. The Tier 1 estimation method consists of the following equation, which relies on default emission factors (IPCC 2006):

Emissions = (number of particle accelerators that use SF_6 by process description in the country) x (SF_6 charge factor, kg) x (SF_6 applicable particle emission factor)

Where:

Number of particle accelerators by type in the country = The total number of particle accelerators by type (industrial high voltage, industrial low voltage and radiotherapy)

SF_6 charge factor = The average SF_6 charge in a particle accelerator by process description.

SF_6 particle accelerator Emission Factor = The average annual SF_6 particle accelerator emission rate as a fraction of the total charge by process description. These factors are presented in **Table 4.30** below.

Table 4.30 IPCC default Tier 1 particle accelerator emission factors

Process Description	SF_6 Charge Factor, kg	Emission Factor, kg/kgSF_6 charge
Industrial Particle Accelerators – high voltage (0.3-23 MV)	1300	0.07
Industrial Particle Accelerators – low voltage (<0.3 MV)	115	0.013
Medical (Radiotherapy)	0.5	2.0

For the Particle Accelerators sector, ICF (ICF 2014) contacted the Science and Technology Facilities Council (STFC) and the Cockcroft Institute to gather activity data for the Tier 1 and Tier 2 methods. STFC and the Cockcroft Institute were able to provide ICF with the charge information, years of operation and status of usage of SF_6 in the research and university particle accelerators in the UK. It is assumed that the charges of the accelerators are constant for all the years. For one facility whose charge was unavailable, a default charge in Tier 1 was assumed.

The Cockcroft Institute also provided an approximate estimate of the number of low voltage industrial accelerators in the UK for 2012—approximately 100 (Cockcroft Institute 2013). The total number of medical accelerators for 2012 was estimated from a list of accelerators compiled by a member of STFC, estimated at 50 (STFC, 2013). Due to the large number of medical and industrial accelerators, collecting accelerator-specific charge data was not feasible. Therefore, a Tier 1 approach was used to estimate emissions. To confirm the number of accelerators, ICF also solicited information from the National Physical Laboratory and the Institute of Engineering and Technology, but without success. In the absence of specific information on the number or percent of medical particle accelerators that use SF_6, ICF conservatively assumed that 100% of UK medical particle accelerators use and emit SF_6. To estimate SF_6 emissions for years 1990-2011 and 2013, emissions have been scaled from the 2012 estimate based on historical UK GDP growth rates.

4.38.3 Uncertainties and Time Series Consistency

Emissions of research and university particle accelerators are very high for the period 1990-1992. This is because of the operation of the Nuclear Structure Facility that held 135 tonnes of SF_6 charge. After its closure in 1992 (assumed to be at the end of 1992), the emissions of research and university particle accelerators and medical and industrial accelerators are comparable. In 2004, the only operational particle accelerator ceased usage of SF_6 and, hence, the emissions are considered to be zero. Three other particle accelerators began operation in 2010, 2011, and 2012, respectively, leading to non-zero but small SF_6 emissions due to their small charges.

For the medical and industrial particle accelerators, the emissions rise as they were estimated based on GDP as proxy.

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

4.38.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Details of verification of emissions are given in **Annex 6**.

4.38.5 Source Specific Recalculations

There have been no recalculations to emissions from this sector.

4.38.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

4.39 SOURCE CATEGORY 2G2E – SF_6 AND PFCS FROM OTHER PRODUCT USE

4.39.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2E1: Integrated circuit or semiconductor manufacture 2G2: SF_6 as a tracer gas 2G2: Training shoes (sporting goods)	T2a OTH T3	D CS CS
Gases Reported	PFCs, SF_6, NF_3		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	All relevant emissions from OTs and CDs are included within the UK totals for this sector. Emissions from sporting goods are calculated by scaling emissions from the UK model using a suitable scaling factor (population). There are no emissions from the manufacture of integrated circuits or semiconductor manufacture, and from training shoes, from the OTs and CDs.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements		

Emissions of PFCs and SF_6 from the production of semiconductors, the use of SF_6 as a tracer gas, and PFCs and SF_6 from sporting goods (training shoes) have been combined in order to preserve the confidentiality of estimates of emissions of SF_6 and PFCs used in training shoes.

4.39.1.1 Integrated circuit or semiconductor manufacture:

PFCs, SF_6 and NF_3 are released from activities in this source sector.

The electronics industry is one of the largest sources of PFC emissions in the UK. The main uses of PFCs are as follows:

- Cleaning of chambers used for chemical vapour deposition (CVD) processes;
- Dry plasma etching;
- Vapour phase soldering and vapour phase blanketing;
- Leak testing of hermetically sealed components; and
- Cooling liquids, e.g. in supercomputers or radar systems.

In addition SF_6 is used in etching processes for polysilicon and nitrite surfaces, and there is some usage of CHF_3 and NF_3.

4.39.1.2 Use of SF_6 as a tracer gas in scientific research:

The UK uses of SF_6 as a tracer in scientific research.

4.39.1.3 Use and disposal of training shoes:

A sports goods manufacturer selling shoes in the UK used SF_6 as a cushioning material in a range of training shoes from 1990 to 2003. Prior to 1990, the manufacturer used perfluoroethane (a PFC) for cushioning. SF_6 is well suited to this application because it is chemically and biologically inert and its high molecular weight means it cannot easily diffuse across membranes. This means the gas is not released until the training shoe is destroyed at the end of its useful life.

The manufacturer committed itself to eliminating SF_6 from its training shoes by 30 June 2003 – a goal which was achieved. It had originally planned to replace all SF_6 applications with nitrogen-filled cushioning but technical difficulties mean it had to switch temporarily to perfluoropropane (a PFC) in some high-performance applications. The use of F gases in footwear was banned in 2006 by the F-gas Regulation and discussions with the manufacturer have confirmed that they are no longer using PFCs or SF_6.

Cushioning units typically outlast the lifetime of the training shoe because the rate of diffusion of SF_6 is so slow. In the UK, training shoes are generally sent to landfill at the end of their useful lives, where any SF_6 or PFC will eventually leak to the atmosphere.

4.39.2 Methodological Issues

4.39.2.1 Semiconductor manufacture:

ICF (2014) updated estimates of emissions from this source.

The 2006 GLs provide an updated method for estimating semiconductor manufacture emissions as compared to the 2000 GPG. Specifically, the 2006 GLs include updated methodologies for each tier, updates to emission factors, as well as inclusion of other sectors in the electronics manufacturing source category – flat panels display manufacturing, and photovoltaic manufacturing. For the semiconductor manufacture sector, the 2006 GLs Tier 1 method estimates emissions based on the amount of substrate processed, in units of m^2. The Tier 1 method in the 2000 GPG most closely resembles the Tier 2a method of the 2006 GLs, which estimates emissions based on gas-specific consumption data, as well as the amount left in shipping containers after use, use rate of gas, fraction of gas used in processes with emission control technologies, and the fraction of gas destroyed by the emission control technology.

The 2006 GL Tier 2a method is represented by the following equation:

Emissions for $E_i = (1-h)*FC_i*(1-U_i)*(1-a_i*d_i)$

Where:

i = *F-gas species*

E_i = emissions of gas_i, kg

h = fraction of gas i remaining in container (heel)

FC_i = consumption of gas_i, kg

U_i = use rate of gas_i

a_i = abatement rate of gas_i

d_i = fraction of gas_i destroyed by the abatement

The Tier 2a method also introduces by-product emissions of CF_4, C_2F_6, C_3F_8 and CHF_3. In the 2000 GPG, by-product emissions were limited to only CF_4. The Tier 2a equation used for by-product emissions is:

By-Product Emissions of gas j $(BPE_{j,i}) = (1-h)*B_{j,i}*FC_i*(1-a_i*d_j)$

Where:

$BPE_{j,i}$ = by-product emissions of gas j from the gas i used, kg

$B_{j,i}$ = emission factor, kg gas j created/kg gas i used

d_j = fraction of gas j by-product destroyed by the abatement

j = CF_4, C_2F_6, CHF_3 and C_3F_8

The 2006 GLs also introduce updated emission factors, or use rates for gases. The destruction rates of abatement systems have been assumed to be the same in the 2006 GLs for all species except NF_3. The destruction rate of NF_3 has been updated to 0.95 from 0.90.

4.39.2.1.1 Approach to estimating emissions

ICF attempted to update consumption data based on actual consumption as opposed to the previous approach of estimating consumption based on growth rates. However, it was not feasible to collect individual gas collection data from each of the semiconductor manufacturers.

ICF identified several potential sources to use to update the activity data (i.e., consumption data) –notably, the National Microelectronics Institute (NMI) and European Semiconductor Industry Association (ESIA). ESIA collects industry F-gas emissions data at the European level and the data are not broken down by Member State; therefore UK-level emissions were not available via ESIA. ICF requested NMI to consult its members to ascertain availability of activity data, but no response was received in time for the analysis. Hence, the previous approach of estimating activity data based on assumed growth rates (which is compliant with the 2006 GLs) was kept.

The NF_3 consumption has been further sub-divided into NF_3 Remote Clean and all other NF_3 consumption (i.e., for in-situ chamber clean and etch processes). NF_3 remote clean refers to a cleaning method for chemical vapour deposition chambers in which the film cleaning-agents formed from NF_3 (F-atoms) are produced in a plasma upstream (remote) from the chamber being cleaned (IPCC 2006). In situ chamber cleans are chemical vapour deposition chamber cleaning processes, which may use NF_3 or other F-gases to generate F-atoms in the chambers whose walls are being cleaned. NF_3 may also be used to etch patterns (i.e., circuits) on semiconductors. The use of NF_3 remote clean is assumed to start in 2003 and growing increasingly over time. As no data on the UK's use of NF_3 remote clean processes was made available from NMI, the US semiconductor market was used as a proxy to estimate the use of NF_3 in remote clean processes relative to all other processes.

Specifically, the share of NF_3 remote clean versus other uses was estimated based on industry-reported NF_3 usage data from US semiconductor manufacturers for the years 2009 and 2010 (US EPA, 2011). This US data was readily available and is believed to be a good proxy for the UK given that semiconductor processes do not typically vary by world region. The ratio of NF_3 remote to other uses was interpolated for years between 2003 and 2009, assuming 0.0 (nil) in the year 2003. This was done as 2006 GLs provide emission factors for the NF_3 use in remote clean and NF_3 in-situ and etch use.

4.39.2.1.2 Emission factors and other default factors

The emission factors used in the updated inventory were taken from 2006 GLs. A summary of the emission factors for the 2006 GL Tier 2a method is provided in the table below.

Table 4.31 Summary of 2006 GL Tier 2a emission factors for the semiconductor manufacture sector

Process Gas (i)[a]	CF_4	C_2F_6	CHF_3	CH_2F_2	C_3F_8	c-C_4F_8	NF_3 Remote	NF_3	SF_6
Emission Factor (1-Ui)[b]	0.9	0.6	0.4	0.1	0.4	0.1	0.02	0.2	0.2
BCF_4	NA	0.2	0.07	0.08	0.1	0.1	0.02[c]	0.09	NA
BC_2F_6	NA	NA	NA	NA	NA	0.1	NA	NA	NA
BC_3F_8	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA = no data available based on information available during time of publication.

[a] Bx = X is a by-product from the usage of another gas (in row headings).

[b] Ui = Utilization rate of gas i.

[c] Estimate reflects presence of low-k, carbide and multi-gas etch processes that may contain C-containing FC additive.

The default value used for the fraction of gas remaining in the shipping container (heel) is 0.10, which is unchanged from the IPCC 2000 GPG. The destruction efficiencies for emission control technologies are updated according to the 2006 GLs. The new default values are unchanged from the 2000 GPG for all gases other than NF_3, 0.90. For NF_3, the default was updated from 0.90 to a new value of 0.95.

Table 4.32 Key assumptions used to estimate emissions from semiconductor manufacture

Gas	Destruction efficiency[40]	1990	1995	2000	2005	2010	2012 onwards
CF_4	0.9	0%	0%	0%	15%	40%	45%
C_2F_6	0.9	0%	0%	0%	15%	40%	45%
C_3F_8	0.9	0%	0%	0%	15%	40%	45%
C_4F_8	0.9	0%	0%	0%	15%	40%	45%
CHF_3	0.9	0%	0%	0%	15%	40%	45%
SF_6	0.9	0%	0%	0%	15%	40%	45%
NF_3	0.95	90%	90%	90%	100%	100%	100%

4.39.2.2 Use of SF_6 as a tracer gas in scientific research:

SF_6 is used in a number of applications in the UK

- Tracer gas to certify fume hoods; and
- UK studies of greenhouse gas emissions

ICF investigated the use of tracer gas to certify fume hoods.

The use of SF_6 as a tracer gas to certify fume hoods is a practice established by ASHRAE in the test procedure ASHRAE-110, “Method of Testing Performance of Laboratory Fume Hoods” (ASHRAE,1995). SF_6 is emitted in the fume hood and the concentration of the gas is measured after some time has passed. This is to ensure that the gases created under the fumes, toxic or otherwise, are properly ventilated. The amount of gas used per test is dependent on the tester. All of the SF_6 used in tracer tests is lost in the atmosphere and so the emissions are treated as prompt emissions—i.e., each test results in direct emissions of SF_6 (IPCC 2006). SF_6 is also used for tracer testing of nuclear power plant control room emergency ventilation systems (CARB, 2009).

Due to data limitations, SF_6 emissions were estimated using a slightly modified Equation 8.23 of Volume 3 of the 2006 GLs. The SF_6 emission is calculated on a per-use basis as opposed to the amount purchased/sold as provided in the equation. This modified method relies on the number of tracer tests conducted annually as the activity data, which when multiplied by the emissions per test as the emission factor, gives the total SF_6 emissions from this sector. This method is represented in the following equation:

Total emissions = emissions per test x number of tests

Additional emissions may also occur from bottling, leakage, and piping; however, such emissions cannot be estimated without activity data and are believed to be de minimis.

[40] Destruction Efficiency: Source: IPCC 2006 Guidelines, Chapter 6, Table 6.6

In order to apply the method above, ICF had to gather information on the number of tracer tests conducted annually (activity data) and the emissions per test (emission factor). ICF first identified various companies that performed fume hood tracer testing. ICF contacted the three largest companies that perform tracer tests in the UK (Crowthorne, Dale Flow, and Invent-UK) and obtained the company-specific emissions per test and the total number of tests performed in 2012 (Crowthorne 2013, Dale Flow 2013, Invent-UK 2013). For the prior years, the total numbers of tests have been estimated by scaling the number of tests performed in 2012 to the UK's historical GDP growth rate. The amount of emissions per test for prior years was held constant unless a company specified that the volume had increased after a certain period. The value of the emissions per test differed among companies and ranged from 0.033 to 0.046 kg SF_6 per test.

ICF also verified when these companies came into existence. Other, smaller companies were identified but were not contacted as—according to qualitative information from Dale Flow (2013)—the bulk of the market is covered by the three major companies, and any additional research was not expected to result in significant changes to the emission estimates, which only account for a very small share of total F-gas emissions.

ICF also contacted Sellafield Ltd, a nuclear decommissioning company, which uses SF_6 to conduct tracer tests, and included their company specific emission factor and total number of emissions (Sellafield, 2013).

Finally, ICF contacted the UK Nuclear Regulation Agency to confirm if there is any use of SF_6 in the tracer testing of nuclear power plant control room emergency ventilation systems in the UK. ICF was unable to obtain information because the inquiry did not fall within the remit of the Office of Nuclear Regulation/Health and Safety Executive. However, ICF experts believe that such use was replaced many years ago.

SF_6 is used as a tracer gas in UK studies of greenhouse gas emissions from ruminant livestock. It is currently the only viable way to measure emissions of methane from ruminant livestock individuals at pasture (Defra, *per. comm.*).

Emissions for this source, which are very small, are now included under 2F9 from 2011 onwards.

A small charge of SF_6 is stored in a permeation tube, which is then introduced to the rumen of the animal. The gas emissions are vacuum sampled from eructation via a tube near the animal's muzzle connected to an evacuated flask. The total CH_4 emissions are inferred from the differential concentrations of SF_6 and CH_4 between the flask and atmosphere.

The total amounts of SF_6 used are given in the table below:

Table 4.33 Quantities of SF_6 used in scientific research

Year	kg SF_6
2011	1.224
2012	1.433
2013	0.270
2014	0.273
Total	**3.200**

More details of the work can be found at www.ghgplatform.org.uk. This research project ended in 2014, so emissions from this source do not occur in 2015 onwards.

4.39.2.3 Use and disposal of training shoes:

Estimates of emissions from sports-shoes were based on a bottom-up Tier 2 estimate, using activity data supplied in confidence by the manufacturer.

A full description of the emissions and associated methodology used is contained in AEA (2004) and AEA (2008).

Speciated emissions for OTs and CDs are reported in this category. Emission estimates from the UK GHGI were scaled by population of each territory as appropriate.

4.39.3 Uncertainties and Time-Series Consistency

The trend in F-gas emissions between years 2003 and 2012 is the result of two competing characteristic features used in the emission estimation methodology – (1) the growth in usage due to assumed growth rates, leading to an increase in emissions; and (2) an increase in abatement practices, leading to a decrease in emissions. After the introduction of abatement practices, the emissions are estimated to decrease despite growth in the industry. However, beginning in 2011, it is observed that the increase in abatement is not enough to keep up with the growth in the industry, resulting in a slight overall increase in emissions.

Estimates of emissions in some categories of this sector are based on very limited and uncertain data, and are therefore uncertain.

More information on uncertainty data used in the uncertainty analysis is presented in **Annex 2**.

4.39.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Details of verification of emissions are given in **Annex 6**.

4.39.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10**.

4.39.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

4.40 SOURCE CATEGORY 2G3A – MEDICAL APPLICATIONS

4.40.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2G3a Medical applications	OTH	CS
Gases Reported	N_2O		
Key Categories	2G: Other Product Manufacture and Use – N_2O (L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	All relevant emissions from OTs and CDs are included within the UK totals for this sector. Emissions from medical applications are calculated by scaling emissions from the UK model using population as a scaling factor.		
Completeness	Emissions from medical applications in veterinary and dental practices and private hospitals are not accounted for; total emissions from these sources will be much smaller than the uncertainty in the conservative NHS estimate. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	None identified		

4.40.2 Methodological Issues

Nitrous oxide emissions from use as an anaesthesia was a new source estimated in the 2015 UK greenhouse gas inventory. A report was produced on the results of research on potential methodologies for a number of sources newly identified in the 2006 IPCC guidelines which includes finding on N_2O used as an anaesthetic[41].

Suppliers of N_2O declined to provide data, therefore emissions have been calculated using the outcomes of a study by NHS England (2013). This report calculates the total N_2O emissions based on the number of bed-days in NHS England 2011 – 2012, multiplied by the EU GHG inventory derived emission factor of 10.3 kg N_2O/bed/year[42]. This provides an estimated total N_2O emission of 1,641,147 kg per annum, arising from the use of anaesthetic at NHS England facilities. This is not the recommended methodology given in the 2006 IPCC guidelines, but as we have been unable to obtain the data required to follow the default methodology (sales of N_2O for anaesthetic use) this was considered the best approach to a country specific estimate for this source.

In order to expand this figure to incorporate all emissions within the United Kingdom a per-capita N_2O emission of 0.031 kg per annum has been derived from the total N_2O figure provided in the Carbon Footprint report. This has then been applied to the total population for the England, Wales, Scotland and Northern Ireland to provide a time-series of emissions.

[41] http://uk-air.defra.gov.uk/assets/documents/reports/cat07/1501271253_Impact_of_changes_to_IPCC_guidelines_report.pdf

[42] http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2013

4.40.3 Uncertainties and Time Series Consistency

As the duration of a patient's hospital stay can vary considerably, the use of bed-days as an indicator of N_2O should be considered to have a high degree of uncertainty. Additionally this methodology doesn't take into account N_2O used in non-NHS hospital environments (for example dental and veterinary practices or private hospitals), however total emissions from these sources are estimated to be much smaller than the uncertainty in the conservative NHS estimate.

The time series estimate does not consider trends in the uptake of alternative anaesthetics or alternative approaches to applying N_2O as an anaesthetic, as some methods can reduce the consumption of N_2O. Though using population as an indicator of trend should well reflect demand for anaesthetics, it would not take into account changing practices. We also make the assumption that the rest of the UK consumes anaesthetic in the same way as England.

4.40.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

4.40.5 Source Specific Recalculations

Population statistics has been slightly revised in 2013 and 2014 (ONS, 2016), causing extremely minor recalculations to the time-series.

For information on the magnitude of recalculations, see **Section 10**.

4.40.6 Source Specific Planned Improvements

The inventory team will continue to search for sources of data relating to the sales of N_2O for anaesthetic use, and will make improvements to the current methodology when this information is available.

4.41 SOURCE CATEGORY 2G3B – OTHER FOOD – CREAM CONSUMPTION

4.41.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2G3B Other Food – Cream Consumption	CS	OTH
Gases Reported	N_2O		
Key Categories	2G: Other Product Manufacture and Use – N_2O (L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	All relevant emissions from OTs and CDs are included within the UK totals for this sector. Emissions from cream consumption are calculated by scaling emissions from the UK model using GDP as a scaling factor.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**		
Major improvements since last submission	None		

Very little UK data are available on the use of N_2O in cream products, therefore the approach adopted has been based on the method used in the Danish GHG Inventory (Katja Hjelgaard, 2015). The method therefore assumes:

- 1% of cream consumption is in the form of whipped cream sprays;
- N_2O consumption in those sprays is equal to 5% of the mass of the cream; and
- All N_2O is emitted.

UK cream consumption data are available from Government (DEFRA) statistics (Drummond, 2016).

4.41.2 Uncertainties and Time Series Consistency

The UK method relies upon the assumption that UK consumption of whipped cream sprays is similar to that in Denmark i.e. 1% of total cream consumption. Overall cream consumption in Denmark and the UK are similar on a per-capita basis, but the market share of whipped cream sprays in the UK is not known, and so the 1% assumption is the most significant source of uncertainty for the UK estimates. The assumption regarding the 5% usage of N_2O relative to cream content is expected to be reasonable – there is no reason to think that the products sold in Denmark and the UK will differ significantly in design. UK cream consumption data are available for the full time-series from 1990 onwards.

4.41.3 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5.**

4.41.4 Source Specific Recalculations

Revisions to milk utilisation data from DEFRA statistics (Drummond, 2016) since 2012 causes a ~30% reduction in activity data from this source.

4.41.5 Source Specific Planned Improvements

No improvements are planned.

4.42 SOURCE CATEGORY 2G4 – CHEMICAL INDUSTRY – OTHER PROCESS SOURCES

4.42.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2G4 Chemical Industry – Other Process Sources	CS	CS
Gases Reported	N_2O		
Key Categories	2G: Other Product Manufacture and Use – N_2O (L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not applicable		
Completeness	All chemical manufacturing sites reporting significant quantities of N_2O, and where that emission is believed to be from a chemical process, rather than combustion, are included. Other sites do report N_2O emissions, but these emissions are small, and there is no evidence that they are from chemical processes. So the estimates are thought to be complete. Emissions from nitric and adipic acid are not included here, being reported in 2B2 and 2B3 instead.		
Major improvements since last submission	Addition of further process to the estimates.		

4.42.2 Methodological Issues

The UK has a large chemicals sector and all manufacturing sites are regulated and required to report emissions of N_2O (as well as other pollutants). From 1998, when reporting was first required, until 2001 there was no threshold for reporting N_2O, but since 2002, reporting is required only when emissions exceed 10 tonnes. Across the 17 years of reported data, N_2O emissions have been reported in at least one year for 19 sites which can loosely be described as chemical sites. For most of those sites, N_2O is reported for only one or two years out of the time-series and we think it is likely that the reported N_2O is an error (operators do occasionally confuse N_2O and NO_X on their reporting submissions) and in a few other cases it is likely that the N_2O occurs from the substantial combustion processes that constitute part of the reporting installation. In three cases however N_2O is reported in multiple years, from processes which are either known to emit the gas, or thought to be the most likely source:

- A process to manufacture nitrous oxide, and to transfer it into gas cylinders for sale. This process was commissioned in 2004;
- A further process manufacturing industrial gases, which probably also supplied nitrous oxide in cylinders and which closed in 2008;
- A catalyst manufacturing process which involves dissolving metals in nitric acid, leading to emissions of oxides of nitrogen (including both NO_X and N_2O). This process has been in operation since the 1940s.

Emission estimates are based on the data reported by the process operators to the Environment Agency for inclusion in the Pollution Inventory. A gap in the reported data for the first site listed above (for 2004) is filled by assuming that operation started half-way through the year and that emissions were 50% of the level reported in 2005. The second plant only reports N_2O back to 2002, but reports NO_x in 2002 as well, and also in 1997-2001. Emissions of N_2O in the years 1997-2001 are therefore assumed to follow the same trend as for NO_x back to 1997 and to be at 1997 levels prior to that. Emissions for the third site for the years 1990-1997 i.e. before reporting of N_2O was required, are assumed to follow the same trend as emissions of NO_x, which is reported back to 1995, and to be the same as in 1995 before that. Using this approach suggests that emissions from this plant were about 2 times higher in 1990 than in 1998, when data are first reported.

4.42.3 Uncertainties and Time Series Consistency

No reported emissions are available for one of the sites in operation during 1990-1997 and for another there is no data between 1990 and 2001 so we have had to estimate emissions using NO_x data where available, or to assume that emissions are the same as in later years. This is the most significant source of uncertainty in the estimates. It is possible but unlikely that other sites that report N_2O, emit the gas from chemical manufacturing processes but if this were the case, these emissions would be much smaller than those from the two sites currently included.

4.42.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5** and the source emissions data from plant operators is subject to the QA/QC procedures of the Environment Agency’s Pollution Inventory.

4.42.5 Source Specific Recalculations

One additional site has been added to the estimates for 1990-2008, and revisions have been made to the way we estimate emissions for years where no data are reported by the operators.

4.42.6 Source Specific Planned Improvements

The estimates will be kept under review, and additional sites added if appropriate.

4.43 SOURCE CATEGORY 2H1 – PULP AND PAPER INDUSTRY

4.43.1 Source Category Description

Emissions sources	2H1: Wood Products Manufacture
Gases Reported	NMVOC
Overseas Territories and Crown Dependencies Reporting	Not occurring
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.
Major improvements since last submission	No major improvements

The UK paper industry is mainly confined to the production of pulp from recycled material and the production of papers using either imported virgin pulp, recycled pulp or a combination of the two. Production of virgin pulp is limited to a few processes producing mechanical or neutral sulphite semi-chemical pulp. Emissions from UK paper processes consist largely of emissions from the associated combustion processes, which supply steam and power to the papermaking processes. These emissions are reported under CRF category 1A2d. Other atmospheric emissions of greenhouse gases from UK paper and pulp processes will be minor and are currently not estimated.

Emissions of NMVOC from the manufacture of chipboard, fibreboard and Oriented Strand Board (OSB) are reported under 2H1. These products differ in the type of wood material that is made into board. Chipboard is made from assorted wood shavings, dust & chippings etc., while fibreboard is made from mechanically pulped wood fibres and OSB is made from long, thin wafers of wood with fairly uniform dimensions. All three processes involve steps for drying of the wood particles and hot pressing of the formed board and both steps give rise to some NMVOC emissions.

4.43.2 Methodological Issues

Emissions of NMVOC from wood product manufacture are estimated using emission factors derived from those available in the USEPA Compilation of Air Emission Factors (USEPA, 2014). Production of the wood products is estimated from data published by the Office for National Statistics (2014). These data are given as areas or volumes of product depending upon the type of product and must be converted to a mass basis by making assumptions about the thickness and/or density of the products.

4.44 SOURCE CATEGORY 2H2 – FOOD AND BEVERAGES INDUSTRY

4.44.1 Source Category Description

Emissions sources	2H2: Brewing (barley malting, fermentation, wort boiling) Bread Baking Cider Manufacture Other Food (animal feed; cakes, biscuits, cereals; coffee, malting, margarine and other solid fats; meat, fish and poultry; sugar) Spirit Manufacture (barley malting, casking distillation, fermentation, maturation, spent grain drying) Wine Manufacture
Gases Reported	NMVOC
Overseas Territories and Crown Dependencies Reporting	Not occurring
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.
Major improvements since last submission	No major improvements

A number of food and drink manufacturing processes give rise to emissions of NMVOC. Most significant are emissions of ethanol from whisky maturation. Whisky is matured for a period of years in wooden barrels. This process develops the character of the whisky but an inevitable consequence is that spirit evaporates from the barrel. Other spirit manufacturing stages such as fermentation, distillation, casking (whisky only) and drying of spent grains also give rise to NMVOC emissions although these emissions are relatively small in comparison with those from maturation. Whisky manufacture is confined mainly to Scotland, which had 5 large grain distilleries and approximately 90 smaller malt distilleries at the end of 2015. There is a single small whisky distillery in Wales and a large whiskey distillery in Northern Ireland. Scotland and England also produce other distilled spirits such as gin and vodka, with production being concentrated in Scotland.

Malt production also creates emissions of NMVOC. Malting is occasionally carried out by distilleries but most malt, both for distillers and breweries, is produced by specialist maltsters. Brewing processes such as fermentation and wort boiling and fermentation for production of cider and wine are all very minor sources of NMVOC.

Bread manufacture involves fermentation reactions and ethanol is released as a result. Most bread in the UK is made in large mechanised bakeries, of which there are about 70. The remainder is made in small –'craft bakeries'. Some other baked products include a fermentation stage and also emit ethanol. Heating of food products can cause reactions that produce organic emissions, and so processes such as drying of vegetable matter, preparation of compounded animal foods and cooking of meat and fish can cause NMVOC emissions. Finally, the processing of oils and fats is also a source of emissions, although emissions of hexane, a solvent used to extract vegetable oil from rape and other oilseeds is included in estimates of solvent use rather than as a food industry emission.

Emissions of CO_2 from this category are not estimated since no appropriate data are available.

4.44.2 Methodological Issues

Emissions of NMVOC from food and drink manufacture are all calculated using emission factors and activity data obtained from either industry or Government sources. In the case of whisky maturation, data are available for volumes of whisky in storage at the end of each year from the Scotch Whisky Association (2016), and so emissions can be calculated by applying an annual emission rate factor with the average volume of whisky in storage for each year. This is more accurate than using an overall emission factor applied to whisky production since whiskies are stored for varying lengths of time and stock levels will rise or fall depending upon production, demand and changes in the length of maturation required.

NMVOC emission factors for food and drink are shown below.

Table 4.34 NMVOC Emission Factors for Food and Drink Processing, 2014

Food/Drink	Process	Emission Factor	Units
Beer	Wort Boiling Fermentation	0.0048[c] 0.02[c]	g/L beer
Cider	Fermentation	0.02[c]	g/L cider
Wine	Fermentation	0.2[c]	kg/m^3
Spirits	Fermentation Distillation Casking Spent grain drying Maturation	1.58[d] 0.79[g] 0.40[h] 1.31[i] 15.78[d]	g/ L alcohol g/ L alcohol g/ L whiskey kg/ t grain g/ L alcohol
Malting	Malting	4.8	Kg/tonne malt
Bread Baking		1[a]	kg/tonne
Meat, Fish & Poultry		0.3[f]	kg/tonne
Sugar		0.017[b]	kg/tonne
Margarine and solid cooking fat		10[f]	kg/tonne

Food/Drink	Process	Emission Factor	Units
Cakes, biscuits, breakfast cereal, animal feed		1[f]	kg/tonne
Malt production (exports)		4.8[c]	kg/ t grain
Coffee Roasting		0.55[f]	kg/tonne

a. Federation of Bakers (2000)
b. Environment Agency (2015)
c. Gibson *et al* (1995)
d. Passant *et al* (1993)
e. Assumes 0.1% loss of alcohol based on advice from distiller
f. EMEP/EEA, 2013
g. Unpublished figure provided by industry
h. Based on loss rate allowed by HMCE during casking operations
i. US EPA, 2007

5 Agriculture (CRF sector 3)

5.1 OVERVIEW OF SECTOR

IPCC Categories Included	3A: Enteric Fermentation 3B: Manure Management 3D: Agricultural Soils 3F: Field Burning of Agricultural Residues 3G: Liming 3H: Urea application
Gases Reported	CO_2, CH_4, N_2O, NO_x, CO, NMVOC, SO_2
Key Categories ('T' or 'L' indicates whether it has been identified in the trend or level assessment respectively and the number indicates which KCA approach it was identified in)	3A: Enteric Fermentation - CH_4 (L2, T2) 3A1: Enteric fermentation from Cattle - CH_4 (L1, T1) 3A2: Enteric fermentation from Sheep - CH_4 (L1, T1) 3B: Manure Management - N_2O (L2) 3B1: Manure management from Cattle - CH_4 (L1) 3D: Agricultural soils - N_2O (L1, T1, L2, T2)
Key Categories (Qualitative)	None identified
Overseas Territories and Crown Dependencies Reporting	Emissions for OTs and CDs are included for enteric fermentation, animal wastes and agricultural soils.
Completeness	A general assessment of completeness for the inventory is included in **Section 1.8**.
Major improvements since last submission	3A - DA-specific milk yields for dairy cattle have now been applied to the underlying calculations (based on DA statistical data), with weighted adjustments such that the UK average dairy cow milk yield equates with that published as UK Government statistics in Agriculture UK. 3D - Added emissions of N_2O via mineralisation from cropland management

The agriculture sector has the second largest contribution to total GHG emissions in the UK, after the energy sector. It contributes approximately 9.0% to the total emissions. The emissions from this sector have shown an overall decrease of 16% since 1990, reflecting trends in livestock numbers and emissions from fertiliser application.

Figure 5.1 Breakdown of total GHG emissions in the Agriculture sector in 2015

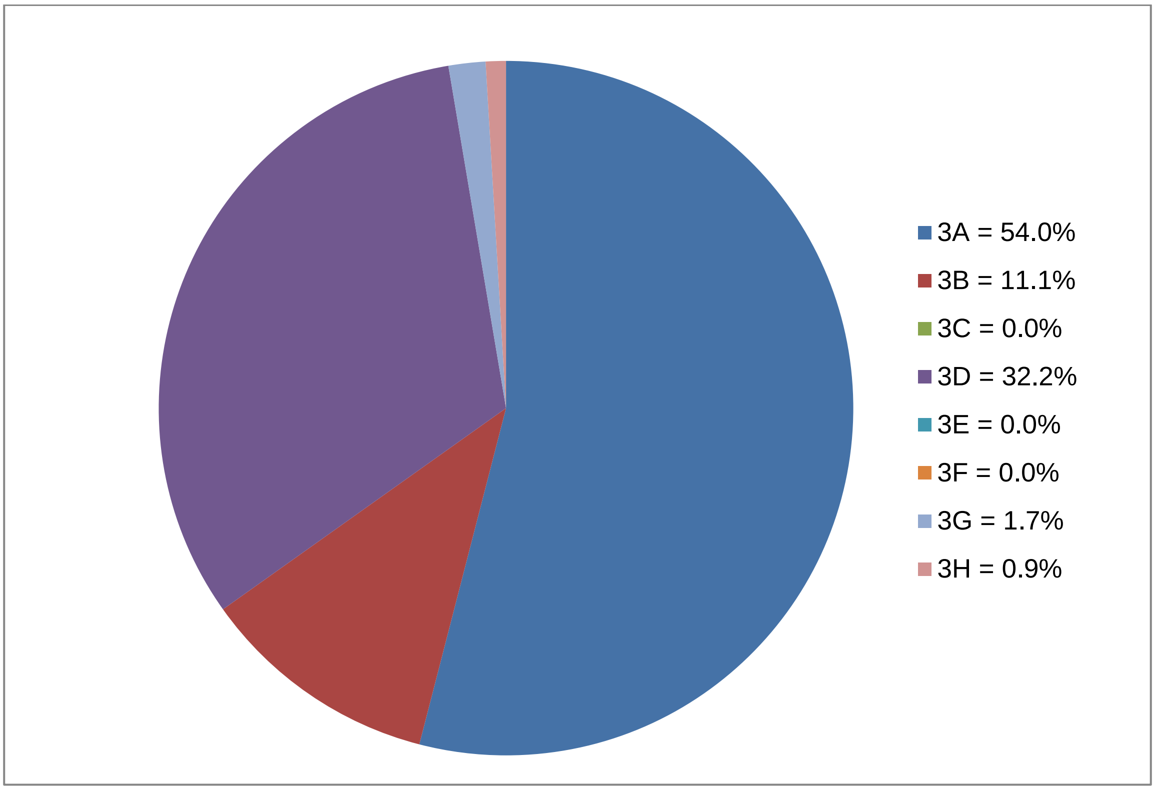
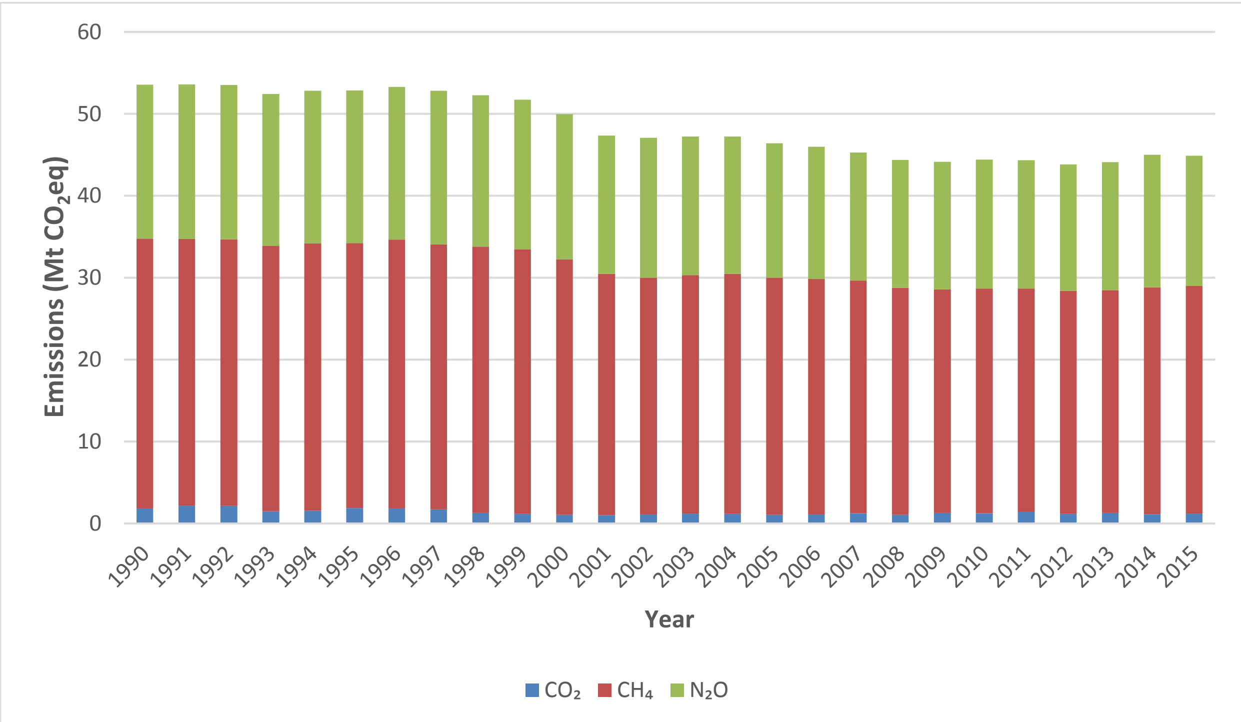


Figure 5.2 Trend in total GHG emissions in the Agriculture sector



5.2 SOURCE CATEGORY 3A – ENTERIC FERMENTATION

5.2.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3A1: Dairy Cows Enteric Beef Cows enteric Other Cattle Enteric 3A2: Sheep Enteric 3A3: Pigs Enteric 3A4: Goats Enteric 3A4: Horses Enteric 3A4: Deer Enteric	T2 T2 T1 T1 T1 T1 T1 T1	D,CS D,CS D D,CS D D D D
Gases Reported	CH_4		
Key Categories	3A: Enteric Fermentation - CH_4 (L2, T2) 3A1: Enteric fermentation from Cattle - CH_4 (L1, T1) 3A2: Enteric fermentation from Sheep - CH_4 (L1, T1)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	A separate category for all OTs and CDs livestock is used in the CRF (3A4). In the case of OTs, IPCC default emission factors were applied to animal numbers. For CDs, UK implied emission factors were applied. Tables of animal numbers used in calculations can be found in **Annex 3.3.**		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	DA-specific milk yields for dairy cattle have now been applied to the underlying calculations (based on DA statistical data), with weighted adjustments such that the UK average dairy cow milk yield equates with that published as UK Government statistics in Agriculture UK.		

Methane is produced in herbivores as a by-product of enteric fermentation. Enteric fermentation is a digestive process whereby carbohydrates are broken down by micro-organisms into simple molecules. Both ruminant animals (e.g. cattle and sheep), and non-ruminant animals (e.g. pigs and horses) produce CH_4, although ruminants are the largest source per unit of feed intake.

5.2.2 Methodological issues

Detailed information on activity data and emissions factors can be found in **Annex 3.3.1.**

Emissions from enteric fermentation are calculated from detailed animal livestock population data collected in the June Agricultural Census and the appropriate emission factors (see **Table A 3.3.3** in **Annex 3**). Livestock population data are reported annually as statistical outputs of the four Devolved Administrations of the UK (i.e. England, Wales, Scotland and Northern

Ireland), based on the annual June Agricultural Survey for each country[43]. These data are summed to provide UK population data for the livestock categories and subcategories as used in the inventory compilation (See **Tables A 3.3.1** and **A 3.3.2** in **Annex 3**). Data for earlier years are often revised so information was taken from the England and the Devolved Administrations' agricultural statistics databases.

Apart from dairy and beef cows, the methane emission factors are IPCC Tier 1 defaults (IPCC, 2006) and do not change from year to year. IPCC Tier 2 methods are implemented for dairy and beef cattle. For lambs we have adjusted the default EF to reflect UK conditions. Further details are available in Annexe 3.

5.2.2.1 Dairy cows

The dairy cattle emission factors (for dairy cows only) are estimated following the IPCC Tier 2 procedure (IPCC, 2006), using country-specific data for dairy cow live weight, milk yield, milk fat content, feed digestibility and activity (proportion of the year spent grazing) and vary from year to year (see **Tables A 3.3.4** and **A 3.3.5** in **Annex 3**). For dairy cows, the calculations are based on the population of the 'dairy breeding herd' which is defined as dairy cows over two years of age with offspring. DA-specific milk yields for dairy cattle have now been applied to the underlying calculations (based on DA statistical data[2]), with weighted adjustments such that the UK average dairy cow milk yield equates with that published as UK Government statistics in the Agriculture in the UK publication[3]. Mature weights for the different dairy size categories were obtained from an analysis of abattoir data (net carcase weight) from seven abattoir companies across Great Britain for the years 2008-2015 combined with British Cattle Movement Society (BCMS) data (analysis conducted by Tracy Pritchard, SRUC). Combining the datasets using ear tag identification enabled carcase weight to be linked with breed, gender, age, whether the animal had produced calves and location. Weighted means were obtained for all dairy females that had been slaughtered post-first calf, taking into account the average carcase weight and number of animals in different age groups. A killing out percentage of 47% was applied to all breeds (Juniper et al., 2006), although statistics are lacking on killing out percentage for different dairy breeds. The 1990-2007 time series was estimated by applying the ratio of the existing UK slaughter data to the estimated dairy liveweights for 2008-2015.

A country-specific value for the digestibility of feed (DE), expressed as a percentage of the gross energy, for dairy cows is used of 74.5%. This value is on the high side of the IPCC (2006) default value for Western Europe of 55-75% for pasture fed animals, but is based on typical diets for cows over the lactating and non-lactating period, combining forage and concentrates, with energy values for the various feeds according to MAFF (1990). The calculations used by national experts to derive a UK specific DE value are provided in **Tables A 3.3.5** and **A 3.3.6** in **Annex 3**. Details of the methodology are provided below:

To estimate feed intake, the UK uses an energy balance approach to estimate the metabolisable energy (ME) requirement for a dairy cow for a year including the lactating and non-lactating period. This accounts for the ME required for maintenance for the entire year, the ME required for milk production during the lactating period and the ME required for pregnancy. The UK has survey data on average concentrate feed use by dairy cows and use

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[43]Data derived as sum of totals for each Devolved Administration (i.e. England, Wales, Scotland and Northern Ireland), obtained from Devolved Administration statistical publications. June survey results: **England**: https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june and Sarah Thompson (DEFRA); **Scotland**: http://www.gov.scot/Topics/Statistics/Browse/Agriculture-Fisheries/PubAbstract; and Graeme Kerr (The Scottish Government); **Wales**: http://gov.wales/statistics-and-research/survey-agricultural-horticulture/?lang=en and John Bleasdale (Welsh Government); **Northern Ireland**: https://www.daera-ni.gov.uk/publications/farm-animal-population-data and Alison Afrifa (DAERA) and Ulrike Dragosits (CEH).

[2]**England & Wales**: Ben Drummond. **Scotland**: Mal.Cooke. **Northern Ireland**: William Taylor

[3]https://www.gov.uk/government/statistical-data-sets/agriculture-in-the-united-kingdom - chapter 8 livestock

these data to derive the amount of energy supplied by concentrates over the entire year. The value of typical concentrate use (not the required or recommended use) for a 7,000 litre yielding cow of 0.29 kg concentrates per litre of milk (Nix, 2009) is derived from such survey data. This does not represent the amount of concentrate feed required to meet the whole energy demand for milk production, but is the typical concentrate use on UK dairy farms for that level of milk yield. The digestibility (DE as % of GE) value for concentrate feed (c. 82%) is derived from the typical mix of protein and energy feed ingredients. Using this value, the annual ME requirement that has to be met from forage can then be derived. The relative proportions of concentrate to forage DM intake per year estimated in this way are 29% concentrate and 71% forage.

The UK does not have detailed survey data on amounts of different forages consumed by dairy cows, so the proportional annual breakdown (40% as fresh grass, 50% as grass silage, 10% as maize silage) is based on expert opinion (Bruce Cottrill, ADAS) taking into account the proportion of time spent at grazing by dairy cows and the amount of maize grown in the UK. The UK benefits from a relatively warm and wet maritime climate that is particularly suited to grassland production, as such grazing periods in the UK may be longer than those in other European countries. The UK is currently undertaking research to improve activity data on typical forage diets for a range of livestock production systems and aims to provide preliminary data feeding into the 2017 submission. The digestibility values for the different forage components are taken from MAFF 1990 (UK Tables of Nutritive Value and Chemical Composition of Feedingstuffs, 1990, Rowett Research Services Ltd). For grazed grass, the value used is not an average of all DE estimates for grass in this database, but is the value specifically given by MAFF 1990 for ‘Fresh grass (grazed) – all species’, which is taken to be representative of the annual average DE for grazed grass (compiled from a total of 244 samples taken throughout the grazing period, and includes grasses with ME values ranging from 7.2 to 14.1, across a range of species including hybrid rye grasses, perennial rye grasses and Tall Fescue). While some farms may specifically feed in-calf heifers and dry cows a poorer quality of forage, this is not considered typical for most dairy farms, where the animals will be receiving forage of the same quality. The details of the calculations are in the **Tables A 3.3.6** and **A 3.3.7** in **Annex 3**.

5.2.2.2 Beef cows

A Tier 2 methodology is used for the calculation of the enteric emissions from beef cows. Mature weights for the different beef size categories were obtained from an analysis of abattoir data (net carcase weight) from seven abattoir companies across Great Britain for the years 2008-2015 combined with British Cattle Movement Society (BCMS) data (analysis conducted by Tracy Pritchard, SRUC). Combining the datasets using ear tag identification enabled carcase weight to be linked with breed, gender, age, whether the animal had produced calves and location. Weighted means were obtained for all beef females that had been slaughtered post-first calf, taking into account the average carcase weight and number of animals in different age groups. A killing out percentage of 50% was applied to all breeds (Minchin et al., 2009), although statistics are lacking on killing out percentage for different beef breeds. The 1990-2007 time series was estimated by applying the ratio of the existing UK slaughter data to the estimated beef liveweights for 2008-2015. The main parameters involved in the calculation of the emissions factors for beef are shown in **Table A 3.3.8** in **Annex 3**. The digestibility value for beef cows used by the UK is 65% for annual average feed composition. This value is based on expert opinion (Bruce Cottrill, ADAS), reflecting the poorer quality diet that beef cows will generally receive in comparison with dairy cows. From the MAFF (1990) source cited above, the DE/GE of fresh grass in the category 8-10 ME is 0.63. For big bale silage - also widely used for beef cattle - in the categories 8-10 and 10-12 ME, the DE/GE ratios are 0.61 and 0.67. And diets of cattle reared predominantly on maize silage will have DE/GE values close to 0.65. NB: for comparison, Ireland reports digestibility of 78 and 71% for dairy and non-dairy cattle in their 1990-2012 inventory and New Zealand reports values of 75

%, for both dairy and non-dairy cattle in their 1990-2012 inventory. Milk yield for beef cows was from estimated from data published in Energy and protein requirements of ruminants (AFRC, 1993).

5.2.2.3 Other cattle

A Tier 1 methodology is used for the calculation of the emissions from other cattle with default EF (2006 guidelines, IPCC, 2006, **Table A 3.3.3** in **Annex 3**). The following six groups are included: dairy heifers, beef heifers, dairy replacements > 1 year, beef all other > 1 year, dairy calves < 1 year, beef calves < 1 year.

5.2.2.4 Sheep

The UK sheep production sector has a complex structure, with many different breeds of sheep and a range of hill, upland and lowland rearing and finishing systems. The UK is currently undertaking a programme of work to improve methodology for calculating emissions from this sector, which will include derivation of monthly sheep and lamb population models and country-specific emission factors. The current approach is to assume the IPCC Tier 1 default emission factor for enteric fermentation for all mature sheep (> 1 year old). Lambs have a lower average live weight than mature sheep and the majority have a lifespan of less than 12 months, and should therefore be associated with a lower emission factor than mature sheep. The UK therefore uses a country-specific emission factor for enteric fermentation for lambs at 40% of that of an adult sheep (Sneath et al. 1997) together with a reduction factor reflecting the reduced lifespan of lambs. The average lifespan of lambs is estimated by Wheeler et al. (2012) as 8.1 months. The animals under category 'other sheep' are largely barren ewes that will be slaughtered at some time during the year. These are therefore assumed to be alive for 6 months of the year, which is reflected in the emission calculation rather than the emission factor. These emission factors are assumed constant over the entire time series.

5.2.2.5 Other livestock

The UK emission factors for pigs, goats, horses and deer are default values (2006 guidelines).

5.2.2.6 Overseas Territories and Crown Dependencies

Emission estimates were compiled by Aether using animal numbers sourced from the territories directly and can be found in **Annex 3.6**. In the case of OTs, IPCC default emission factors were applied to animal numbers. For CDs, UK implied emission factors were applied.

5.2.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category.

Emissions are calculated from animal population data and appropriate emission factors. The animal population data are collected in the June Agricultural Census, published annually by the devolved administrations (i.e. England, Wales, Scotland and Northern Ireland). These are long running publications and the compilers of the activity data strive to use consistent methods to produce the activity data. The time-series consistency of these activity data is very good due to the continuity in data provided.

Control measures introduced in response to the BSE outbreak in the UK introduced an inconsistency in the slaughter weight statistics and the derived dairy cow live weights for the years 1997 to 2005. To correct for the artefacts introduced by these control measures in the data time-series, data for this period were interpolated using the linear trend of increasing lives weight with time for the years immediately prior to and following this period.

The estimates of uncertainties in emissions were calculated using Approach 2 (Monte Carlo simulation) described by the IPCC for 1990 and 2014. Activity data uncertainties were provided by the devolved administrations. Tier 2 methods were used to estimate the emission factors for dairy and beef cows and so we estimated the uncertainty in these emission factors by propagating the uncertainty through from the variables used to calculate the emission factors (see Milne et al., 2014). For all other animal categories we used the IPCC Tier 1 emission factors. We chose to use the maximum uncertainty range suggested by Eggleston et al. (2006). That is, ±50% of the expected value.

5.2.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.10**.

5.2.5 Source-specific recalculations

Details of and justifications for recalculations to activity data and to emission factors are given in **Table 5.1** and **Table 5.2**, respectively. For information on the magnitude of recalculations to Source Category 3A, see **Section 10** the 2006 guidelines have been adopted in this inventory.

Table 5.1 3A Source specific recalculations to activity data since previous submission

IPCC Category	Source Name	2016 submission 1990	2016 submission 2014	2017 submission 1990	2017 submission 2014	Units	Comment/Justification
3.A.1	Enteric Fermentation - Cattle	872.25	758.01	875.32	763.44	kt	Added country-specific dairy cow milk yield timeseries (1990-2015). Updated dairy and beef cow live weights timeseries (1990-2015). Updated livestock housing periods to be consistent with NH_3 inventory. Updated cattle numbers for England (1999-2000) and Wales (2007) to be consistent with the published census data.
3.A.2	Enteric Fermentation - Sheep	222.02	169.69	222.44	169.69	kt	Updated sheep numbers for England (1990-2000) and Scotland (2009 and 2011) to be consistent with the published census data (which resulted in reallocation of animals between categories for England from 1990-2000).
3.A.3	Enteric Fermentation - Swine	11.32	7.22	11.32	7.22	kt	Updated pig numbers for England (1999-2000) and Scotland (2009) to be consistent with the published census data.
3.A.4	Enteric Fermentation - Horses	10.26	17.78	10.26	17.77	kt	Updated horse numbers for NI (1996, 1997, 2013, 2014).
3.A.4	Enteric Fermentation - Goats	0.49	0.500	0.49	0.50	kt	Updated goat numbers for Scotland (2009) to be consistent with the published census data.

Table 5.2 3A Recalculations to Emission Factors since the previous inventory

IPCC Category	Source Name	2016 submission 1990	2016 submission 2014	2017 submission 1990	2017 submission 2014	Units	Comment/Justification
3.A.1	Enteric fermentation - Dairy cows - Non-dairy cows	100.885 62.596	130.854 64.669	101.512 62.733	132.492 64.972	kg CH_4 head^{-1} yr^{-1}	As IPCC category 3.A.1 above
3.A.2	Enteric fermentation - Sheep	4.993	5.029	5.002	5.029	kg CH_4 head^{-1} yr^{-1}	As IPCC category 3.A.2 above. Although the individual EF's have not changed for adult sheep and lambs; the overall IEF for sheep has changed from 1990-2000 for England due to the reallocation of animals between the adult sheep/lamb categories.

5.2.6 Source-specific planned improvements

Emission factors and activity data will be reviewed. The Tier 2 structure will be incorporated for all key animal categories (cattle, pigs and sheep) and calculations included when activity data are available.

5.3 SOURCE CATEGORY 3B – MANURE MANAGEMENT

5.3.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3B11: Dairy Cattle Wastes Other Cattle Wastes 3B12: Sheep Wastes 3B13: Pigs Wastes 3B14: Goats Wastes 3B14: Horses Wastes 3B14: Broilers Wastes Laying Hens Wastes Other Poultry Wastes 3B14: Deer Wastes	T2 T2 T2 T2 T2 T2 T2 T2 T2 T1,T2	CS, D CS, D CS, D CS, D CS, D CS, D CS, D CS, D CS, D D
Gases Reported	CH_4, N_2O		
Key Categories	3B: Manure Management - N_2O (L2) 3B1: Manure management from Cattle - CH_4 (L1)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	In the case of OTs, IPCC default emission factors were applied to the data. For CDs, UK implied emission factors were applied for both CH_4 and N_2O. Animal numbers can be found in **Annex 3.6**.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	None.		

This category reports emissions of CH_4 from animal manures as well as N_2O emissions from their manures arising during its storage.

5.3.2 Methodological issues

5.3.2.1 Methane emissions from animal manures

Methane is produced from the decomposition of manure under anaerobic conditions. When manure is stored or treated as a liquid in a lagoon, pond or tank it tends to decompose anaerobically and produce a significant quantity of methane. When manure is handled as a solid or when it is deposited on pastures, it tends to decompose aerobically and little or no methane is produced. Hence the system of manure management used affects emission rates. Emissions of methane from animal manures are calculated from livestock population data provided by the devolved administrations as described in **Section 5.2.2**. The emission factors are listed in **Table A 3.3.3** in **Annex 3**. **Table A 3.3.10** in **Annex 3** shows the methane conversion factors assumed for the different systems.

The emission factors for manure management are calculated following IPCC Tier 2 methodology using default IPCC data for volatile solids (VS) and methane producing potential (B_o) parameters for each livestock type (except for dairy and beef cows, where a Tier 2 calculation (IPCC 2006, Equation 10.24) is used to determine VS, and deer where we use Tier 1 IPCC default methodology and emission factor); country-specific data for the proportion of manure from each livestock type managed according to the different animal waste management systems (AWMS) and IPCC default methane conversion factors for the different AWMS (IPCC 2006, Table 10.17). The emission factors are listed in **Table A 3.3.3** in **Annex 3**. **Table A 3.3.10** in **Annex 3** shows the methane conversion factors assumed for the different systems.

Emission factors and underlying data for dairy cows, beef cows and other cattle are given in **Tables A 3.3.11** to **A 3.3.13** in **Annex 3.**

Country-specific data on the proportion of manure managed in the different AWMS data derive from a number of sources, including published ad-hoc surveys (Manure Management report, Ken Smith); Smith et al 2000, 2001a,b; C Savery & B Cottrill, ADAS, pers comm.; ADAS 1990-2000; Sheppard, 1998, 2002; BSFP 2007 - 2013 (Table D1.5); T. Watcher (EPR), pers. comm.; MMS 1996).More recently, relevant data from the Farm Practices Surveys for England and a time series is included to reflect changes in practice over time (data for 2015 are given in **Table A 3.3.12** in **Annex 3.**).

5.3.2.2 Nitrous Oxide emissions from Animal Waste Management Systems

Animals are assumed not to give rise to nitrous oxide emissions directly, but emissions will arise from N excreted by livestock. Emissions from manures during storage are calculated for a number of animal waste management systems (AWMS) defined by IPCC. Calculation follows IPCC (2006) (equation 10.25) for each livestock category and subcategory, using country-specific data for nitrogen excretion by the different livestock types and for the proportion of manure managed according to the different AWMS, and default emission factors for the different AWMS. Country-specific values for nitrogen excretion per head for the different livestock types were derived from the report of Defra project WT0715NVZ (Cottrill and Smith, 2007) with interpretation by Cottrill and Smith (ADAS) **Table A 3.3.11** in **Annex 3**. N excretion for dairy cattle is derived from a relationship with annual milk yield (Cottrill and Smith, 2007). The proportion of manure managed in the different systems as described in **Section 5.3.2.1.**

The conversion of excreted N into N_2O emissions is determined by the type of manure management system used. The distribution of waste management systems for each animal type ($AWMS_{(T)}$) is given in **Table A 3.3.12** in **Annex 3**. Emissions from poultry are calculated following IPCC (2006) where manure is allocated to poultry with or without bedding or destined for incineration.

Emissions from the following AWMS are reported under the Manure Management IPCC category:

- Uncovered anaerobic lagoons. These are assumed not to be in use in the UK;
- Liquid/slurry;
- Deep bedding (previously deep litter); and
- Poultry manure with/without bedding or destined for incineration; IPCC (2006).

According to IPCC (2006) guidelines, the following AWMS are reported in the Agricultural Soils category:

- All animal manures and slurries applied to soils; and
- Pasture range and paddock

Emissions from the combustion of poultry bedding for electricity generation are reported under power stations. Emissions occurring during storage of poultry bedding that will later be used for energy generation are included in the agricultural inventory (tonnage of poultry bedding incinerated obtained directly from EPR (Teresa Wachter Fuel Operations Manager, Energy Power Resources Limited), a total of 602,000 tonnes for 2015.

Indirect N_2O emissions from manure management comprise N volatilisation from manure management systems calculated using Equation 10.27 (IPCC 2006 guidelines), along with country specific fractions ($Frac_{GasMS}$), derived directly from the UK agriculture ammonia emission inventory, for N loss due to volatilisation of NH_3 and NO_x, disaggregated by manure management system. Emissions of N_2O from the leaching/runoff associated with the storage of deep bedding as field heaps have been estimated using Equation 10.29 (IPCC 2006 guidelines) with a country specific $Frac_{LEACH}$ value of 0.03 (Nicholson et al., 2011).

Table A 3.3.13 in **Annex 3** gives the N_2O emission factor for each animal waste management system ($EF3_{(AWMS)}$). These are expressed as the emission of N_2O-N per mass of excreted N processed by the waste management system.

5.3.2.3 Emissions in the Overseas Territories and Crown Dependencies

Animal numbers are sourced from the territories directly and can be found in **Annex 3.6**. In the case of OTs, IPCC default emissions factors were applied to the data. For CDs, UK implied emission factors were applied to the data, both for CH_4 and N_2O.

5.3.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category.

Emissions are calculated from livestock population data and appropriate emission factors. The livestock population data are collected in the June Agricultural Census, published annually by the devolved administrations (i.e. England, Wales, Scotland and Northern Ireland). These are long running publications and the compilers of the activity data strive to use consistent methods to produce the activity data. The time-series consistency of these activity data is very good due to the continuity in data provided.

The estimates of uncertainties in emissions were calculated using Approach 2 (Monte Carlo simulation) described by the IPCC. The uncertainties in the estimates of livestock data were provided by the devolved administrations. Tier 2 calculations were used to estimate the emission factors for methane emissions from manure management for all of the animal categories except for deer. We assumed that uncertainty in the calculated emission factors was normally distributed, with a 95% confidence interval of ±20 % of the expected value for Tier 2 emission factors and with a 95% confidence interval of ±30 % of the mean for Tier 1 (Eggleston et al., 2006). We followed the IPCC recommendation and assumed uncertainties for N excretion were ±50 % for all animal categories except for dairy cows in 2015. This category was based on more accurately determined statistics and so we assumed ±25 % as advised in the 2006 guidelines. Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures which are discussed in **Section 5.10.**

5.3.4 Source-specific recalculations

Details of and justifications for recalculations to activity data and to emission factors are given in **Table 5.3** and **Table 5.4** respectively. For information on the magnitude of recalculations to Source Category 3B, see **Section 10**.

Table 5.3 3B Source specific recalculations to activity data since previous submission

IPCC Category	Source Name	2016 submission		2017 submission		Units	Comment/Justification
		1990	2014	1990	2014		
3.B.1.1	- Methane Emissions from Manure Management - Cattle	121.630	102.853	122.025	103.483	kt	Added country-specific dairy cow milk yield timeseries (1990-2015). Updated dairy and beef cow live weights timeseries (1990-2015). Updated livestock housing periods to be consistent with NH_3 inventory. Updated cattle numbers for England (1999-2000) and Wales (2007) to be consistent with the published census data.
3.B.1.2	Methane Emissions from Manure Management – Sheep	8.651	6.612	8.668	6.612	kt	Updated sheep numbers for England (1990-2000) and Scotland (2009 and 2011) to be consistent with the published census data (which resulted in reallocation of animals between categories for England from 1990-2000).
3.B.1.3	Methane Emissions from Manure Management - Swine	43.615	25.075	43.615	25.075	kt	Updated pig numbers for England (1999-2000) and Scotland (2009) to be consistent with the published census data.
3.B.1.4	Methane Emissions from Manure Management – Horses	0.890	1.544	0.890	1.543	kt	Updated horse numbers for NI (1996, 1997, 2013, 2014).
3.B.1.4	- Methane Emissions from Manure Management – Goats	0.030	0.031	0.030	0.031	kt	Updated goat numbers for Scotland (2009) to be consistent with the published census data.
3.B.1.4	Methane Emissions from Manure Management – Deer	0.010	0.007	0.010	0.007	kt	Updated deer numbers for Scotland (2004, 2007, 2009) to be consistent with the published census data.

IPCC Category	Source Name	2016 submission		2017 submission		Units	Comment/Justification
		1990	2014	1990	2014		
3.B.1.4	Methane Emissions from Manure Management – Poultry	2.509	3.350	2.549	3.350	kt	Updated poultry numbers for all DA's throughout timeseries (1990-2015). Updated AWMS timeseries based on a recent review of the available data (1990-2015).
3.B.2.1	Nitrous oxide Emissions from Manure Management - Cattle	3.6948	3.0294	3.6954	3.0280	kt	Added country-specific dairy cow milk yield timeseries (1990-2015). Updated cattle numbers for England (1999-2000) and Wales (2007) to be consistent with the published census data.
3.B.2.2	Nitrous oxide Emissions from Manure Management – Sheep	0.15404	0.11783	0.15449	0.11783	kt	Updated sheep numbers for England (1990-2000) and Scotland (2009 and 2011) to be consistent with the published census data (which resulted in reallocation of animals between categories for England from 1990-2000).
3.B.1.3	Nitrous oxide Emissions from Manure Management - Swine	0.6102	0.3757	0.6102	0.3757	kt	Updated pig numbers for England (1999-2000) and Scotland (2009) to be consistent with the published census data.
3.B.1.4	Nitrous oxide Emissions from Manure Management – Goats	0.0026	0.0027	0.0026	0.0027	kt	Updated goat numbers for Scotland (2009) to be consistent with the published census data.
3.B.1.4	Nitrous oxide Emissions from Manure Management – Deer	0.0024	0.0016	0.0024	0.0016	kt	Updated deer numbers for Scotland (2004, 2007, 2009) to be consistent with the published census data.
3.B.2.4	Nitrous oxide Emissions from Manure Management – Poultry	0.1450	0.1491	0.1458	0.1491	kt	Updated poultry numbers for all DA's throughout timeseries (1990-2015).

IPCC Category	Source Name	2016 submission		2017 submission		Units	Comment/Justification
		1990	2014	1990	2014		
							Updated AWMS timeseries based on a recent review of the available data (1990-2015).
3.B.2.5	Nitrous oxide Emissions from Manure Management – Indirect emissions - Atmospheric deposition - Leaching and runoff	1.3345 0.0452	1.2275 0.0347	1.2801 0.0453	1.1819 0.0347	kt	Country-specific $Frac_{GasMS}$ values updated to reflect changes in the NH_3 inventory. Updated AWMS timeseries based on a recent review of the available data (1990-2015). Added country-specific dairy cow milk yield timeseries (1990-2015). Updated: Cattle numbers for England (1999-2000) and Wales (2007); sheep numbers for England (1990-2000) and Scotland (2009); pig numbers for England (1999-2000) and Scotland (2009); goat numbers for Scotland (2009 and 2011); deer numbers for Scotland (2004, 2007, 2009) and poultry numbers for all DA's throughout timeseries (1990-2015) to be consistent with published census data.

Table 5.4 3B Recalculations to Emission Factors since the previous inventory

IPCC Category	Source Name	2016 submission		2017 submission		Units	Comment/Justification
		1990	2014	1990	2014		
	-						

IPCC Category	Source Name	2016 submission 1990	2016 submission 2014	2017 submission 1990	2017 submission 2014	Units	Comment/Justification
3.B.1.1	Methane Emissions from Manure Management - Dairy cows - Non-dairy cows	14.0628 8.7301	17.5156 8.8301	14.1507 8.7455	17.7263 8.8603	kg CH_4/hd/yr	As IPCC category 3.B.1.1 above
3.B.1.2	- Methane Emissions from Manure Management - Sheep	0.1945	0.19560	0.1949	0.1960	kg CH_4/hd/yr	As IPCC category 3.B.1.2 above. Although the individual EF's have not changed for adult sheep and lambs; the overall IEF for sheep has changed from 1990-2000 for England due to the reallocation of animals between the adult sheep/lamb categories.
3.B.1.4	Methane Emissions from Manure Management - Poultry -	0.0196	0.0197	0.0199	0.0197	kg CH_4/hd/yr	As IPCC category 3.B.1.4 above
3.B.2.1	Nitrous oxide Emissions from Manure Management - Dairy cows - Non-dairy cows	0.4352 0.2627	0.5175 0.2597	0.4355 0.2627	0.5168 0.2597	kg N_2O/hd/yr	As IPCC category 3.B.2.1 above
3.B.2.2	- Nitrous oxide Emissions from Manure Management – Sheep	0.00346	0.00349	0.00347	0.00349	kg N_2O/hd/yr	As IPCC category 3.B.2.2 above. Although the individual EF's have not changed for adult sheep and lambs; the overall IEF for sheep has changed from 1990-2000 for England due to the reallocation of animals between the adult sheep/lamb categories.
3.B.2.4	- Nitrous oxide Emissions from Manure Management – Poultry	0.00113	0.00088	0.00114	0.00088	kg N_2O/hd/yr	As IPCC category 3.B.2.4 above

5.3.5 Source-specific planned improvements

Emission factors and activity data will be reviewed including the use of more detailed emission factors and activity data to improve emission estimates and allow estimation of the effect of future mitigation policies.

5.4 SOURCE CATEGORY 3C – RICE CULTIVATION

This source is not relevant in the UK.

5.5 SOURCE CATEGORY 3D – AGRICULTURAL SOILS

5.5.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3D1: Direct N_2O Emissions From Managed Soils 3D2: Indirect N_2O Emissions From Managed Soil	T2, T1 T2,T1,CS	D, CS D, CS
Gases Reported	N_2O		
Key Categories	3D: Agricultural soils - N_2O (L1, T1, L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Emissions included under 3D1.7 'other' within the CRF. In the case of OTs, IPCC default emission factors were applied to the data. For CDs, UK implied emission factors were applied.		
Completeness	A general assessment of completeness for the inventory is included in **Section 1.8.**		
Major improvements since last submission	Added emissions of N_2O via mineralisation from cropland management		

Direct emissions of nitrous oxide from agricultural soils are estimated using the IPCC recommended methodology (IPCC, 2006) but incorporating country specific EFs and UK specific parameters. The IPCC method involves estimating contributions from:

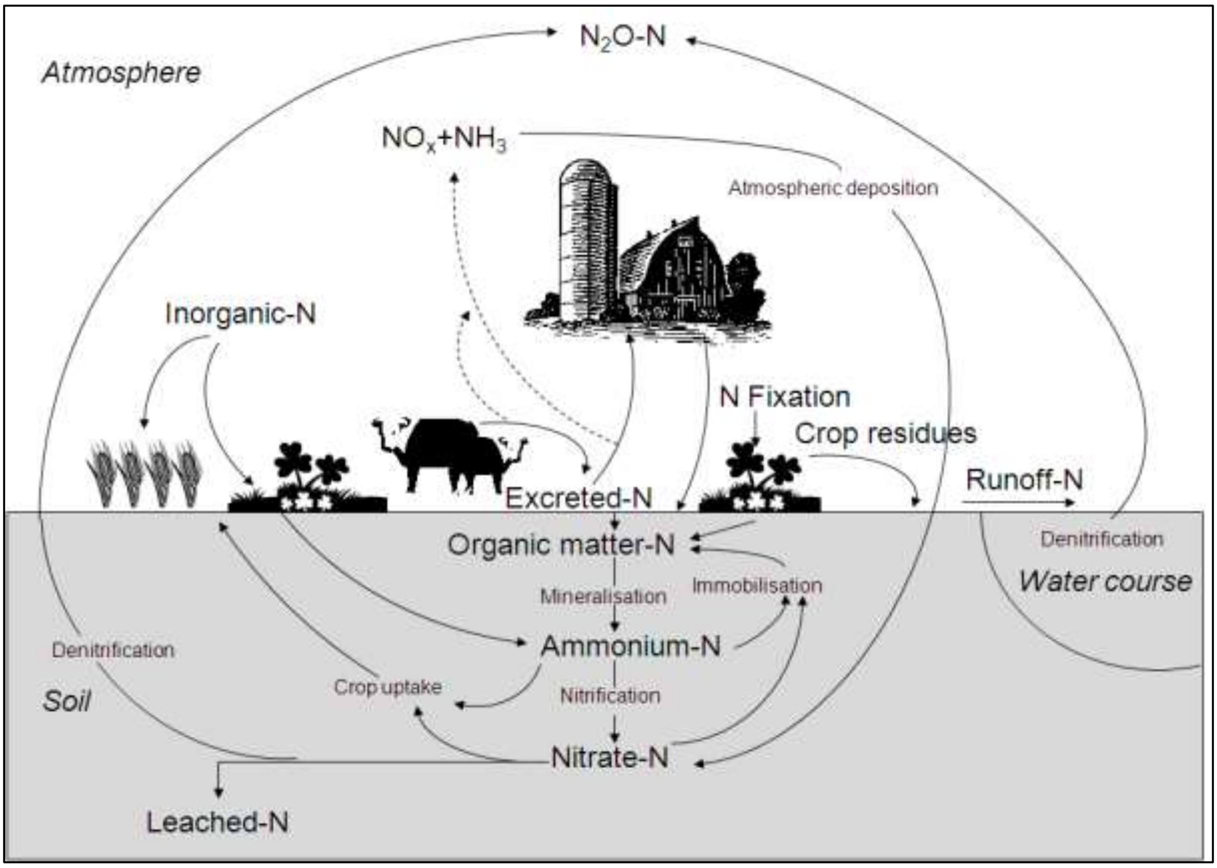
(i) The use of inorganic fertilizer
(ii) Application of livestock manures to land
(iii) Application of sewage sludge to land
(iv) Urine and dung deposited by grazing animals in the field
(v) Crop residues returned to soils
(vi) Mineralisation
(vii) Cultivation of histosols (organic soils)

In addition to these, the following indirect emission sources are estimated:

(viii) Emission of N_2O from atmospheric deposition of agricultural NO_x and NH_3 (from (i),(ii),(iii) and (iv))
(ix) Emission of N_2O from leaching and run-off of agricultural nitrate (from (i),(ii),(iii),(iv),(v) and (vi))

Descriptions of the methods used are described in **Section 5.5.2**. A nitrogen cycle is included to describe the sources of N_2O from agriculture (**Figure 5.3**).

Figure 5.3 Simplified nitrogen cycle highlighting the steps involved in the production of N_2O from agriculture.



5.5.2 Methodological issues

In addition to N_2O emissions from mineralisation of Soil Organic Matter (SOM) as a result of Land Use Change to Cropland, we have added N_2O emissions from mineralisation of SOM resulting from Cropland Management activities on Cropland Remaining Cropland. Detailed information on estimation of change in SOM due to Cropland Management is presented in **Annex 3.4**. Emissions of N_2O are estimated from the change in SOM using Tier 1 methodology.

5.5.2.1 Inorganic Fertiliser

Emissions from the application of inorganic fertilizer are calculated using the IPCC (2006) Tier 2 methodology (equation 11.1). Country specific emission factors (EF_1) are applied to different fertiliser types and land use (see **Table A 3.3.14**).

Annual consumption of synthetic fertilizer is estimated based on crop areas from the Devolved Administrations[44] and the British Survey of Fertiliser Practice (plus country-specific data for Northern Ireland provided by Paul Caskie, DARDNI) as shown in **Table A 3.3.15** in **Annex 3**.

[44]**England**: https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june and Sarah Thompson (DEFRA). **Scotland**: http://www.gov.scot/Topics/Statistics/Browse/Agriculture-Fisheries/PubAbstract/; and Graeme Kerr (The Scottish Government). **Wales:** http://gov.wales/statistics-and-research/survey-agricultural-horticulture/?lang=en and John Bleasdale (Welsh Government). **Northern Ireland**: http://www.daera-ni.gov.uk/publications/crop-and-grass-areas-1981-crops-2015, Alison Alfrifa (DAERA).

Table A 3.3.16 in **Annex 3** shows the trend in areas and fertiliser N application rates for the major crop categories over the period 1990-2015.

5.5.2.2 Application of livestock manures to land

Following the IPCC guidance, emissions from animal manures and slurries used as organic fertilizers are reported under agricultural soils using IPCC Tier 2 methodology and country-specific data for the amount of manure nitrogen applied to the land. Country specific emission factors (EF_1), derived from the results of Defra project AC0116, are applied to different manure types; for liquid (including daily spread) manure an EF_1 of 0.00601 kg N_2O-N/kg N input is used and for deep bedding an EF1 of 0.00364 kg N_2O-N/kg N input is used.

The summation is for all animal types and manure previously stored in categories defined as a) liquid, b) deep bedding and c) poultry manure without bedding and poultry manure with bedding and destined for incineration.

The UK follows the 2006 guidelines. This assumes that a significant proportion of the total N excreted by animals in managed systems is lost prior to final application to managed soils. The estimate of managed manure N available for application to managed soils is based on equation 10.34 in the 2006GL which takes account of the total nitrogen loss from manure management ($Frac_{LossMS}$) which are country specific values derived directly from the UK agriculture ammonia emission inventory, and N added in the form of bedding, disaggregated by manure management system. For daily spreading of manure and application of previously stored manures to land, the emission is given by equation 11.1 of the 2006 guidelines. The summation is for all animal types and manure that is daily spread or previously stored in categories defined as a) liquid, b) deep bedding and c) other (poultry manure without bedding or poultry manure with bedding). The fraction of livestock N excretion in excrements burned for fuel is expressed as a fraction of all livestock groups N.

5.5.2.3 Application of sewage sludge to land

Following the 2006 IPCC guidelines, emissions from sewage sludge used as fertilizer are reported under agricultural soils. The calculation involves estimating the amount of nitrogen contained per dry matter unit of sludge that is applied to land and applying IPCC emission factors (see **Table A 3.3.17**). Data sources for the annual production of sewage sludge (as dry matter) are described in Waste sector, see **Section 7**.

The UK follows the 2006 IPCC guidelines (equation 11.1).

5.5.2.4 Urine and dung deposited by grazing animals in the field

Emissions from urine and dung deposited by grazing animals are reported under agricultural soils by IPCC. The method of calculation is the same as that for AWMS (**Section 5.3.2.2**), using country-specific emissions factors (EF_3) derived from experimental studies carried out under Defra project AC0116. Although no experiments were conducted for sheep grazing returns, the default IPCC EF_3 value for sheep was replaced by the UK cattle value to avoid the anomaly of the sheep EF being greater than the cattle EF, contrary to the IPCC defaults (**Table A 3.3.13** in **Annex 3**).

5.5.2.5 Crop Residues returned to soils

Emissions of nitrous oxide from the ploughing in of crop residues are calculated using the 2006 guidelines methodology and IPCC default emission factors using equation 11.1 of the 2006 IPCC guidelines.

Production data of crops are taken from various sources[45] and are shown in **Table A 3.3.19** in **Annex 3**. The dry mass fraction of crops and residue fraction are given in **Table A 3.3.18** in **Annex 3**. Field burning has largely ceased in the UK since 1993. For years prior to 1993, field-burning data were taken from the annual MAFF Straw Disposal Survey (MAFF, 1995). Dry matter contents of crops are derived from Burton (1982), Nix (1997), PGRE (1998), and BLRA (1998).

5.5.2.6 Mineralisation

N_2O emissions from mineralisation of soil organic matter on land converted to Cropland more than 20 years ago are included in the Agricultural inventory (emissions from more recent land use change are included in the LULUCF inventory). The emissions are estimated using the areas of Forest land and Grassland converted to Cropland from the land use change matrices. The land use change matrices are calculated from the Monitoring Landscape Change (MLC) data from 1947 & 1980 (MLC 1986) and the Countryside Surveys (CS) of 1984, 1990, 1998 (Haines-Young et al. 2000) and 2007 (Smart et al. 2009) for Great Britain. For Northern Ireland the data comes from the Northern Ireland Countryside Surveys of 1990, 1998 (Cooper and McCann 2002) and 2007 (Cooper, McCann and Rogers 2009).

N_2O emissions from mineralisation of soil organic matter as a result of Cropland Management activities are estimated from the change in soil carbon stocks due to Cropland Management using a Tier 1 approach. The methodology used to assess change in soil carbon stocks due to Cropland Management is described in **Section 6.3.4** and **Annex A 3.4.2.2**

5.5.2.7 Cultivation of histosols (organic soils)

Emissions from histosols are estimated using the IPCC (2006) default factor of 8 kg N_2O-N/ha/yr. The area of cultivated histosols is estimated at 285,700 ha (as in **Annex 3.3.3.7**).

5.5.2.8 Atmospheric deposition of NO_X and NH_3

Indirect emissions of N_2O from the atmospheric deposition of ammonia and NO_x are estimated according to the 2006 IPCC guidelines using default EF4 for fertiliser N application and manure application to soils, and country specific value derived directly from the UK agriculture ammonia emission inventory, for the fraction of N that is volatilised ($Frac_{GASF}$ and $Frac_{GASM}$, respectively). Another source of NH_3 and NO_x is sewage sludge applied to soils for which the default EF4 is used. Equation 11.9 of the 2006 IPCC guidelines was applied.

The method used corrects for the N content of manures used as fuel (poultry bedding incineration).

5.5.2.9 Leaching and runoff

Indirect emissions of N_2O from leaching and runoff are estimated according the 2006 IPCC guidelines using equation 11.10 and the default nitrogen leaching/runoff factor (EF5). The sources of nitrogen considered are synthetic fertiliser application, animal manures and sewage sludge applied to soils, excretal grazing returns (dung and urine), crop residues and

[45] Data includes England, Wales, Scotland and Northern Ireland; Cereal and oilseed production for England, Wales, Scotland, Northern Ireland: https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june; Rye, mixed corn and triticale production for England, Wales, Northern Ireland: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/468190/Minor cereals 2015; Linseed, sugar beet, peas and beans (dry) production for England, Wales, Northern Ireland: https://www.gov.uk/government/statistical-data-sets/agriculture-in-the-united-kingdom - chapter 7 crops; Vegetable production for England, Wales, Northern Ireland: BHS vegetable survey, https://www.gov.uk/government/statistics/horticulture-statistics-2015; Potato and maize production for England and Wales: Allan Howsam (DEFRA); All other production data for Wales: John Bleasdale (Welsh Government); All other production data for Scotland: Paul Gona (The Scottish Government); All other production data for Northern Ireland: https://www.daera-ni.gov.uk/publications/statistics-crop-production-form-1981.

mineralisation. The fraction of N that is leached ($Frac_{LEACH}$) is a country specific value (0.1) for both inorganic fertiliser applied to grassland and excretal returns from grazing livestock, based on a modelling study using the NITCAT model at a UK county level dissagregation (Cardenas et al., 2013). For fertiliser to arable land, crop residues, sewage sludge and manure application to land the default $Frac_{LEACH}$ value (0.3) is used as this was supported by Cardenas et al (2013). For mineralisation the default value was also used (0.3).

The method used corrects for the N content of manures used as fuel (poultry bedding incineration).

5.5.2.10 Overseas Territories and Crown Dependencies

The Tier 1 methodology from the IPCC Guidelines was applied to calculate emissions from agricultural soils for the OTs and CDs. Livestock data were provided from each of the OTs/ CDs. The quantity of synthetic fertiliser applied was obtained directly from OTs and crop production was sourced from FAO. Cropland and grassland area was provided by Defra, and can be found **Annex 3.6**. Emission factors taken from the 2006 IPCC guidelines and Western European emission factors were applied to all CDs (Isle of Man, Guernsey and Jersey) whilst Latin American emission factors were applied to all OTs with significant agricultural sectors (Cayman Islands, Falkland Islands, and Bermuda). In the case of OTs, IPCC default emission factors were applied to the data. For CDs, UK implied emission factors were applied.

5.5.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category.

Emissions are calculated from a range of activity data and appropriate emission factors (see **Annex 3**). Emissions of N_2O from the use of fertilizers are important in this source category. The annual consumption of synthetic fertilizer is estimated based on crop areas (crop area data reported annually by the Devolved Administrations) and fertilizer application rates (reported annually in the British Survey of Fertiliser Practice). These are both long running datasets and the compilers of the activity data strive to use consistent methods to produce the activity data. The time-series consistency of these activity data is very good due to the continuity in data provided.

The estimates of uncertainties in emissions were calculated using Approach 2 (Monte Carlo simulation) described by the IPCC. The uncertainties in the estimates of crop areas were provided by the devolved administrations, and the uncertainties in estimates of fertilizer application rates to crops were calculated from the British Survey of Fertilizer Practice (BSFP). Together these give estimates of fertilizer use. Estimates of the uncertainty in the amount of sewage applied to the land, the nitrogen returned as crop residues and nitrogen from biological fixation were based on Monni et al. (2007) and for estimates of uncertainties associated with nitrogen excretion we followed the IPCC guidelines (Penman et al., 2000) (for more details see Milne et al., 2014). The uncertainties in the new UK specific emission factors and model parameters were calculated from the data used to derive the emission factors. In other cases the uncertainty was taken from the IPCC guidelines.

5.5.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.10.**

5.5.5 Source-specific recalculations

We have included emissions from mineralisation from Cropland Management. Urea use data time series was revised for Northern Ireland.

Details of and justifications for recalculations to activity data are given in **Table 5.5**. For information on the magnitude of recalculations to Source Category 3D, see **Section 10.**

Table 5.5 3D Source specific recalculations to activity data since previous submission

IPCC Category	Source Name	2016 submission		2017 submission		Units	Comment/Justification
		1990	2014	1990	2014		
3.D.1.1	Direct Nitrous Oxide Emissions from Managed Soils – Inorganic N fertilisers	25.33	16.87	25.30	16.87	kt	Updated crop areas timeseries (1990-2015). Updated urea and UAN values to reflect updates in the NH_3 inventory (1990-2015).
3.D.1.2	Direct Nitrous Oxide Emissions from Managed Soils – Organic N fertilisers (Animal manure)	3.01	2.34	3.03	2.35	kt	Country-specific $Frac_{LossMS}$ values updated to reflect changes in the NH_3 inventory (1990-2015). Updated AWMS timeseries based on a recent review of the available data (1990-2015). Updated: Cattle numbers for England (1999-2000) and Wales (2007); sheep numbers for England (1990-2000) and Scotland (2009 and 2011); pig numbers for England (1999-2000) and Scotland (2009); goat numbers for Scotland (2009); deer numbers for Scotland (2004, 2007, 2009) and poultry numbers for all DA's throughout timeseries (1990-2015) to be consistent with published census data. Added country-specific dairy cow milk yield timeseries (1990-2015). Updated livestock housing periods to be consistent with NH_3 inventory.

IPCC Category	Source Name	2016 submission		2017 submission		Units	Comment/Justification
		1990	2014	1990	2014		
3.D.1.3	Direct Nitrous Oxide Emissions from Managed Soils –Urine and dung deposited by Grazing Animals	4.88	4.27	4.89	4.27	kt	Updated: Cattle numbers for England (1999-2000) and Wales (2007); sheep numbers for England (1990-2000) and Scotland (2009 and 2011); pig numbers for England (1999-2000) and Scotland (2009); goat numbers for Scotland (2009); deer numbers for Scotland (2004, 2007, 2009) and poultry numbers for all DA's throughout timeseries (1990-2015) to be consistent with published census data. Added country-specific dairy cow milk yield timeseries (1990-2015). Updated AWMS timeseries based on a recent review of the available data (1990-2015).
3.D.1.4	Direct Nitrous Oxide Emissions from Managed Soils –Crop residues	8.76	10.39	8.69	10.39	kt	Updated crop production timeseries (1990-2015) to be consistent with published census data.
3.D.1.5	Direct Nitrous Oxide Emissions from Managed Soils - Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter	0.39	0.88	0.62	1.39	kt	Updated mineralisation data timeseries as supplied by CEH (1990-2015). The updates comprise: a) correction of error in the conversion factor used to convert change in soil carbon stock to N_2O. b) updates to the land use change matrices which affect emissions from land conversion to Cropland c) inclusion of N_2O emission from soils as a result of Cropland Management for the first time

IPCC Category	Source Name	2016 submission		2017 submission		Units	Comment/Justification
		1990	2014	1990	2014		
3.D.2.1	Indirect Nitrous Oxide Emissions from Managed Soils – Atmospheric Deposition	2.03	1.75	2.04	1.75	kt	Country-specific $Frac_{GASF}$, $Frac_{GasM}$ and $Frac_{LossMS}$ values updated to reflect changes in the NH_3 inventory (1990-2015). Updated: Cattle numbers for England (1999-2000) and Wales (2007); sheep numbers for England (1990-2000) and Scotland (2009 and 2011); pig numbers for England (1999-2000) and Scotland (2009); goat numbers for Scotland (2009); deer numbers for Scotland (2004, 2007, 2009) and poultry numbers for all DA's throughout timeseries (1990-2015) to be consistent with published census data. Added country-specific dairy cow milk yield timeseries (1990-2015). Updated AWMS timeseries based on a recent review of the available data (1990-2015). Updated livestock housing periods to be consistent with NH_3 inventory.

IPCC Category	Source Name	2016 submission		2017 submission		Units	Comment/Justification
		1990	2014	1990	2014		
3.D.2.2	Indirect Emissions – Nitrogen Leaching and Runoff	7.89	7.36	8.03	7.68	kt	Country-specific $Frac_{LossMS}$ values updated to reflect changes in the NH_3 inventory (1990-2015). Updated: Cattle numbers for England (1999-2000) and Wales (2007); sheep numbers for England (1990-2000) and Scotland (2009 and 2011); pig numbers for England (1999-2000) and Scotland (2009); goat numbers for Scotland (2009); deer numbers for Scotland (2004, 2007, 2009) and poultry numbers for all DA's throughout timeseries (1990-2015) to be consistent with published census data. Added country-specific dairy cow milk yield timeseries (1990-2015). Updated AWMS timeseries based on a recent review of the available data (1990-2015). Updated crop area and production timeseries (1990-2015) to be consistent with published census data. Updated livestock housing periods to be consistent with NH_3 inventory. Updated mineralisation data timeseries as supplied by CEH (1990-2015).

Table 5.6 Recalculations since the previous inventory

IPCC Category	Source Name	2016 submission		2017 submission		Units	Comment/Justification
		1990	2014	1990	2014		
3.D.1.1	Direct Nitrous Oxide Emissions from Managed Soils – Inorganic N fertilisers	0.010261	0.009327	0.010259	0.009327	kg N_2O-N/kg N	As IPCC category 3.D.1.1 above
3.D.1.2	Direct Nitrous Oxide Emissions from Managed Soils – Organic N fertilisers (Animal manure)	0.004581	0.004605	0.004572	0.004597	kg N_2O-N/kg N	As IPCC category 3.D.1.2 above

5.5.6 Source-specific planned improvements

Emission factors and activity data will be kept under review. UK emission factors are currently under review for:

- EF1, emissions fro agricultural soils
- EF5, nitrogen leaching/runoff factor; from a field measurement programme

5.6 SOURCE CATEGORY 3E – PRESCRIBED BURNING OF SAVANNAS

This source is not relevant in the UK.

5.7 SOURCE CATEGORY 3F – FIELD BURNING OF AGRICULTURAL RESIDUES

5.7.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3F11: Wheat 3F12: Barley	T1 T1	D D
Gases Reported	CH_4, N_2O, NO_x, CO, NMVOC, SO_2		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	No data available for this source. No emissions reported		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8.**		
Major improvements since last submission	None		

This sector covers the emissions of non-CO_2 greenhouse gases from the burning (in the field) of crop residue and other agricultural waste on site.

5.7.2 Methodological issues

The National Atmospheric Emissions Inventory reports emissions from field burning under the category agricultural incineration. The estimates are derived from emission factors calculated according to IPCC (1997) and from USEPA (1997).

The estimates of the masses of residue burnt of barley, oats, wheat and linseed are based on crop production data (Lindsay Holmes, DEFRA (England & Wales), Nicola Kerr, The Scottish Government and Alison Lambert, Conor McCormack, DAERA) and data on the fraction of crop residues burnt (MAFF, 1995; ADAS, 1995). Field burning ceased in 1993 in England and Wales. Burning in Scotland and Northern Ireland is considered negligible, so no estimates are reported from 1993 onwards. The carbon dioxide emissions are not estimated because these are part of the annual carbon cycle.

5.7.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2**, shown in **Table A 7.4.1**, provides estimates of uncertainty according to IPCC source category.

Field burning ceased in 1994, and emissions are reported as NO after this date.

5.7.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.10.**

5.7.5 Source-specific recalculations

Crop areas were updated.

Table 5.7 Source Category 3F – Source specific recalculations to activity data since previous submission

IPCC Category	Source Name	2016 submission		2017 submission		Units	Comment/Justification
		1990	2014	1990	2014		
3.F	Field burning	0.21309	0.00000	0.21297	0.00000	kt	Updated crop area timeseries (1990-2015) to be consistent with published census data.

5.7.6 Source-specific planned improvements

No improvements are planned.

5.8 SOURCE CATEGORY 3G - LIMING

5.8.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3G1: Limestone $CaCO_3$ 3G2: Dolomite $CaMg(CO_3)_2$	T1 T1	D D
Gases Reported	CO_2		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Emissions from 3G1 have been estimated for CDs. Emissions for OTs have not been estimated.		
Completeness	A general assessment of completeness for the inventory is included in **Section 1.8**		
Major improvements since last submission	None		

CO_2 emissions due to the application of lime and related compounds are estimated by CEH using the Tier 1 methodology from the IPCC 2006 Guidelines. For calcium carbonate (limestone, chalk and LimeX (an emission factor of 120 tC/kt applied is used, and for dolomite application, 130 tC/kt. These factors are based on the stoichiometry of the CO_2 loss from the carbonates and assume pure limestone/chalk and dolomite. The calcium carbonate content of LimeX (a bi-product of sugar refining) is taken to be 46% based on data from British Sugar.

5.8.2 Methodological issues

The sources of activity data for liming of Agricultural Land are the Minerals Extraction in Great Britain reports, the British Sugar website, the British Survey of Fertiliser Practice, the June Agricultural Censuses and the Statistical Review of Northern Ireland Agriculture. In the LULUCF NIR this has been mentioned in the section “Information on approaches used for representing land areas and on land use databases used for the inventory preparation.

It is assumed that all Cropland is limed and that the areas of Grassland receiving lime are judged pasture grassland (short term (<5 years old) and permanent grassland (>5 years old)) areas reported in the annual June Agricultural Census and the proportion of grassland receiving lime reported in the British Survey of Fertiliser Practice (2015). It is assumed that no lime is applied to unimproved rough grazing.

The amount of lime, dolomite and chalk produced for agricultural use annually in Great Britain is reported in the report annual report on Minerals Extraction in Great Britain (ONS 2016a) (available from 1994, sourced from BGS for 1990-1994). As Minerals Extraction in Great Britain date for 2015 were unavailable data for 2014 were rolled forward to give the 2015 values. These will be revised when data for 2015 are published. All such minerals are assumed to be used within Great Britain in the year of production. Only dolomite is subjected to calcination. However, some of this calcinated dolomite is not suitable for steel making and is returned for addition to agricultural dolomite – this fraction is reported annually by the Office for National Statistics (ONS 2016a) as ‘material for calcination’ under agricultural end use. Calcinated dolomite, having already had its CO_2 removed, will therefore not cause emissions of CO_2 and hence is not included here. Lime (calcinated limestone) is also used for carbonation in the refining of sugar and is been included in the inventory. The amount of lime purchased annually for agricultural use in Northern Ireland is reported in the Statistical Review of Northern Ireland Agriculture (Department of Agriculture, Environment and Rural Affairs, 2015). It is assumed that this is all limestone, as there are limestone deposits but no dolomite deposits in Northern Ireland.

In the UK lime is applied to both grassland and cropland. Totals areas of grassland and cropland are obtained from annual June Agricultural Census data. The annual percentages of arable and grassland areas receiving lime in administration in Great Britain for 1994-2015 were obtained from the British Survey of Fertiliser Practice (ONS 2016b). Percentages for 1990-1993 were assumed to be equal to those for 1994.

LimeX, by-product of sugar production, is used as a liming material but and therefore not included in BGS data on quarried liming products. Use of LimeX for agricultural liming is estimated using an approximate annual as value quoted on the British Sugar website http://www.britishsugar.co.uk/LimeX.aspx as the exact sales of LimeX are commercially confidential. LimeX is made up of two products with different carbonate content and the median value of these was used to calculate emission as data on the use of each product is commercial confidential.

5.8.2.1 Overseas Territories and Crown Dependencies

Emission estimates are provided for Isle of Man, Jersey and Guernsey, and are calculated by CEH. Emissions from Liming don’t occur in the Falkland’s, and this category has not been estimated in the Caymans. These emissions, however, are thought to include both Limestone and Dolomite, but data characreristics mean emissions from either rocky type canot be split. As the IPCC 2006 default emission factor in this case refers to Limestone, these emissions have been allocated accordingly.

5.8.3 Uncertainties and time-series consistency

Uncertainty in both the activity data and emission factor are judged to be low. The main source of uncertainty in the estimates is caused by non-publication of some activity data due to commercial restrictions although these are not judged to be very significant.

There is good time series consistency as there has been continuity in the published data sources.

5.8.4 Source-specific QA/QC and verification

Emissions from liming are calculated by the Centre for Ecology and Hydrology (CEH) which has adopted the quality assurance principles set out in the Joint Code of Practice for Research issued by the Biotechnology and Biological Sciences Research Council, the Department for Environment, Food and Rural Affairs, the Food Standards Agency and the Natural Environment Research Council. CEH is currently in the process of applying for ISO9001, the internationally recognised standard for the quality management of businesses.

In addition to internal quality assurance procedures the submitted inventory data is also checked by Ricardo Energy & Environment (the national inventory compilers) and the European Commission.

In collaboration with Ricardo Energy & Environment, CEH has been developing a QA/QC plan to standardise and structure the way checks on inventory data are carried out. The plan is now being implemented and will be reviewed and updated as required. The QA/QC Plan is embedded into all planning, preparation and management activities of the Inventory. The plan sets out five key Data Quality Objectives (DQOs), covering all principles of Transparency, Consistency, Completeness, Comparability and Accuracy, which help to focus the aims of the annual checking.

5.8.5 Source-specific recalculations

None

Table 5.8 3G Source specific recalculations to activity data since previous submission

IPCC Cate gory	Source Name	2016 submission		2017 submission		Unit s	Comment/Justification
		1990	2014	1990	2014		
3.G	Liming	1576.48	1037.96	1576.48	786.46	kt	Added 2015 liming data and updated 2014 provisional data as supplied by CEH.

5.9 SOURCE CATEGORY 3H - UREA APPLICATION

5.9.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3H: Urea Application	T1	D
Gases Reported	CO_2		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Emissions from 3H have been estimated for all OTs and CDs, excluding the Falkland Islands		
Completeness	A general assessment of completeness for the inventory is included in **Section 1.8**		
Major improvements since last submission	None		

CO_2 emissions due to the application of urea and related compounds are estimated using the Tier 1 methodology from the IPCC 2006 Guidelines.

5.9.2 Methodological issues

The annual amount of fertiliser as urea and urea ammonium nitrate (UAN) used in ktN was taken from the NH_3 inventory and values came from the BSFP. Both fertilisers are applied to grassland and cropland in the UK. It was assumed that 35% of UAN was urea. The EF used was the IPCC default value of 0.2 tonne of C tonnes of urea^{-1}.

5.9.2.1 Overseas Territories and Crown Dependencies

For all Crown Dependencies, emissions have been estimated applying implied emission factors for urea application per hectare, sourced directly from Rothamsted, to cropland and grassland landcover data. . For the Cayman Islands, the amount of urea applied was provided by the focal point, and IPCC default value used for the estimates. Emissions for the Falklands Islands and Bermuda were not calculated due to lack of data availability.

5.9.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category.

Emissions are calculated from activity data and appropriate emission factors (see **Section A 3.5.3**). No uncertainty was calculated in the inventory - we assumed that all C in urea is converted to CO_2. According to the IPCC (2006) a default uncertainty of -50% may be applied (Note: uncertainties cannot exceed the default emission factor because this value represents the absolute maximum emissions associated with urea fertilization)

5.9.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.10**

5.9.5 Source-specific recalculations

None.

Table 5.10 3F Source specific recalculations to activity data since previous submission

IPCC Category	Source Name	2016 submission		2017 submission		Units	Comment/Justification
		1990	2014	1990	2014		
3.H	Urea application	250.76	350.96	252.19	350.96	kt	Updated fertiliser values (to reflect updates in the NH_3 inventory).

5.10 GENERAL COMMENTS ON QA/QC

The livestock activity data used for constructing the inventory is supplied annually from the June census[1], which follow documented QA procedures. Activity data on mineral fertiliser are calculated using application rates from Defra's annual British Survey of Fertiliser Practice (BSFP) multiplied by crop areas from the June Census. Data from the June Census, in the form of *.PDF files, can be downloaded from the Devolved Administrations websites and incorporated into inventory spreadsheets without the need for manual data entry, eliminating the need for double entry procedures. Annual comparisons of emission factors and other coefficients used are made by contractors compiling the inventory on behalf of Defra and by Defra itself. Any changes are documented in the spreadsheet and in the accompanying chapter of the National Inventory Report. Hardcopies of the submitted inventories, associated emails and copies of activity data are filed in Government secure files adhering to Government rules on document management.

Defra contractors who work on compiling the agricultural inventory, Rothamsted Research, operate strict internal quality assurance systems with a management team for each project overseen by an experienced scientist with expertise in the topic area. A Laboratory Notebook scheme provides quality control through all phases of the research and these are archived in secure facilities at the end of the project. All experiments are approved by a consultant statistician at each of the planning, data analysis and interpretation and synthesis stages. A range of internal checks exists to ensure that projects run to schedule, and internal and external (*viz*. visiting group procedures, etc.) reviews ensure the quality of the outputs.

The data for livestock numbers and crop areas are supplemented by data provided by the Centre for Ecology and Hydrology (U. Dragosits) for England, Scotland and Northern Ireland but not Wales. The livestock and crop area data are also used to generate the NH_3 inventory.

6 Land-Use, Land Use Change and Forestry (CRF Sector 4)

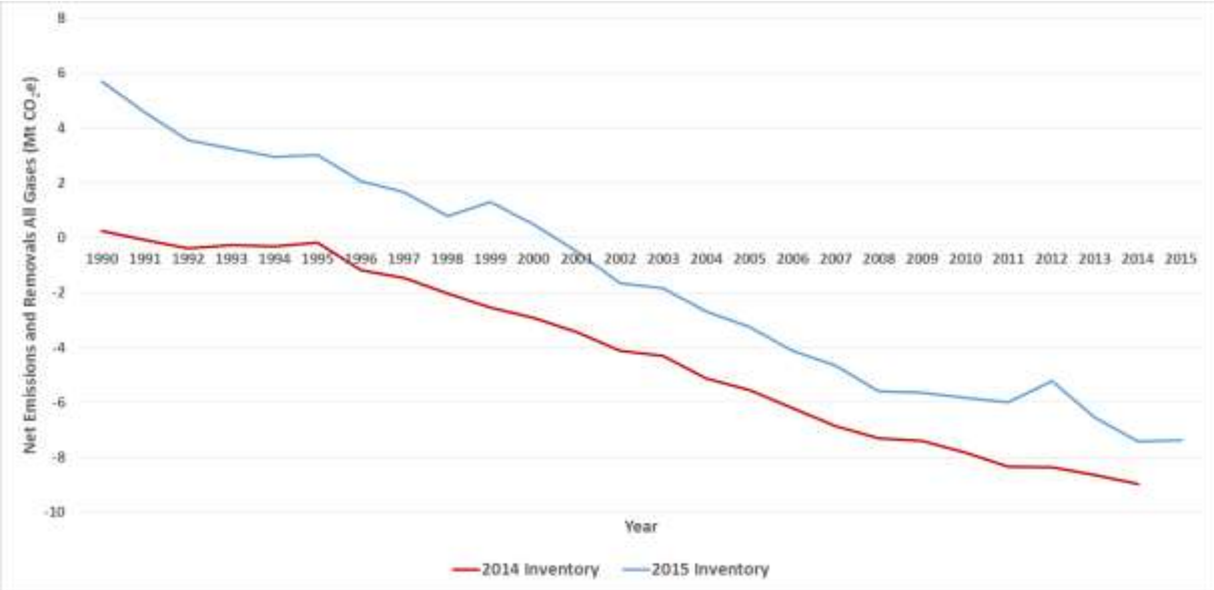
6.1 OVERVIEW OF SECTOR

IPCC Categories Included	4A: Forest Land 4B: Cropland 4C: Grassland 4D: Wetlands 4E: Settlements 4G: Harvested wood products 4H: Other
Gases Reported	CO_2, CH_4, N_2O, NO_x, CO
Key Categories ('T' or 'L' indicates whether it has been identified in the trend or level assessment respectively and the number indicates which KCA approach it was identified in)	4A: Forest Land - CO_2 (L1, T1, L2, T2) 4B: Cropland - CO_2 (L1, T1, L2, T2) 4C: Grassland - CO_2 (L1, T1, L2, T2) 4E: Settlements - CO_2 (L1, T1, L2, T2) 4G: Harvested Wood Products – CO_2 (L1, L2)
Key Categories (Qualitative)	None identified
Overseas Territories and Crown Dependencies Reporting	Reported under the relevant sector 4 sub-categories at Tier 1
Completeness	No known omissions- areas are reported for land uses with no associated emissions. A general assessment of completeness for the inventory is included in **Section 1.8**.
Major improvements since last submission	Inclusion of new activity data from the National Forest Inventory and small woods assessment for reporting Forest Land and deforestation activities. Revision of Forest Land soil and litter carbon stock change modelling Inclusion of indirect emissions of N_2O from atmospheric deposition and leaching Revision of N_2O-N conversion factor for LUC to Cropland, Grassland and Settlements Inclusion of hedges in modelling of carbon stock changes due to grassland management

CRF Sector 4 includes carbon stock changes and emissions of greenhouse gases (CO_2, CH_4, N_2O, NO_x and CO) from Land Use, Land Use Change and Forestry (LULUCF). Removals of carbon dioxide are conventionally presented as negative quantities. In the 1990-2014 inventory, the sector reported a net sink since 1991, with a net removal in 2014 of -8.96 Mt

CO_2 equivalent **(Figure 6.1**), or -8.97 Mt CO_2 equivalent including the Overseas Territories and Crown Dependencies (OTs and CDs). The overall trend for 1990-2015 inventory is similar to the 1990-2014 inventory, although the LULUCF sector now reports a smaller sink. The 1990-2015 inventory shows the sector becoming a sink from 2001, ten years later than in the 1990-2014 inventory (**Figure 6.1**). The sector has a net removal in 2015 of -7.38 Mt CO_2 equivalent, or -7.37 Mt CO_2 equivalent when the OTs and CDs are included. Summary analysis of the trends in greenhouse gas emissions from the LULUCF sector is provided in **Section 2.** The methodological differences between the 2014 and 2015 inventories are explained in this chapter, with summary information provided in the table at the start of this chapter (*Major improvements since last submission*).

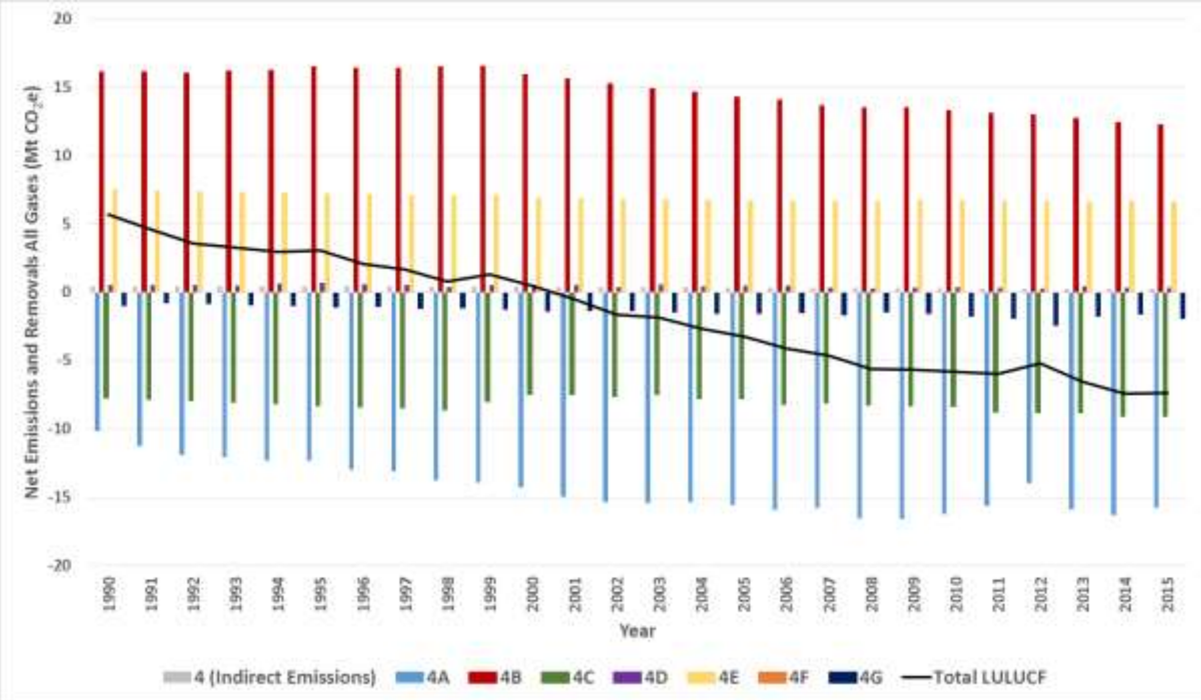
Figure 6.1 LULUCF change in net emissions for all gases between the 2014 and 2015 inventories



The LULUCF sector covers emissions and removals of direct and indirect greenhouse gases under eight categories: 4A: Forest Land, 4B: Cropland, 4C: Grassland, 4D: Wetlands, 4E: Settlements, 4F Other Land, 4G: Harvested Wood Products (HWP), 4H: Other.

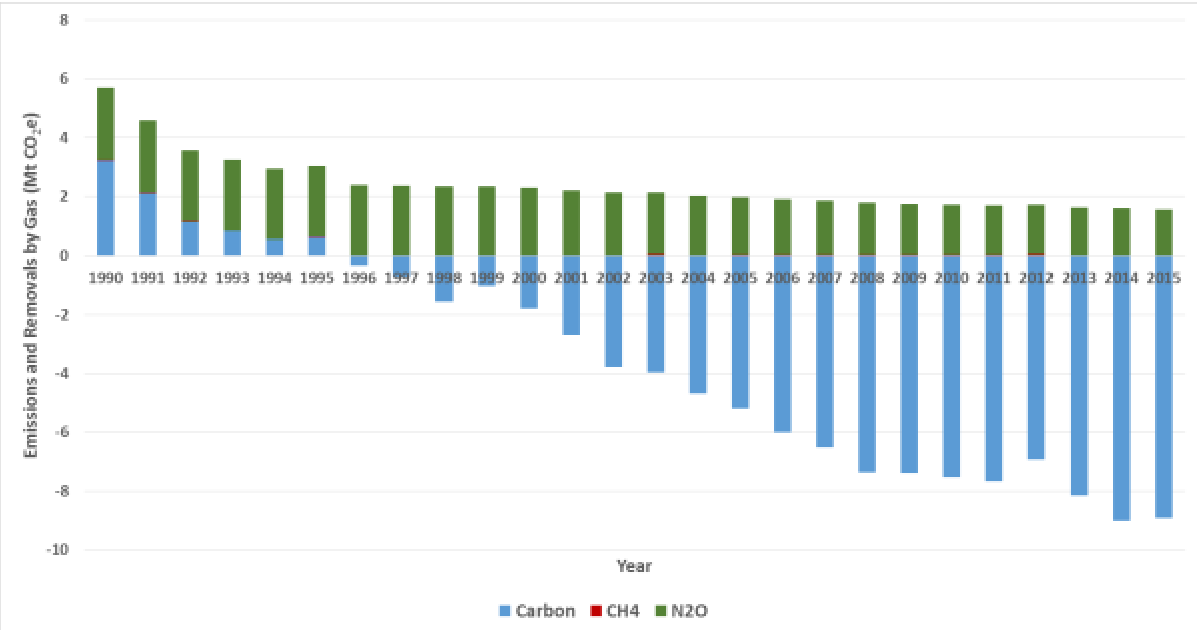
Categories 4A: Forest Land, 4C: Grassland and 4G: HWP are net sinks. 4B: Cropland, 4D: Wetlands and 4E: Settlements are net sources (**Figure 6.2**).The UK does not report any emissions or removals from 4F: Other Land or 4H: Other.

Figure 6.2 LULUCF emissions and removals from the UK 1990-2015 by category



The LULUCF sector is the only sector within the national greenhouse gas inventory to report net removals. The net sink reported since 2001 is provided by removals from carbon stock gains in above- and below-ground biomass, soils and harvested wood products exceeding emissions from carbon stock losses and GHG emissions from LULUCF activities. The sector is a source of methane and nitrous oxide, but these are small in relation to carbon fluxes, and after 2001, do not collectively exceed the net carbon removals (**Figure 6.3**).

Figure 6.3 LULUCF emissions and removals from the UK 1990-2015 by gas



The inclusion of new activities and the revisions to the methodology and to activity data are described in this chapter and **Annex 3.4** on methods used to estimate emissions and removals. Activities under Article 3.3 and Article 3.4 of the Kyoto Protocol are reported in **Chapter 11**.

Each section of this chapter will discuss carbon stock changes and then GHG emissions. Planned improvements to the inventory are described in the relevant category.

GHG emissions and removals from the UK CDs and OTs are reported under the relevant categories of CRF Sector 4. The data, assumptions and methodologies are explained in section 6.9. Availability of data for the different OTs and CDs is very variable, so that emission estimates can only be made for the CDs of Jersey, Guernsey and the Isle of Man and the OT of the Falkland Islands. These four comprise over 95% of the area in all the OTs and CDs. Gibraltar wished to produce its own inventory: in this case LULUCF net emissions/removals are likely to be extremely small, given the size of the country (6km^2), and will have little impact on overall numbers. Lack of suitable data for the Caribbean territories (as discussed in the 1990-2006 NIR[46] makes it impossible to create inventories for them at present but this is kept under review.

6.1.1 The land use transition matrix

Reporting in CRF Sector 4 is based on broad land categories: Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land. According to the IPCC Guidelines for Agriculture, Forestry and Other Land Use (2006), all land areas within a country should be assigned to one of these categories. UK definitions for the land use categories are given in the individual category sections in this chapter.

Annual land use change matrices from 1990 to the current inventory year are reported in Table 4.1 (for each year) in the CRF tables and are therefore not repeated in the NIR. The Standard Area Measurement to mean high water is used for the total area of the UK (24,418 kha) (Office for National Statistics 2016). The area of each land use sub-category in the land use transition matrix is calculated as follows:

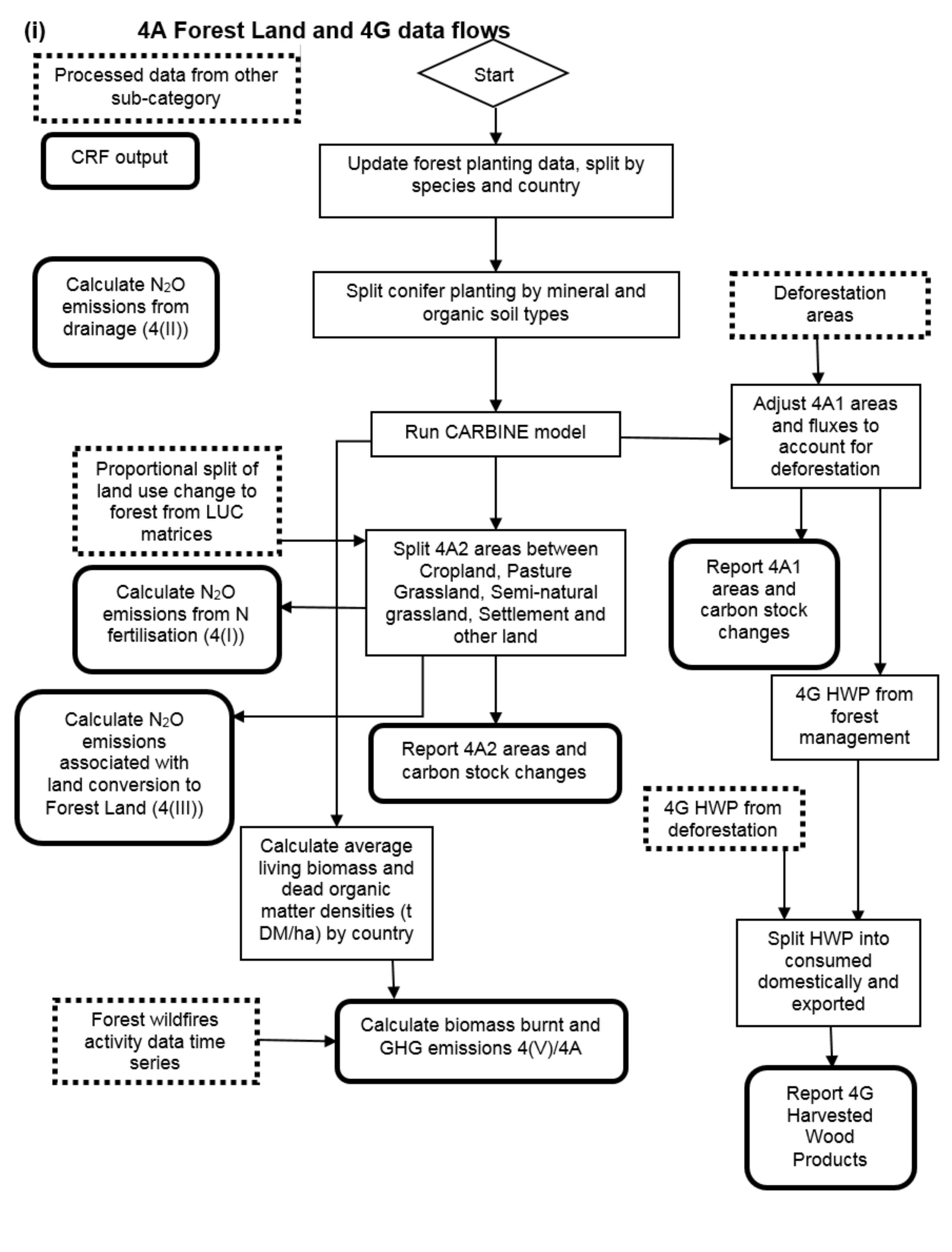
- 4A Forest Land: the area is based on the National Forest Inventory and small woods assessment, with the complete combined dataset first available in 2016/17.
- 4B Cropland: the total cropland area reported in the UK agricultural census (Defra 2015)
    - 4B1 is the total cropland area minus the area of 4B2
    - 4B2 is the area of land use change to Cropland used in the deforestation and LUC soil models
- 4C Grassland: the sum of the area of drained histosols on improved grassland (Anthony unpublished report for Defra project AC0114 pers. Comm.), the area of land use change to Grassland (for 4C1 and 4C2) and a buffer area of undisturbed grassland on mineral soils.
    - Land use change to Grassland is the sum of the areas used by the LUC soil model and conversion from forest and peat extraction areas.
    - Grassland is the largest land area in the UK, the majority being extensively-grazed semi-natural grassland. The undisturbed grassland area (calculated as the area remaining after all other land use areas are subtracted from the total UK land area (Office for National Statistics 2016) is used as a buffer to ensure that all categories add up to the total area of the UK. The use of this category, being the largest area, was recommended by UNFCCC reviewers, rather than using the Other Land category.

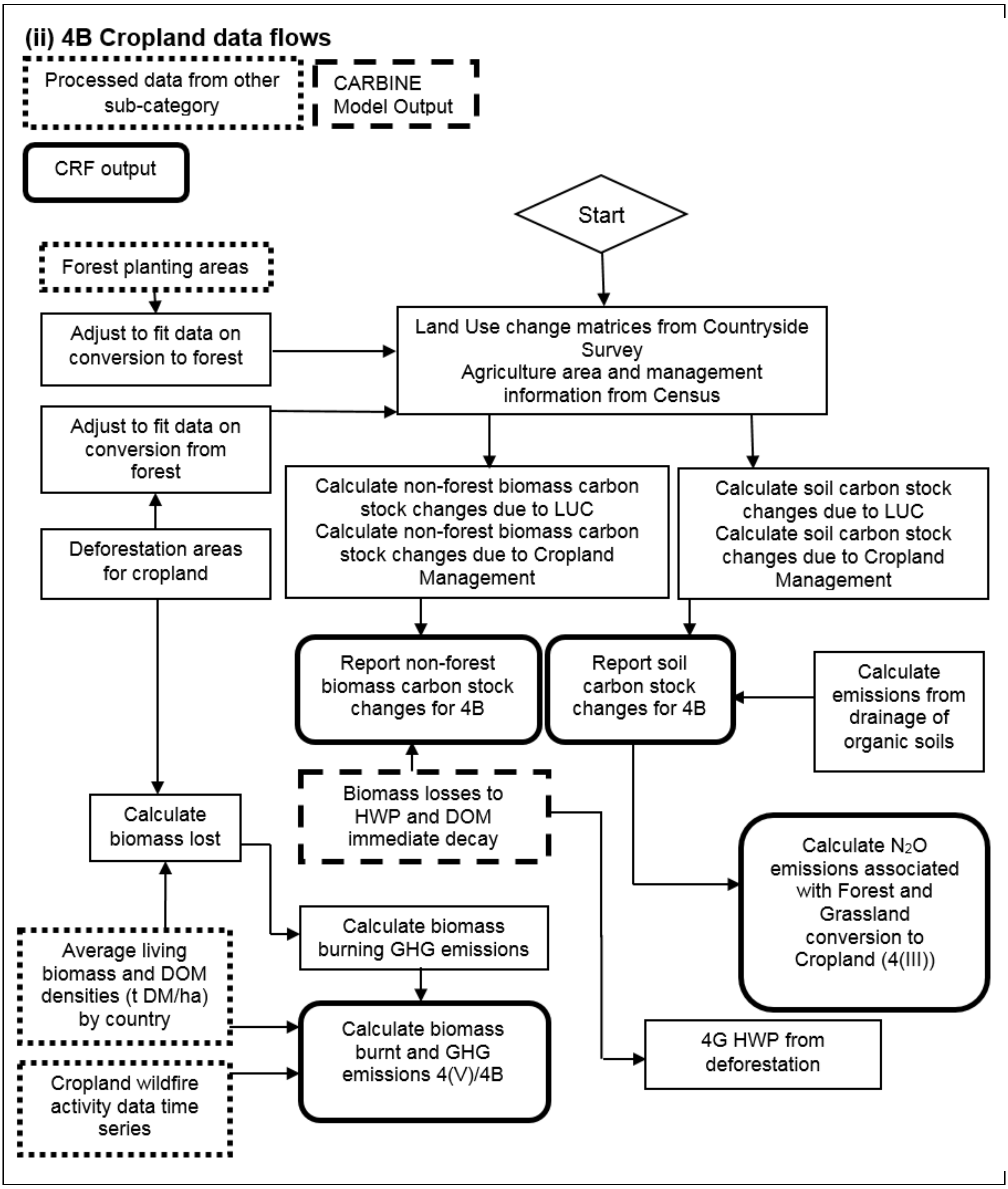
[46] http://naei.defra.gov.uk/reports/reports?report_id=507)

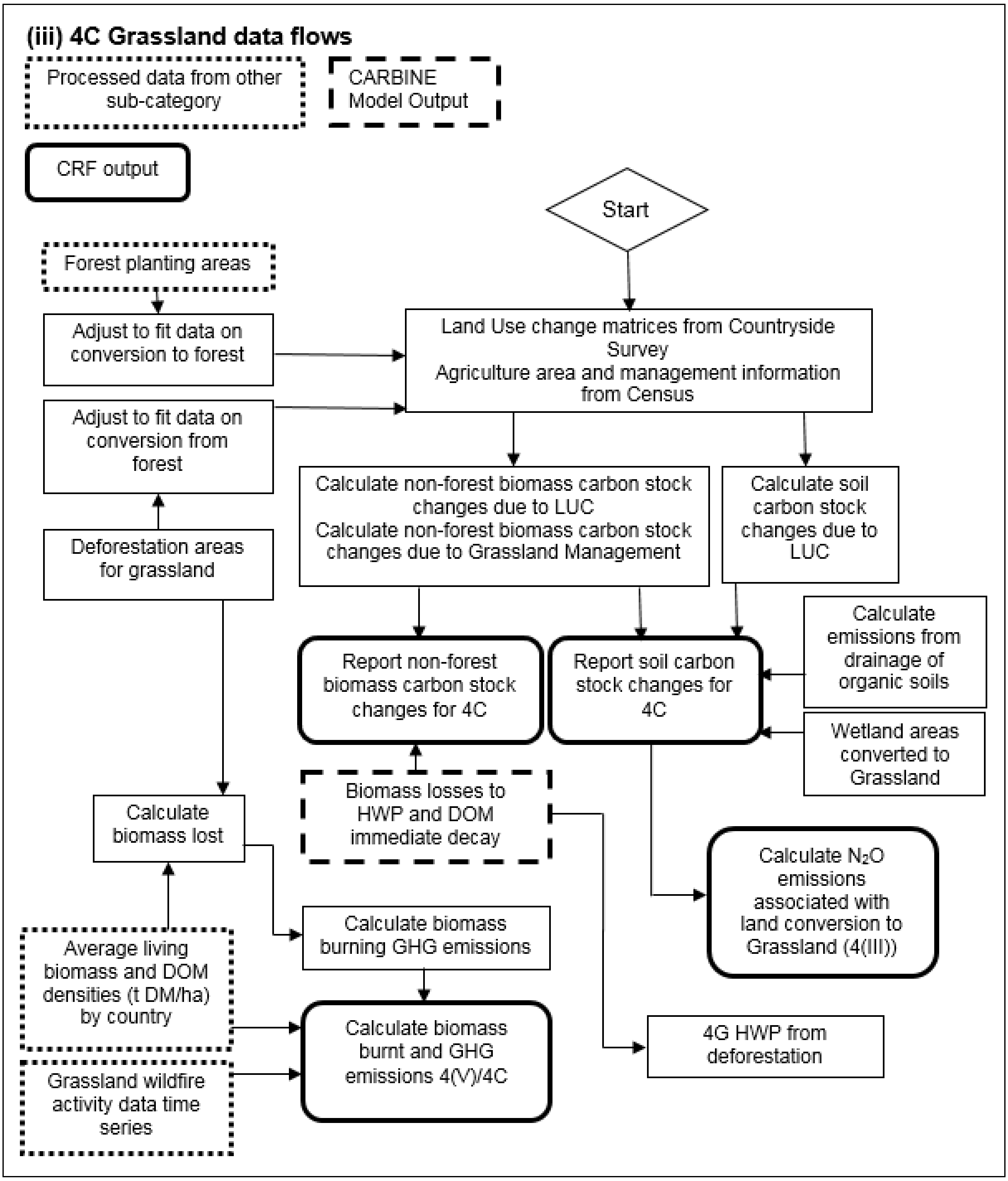
- 4D Wetlands: the sum of areas of peat extraction, Other Wetlands and areas of land use change to peat extraction and flooded land
    - Other Wetlands are the area of inland water >1 km^2 minus the area of newly flooded land (assumed to be converted from undisturbed grassland).
- 4E Settlements: the sum of areas of land use change to Settlements used in the deforestation and LUC soil model and an area of undisturbed settlement
    - Undisturbed settlement is a time series compiled from the Countryside Survey and national statistics- it has no associated emissions
- 4F Other Land: the sum of inland water <1 km^2, inland rock and a forest conversion buffer (to reflect the land use change from Other Land to Forest in 4A). Generally, this land use type does not produce any emissions or removals in the UK, but the LUC methodology includes a small area of Other Land conversion to Forest Land, hence the need for a buffer, to ensure area matrix consistency.

A flow chart has been developed to show the interrelationship between different data sources and the main calculation steps (**Figure 6.4**).

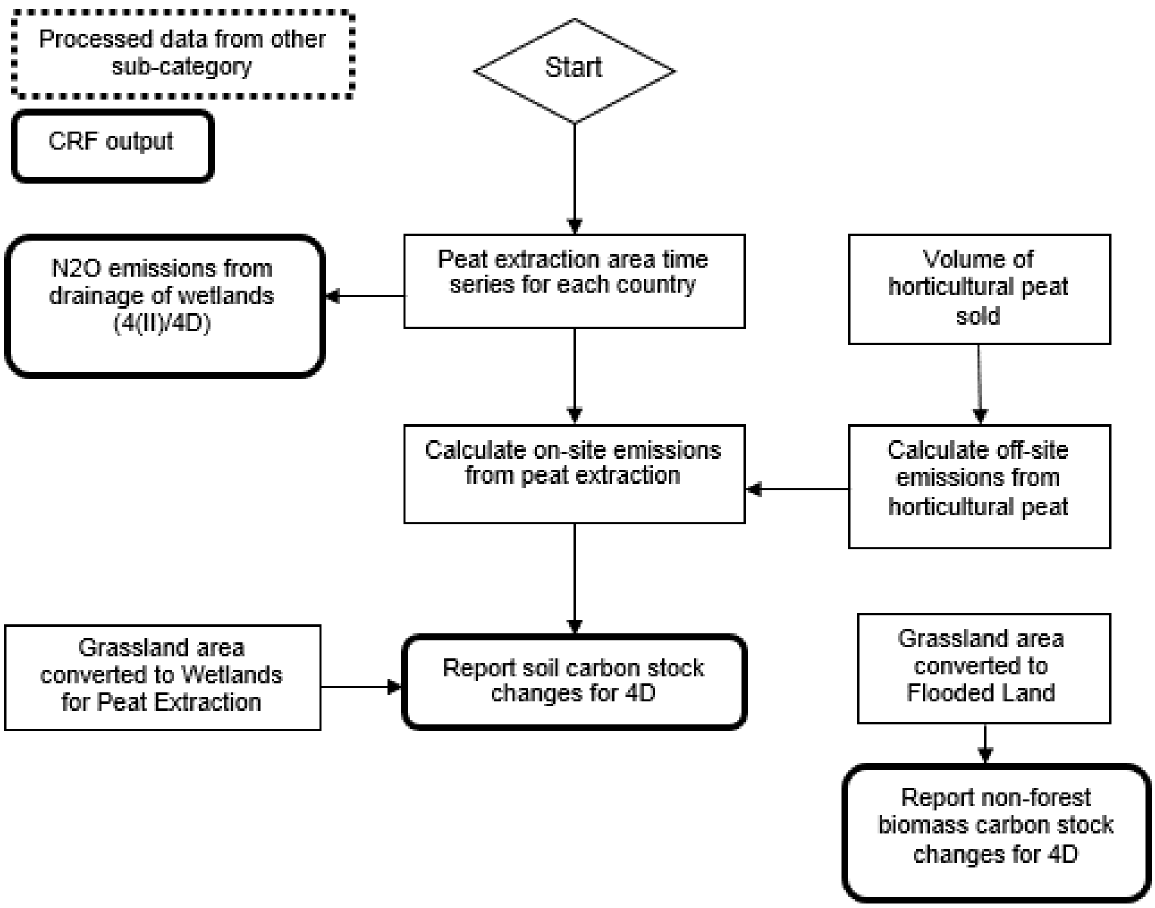
Figure 6.4 Data flow diagrams for each land use sub-category, showing cross-linkages between sectors: (i) 4A and 4G, (ii) 4B, (iii) 4C, (iv) 4D, (v) 4E



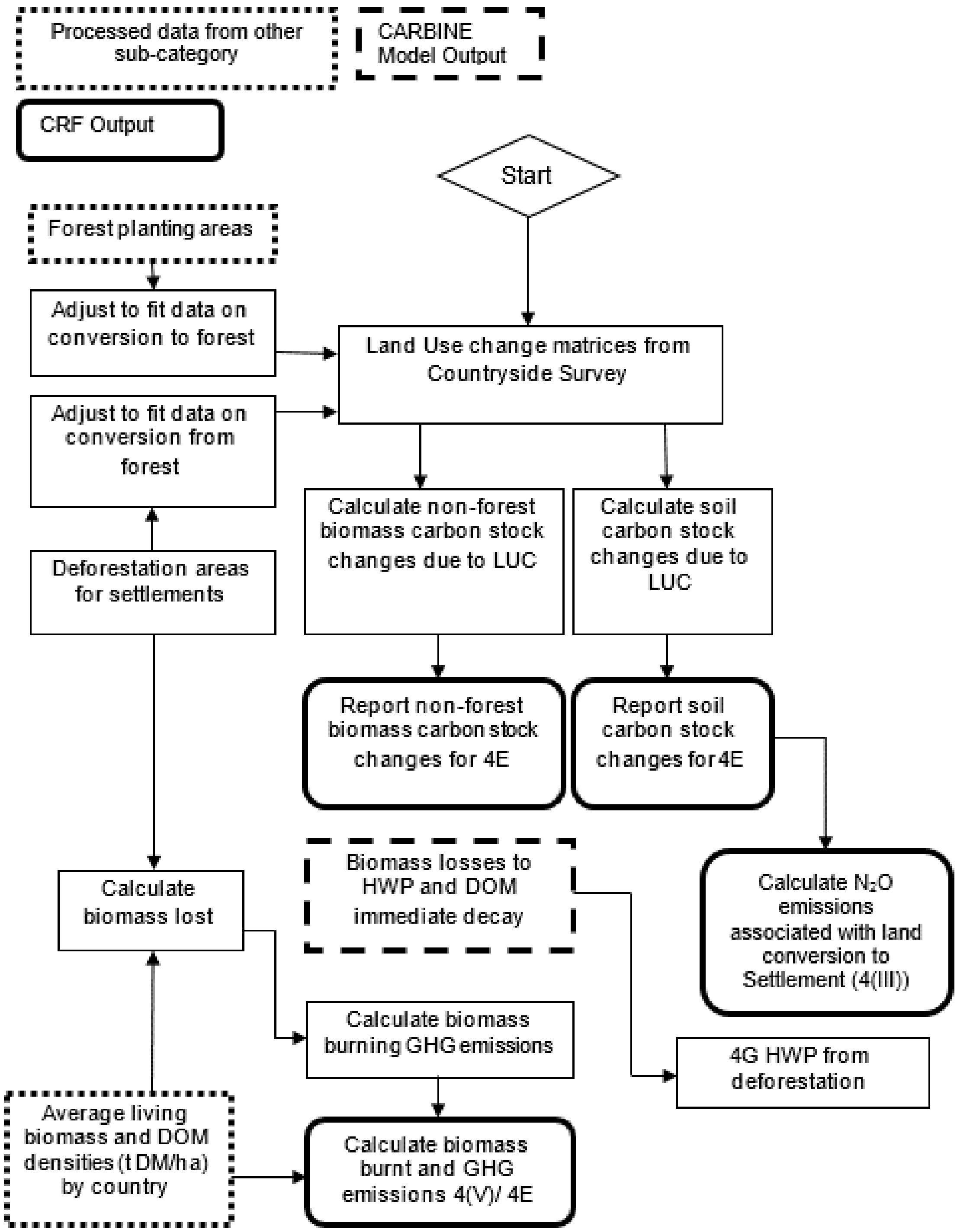

(ii) 4B Cropland data flows
Processed data from other sub-category
CARBINE Model Output
CRF output
Start
Forest planting areas
Adjust to fit data on conversion to forest
Land Use change matrices from Countryside Survey
Agriculture area and management information from Census
Adjust to fit data on conversion from forest
Calculate non-forest biomass carbon stock changes due to LUC
Calculate non-forest biomass carbon stock changes due to Cropland Management
Calculate soil carbon stock changes due to LUC
Calculate soil carbon stock changes due to Cropland Management
Deforestation areas for cropland
Report non-forest biomass carbon stock changes for 4B
Report soil carbon stock changes for 4B
Calculate emissions from drainage of organic soils
Biomass losses to HWP and DOM immediate decay
Calculate biomass lost
Calculate N2O emissions associated with Forest and Grassland conversion to Cropland (4(III))
Calculate biomass burning GHG emissions
Average living biomass and DOM densities (t DM/ha) by country
Calculate biomass burnt and GHG emissions 4(V)/4B
4G HWP from deforestation
Cropland wildfire activity data time series


(iii) 4C Grassland data flows
Processed data from other sub-category
CARBINE Model Output
CRF output
Start
Forest planting areas
Adjust to fit data on conversion to forest
Land Use change matrices from Countryside Survey
Agriculture area and management information from Census
Adjust to fit data on conversion from forest
Calculate non-forest biomass carbon stock changes due to LUC
Calculate non-forest biomass carbon stock changes due to Grassland Management
Calculate soil carbon stock changes due to LUC
Deforestation areas for grassland
Calculate emissions from drainage of organic soils
Report non-forest biomass carbon stock changes for 4C
Report soil carbon stock changes for 4C
Wetland areas converted to Grassland
Biomass losses to HWP and DOM immediate decay
Calculate biomass lost
Calculate N_2O emissions associated with land conversion to Grassland (4(III))
Calculate biomass burning GHG emissions
Average living biomass and DOM densities (t DM/ha) by country
Calculate biomass burnt and GHG emissions 4(V)/4C
4G HWP from deforestation
Grassland wildfire activity data time series

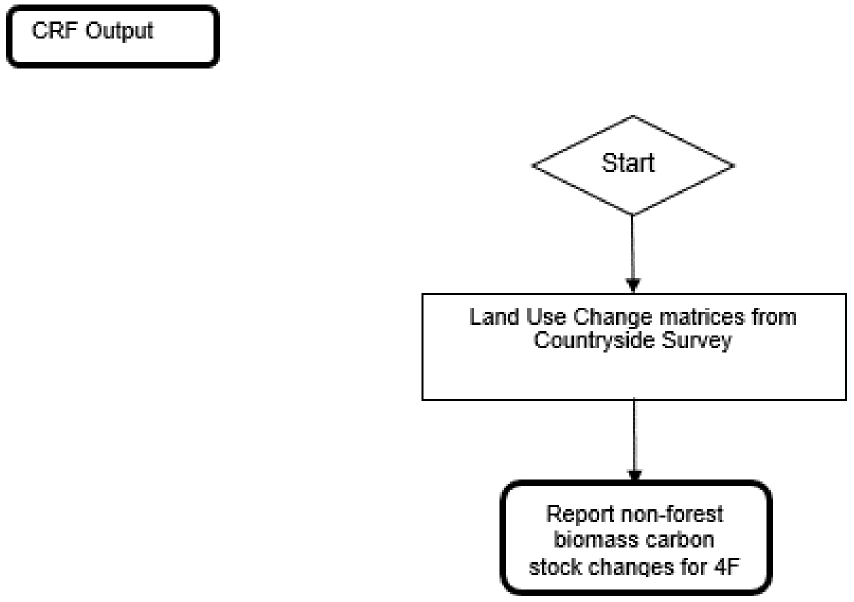
(iv) 4D Wetlands data flows



(v) 4E Settlements data flows



(vi) 4F Other Land data flows



Work is ongoing to improve the representation of land use change via a new approach to assimilate multiple land use data sets. A BEIS-funded project is currently in progress (March-May 2017) to assess the potential of earth observation datasets at different scales to provide land use/land cover data suitable for LULUCF modelling and reporting.

The areas of land in the different land use categories in the OTs and CDs are shown in **Table 6.1**. Insufficient data exist to construct full land use change matrices in these cases.

Table 6.1 Areas of land by category in the Crown Dependencies and Overseas Territories 1990-2015, kha

Land category	Sub-category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Forest remaining Forest		2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6	3.7	3.8	3.9
Land converted to forest	Grassland converted to Forest	2.1	2.0	1.9	1.7	1.6	1.5	1.3	1.2	1.1	0.9	0.8	0.7	0.7
Cropland remaining Cropland		12.7	12.6	12.5	12.4	12.2	11.9	11.9	11.9	11.7	11.4	11.2	10.1	10.1
Land converted to Cropland	Grassland converted to Cropland	0.1	0.3	0.3	0.4	0.4	0.4	0.6	1.2	1.2	1.2	1.3	1.3	1.5
Grassland remaining Grassland		1263.4	1263.2	1263.2	1263.0	1262.8	1262.8	1262.6	1261.9	1261.9	1261.8	1261.6	1261.6	1261.3
Land converted to Grassland	Forest converted to Grassland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Land converted to Grassland	Cropland converted to Grassland	1.4	1.5	1.6	1.7	1.9	2.2	2.2	2.2	2.3	2.6	2.7	3.6	3.5
Land converted to Grassland	Settlement converted to Grassland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland remaining Wetland		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Land converted to Wetland	Grassland converted to Wetland (Inland Water)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements remaining Settlements		9.4	9.5	9.5	9.4	9.6	9.7	9.7	9.8	9.9	9.9	10.0	10.0	10.0
Land converted to Settlement	Cropland converted to Settlement	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4

Land category	Sub-category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Land converted to Settlement	Grassland converted to Settlements	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.2
Other Land remaining Other Land		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Land converted to Other Land	Grassland converted to Other Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total area		1292.8	1292.8	1292.8	1292.8	1292.8	1292.8	1292.8	1292.8	1292.8	1292.8	1292.8	1292.8	1292.8

Land category	Sub-category	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Forest remaining Forest		4.0	4.0	4.1	4.2	4.3	4.3	4.4	4.5	4.5	4.5	4.5	4.5	4.5
Land converted to forest	Grassland converted to Forest	0.6	0.5	0.5	0.4	0.3	0.3	0.2	0.1	0.1	0.2	0.2	0.2	0.2
Cropland remaining Cropland		9.9	9.5	9.6	8.2	7.9	7.7	7.7	7.1	7.1	7.2	5.7	6.3	5.6
Land converted to Cropland	Grassland converted to Cropland	1.6	2.2	2.5	2.9	3.2	4.3	4.4	4.8	4.7	4.7	4.9	4.6	4.8
Grassland remaining Grassland		1261.2	1260.9	1260.5	1260.2	1260.0	1259.8	1258.9	1259.4	1259.2	1258.1	1258.9	1258.0	1258.5
Land converted to Grassland	Forest converted to Grassland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Land converted to Grassland	Cropland converted to Grassland	3.6	3.4	3.3	4.3	4.4	3.5	4.2	3.7	4.0	4.9	5.4	5.9	5.9
Land converted to Grassland	Settlement converted to Grassland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Land category	Sub-category	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Wetland remaining Wetland		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Land converted to Wetland	Grassland converted to Wetland (Inland Water)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements remaining Settlements		10.1	10.1	10.1	10.2	10.2	10.2	10.3	10.3	10.4	10.4	10.5	10.5	10.6
Land converted to Settlement	Cropland converted to Settlement	0.4	0.5	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Land converted to Settlement	Grassland converted to Settlements	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.7	1.6	1.7	1.7
Other Land remaining Other Land		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Land converted to Other Land	Grassland converted to Other Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total area		**1292.8**	**1292.8**	**1292.8**	**1292.8**	**1292.8**	**1292.8**	**1292.8**	**1292.8**	**1292.8**	**1292.8**	**1292.8**	**1292.8**	**1292.9**

6.2 CATEGORY 4A – FOREST LAND

6.2.1 Description

Emissions sources	4A Forest Land: carbon stock change 4(I) Direct nitrous oxide (N_2O) emissions from nitrogen (N) inputs to managed soils 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils 4(III) Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils 4(V) Biomass burning
Gases Reported	CO_2, CH_4, N_2O
Methods	T3 for carbon stock changes, T1 for other emissions
Emission Factors	Country-specific for T3 methods
Key Categories	4A: Forest land - CO_2 (L1, T1, L2, T2)
Key Categories (Qualitative)	None identified
Overseas Territories and Crown Dependencies Reporting	Reported under the relevant Sector 4 sub-categories at Tier 3
Completeness	No known omissions
Major improvements since last submission	Revision of the forest area data to include the National Forest Inventory and small woods datasets. Incorporation of a new module in the CARBINE forest accounting model to improve modelling of carbon stock changes in soil and litter.

This category is divided into Category 4.A.1 Forest remaining Forest Land and Category 4.A.2 Land converted to Forest Land. This inventory uses a 20-year transition period for land use conversion to Forest.

Forest Land includes carbon stock gains and losses and GHG emissions from forest management and overall is the biggest net sink in the UK. All UK forests are temperate and about 73% of these have been planted since 1921 on land that had not been forested for many decades.

The UK reports carbon stock changes in all forests. Forest surveys have been intermittent in the UK and there is no network of permanent sample plots suitable for constructing a GHG inventory. Consequently, estimates of carbon stock gains and losses for biomass and soils are modelled based on planting history and productivity (yield class) data. The area of forest reported in 4.A.1 includes all forest older than 20 years. Forest carbon stock changes and fluxes are modelled by the CARBINE, the Forest Research forest carbon stock model (described in **Annex 3.4.1**). The first national survey of forests was undertaken in 1921. The planting year of all forest has been estimated from data in the National Forest Inventory, together with administrative records, using the methodology described in **Annexe 3.4.1**, and the carbon stocks of these areas modelled in the same way by CARBINE. The forest area and carbon stock changes in CRF Table 4.A take account of losses of forest land converted to other categories (deforestation) and the associated carbon stock changes and emissions and removals are then estimated and reported under the category concerned.

In the UK nitrogen fertilisers (inorganic only) are only applied to forest when absolutely necessary. This would occur during the first rotation on ‘poor’ soils, such as reclaimed slag heaps, impoverished brown field sites and upland organic soils. In terms of the inventory, this means that N fertilisation is assumed for all areas of Settlements or Other Land converted to Forest Land and Grassland converted to Forest Land on organic soils. N_2O emissions from this fertilisation are reported under 4.A.2 in CRF Table 4(I). Nitrogen fertilisers are not generally applied to native woodlands, mature forests or re-planted forests in the UK, so emissions of N_2O from N fertilisation of forests (CRF Table 4(I)) for 4.A.1 are reported as Not Occurring.

Drainage of forest land occurs in UK forests planted since 1920 on certain soil types. It is assumed that all forests planted on organic soils are cultivated prior to planting and are effectively drained. Forests planted on mineral or organo-mineral soils which have slow natural drainage and are prone to waterlogging are also assumed to be artificially drained. CO_2 emissions from drainage are included with carbon stock changes in Table 4.A and N_2O emissions from drainage in Table 4(II). There is insufficient information to enable reporting of methane and rewetting emissions.

Controlled burning of forest land (for example for habitat management) does not take place in the UK. Wildfires do occur but the activity data are not sufficient to split between 4.A.1 and 4.A.2. Therefore emissions of greenhouse gases from wildfires are all reported under 4.A.1 in Table 4(V). It is assumed that land use change does not occur following wildfire.

6.2.2 Information on approaches used for representing land areas and on land use databases used for the inventory preparation

The UK uses Approach 2 (IPCC 2006) for the representation of land use areas in the inventory, and compiles several different data sources into a non-spatially-explicit land use conversion matrix. The data sources are available at the individual country level (England, Scotland, Wales and Northern Ireland) and results are combined to give UK totals.

The agencies responsible for forests in the UK are the Forestry Commission (England and Scotland), Natural Resources Wales (Wales) and the Forest Service (Northern Ireland). Areas of forest planted annually are published in Forest Statistics (described below) and a detailed breakdown (by forest type and management) is used as input to the CARBINE model, supplemented by information from the NFI field survey. The allocation of land use change from other land use categories is based on the proportional changes in the land use change matrices from the Countryside Survey.

Forestry Statistics is published each September by the Forestry Commission (FC) at http://www.forestry.gov.uk/statistics. It includes national statistics on new planting and restocking, based on operational data for the Forestry Commission/Natural Resources Wales (NRW)/Forest Service (NIFS) estates and grant scheme data. There are annual statistics on woodland area in each country.

The National Forest Inventory[47] (NFI) provides woodland statistics for Great Britain, (England, Wales and Scotland), broken down by region or county. It comprises a digital woodland map based on comprehensive aerial photography and a field survey using 15,000 one-hectare sample squares. The digital map and field survey cover all woodland areas down to 0.5 hectares. An initial digital woodland map was published in spring 2011. The NFI woodland field survey provides direct assessments of woodland growing stock including species composition, stand structure, tree age (distribution) productivity indices, numbers of trees, and diameter and height distribution. Standing biomass (and carbon) in trees including above and below ground biomass can be derived from these assessments using GB-specific conversion factors and

[47] http://www.forestry.gov.uk/inventory

allometric equations. A complete 5-year cycle of ground survey was completed in 2015, which will enable direct verification of tree forest carbon stocks; an interim assessment was published in 2014. NFI data do not allow the carbon stocks of deadwood or litter to be estimated. The NFI has been supplemented by an assessment of the area of small woods (woodland between 0.1 ha and 0.5ha) to align with the minimum woodland area for UNFCCC reporting as set out in CMP.7 (Forestry Commission, 2017). The analysis of small woods area included no characterisation of the resource. Since there is currently no information on its age-distribution, it was assumed to have established since 1980, the date of the previous small-wood census, as an interim implementation. The planting rates given in **Table A 3.4.2** are therefore significantly different to those reported as official planting statistics.

For Great Britain pre-2011, non-forest services (State forest) areas are based on the NFI. For 2012 onwards, non- forest services areas (including non-FC/NRW/NIFS publically-owned woodland) from the NFI are adjusted for new planting, deforestation and sales of FC woodland. No adjustment is made for woodland converted to another land-use, nor for changes in woodland composition at restocking, as the areas affected are judged to be small.

The NFI does not include Northern Ireland, data based on new planting are used to estimate forest area there. The methodology will move to using the Northern Ireland woodland base map data[48] in a future inventory.

6.2.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

The definition of forest in United Kingdom forestry statistics and used for the GHGI is land under stands of trees with a canopy cover of at least 20% (or having the potential to achieve this), including integral open space, and including felled areas that are awaiting restocking. The UK has recently completed a programme of work in place to incorporate small areas of woodland covering between 0.1 and 0.5 ha and these small woods have been included in the 1990-2015 inventory for the first time to supplement data from the National Forest Inventory which maps woods larger than 0.5 ha.

The definition of woodland has changed slightly between the NFI and its predecessor the National Inventory of Woodlands and Trees (NIWT), used in previous inventories. The NFI (Forestry Commission 2011) uses a minimum area of 0.5 hectares (rather than 0.1 ha) and a lower integral open space threshold of 0.5 ha (as opposed to 1 ha), which requires a downward adjustment to areas. However, the main differences in 2010 GB woodland cover between the NFI (2982 kha) and previous estimates (2757 kha, Forestry Statistics 2010) arise from identified errors in the previous woodland survey, particularly the under-estimate of woodland areas between 0.5 and 2 hectares. Estimates of woodland loss have been assessed, which affect the total estimated woodland area in the GHGI (but are not yet reflected in the national Forestry Statistics). The NFI area estimates are used for the 1990-2015 inventory submission for the first time.

6.2.4 Methodological Issues

In this inventory submission the carbon uptake by UK forests is calculated using a carbon accounting model, CARBINE. Overall carbon uptake is calculated as the net change in the pools of carbon in standing trees, litter, soil and products from harvested material, for conifer and broadleaf forests. The model is able to represent all of the introduced and native plantation and naturally-occurring species relevant to UK forestry, the different growth rates of forests and four broad classes of forest management (clear-fell with thinnings, clear-fell without

[48] https://data.gov.uk/dataset/forest-service-northern-ireland-woodland-basemap-april-2013-metadata

thinnings, thinned but not clear-felled and no timber production). The forest carbon sub-model is further compartmentalised to represent fractions associated with tree stems, branches, foliage, and roots. Modelling of soil carbon stocks in CARBINE has been improved for the 1990-2015 inventory with the addition of a new soil carbon module. The method can be described as Tier 3, as defined in the Good Practice Guidance for LULUCF (IPCC 2006). An interim parameterisation of the new soil sub-model has been implemented for the 1990-2015 inventory. The main area where further work is required is parametisation of litter input from ground flora and other non-forest vegetation, which currently assumes a value of zero. As a result, soil carbon emissions associated with afforestation are artificially high for the period before canopy closure, reducing removals from land converted to forest. The CARBINE model produces separate gains and losses for carbon stock change in living biomass, rather than net change. Carbon stock changes in dead wood are included with carbon stock changes in litter. Further detail on the CARBINE model is given in **Annex 3.4.1** and Matthews *et al*. (2014).

Other greenhouse gas emissions, including those arising from forest fertilisation and wildfires together with estimates of N_2O emissions from forest drainage, are estimated using Tier 1 or Tier 2 approaches, and are described in **Annex 3.4.**

6.2.5 Uncertainties and Time-Series Consistency

An uncertainty analysis was undertaken in 2011 to reassess sources of uncertainty (input data, model parameters and structural/model choice) in the LULUCF sector and identify priority areas for improvement (**Annex 3.4.12**). Monte Carlo simulations were run to propagate input and parameter uncertainty for different source categories, and the uncertainty arising from model choice was quantified by using alternative sub-models for key processes. The main sources of uncertainty (ranked by standard deviation in output distributions) are afforestation model parameters, afforestation input data, forest soil carbon model choice and afforestation model choice. Although this analysis was done for the C-Flow model, the functionality of CARBINE is broadly similar and we assume that the uncertainty of the inputs and parameters are also similar. These assumptions are currently under review and will be updated. The main difference due to the switch to the CARBINE model is that there is a greater range of species, growth rates and possible management regimes giving a more realistic representation of forestry in the UK (Matthews *et al.* 2014). Future uncertainty analyses will include the processes represented in CARBINE and the revised forestry datasets.

The planting statistics used as activity data mostly come from operational systems, for grants and for planting on the National Forest Estates of the four countries comprising the UK (supplemented by information from the NFI field survey), and have no measures of statistical uncertainty attached to them as complete coverage is assumed. Grants are paid once planting has occurred. The grant-aided planting is allocated by year of payment, so all the recorded planting should have taken place. There is ongoing work within the Forestry Commission to assess the level of error attached to the data, e.g. for failed planting. The area of forest in GB is based on the new National Forest Inventory (NFI) woodland map, together with small woods of between 0.1 and 0.5ha. A field survey used to estimate the stocked area and composition (including age distribution) of the non-FC/NRW forest estate is based on a sub-sampling of the population and scaling to the mapped level.

The combined uncertainty (based on inputs and parameters) assessed using a simple Tier 1 approach and the 2015 mean values for 4A Forest Land was 31% for CO_2. The combined uncertainty for CH_4 was 55% in 2015 (wildfires). No forest wildfires in 2015 were recorded at the time of inventory compilation, and therefore no CH_4 emissions from Forest were reported. The combined uncertainty for N_2O 115% for 1990 and 105% for 2015 (mineralisation from LUC, wildfires and forest fertilisation).

With regard to series consistency:

- For forest carbon stock changes, N fertilization of forests and emissions from drainage, time series consistency is expected to be good as activity data are obtained consistently from the same national forestry sources; and,
- For emissions from wildfires, data have been collated from several published sources. From 1990 – 2004 all data originate from the state forestry agencies so there is good time series consistency during this period. Data have been extrapolated for 2005-2009. A newer and more complete data source is used from 2010 onwards, and gives wildfire burnt areas which are the same magnitude as the previous dataset.

6.2.6 Category-Specific QA/QC and Verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 6.10**. Information on forest planting and the area affected by wildfires is consistent with that reported to the FAO (2005, 2010).

As part of a separate research project, a comparison has been made of the predictions made by the CEH C-Flow model and Forest Research CARBINE model. The results demonstrated that the models produce consistent predictions when given the same input data and assumptions (e.g. about woodland management practices). Further work has been undertaken comparing the inventory as predicted by CARBINE to the inventory as predicted by C-Flow and detailing the changes in assumptions that drive the changes in the inventory (Matthews et al., 2014). Verification of carbon stock changes will be undertaken once the second cycle of the NFI is completed (in 2020).

A review of inventory data and models has been undertaken (Levy and Rowland, 2011), during which data were collated and critically assessed on soil carbon stocks following afforestation. Generally, soil carbon stocks are assumed to increase after afforestation in the UK, following on as a result of the increased above-ground biomass and litter inputs,based on a small number of long term studies. In fact, in the UK studies which attempt to measure this, soil carbon stocks in forested plots were 15 to 60 % lower than in adjacent unplanted, grassland or moorland (Reay et al., 2001; Chapman et al. 2003; Zerva and Mencuccini 2005; Mitchell et al. 2007; Bellamy and Rivas-Casado 2009; Levy and Clark 2009)). These results are in agreement with global meta-analyses, which have reported mean changes in soil carbon stocks of around -10 %, -7 %, +3 % and -4 % associated with conversion of pasture to forest plantation (Guo and Gifford 2002; Berthrong, Jobbagy et al. 2009; Laganiere, Angers et al. 2010; Poeplau, Don et al. 2011 respectively). The treatment of the litter layer in these studies is a significant uncertainty, as it is possible that some of the reported decreases in soil carbon following afforestation were compensated by increases in carbon stocks of the above-ground litter layer which is not included in the soil samples.

A new soil and litter model has been implemented in CARBINE to better model the carbon emissions from forest soils. The full specification and information on the validation of this model will be published in a separate technical report.

6.2.7 Category-Specific Recalculations

The reported overall net GHG sink in category 4A has increased by between 5% and 33% depending on the year compared to the 2014 inventory (**Figure 6.5**). The main causes of this change were use of the new NFI and small woods datasets to replace NIWT as activity data and improved modelling of soil carbon stocks. Details of the magnitude of the changes and the justifications for each emissions source are given in **Table 6.2**.

Figure 6.5 **4A Forest Land changes in net emissions between the 1990-2014 and 1990-2015 inventories**

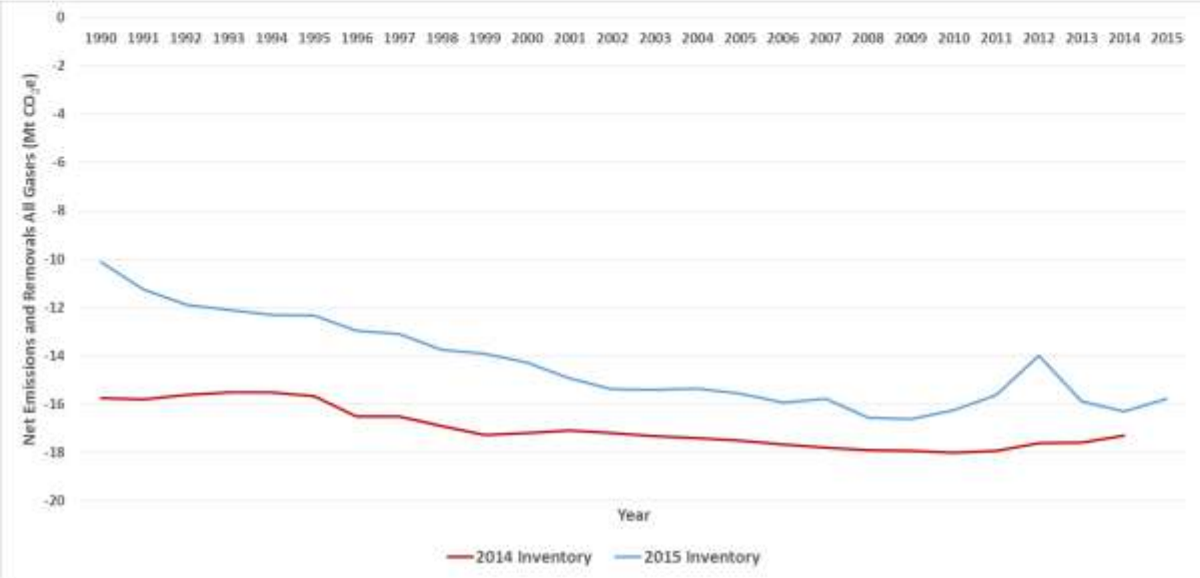


Table 6.2 4A Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4A1	Carbon stock change in living biomass - gains	-4645	-6164	-5273	-7034	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics.
4A1	Carbon stock change in living biomass - losses	2656	3186	2610	3478	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics.
4A1	Net carbon stock change in litter	-425.5	-562.5	-116.2	-91.32	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.
4A1	Net carbon stock change in soils - mineral soils	-407.4	-495.5	-549.6	-931.5	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to include the Scotia to improve modelling of carbon dynamics in soil and litter.
4A1	Net carbon stock change in soils - organic soils	-135.7	-183.3	-15.35	-132.9	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.
4A1/4(V)	Biomass burning - wildfires	11.66	26.58	10.14	18.26	Gg C	Improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a wildfire. There were also minor changes to the wildfires areas due to improved activity data.
4A2.1	Carbon stock change in living biomass - gains	-26.97	-22.22	-52.3	-46.71	Gg C	The forest activity data was revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics.

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4A2.1	Carbon stock change in living biomass - losses	1.099	0.4603	1.165	0.2025	Gg C	The forest activity data was revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics.
4A2.1	Net carbon stock change in litter	-1.239	-0.8036	-1.133	-0.9605	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.
4A2.1	Net carbon stock change in soils - mineral soils	-26.2	-46.62	91.51	58.37	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.
4A2.1	Net carbon stock change in soils - organic soils	-8.41	-1.804	6.09	1.825	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.
4A2.2	Carbon stock change in living biomass - gains	-589.5	-197.3	-773.3	-303.4	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics.
4A2.2	Carbon stock change in living biomass - losses	18.28	3.989	13.78	2.857	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics.
4A2.2	Net carbon stock change in litter	-25.14	-7.305	-16.95	-6.395	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4A2.2	Net carbon stock change in soils - mineral soils	-380.5	-179.4	976.3	423.4	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.
4A2.2	Net carbon stock change in soils - organic soils	-294.5	-35.19	203.8	29.84	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.
4A2.4	Carbon stock change in living biomass - gains	-12.81	-20.11	-16.88	-39.48	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics.
4A2.4	Carbon stock change in living biomass - losses	0.3605	0.4229	0.2895	0.2843	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics.
4A2.4	Net carbon stock change in litter	-0.5292	-0.739	-0.3651	-0.8219	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.
4A2.4	Net carbon stock change in soils - mineral soils	-9.029	-29.09	21.82	53.66	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.
4A2.4	Net carbon stock change in soils - organic soils	-6.68	-2.957	4.552	2.904	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4A2.5	Carbon stock change in living biomass - gains	-0.4367	-2.639	-1.392	-4.611	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics.
4A2.5	Carbon stock change in living biomass - losses	0.02702	0.0526	0.03643	0.03776	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics.
4A2.5	Net carbon stock change in litter	-0.02345	-0.09666	-0.03028	-0.096	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.
4A2.5	Net carbon stock change in soils - mineral soils	-0.4357	-2.924	2.72	6.401	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.
4A2.5	Net carbon stock change in soils - organic soils	-0.1256	-0.4438	0.08553	0.3884	Gg C	The forest activity data were revised to use the NFI dataset, revised small woodland areas and improved alignment with wood production statistics. Forestry modelling was updated to improve modelling of carbon dynamics in soil and litter.
4A1/4(V)	Biomass burning - wildfires	0.1488	0.3345	0.1297	0.2365	Gg CH_4	Improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a wildfire. There were also minor changes to the wildfires areas due to improved activity data.
4A1/4(V)	Biomass burning - wildfires	0.008231	0.0185	0.007174	0.01308	Gg N_2O	Improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a wildfire. There were also minor changes to the wildfires areas due to improved activity data.

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4A2.1/4(III)	Direct N_2O from N mineralisation	NE	NE	0.09586	0.06115	Gg N_2O	Reported for the first time. The forestry modelling update to include the Scotia soil and litter model results in a carbon stock loss from mineral soils following land use conversion to Forest Land, hence direct N_2O emissions are calculated.
4A2.2/4(III)	Direct N_2O from N mineralisation	NE	NE	1.023	0.4438	Gg N_2O	Reported for the first time. The forestry modelling update to improve modelling of carbon dynamics in soil and litter results in a carbon stock loss from mineral soils following land use conversion to Forest Land, hence direct N_2O emissions are calculated.
4A2.4/4(III)	Direct N_2O from N mineralisation	NE	NE	0.02286	0.05622	Gg N_2O	Reported for the first time. The forestry modelling update to improve modelling of carbon dynamics in soil and litter results in a carbon stock loss from mineral soils following land use conversion to Forest Land, hence direct N_2O emissions are calculated.
4A2.5/4(III)	Direct N_2O from N mineralisation	NE	NE	0.00285	0.006706	Gg N_2O	Reported for the first time. The forestry modelling update to improve modelling of carbon dynamics in soil and litter results in a carbon stock loss from mineral soils following land use conversion to Forest Land, hence direct N_2O emissions are calculated.
4A2/4(I)	Direct N_2O emissions from inorganic fertilisers	0.01536	0.004597	0.03335	0.01457	Gg N_2O	The forest activity data were revised to use the NFI dataset and revised small woodland areas. An error in the application of the conversion factor from N_2O-N to N_2O has also been corrected.
4A/4(II)	Emissions and removals from drainage of organic and mineral soils	0.1385	0.1545	0.1652	0.1906	Gg N_2O	The forest activity data were revised to use the NFI dataset and revised small woodland areas.

6.2.8 Category-Specific Planned Improvements

The NFI does not include Northern Ireland so data based on new planting are used to estimate forest area there. The methodology will move to using the Northern Ireland woodland base map data.

The area reported under 4.A.1 Forest remaining Forest is likely to be revised when the final statistics on small woods are published.

6.3 CATEGORY 4B – CROPLAND

6.3.1 Description

Emissions sources	4B Cropland: carbon stock change 4B Cropland: 4(II) emissions from historical drainage of organic soils. 4B Cropland:4(III) N_2O emissions from disturbance associated with LUC to Cropland 4B Cropland:4(V) Biomass burning
Gases Reported	CO_2, CH_4, N_2O
Methods	T3 for carbon stock changes, T1 for other emissions
Emission Factors	Country-specific for T3 methods
Key Categories	4B: Cropland - CO_2 (L1, T1, L2, T2)
Key Categories (Qualitative)	None identified
Overseas Territories and Crown Dependencies Reporting	Reported under the relevant Sector4 sub-categories at Tier 1
Completeness	No known omissions- areas are reported for land uses with no associated emissions.
Major improvements since last submission	Revision of the deforestation activity data used for input to the soil carbon stock change model to include the National Forest Inventory and small woods datasets. Correction of an error in the conversion factor for N_2O-N mineralised due to LUC to Cropland. Revision of the Land Use Change Matrix for the Guernsey. Use of updated agricultural census data for the Falkland Islands.

The category is disaggregated into 4.B.1 Cropland remaining Cropland and 4.B.2 Land converted to Cropland.

Ongoing carbon stock changes in soils arising from historical land use change to Cropland more than 20 years before the inventory reporting year are reported under 4.B.1 Cropland remaining Cropland, along with emissions from organic soils as a result of drainage.

Changes in soil and biomass carbon stock resulting from changes in Cropland Management are now included in the inventory and are reported under 4.B.1 Cropland remaining Cropland.

Carbon stock changes and biomass burning emissions due to conversion of other land categories to Cropland in the previous 20 years before the reporting year are reported under category 4.B.2 Land converted to Cropland (biomass burning emissions occur in the same year as the land use conversion, while loss of soil carbon occurs over a longer period). All forms of land use change, including deforestation, are considered and both mineral and organic soils are included. In some categories, e.g. Forest Land converted to Cropland, the area of land undergoing transition falls to zero and is subsequently reported as Not Occurring.

Carbon stock changes from drainage of Cropland on organic soils arise from areas which were drained many decades ago for agriculture, allowing oxygen into previously water logged soils. As a result, soil carbon in these areas continues to oxidise and is released as CO_2, resulting in an ongoing change in soil carbon stock. These emissions are reported in Table 4(II)

Nitrous oxide emissions from soil disturbance associated with land use conversion to Cropland less than 20 years ago (Table 4(III)) are reported in Land Converted to Cropland: these arise from Forest Land and Grassland being converted to Cropland. Ongoing nitrous oxide emissions from soil as a result of land use change more than 20 years ago are reported in the Agricultural sector inventory as nitrous oxide emissions from managed agricultural soils. Nitrous oxide emissions from loss of soil organic matter as a result of Cropland Management are also reported in the Agricultural sector inventory as N_2O emissions from managed agricultural soils.

Emissions of CO_2, CH_4 and N_2O from biomass burning arising from Forest Land conversion to Cropland are reported in Table 4(V). Burning of agricultural residues (cereal straw or stubble) are reported under category 3F Field Burning of Agricultural Residues. Emissions from application of lime to Cropland, which were previously reported in the LULUCF sector, are now reported in the Agriculture sector as a result of the 2006 AFOLU guidance. Emissions from wildfires on Cropland are included in the inventory and are reported in CRF Table 4(V). Full details of the method and activity data are given in **Annex 3.4.**

6.3.2 Information on approaches used for representing land areas and on land use databases used for the inventory preparation

The UK uses Approach 2 (IPCC 2006) for the representation of land use areas in the inventory, and compiles several different data sources into a non-spatially-explicit land use conversion matrix. The data sources are available at the individual country level (England, Scotland, Wales and Northern Ireland) and results are combined to give UK totals. The approaches used for representing land use areas in the inventory are described in **Section 6.1.1.**

Data sources that contain area information for reporting carbon stock changes and/or emissions from Cropland are habitat/landscape surveys; an assessment of Cropland drainage; agricultural survey data; and data on wildfires on agricultural land from Fire and Rescue service and satellite data.

Areas of Cropland that are losing carbon due to historical drainage (reported under Cropland remaining Cropland) have been assessed by Anthony *et al*. (personal communication-unpublished report from Defra project AC0114, 2013) Their analysis overlaid areas of Cropland from the Land Cover Map and the Integrated Administration and Control System (IACS) with mapping of organic soils from soil surveys. All Cropland on organic soils was assumed to be drained. The vast majority of Cropland on drained organic soils is in England, but small areas in the other UK administrations are also identified.

The areas of the main crop types used to assess changes in soil and biomass carbon stocks resulting from Cropland Management are obtained from the June Agricultural Censuses for each UK administration (Defra, 2015a; Welsh Government, 2015; Scottish Government 2015; DAERA, 2015). The areas of Cropland receiving inputs of manure, fertiliser and crop residues are obtained from the British Survey of Fertiliser Practice (Defra, 2015b).

From 2010 areas of wildfire on Cropland are taken from Fire and Rescue service data. Between 2001 and 2009 the area of wildfire on Cropland is calculated by using satellite data on the total area of wildfires in the UK which are apportioned to land use using the same ratios as found in the Fire and Rescue service data. Cropland wildfire areas prior to 2001 are extrapolated (see **Annex 3.4.5** for details).

6.3.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

Cropland is defined in accordance with the Agriculture, Forestry and Other Land Use Guidance (IPCC 2006). For pre-1980 land use matrices cropland is the sum of the Crops and Market Garden land cover types in the Monitoring Landscape Change project (MLC 1986). Land classified as Orchards in the MLC survey should have been included in Cropland but was assigned to the Forest land category: this will be rectified in future submissions, but is estimated to have a minor impact given the area of orchards in comparison to either the Cropland or Forest Land categories. Post-1980, Cropland is the area of cropland reported in the June Agricultural censuses (Defra 2015a).

Crop types definitions are those used in the June Agricultural censuses.

6.3.4 Methodological Issues

Changes in biomass and soil carbon due to land use change are estimated using a land use matrix approach. A summary of data flows associated with the land use matrix is given in **Section 6.26.1.1.** Fluxes arising from land use change in the 20 years before the inventory year are reported under 4B2 Land converted to Cropland. Ongoing fluxes soils as a result of land use change more than 20 years before the inventory year are reported under 4B1 Cropland remaining Cropland. Detailed descriptions of the methods and emission factors used for the activities in this Category can be found in **Annex 3.4.2**.

A dynamic model of carbon stock change is used with the land use change matrices to estimate soil carbon stock changes due to all land use change, including change to and from Cropland. In the model soil carbon stock changes follow an exponential path between initial and final land uses with the most rapid change in the early years after land use change. It is assumed that land use change does not occur on the cropland on organic soils because of the productivity of these areas. The carbon stocks for each land use category are calculated as averages for Scotland, England, Northern Ireland and Wales using a database of soil carbon density for the UK (Milne and Brown 1997; Cruickshank *et al*. 1998; Bradley *et al*. 2005) which has been constructed based on information on soil type, land cover and carbon content of soil cores to a depth of 1 m or to bedrock, whichever was the shallower, for mineral and organo-mineral soils. Deep peat in the north of Scotland was identified separately and depths to 5 m are included. The rate of loss or gain of soil carbon is dependent on the type of land use transition. A Monte Carlo approach is used to vary the rate of change, the area activity data and the values for soil carbon equilibrium (under initial and final land use) for all administrations in the UK. The mean soil carbon flux for each region resulting from these imposed random choices is then reported as the estimate for the Inventory.

N_2O emissions associated with the conversion of land to Cropland are reported using the areas of Forest land and Grassland converted to Cropland from the land use change matrices and the IPCC Tier 1 emission factors. N_2O emissions from land use change less than 20 years ago are reported in Land converted to Cropland. Ongoing emissions from land converted to Cropland more than 20 years ago are reported as emissions from managed agricultural soils in the Agricultural sector inventory.

Carbon stock change in mineral soils as a result of Cropland Management is estimated using Tier 1 stock change factors for most activities. A Tier 2 stock change factor is used for tillage reduction and activity data from agricultural surveys. Nitrous oxide emissions resulting for loss of soil organic matter due to cropland management activities estimated from carbon stock changes using Tier 1 methodology and are reported in the Agricultural sector inventory as emissions from managed agricultural soils.

Carbon stock change in biomass as a result of Cropland Management is estimated using literature-derived Tier 2 stock change factors and activity data from agricultural surveys.

Emissions from Cropland on drained organic soils are reported using Tier 1 emission factors which assume constant rates of soil organic carbon loss and activity data from Anthony (personal communication, 2013).

Emissions from wildfires on Cropland are reporting using Tier 1 emission factors and activity from the Fire and Rescue Service's Incident Reporting system from 2010 onwards, remotely sensed FIRMS thermal anomaly data from 2001 – 2009 and extrapolation prior to this.

6.3.5 Uncertainties and Time-Series Consistency

The uncertainty analysis in the Annexes provides estimates of uncertainty according to the source category and gas. 4B Cropland was estimated to have a combined uncertainty of 45% for CO_2 (from LUC to cropland, cropland management, wildfires on Cropland and emissions from Cropland on drained organic soils).

The areas undergoing land use change are the biggest source of uncertainty in the LULUCF inventory (see **Annex 3.4.12**), but model choice and soil carbon parameters are also significant. Work on assimilating more land use data sets is planned, which should constrain the high uncertainties associated with this. Emissions from Cropland on drained organic soils has the largest uncertainties of the minor emissions sources (i.e. not land use change) as the effects of drainage are highly uncertain. Work in implementing the Wetlands Supplement may decrease this uncertainty.

The combined uncertainty for CH_4 is 54% (from wildfires) and for N_2O is 35% (from wildfires and N mineralisation associated with land conversion and cropland management activities).

With regard to time series consistency:

- For drainage of organic soils (4B1) the activity data uses areas of drained organic soil from Anthony (personal communication, unpublished report from Defra project AC0114, 2013). It is assumed that all drainage of organic soils on Cropland occurred before 1990 as recent policy has favoured protection of organic soils. There have been no policy incentives to encourage new land drainage for agricultural use since 1990, and major drainage of large areas of Cropland on organic soils in areas such as the East Anglian fens is known to have occurred well before this. No Cropland on drained organic soils has been rewetted since 1990 as there have been no incentives to promote this, therefore a single area is used throughout the time series.
- For changes in non-forest biomass and soil carbon stocks due to land use change the data sources for Great Britain have maintained consistent methodology over the time series. Consistency between these and Northern Ireland data sources has improved with better methodological integration between land use surveys. In particular the methodology use for Countryside Surveys in GB and NI has improved since 1990.
- For emissions due to controlled biomass burning after conversion of Forest Land to Cropland, the time series consistency is high as country-specific data sets are used.
- For emissions from wildfires, a new activity dataset became available for 2010 onwards. Burnt areas have been extrapolated back to 2001 based on remote sensing data, but between 1990 and 2001 there are no observed data on the extent of wildfires on Cropland, and the time series is filled by extrapolating the 2001 – 2011 average wildfire area.

- For carbon stock changes of soil and biomass resulting from cropland management activities, the activity data come from June Agricultural censuses and the British Survey of Fertiliser Practice. The June Agricultural censuses are very long standing datasets with good time series consistency. The British Survey of Fertiliser Practice has contained information on the proportion of Cropland receiving manure since 2008. For years prior to 2008, the 2008 – 2015 average value has been used. The British Survey of Fertiliser Practice has contained information on the proportion of Cropland receiving fertiliser since 1992. For years prior to 1992, the 1992 - 2001 average value has been used.

6.3.6 Category-Specific QA/QC and Verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 6.10**.

A resampling of the 1980-based National Soil Inventory (NSI) in England and Wales in 1995-2003 found large losses of soil carbon across all land use types (Bellamy *et al*. 2005). It was hypothesized that this loss was due to climate change because all land uses showed losses, suggesting that the UK's LUC modelling approach was incorrect. In contrast, a more recent study using Countryside Survey (CS) data (Reynolds *et al.* 2013) found no significant change in soil carbon stocks under most Grassland habitat types between 1978 and 2007. The reason for the different results obtained by NSI and CS is not clear, although there are methodological differences between the two surveys. Subsequent modelling studies (Smith *et al*. 2007; Kirk and Bellamy 2010, Foerid *et al*. 2012; Guenet *et al*. 2013) have shown that climate changes could only account for a small part of the decrease in soil carbon reported in Bellamy *et al*. (2005). Guenet *et al*. (2013) also highlighted the importance of prior land use history in priming soil carbon dynamic models.

6.3.7 Category-Specific Recalculations

The land use change model for soil carbon stock changes has been re-run with revised deforestation activity data based on the National Forest Inventory with supplementary data on the area of small woods. Input data on the carbon stocks of Forest soils was also revised due to improvements to soil carbon modelling within the CARBINE forest carbon model.

An error in the factor used to calculate the amount of nitrous oxide emitted as a result of loss of soil organic matter due to land use change was corrected.

More detailed activity data on crop type has changed the values of soil carbon stock change and living biomass carbon stock change from cropland management activities.

The have been minor changes in the wildfire areas due to revised activity data.

The cumulative change between the 1990 – 2014 inventory and the 1990 - 2015 inventory is shown in **Figure 6.6**. Changes in emissions are described in **Table 6.3**.

Figure 6.6 4B Cropland change in net emissions between the 1990-2014 and 1990-2015 inventories

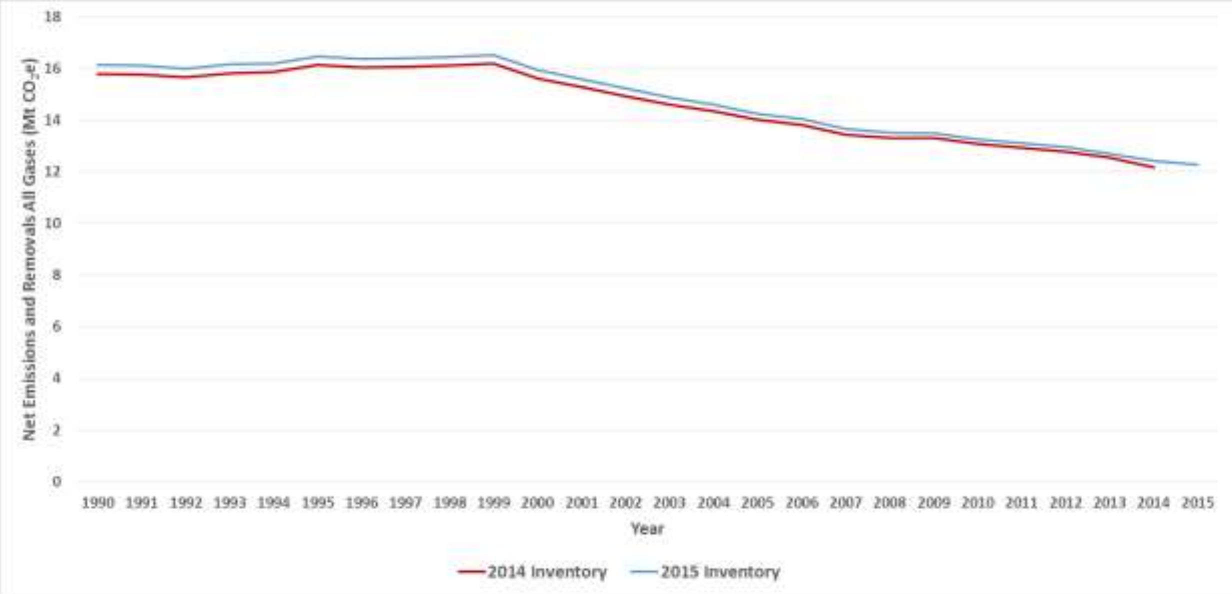


Table 6.3 4B Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4B1	Carbon stock change in living biomass - gains	-0.4581	-10.67	-0.3938	-10.57	Gg C	The latest available crop area activity data has been included and some historic data has been revised.
4B1	Carbon stock change in living biomass - losses	6.525	0.153	6.504	0.153	Gg C	The latest available crop area activity data has been included and some historic data has been revised.
4B1	Net carbon stock change in soils - mineral soils	354	1142	347.4	1160	Gg C	The latest available crop area activity data has been included and some historic data has been revised.
4B2.1/4(V)	Biomass burning - controlled burning	0.2081	0.2443	0.1898	0	Gg C	Improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a burning. The deforestation areas have been revised with inclusion of the NFI and small wood datasets.
4B2.1	Carbon stock change in living biomass - losses	0.3001	0.368	0.2829	0	Gg C	The deforestation areas have been revised with inclusion of the NFI and small woodlands datasets. The improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model and hence changed the losses following deforestation.
4B2.1	Net carbon stock change in dead organic matter	0.06457	0.06019	0.04981	0	Gg C	The deforestation areas have been revised with inclusion of the NFI and small wood datasets. The improvements to forest activity data changed the average

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
							biomass density estimates output from the CARBINE forest model and hence changed the losses following deforestation.
4B2.1	Net carbon stock change in soils - mineral soils	0.01097	0.5863	0.01097	0.2208	Gg C	The deforestation areas have been revised with inclusion of the NFI and small wood datasets.
4B2.2	Carbon stock change in living biomass - losses	65.41	36.77	65.41	36.85	Gg C	The land use change matrix for Guernsey was revised after reviewing the habitat survey activity data.
4B2.2	Net carbon stock change in soils - mineral soils	3267	1605	3267	1605	Gg C	The land use change matrix for Guernsey was revised after reviewing the habitat survey activity data.
4B1/4(V)	Biomass burning - wildfires	0.000988	0.000918	0.00133	0.000918	Gg CH_4	Minor changes to wildfire area due to inclusion of latest available activity data.
4B2.1/4(V)	Biomass burning - controlled burning	0.00229	0.00268	0.00208	0	Gg CH_4	Improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a burning. The deforestation areas have been revised with inclusion of the NFI and small wood datasets.
4B1/4(V)	Biomass burning - wildfires	0.000026	0.000024	0.000035	0.000024	Gg N_2O	Minor changes to wildfire area due to inclusion of latest available activity data.
4B2.1/4(III)	Direct N_2O from N mineralisation	0.0000073	0.00039	0.000011	0.00023	Gg N_2O	The deforestation areas have been revised with inclusion of the NFI and small wood datasets. An error in the application of the conversion factor from N_2O-N to N_2O has been corrected.

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4B2.1/4(V)	Biomass burning - controlled burning	0.000126	0.000148	0.000115	0	Gg N_2O	Improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a burning. The deforestation areas have been revised with inclusion of the NFI and small wood datasets.
4B2.2/4(III)	Direct N_2O from N mineralisation	2.178	1.079	3.422	1.689	Gg N_2O	An error in the application of the conversion factor from N_2O-N to N_2O has been corrected.

6.3.8 Category-Specific Planned Improvements

A vector based approach to tracking land use change is being developed which could assimilate data from the European Commission Integrated Administration and Control System (IACS) data to provide a more accurate assessment of Grassland/Cropland rotation lengths for each UK administration. This will be incorporated with the move to using a vector approach to land use change more widely in the LULUCF inventory. Incorporating IACS data in a vector based model will also allow improved tracking of changes in Cropland Management.

A BEIS-funded project to implement the Wetlands Supplement (IPCC, 2013a) guidance is due for completion in 2017.

6.4 CATEGORY 4C – GRASSLAND

6.4.1 Description

Emissions sources	4C Grassland: carbon stock change 4C Grassland: 4(II) Emissions from drainage of organic soils. 4C Grassland: 4(III) Direct N_2O emissions from N mineralisation. 4C Grassland: 4(V) Biomass burning
Gases Reported	CO_2, CH_4, N_2O
Methods	T3 for carbon stock changes, T1 for other emissions
Emission Factors	Country-specific for T3 methods
Key Categories	4C: Grassland - CO_2 (L1, T1, L2, T2)
Key Categories (Qualitative)	None identified
Overseas Territories and Crown Dependencies Reporting	Reported under the relevant Sector 4 sub-categories at Tier 1
Completeness	No known omissions- areas are reported for land uses with no associated emissions.
Major improvements since last submission	Change in hedge biomass carbon stock changes is now included in the estimate of carbon stock change due to from grassland management activities. Revision of the deforestation activity data used for input to the soil carbon stock change model to include the National Forest Inventory and small woods datasets. Correction of an error in the conversion factor for N_2O-N mineralised due to LUC to Grassland. Peat extraction site areas have been revised with improved activity data which impacts the area of Wetland converted to Grassland. Revision of the Land Use Change Matrix for the Guernsey. Use of updated agricultural census data for the Falkland Islands.

The category is disaggregated into 4.C.1 Grassland remaining Grassland and 4.C.2 Land converted to Grassland.

Ongoing carbon stock changes in soils arising from historical land use change to Grassland more than 20 years before the inventory reporting year are reported under 4.C.1 Grassland remaining Grassland. The area of undisturbed grassland which has not been converted from other land uses in the past (7,933 kha in 2015) is also reported here. Undisturbed grassland is used as a buffer category (on the recommendation of UNFCCC reviewers, as Grassland is the most extensive land type in the UK) and is calculated as the difference between the total land area (from the official national statistic of UK land area, Office for National Statistics 2016) and the sum of all other land use areas (calculated from land use matrices, afforestation areas, peat extraction areas etc.) for each year. No anthropogenic emissions or removals are associated with this undisturbed area.

Carbon stock changes and biomass burning emissions due to the conversion of other land categories to Grassland in the 20 years before the inventory reporting year are reported under 4.C.2 Land converted to Grassland, Carbon stock changes take account of the lagged effects of conversions up to 20 years previously (after 20 years emissions continue, but are reported in Grassland remaining Grassland). Biomass burning emissions occur in the same year as the land use conversion). All forms of land use change to Grassland, including deforestation, are considered and both mineral and organic soils are included.

Changes in biomass carbon stock resulting from changes in grassland management activities are included in the inventory and are reported under 4.C.1 Grassland remaining Grassland. Change in hedge biomass carbon stock is included in the inventory for the first time.

Carbon stock changes from drainage of Grassland on organic soils arise from areas which were drained many decades ago for agriculture which allowed oxygen into previously waterlogged soils. As a result, soil carbon in these areas continues to oxidise and be released as CO_2, resulting in an ongoing change in soil carbon stock. These emissions are reported in Table 4(II).

Nitrous oxide emissions from soil disturbance associated with land-use conversion to Grassland (Table 4(III)) are reported: these arise from Forest Land being converted to Grassland.

Emissions of CO_2, CH_4 and N_2O from the burning of forest biomass when Forest Land is converted to Grassland and emissions from wildfires on Grassland are reported under Table 4(V). Full details of the methods and activity data are given in **Annex 3.4.4** and **Annex 3.4.5**.

6.4.2 Information on approaches used for representing land areas and on land use databases used for the inventory preparation

The UK uses Approach 2 (IPCC 2006) for the representation of land use areas in the inventory, and compiles several different data sources into a non-spatially-explicit land use conversion matrix. The data sources are available at the individual country level (England, Scotland, Wales and Northern Ireland) and results are combined to give UK totals. The approaches used for representing land use areas in the inventory are described in **Section 6.1.1.**

Data sources that contain area information for reporting carbon stock changes and/or emissions from Grassland are habitat/landscape surveys; Forestry Commission data on unconditional felling licences; an assessment of the area of improved Grassland on drained organic soils; and data on wildfires on agricultural land from Fire and Rescue service and satellite data.

Areas of Forest Land converted to Grassland (deforestation) are estimated from unconditional felling licence data and administrative information from the national forest estates from the Forestry Commission and land conversion ratios from Countryside Survey. The area of unconditional felling licences[49] (felling licences granted without a requirement to restock) in

[49] http://www.forestry.gov.uk/datadownload

England (1992-present), Scotland (1998-present) and Wales (1996-present) is used to estimate deforestation to rural land uses. Countryside Survey (CS) data (1990-2007) are used to fill gaps in the time series and to estimate deforestation in Northern Ireland (where no suitable activity data are available). Details are given in **Annex 3.4.4**.

Change in biomass carbon stocks as a result of change in Grassland Management is estimated using data on the area of different grassland types from Countryside Survey. This includes data on the length and condition of hedges.

Areas of improved Grassland that are a source of carbon emissions due to historical drainage (reported under Grassland remaining Grassland) have been assessed by Anthony *et al* (personal communication- unpublished report from Defra project AC0114, 2013). Their analysis overlaid areas of improved Grassland from the Land Cover Map and the Integrated Administration and Control System (IACS) with mapping of organic soils from soil surveys. All improved Grassland on organic soils is assumed to be drained. Anthony *et al*.'s methodology could not assess the extent of semi-natural Grassland on drained organic soils as it cannot be assumed that all unimproved Grassland on organic soils is drained. Assessment of the area of unimproved Grassland on drained organic soils is being undertaken as part of an ongoing research programme to support implementation of the Wetland Supplement guidance.

From 2010 areas of wildfire on Grassland are taken from Fire and Rescue service data. Between 2001 and 2009 the area of wildfire on Grassland is calculated by using satellite data on the total area of wildfires in the UK which are apportioned to land use using the same ratios as found in the Fire and Rescue service data. Grassland wildfire areas prior to 2001 are extrapolated.

6.4.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

Grassland is defined in accordance with the Agriculture, Forestry and Other Land Uses guidance (IPCC 2006). Grazing is the main land use on wetlands, so areas of wetland habitat not used for peat extraction, such as bogs, are also included in the Grassland category. For pre-1980 land use matrices Grassland is the sum of the following land cover types in the Monitoring Landscape Change project (MLC 1986): upland heath, upland smooth grass, upland coarse grass, blanket bog, bracken, lowland rough grass, lowland heather, gorse, neglected grassland, marsh, improved grassland, rough pasture, peat bog, fresh marsh and salt marsh. Post-1980, grassland is the sum of the following Broad Habitat types in the Countryside Survey: improved grassland, neutral grassland, calcareous grassland, acid grassland, bracken, dwarf shrub heath, fen/marsh/swamp, bogs, montane, supra littoral sediment and littoral sediment (Jackson, 2000).

6.4.4 Methodological Issues

Activity data for land use change are estimated using a land use matrix approach. A summary of data flows associated with the land use matrix is given in **Section 6.1.1**. Carbon stock changes and fluxes arising from land use change in the 20 years before the inventory year are reported under 4C2 Land converted to Grassland. Carbon stock changes and fluxes from historical land use change (more than 20 years before the inventory year) are reported under 4C1 Grassland remaining Grassland. Detailed descriptions of the methods and emission factors used for the activities in this Category can be found in **Annex 3.4.2**.

The dynamic model of soil carbon stock change is described in **Section 6.3.4**. N_2O emissions associated with the conversion of land to Grassland are reported using the areas of Forest land converted to Grassland from the land use change matrices and the IPCC Tier 1 emission factors.

6.4.5 Uncertainties and Time-Series Consistency

The uncertainty analysis in the Annexes provides estimates of uncertainty according to the GPG source category and gas. 4C Grassland was estimated to have an uncertainty of 60% in 1990, reducing to 50% in 2015 for CO_2 (from LUC to Grassland, grassland management effects on biomass carbon stocks, wildfires on Grassland and emissions from Grassland on drained organic soils).

The areas undergoing land use change are the biggest source of uncertainty in the LULUCF inventory (see **Annex 3.4.12**), but model choice and soil carbon parameters are also significant. Work on assimilating more land use data sets is planned, which should constrain the high uncertainties associated with this. Emissions from Grassland on drained organic soils has the largest uncertainties of the minor emissions sources (i.e. not land use change) as the effects of drainage are highly uncertain. Work in implementing the Wetlands Supplement may decrease this uncertainty.

The combined uncertainty for CH_4 is 55% (from wildfires) and for N_2O is 55 % in 1990 increasing to 125 % in 2015 (from wildfires and N mineralisation associated with land conversion and grassland management activities).

With regard to series consistency:

- For drainage of organic soils (4C1) the activity data uses areas of drained organic soil from Anthony (personal communication, 2013). It is assumed that all drainage of organic soils under improved Grassland occurred before 1990, as policy has favoured protection of organic soils. There have been no policy incentives to encourage new land drainage for agricultural use since before 1990, and major drainage of large areas of improved Grassland on organic soils in areas such as the Somerset Levels fens is known to have occurred well before this. No improved Grassland on drained organic soils has been rewetted since 1990 as there have been no policy incentives for this, therefore a single area is used throughout the time series;
- For changes in non-forest biomass and soil carbon stocks due to land use change the data sources for Great Britain have maintained consistent methodology over the time series. Consistency between these and Northern Ireland data sources has improved with better methodological integration between land use surveys. In particular the methodology use for Countryside Surveys in GB and NI has improved since 1990;
- For emissions due to controlled biomass burning after conversion of Forest Land to Grassland, the time series consistency has improved to high with the introduction of country-specific data sets covering the period since 1990;
- For biomass carbon stock changes resulting from grassland management, activity data come from Countryside Survey. This is the same dataset used to estimate change in carbon stocks due to land use change and has good internal consistency for Great Britain. Consistency between these and Northern Ireland data sources has improved with better methodological integration between land use surveys.
- For emissions from wildfires, a new activity dataset became available for 2010 onwards. Burnt areas have been extrapolated back to 2001 based on remote sensing data, but between 1990 and 2001 there are no appropriate data to use for extrapolation, so emissions were estimated using in the for 2001 -2010 ten year average.

6.4.6 Category-Specific QA/QC and Verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 6.10**.

As discussed in **Section 6.3.6** resampling of the 1980-based National Soil Inventory (NSI) in England and Wales in 1995-2003 found large losses of soil carbon across all land use types (Bellamy *et al*. 2005) but, a more recent study using Countryside Survey (CS) data (Reynolds *et al.* 2013) found no significant change in soil carbon stocks under most Grassland habitat types between 1978 and 2007. The possible reasons for these differences are discussed in **Section 6.3.6**.

6.4.7 Category-Specific Recalculations

Biomass carbon stock changes of hedges have been included in grassland management activities for the first time. This has a particularly marked effect between 1990 and 1998 when policies to encourage hedge creation increased removals by Grassland.

The land use change model for soil carbon stock changes has been re-run with revised deforestation activity data based on the National Forest Inventory with supplementary data on the area of small woods. Input data on the carbon stocks of Forest soils was also revised due to improvements to soil carbon modelling within the CARBINE forest carbon model.

An error in the factor used to calculate the amount of nitrous oxide emitted as a result of loss of soil organic matter due to land use change was corrected.

The have been minor changes in the wildfire areas due to revised activity data.

Full details of changes leading to recalculations are given in **Table 6.4**.

Figure 6.7 4C Grassland change in net emissions between the 1990-2014 and 1990-2015 inventories

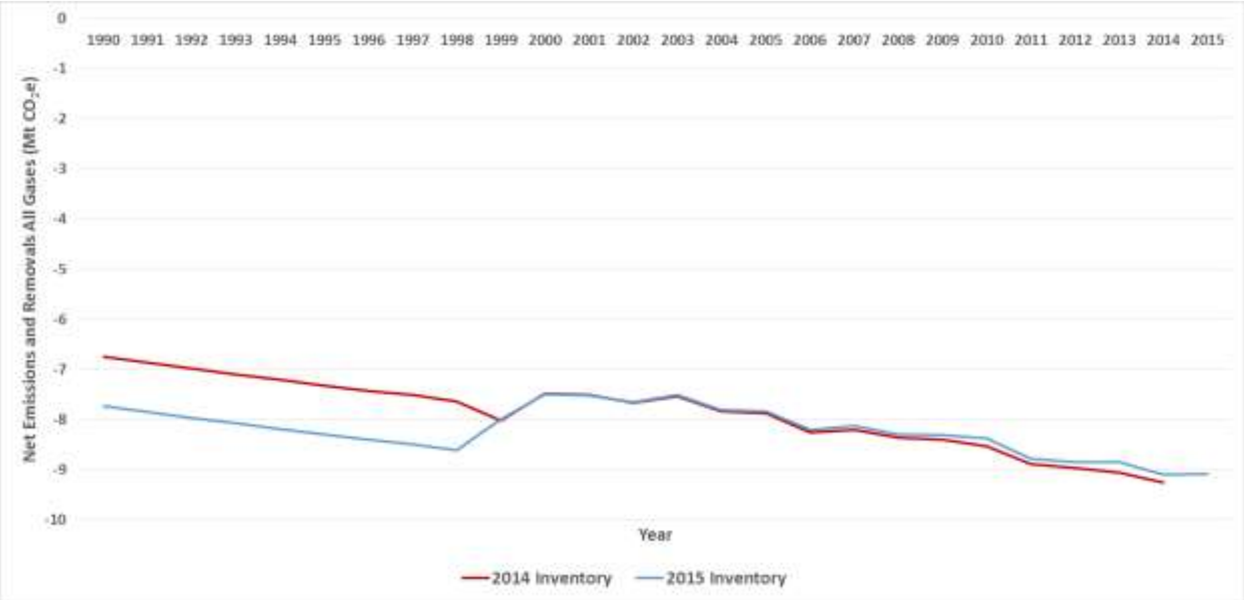


Table 6.4 4C Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4C1	Carbon stock change in living biomass - gains	0	-22.45	-270.7	-28.97	Gg C	Inclusion of new methodology for calculating biomass carbon stock change from hedges as a result of grassland management.
4C1	Carbon stock change in living biomass - losses	85.01	28.54	90.48	43.94	Gg C	Inclusion of new methodology for calculating biomass carbon stock change from hedges as a result of grassland management.
4C2.1/4(V)	Biomass burning - controlled burning	5.263	51.83	4.538	63.07	Gg C	Improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a burning. The deforestation areas have been revised with inclusion of the NFI and small wood datasets.
4C2.1	Carbon stock change in living biomass - losses	7.791	78.63	6.79	93.91	Gg C	The deforestation areas have been revised with inclusion of the NFI and small wood datasets. The improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model and hence changed the losses following deforestation.

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4C2.1	Net carbon stock change in dead organic matter	1.434	12.2	1.163	16.91	Gg C	The deforestation areas have been revised with inclusion of the NFI and small wood datasets. The improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model and hence changed the losses following deforestation.
4C2.1	Net carbon stock change in soils - mineral soils	0.08922	65.2	0.08922	65.25	Gg C	The deforestation areas have been revised with inclusion of the NFI and small wood datasets.
4C2.2	Carbon stock change in living biomass - losses	0.7244	1.588	0.7244	1.357	Gg C	The activity data for Jersey and Isle of Man were updated with the latest agricultural datasets.
4C2.2	Net carbon stock change in soils - mineral soils	-1316	-1150	-1316	-1149	Gg C	The activity data for Jersey and Isle of Man were updated with the latest agricultural datasets.
4C2.3	Carbon stock change in living biomass - gains	-3.237	-0.4267	-3.488	-0.3292	Gg C	The peat extraction areas have been revised with improved activity data which impacts the area of Wetland converted to Grassland.
4C2.3	Net carbon stock change in soils - organic soils	0.1266	1.168	0.1364	1.469	Gg C	The peat extraction areas have been revised with improved activity data which impacts the area of Wetland converted to Grassland.

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4C2.4	Carbon stock change in living biomass - losses	3.699	6.166	3.699	6.155	Gg C	The land use change matrix for Guernsey was revised after reviewing the habitat survey activity data.
4C2.4	Net carbon stock change in soils - mineral soils	-162.5	-250.6	-162.5	-250.5	Gg C	The land use change matrix for Guernsey was revised after reviewing the habitat survey activity data.
4C1/4(V)	Biomass burning - wildfires	0.3606	0.2995	0.3465	0.1915	Gg CH_4	Minor changes to the wildfires areas due to the inclusion of the latest available activity data.
4C2.1/4(V)	Biomass burning - controlled burning	0.05781	0.5692	0.04984	0.6928	Gg CH_4	Improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a burning. The deforestation areas have been revised with inclusion of the NFI and small wood datasets.
4C1/4(III)	Direct N_2O from N mineralisation	0.000017	0.00003	0.000026	0.000047	Gg N_2O	An error in the application of the conversion factor from N_2O-N to N_2O has been corrected.
4C1/4(V)	Biomass burning - wildfires	0.03293	0.02735	0.03164	0.01748	Gg N_2O	Minor changes to the wildfires areas due to the inclusion of the latest available activity data.

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4C2.1/4(III)	Direct N_2O from N mineralisation	0.00006	0.04346	0.00009	0.06836	Gg N_2O	The deforestation areas have been revised with inclusion of the NFI and small wood datasets. An error in the application of the conversion factor from N_2O-N to N_2O has been corrected.
4C2.1/4(V)	Biomass burning - controlled burning	0.003198	0.03149	0.002757	0.03832	Gg N_2O	Improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a burning. The deforestation areas have been revised with inclusion of the NFI and small wood datasets.

6.4.8 Category-Specific Planned Improvements

A BEIS-funded research project is underway to improve understanding of the effect of grassland management practices on carbon stock changes in organic and organo-mineral soils. This will fill a knowledge gap and enable carbon stock changes resulting from Grassland management to be included in the inventory.

A vector based approach to tracking land use change is being developed with BEIS funding which could assimilate data from the European Commission Integrated Administration and Control System (IACS) data to provide a more accurate assessment of Grassland/Cropland rotation lengths for each UK administration.

A BEIS-funded project to implement the Wetlands Supplement (IPCC, 2013a) guidance is due for completion in 2017.

6.5 CATEGORY 4D – WETLANDS

6.5.1 Description

Emissions sources	4D Wetlands: Carbon stock change 4D Wetlands: 4(II) Non-CO_2 emissions from drainage of soils
Gases Reported	CO_2, N_2O
Methods	Tier 1
Emission Factors	Country specific and default EFs
Key Categories	None identified
Key Categories (Qualitative)	None identified
Overseas Territories and Crown Dependencies Reporting	Not occurring
Completeness	No known omissions- areas are reported for land uses with no associated emissions.
Major improvements since last submission	Peat extraction areas have been revised due to improved activity data.

According to the IPCC (2006), Wetlands include any land that is covered or saturated by water for all or part of the year, and that does not fall into the Forest Land, Cropland, or Grassland categories. The IPCC 2006 Guidelines define managed wetlands as those where the water table is artificially changed (i.e. raised or drained) or those created by human activity. Natural emissions and removals from wetlands which are not the result of human activity are not estimated. The Wetlands sector includes emissions from peatlands that are cleared and drained for peat production (for energy or horticultural purposes) and for areas converted to permanently flooded land (reservoirs). As explained above, most UK wetland habitats (e.g. marsh, bog, swamp and fen) are grazed and their emissions and removals are estimated with Grassland. A research project is currently in progress to identify UK-specific activity data and emission factors to use with the 2013 Wetlands Supplement methodology.

In the UK, estimates are made of emissions from on-site peat production and off-site emissions from horticultural peat under 4.D.1 Wetlands remaining Wetlands. Small areas of grassland converted to Wetland for peat extraction (4.D.2.1) and to flooded land (4.D.2.2) are included under 4.D.2 Land converted to Wetlands, with the associated soil emissions and living biomass carbon stock changes estimated using the appropriate Tier 1 methodologies. N_2O emissions from wetland drainage (as part of peat production) are reported under 4.D/4(II). Peat cutting is known to occur in the Falkland islands for use as domestic fuel, but emissions from this are not included in the inventory at present due to a lack of information on the quantities of peat extracted and the areas affected.

The area of UK natural inland water (115.74 kha) is reported in the category Other Wetlands remaining Other Wetlands and the area of reservoirs created before 1990 (50.84 kha) is reported in Flooded Land remaining Flooded Land. A small number of reservoirs have been created since 1990, and emissions from these due to change in biomass carbon stocks on conversion are included in the inventory (under Grassland converted to Flooded Land).

6.5.2 Information on approaches used for representing land areas and on land use databases used for the inventory preparation

For Wetlands, the approach differs from that used for other land use categories, because peat extraction sites and reservoirs are not explicitly identified in the habitat/landscape surveys used for the land use matrix.

Peat extraction sites are most likely to fall under the “Inland rock” broad habitat (4F Other Land) or “Bog” broad habitat (4C Grassland) if some vegetation cover remains (Maskell *et al*. 2008). Reservoirs will fall under the “Standing open water and canals” broad habitat (4F Other Land). Peat extraction sites and reservoirs need to be explicitly identified and their areas transferred into 4D Wetlands from the land use categories in which Countryside Survey places them. Data from the Directory of Mines and Quarries, Google Earth, the Minerals Extraction in Great Britain report and its predecessor the Minerals Raised Inquiry, and papers on peat extraction in Northern Ireland were used in combination to produce an activity dataset for active peat extraction areas in the UK (see **Annex 3.4.8** for further details).

Activity data for reservoirs were compiled from the Public Register of Large Raised Reservoirs (supplied by the Environment Agency for England and Wales) and the SEPA Water Body Classification database (see **Annex 3.4.9** for further details).

6.5.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

The area of inland water is taken from the “UK Standard Area Measurements” (Office for National Statistics 2016). It defines inland water as ‘bounded’ permanent water bodies, e.g. lakes, lochs and reservoirs, exceeding 1 km^2 (100 hectares) in area. ‘Open’ tracts of water, e.g. rivers, canals and streams are excluded from this definition. Reservoirs (flooded land) were identified either by their inclusion in the Public Register of Large Raised Reservoirs or by their classification as “Heavily modified” in the SEPA Water Body Classification database.

6.5.4 Methodological Issues

Emissions from peat extraction have been estimated using the Tier 1 methodology, which does not distinguish between peat extraction production phases (i.e. it includes conversion and vegetation clearing). On-site emissions associated with peat extraction are reported under 4.D.1 Wetlands remaining Wetlands. All carbon in horticultural peat is assumed to be emitted during the extraction year. Methane emissions are assumed to be insignificant. N_2O emissions from drainage are reported (although emissions are considered insignificant on nutrient-poor peatlands). The latest Directory of Mines and Quarries categorises sites as producing horticultural or energy source (fuel) peat. This information is used to extract the area of nutrient-rich peats that will produce N_2O emissions (following the IPCC Tier 1 methodology). Further information is given in **Annex 3.4.8**.

Google Earth imagery is used to track the change in the area of individual extraction sites over time. Google Earth is imagery is checked annually and extraction site areas are updated as new imagery becomes available.

The site records show that the area under active peat extraction diminished between 1990 and 2002 for Great Britain and 1991 and 2007 for Northern Ireland. Some sites show no change in area on the Google Earth imagery, and are assumed to be abandoned extraction sites that are still producing emissions (reported under 4D1). Sites where extraction is no longer visible on the Google Earth imagery are assumed to have been converted to Grassland. Changes in biomass carbon and organic soil carbon from this land use change are reported using the Tier 1 approach from the IPCC 2006 Guidelines.

A small area of land conversion to Wetlands occurs between 2003 and 2005, which is assumed to be all from Grassland based on the examination of Google Earth imagery. This area and the associated on-site emissions are reported under 4D.2 Land converted to Wetlands, using the 5-year transition period recommended by the IPCC 2006 Guidelines.

A Tier 1 methodology was applied for emissions from Flooded Lands. In accordance with the guidance, this estimated carbon stock changes in living biomass stock in the year of flooding (for reservoirs established since 1990) but not carbon stock changes in soils. The locations of the reservoirs was established on maps, and due to their location in upland areas, all were assumed to be Grassland prior to flooding. A living biomass density of 2 t dry matter/ha was used to estimate carbon stock losses.

6.5.5 Uncertainties and Time-Series Consistency

Uncertainties for the peat extraction site activity data are estimated to be >100% in 1990 and 50% in 2009 (due to improved activity data). Uncertainties in the emission factors for peat extracted for horticultural and fuel use and for emissions from Flooded Land are the default IPCC values given in the 2006 Guidelines. Uncertainty in the Flooded Land activity data was very low as there were a limited number of reservoirs established since 1990 (five in total).

Overall for the Wetlands category uncertainty in CO_2 emissions was 100% in 1990 falling to 50 % in 2015. Uncertainty in methane emissions was 55% throughout the time series and uncertainty in N_2O emissions was 100% throughout the time series.

Time- series consistency for activity data for peat extraction sites is affected by uncertainty in survey dates. Time- series consistency for flooded lands was good due to the complete nature of the data set.

6.5.6 Category-Specific QA/QC and Verification

The peat extraction site activity dataset developed was partially verified by comparing the measured areas with reported areas of planning permission (which were available for some extraction sites in England and Scotland). The measured areas either matched or were smaller than the planning permission areas, which is to be expected as it is known that not all areas with planning permission are undergoing active extraction.

The locations and previous land-use of new reservoirs were verified using the www.magic.gov.uk geographic information portal.

6.5.7 Category-Specific Recalculations

There have been small updates to the areas of some peat extraction sites due to the availability of updated Google Earth imagery. The activity data for 2013-2014 was updated with the latest published information on peat volume sales (Office for National Statistics 2014). Volumes for 2015 were assumed to be equal to those in 2014. The changes in emissions are shown in **Table 6.5.**

Figure 6.8 4D Wetlands change in net emissions between the 1990-2014 and 1990-2015 inventories

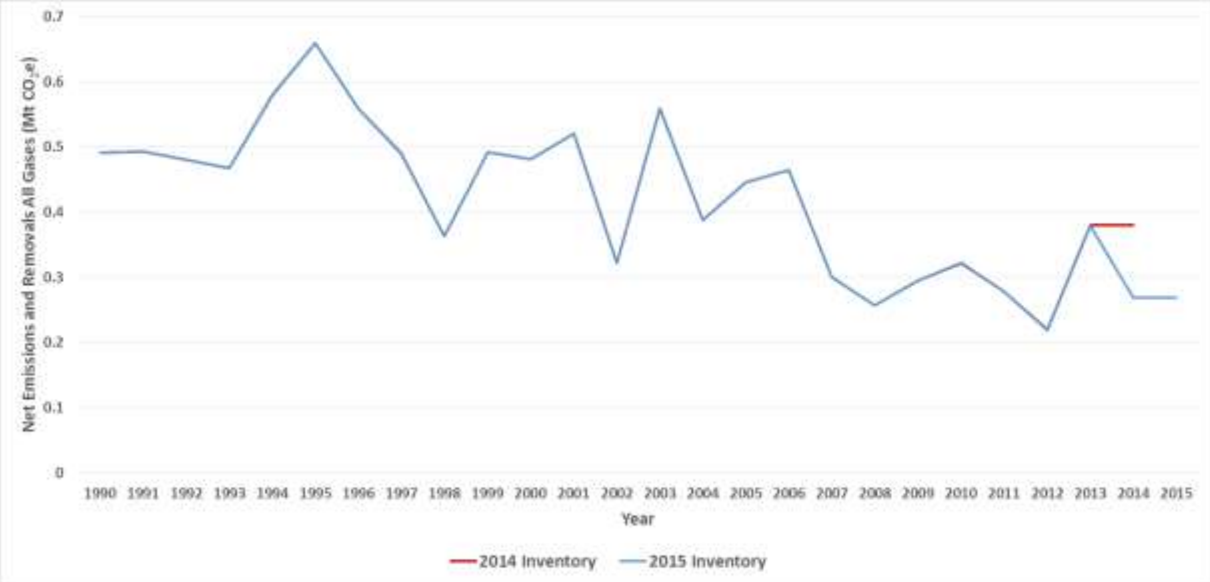


Table 6.5 4D Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4D1.1	Net carbon stock change in soils - organic soils	132.8	103.5	132.8	73.28	Gg C	The peat extraction areas have been revised with improved activity data.
4D2	Net carbon stock change in soils - organic soils	0.0119	0.004856	0.01129	0.003195	Gg C	The peat extraction areas have been revised with improved activity data.
4D/4(II)	Emissions and removals from drainage of organic soils	0.01387	0.0010	0.01387	0.000991	Gg N_2O	The peat extraction areas have been revised with improved activity data.

6.5.8 Category-specific planned improvements

A BEIS-funded project to implement the Wetlands Supplement (IPCC, 2013a) guidance is due for completion in 2017.

6.6 CATEGORY 4E – SETTLEMENTS

6.6.1 Description

Emissions sources	4E Settlements: Carbon stock change 4E Settlements: Direct N_2O emissions from N mineralization 4E Settlements: 4(V) Biomass burning
Gases Reported	CO_2, CH_4, N_2O
Methods	T3 for carbon stock changes, T1 for other emissions
Emission Factors	Country-specific for T3 methods
Key Categories	4E: Settlements – CO_2 (L1, T1, L2, T2)
Key Categories (Qualitative)	None identified
Overseas Territories and Crown Dependencies Reporting	Reported under the relevant Sector 4 sub-categories at Tier 1
Completeness	No known omissions- areas are reported for land uses with no associated emissions.
Major improvements since last submission	Revision of the deforestation activity data used for input to the soil carbon stock change model to include the National Forest Inventory and small woods datasets. Correction of an error in the conversion factor for N_2O-N mineralised. Revision of the Land Use Change Matrix for the Guernsey. Correction for the activity data for the Falkland Islands.

This category is disaggregated into 4.E.1 Settlements remaining Settlements and 4.E.2 Land converted to Settlements.

Ongoing carbon stock changes in soils and direct N_2O emissions from N mineralization arising from historical land use change to Settlements more than 20 years before the inventory reporting year are reported under 4.E.1 Settlement remaining Settlement. Carbon stock changes, N_2O emissions from N mineralization and biomass burning emissions in the previous 20 years before the reporting year are reported under category 4.E.2 (biomass burning emissions occur in the same year as the land use conversion). All forms of land use change, including deforestation, are considered and both mineral and organic soils are included.

Direct emissions of N_2O from N mineralization associated with land use change or land management are reported under Table 4(III). Emissions of CO_2, CH_4 and N_2O from the burning of forest biomass when Forest Land is converted to Settlement are reported under Table 4(V).

6.6.2 Information on approaches used for representing land areas and on land use databases used for the inventory preparation

The approaches used for representing land use areas in the inventory are described in **Section 6.1.1.**

The activity data on areas of Forest Land converted to Settlement (deforestation) from 2000 onwards have been updated with data collated from multiple sources (see section **6.4.2** and **Annex 3.4.4** for details). Before 2000, data on forest-urban land conversion in England was obtained from the Ordnance Survey (the national mapping agency) via the Department of Communities and Local Government. Land conversion ratios from Countryside Survey were then used to extrapolate from England to the other countries in the UK. Details are given in **Annex 3.4**.

6.6.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

Settlement is defined in accordance with the Agriculture, Forestry and Other Land Use Guidance (IPCC 2006). For pre-1980 land use matrices Settlement land is the sum of the Built-up, Urban open, Transport, Mineral workings and Derelict land cover types in the Monitoring Landscape Change project (MLC 1986). Post-1980, Settlement land corresponds to the "Built-up and Gardens" and "Boundary and linear features" Broad Habitat types in the Countryside Survey (Haines-Young *et al*. 2000, Appendix A), defined as:

- Built-up and Gardens: "Covers urban and rural settlements, farm buildings, caravan parks and other man-made built structures such as industrial estates, retail parks, waste and derelict ground, urban parkland and urban transport infrastructure. It also includes domestic gardens and allotments."; and
- Boundary and linear features: "a diverse range of linearly arranged landscape features such as hedgerows, walls, stone and earth banks, grass strips and dry ditches. This habitat type also includes some of the built components of the rural landscape including roads, tracks and railways and their associated narrow verges of semi-natural habitat."

Some components of the "Boundary and linear features" Broad Habitat type could fall under the definition of Cropland or Grassland. It is not possible to disaggregate this Broad Habitat further and the assignment to a single land use category avoids double-counting. In the latest 2007 Countryside Survey the "Boundary and linear features" Broad Habitat type covered 2% of the UK land area.

6.6.4 Methodological Issues

A summary of the land use matrix approach and the dynamic model of soil carbon stock change used to estimate changes in biomass and soil carbon due to land use change is given in **Section 6.3.4**.

Carbon stock changes and fluxes arising from land use change in the 20 years before the inventory year are reported under 4E2 Land converted to Settlement. Fluxes from historical land use change (more than 20 years before the inventory year) are reported under 4E1 Settlement remaining Settlement.

Emissions of N_2O from N mineralization associated with land use change to Settlement are reported using Tier 1 methodology from the 2006 AFOLU guidance. Detailed descriptions of the methods and emission factors used for the activities in this Category can be found in **Annex 3.4.7**.

6.6.5 Uncertainties and Time-Series Consistency

The uncertainty analysis in the Annexes provides estimates of uncertainty according to the GPG source category and gas. 4E Settlement was estimated to have a combined uncertainty of 50% for CO_2 (from LUC to settlement). No methane emissions are reported for Settlements and therefore no uncertainty is estimated for methane emissions. Uncertainty of N_2O emissions was 135% in 1990, reducing to 15 % in 2015.

The areas undergoing land use change are the biggest source of uncertainty in the LULUCF inventory (see **Annex 3.4.13**), but model choice and soil carbon parameters are also significant. Work on assimilating more land use data sets, which should constrain the high uncertainties associated with area, is ongoing but not yet complete. The collation of multiple deforestation datasets has reduced the uncertainty in this area.

With regard to series consistency:

- For changes in non-forest biomass and soil carbon stocks due to land use change the data sources for Great Britain have maintained consistent methodology over the time series. Consistency between these and Northern Ireland data sources has improved with better methodological integration between land use surveys. In particular the methodology use for Countryside Surveys in GB and NI has improved since 1990; and
- For emissions due to biomass burning after conversion of Forest Land to Settlement, there is good time series consistency as there has been continuity in the activity data source.

6.6.6 Category-Specific QA/QC and Verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 6.10**. Research described in **Section 6.1.1.** is also relevant to this section.

6.6.7 Category-Specific Recalculations

The recalculations described in Table 6.6 have resulted in a small increase in the size of the overall net GHG source in category 4E between the 1990-2014 and the 1990-2015 inventories (**Figure 6.9**). The main effects are increased emissions of CO_2 and N_2O from land use change to Settlement because of improved data on Deforestation to Settlement and correction of an error in the emission factor used to estimate emissions of N_2O from mineralisation which as increased reported N_2O emissions slightly.

Figure 6.9 4E Settlements change in net emissions between the 1990 - 2014 and 1990 - 2015 inventories

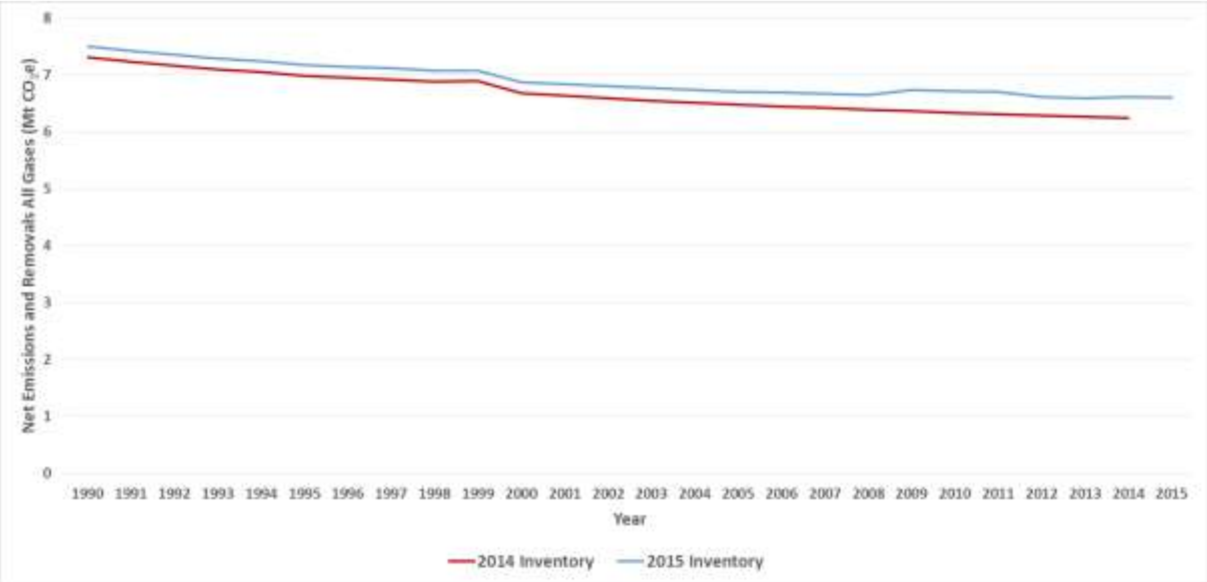


Table 6.6 4E Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4E2.1/4(V)	Biomass burning - controlled burning	14.00	4.809	12.32	16.20	Gg C	Improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a burning. The deforestation areas have been revised with inclusion of the NFI and small woods datasets.
4E2.1	Carbon stock change in living biomass - losses	20.57	7.237	18.42	24.03	Gg C	The deforestation areas have been revised with inclusion of the NFI and small woods datasets. The improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model and hence changed the losses following deforestation.
4E2.1	Net carbon stock change in dead organic matter	3.957	1.191	3.176	4.364	Gg C	The deforestation areas have been revised with inclusion of the NFI and small woods datasets. The improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model and hence changed the losses following deforestation.
4E2.1	Net carbon stock change in soils - mineral soils	10.43	19.25	10.43	34.78	Gg C	The deforestation areas have been revised with inclusion of the NFI and small woods datasets.

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4E2.2	Carbon stock change in living biomass - gains	-3.319	-6.684	-3.319	-6.686	Gg C	The land use change matrix for Guernsey was revised after reviewing the habitat survey activity data.
4E2.2	Net carbon stock change in soils - mineral soils	221.4	181.7	221.4	182.6	Gg C	The land use change matrix for Guernsey was revised after reviewing the habitat survey activity data.
4E2.3	Carbon stock change in living biomass - gains	-11.59	-8.473	-11.59	-8.532	Gg C	The activity data for conversion of grassland to settlements in the Falklands was corrected to extend from 2005 to 2015. The land use change matrix for Guernsey was revised after reviewing the habitat survey activity data.
4E2.3	Net carbon stock change in soils - mineral soils	1190	787.7	1190	787	Gg C	The land use change matrix for Guernsey was revised after reviewing the habitat survey activity data.
4E2.3	Net carbon stock change in soils - organic soils	0	1.618	0	3.517	Gg C	The activity data for the Falklands was updated with the latest agricultural datasets.
4E2.1/4(V)	Biomass burning - controlled burning	0.1537	0.05282	0.1354	0.1779	Gg CH_4	Improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a burning. The deforestation areas have been revised with inclusion of the NFI and small woods datasets.
4E1/4(III)	Direct N_2O from N mineralisation	0.2962	0.4169	0.4655	0.6552	Gg N_2O	An error in the application of the conversion factor from N_2O-N to N_2O has been corrected.

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4E2.1/4(III)	Direct N_2O from N mineralisation	0.006951	0.01283	0.01092	0.03644	Gg N_2O	The deforestation areas have been revised with inclusion of the NFI and small woods datasets. An error in the application of the conversion factor from N_2O-N to N_2O has been corrected.
4E2.1/4(V)	Biomass burning - controlled burning	0.008504	0.002922	0.007488	0.009844	Gg N_2O	Improvements to forest activity data changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a burning. The deforestation areas have been revised with inclusion of the NFI and small woods datasets.
4E2.2/4(III)	Direct N_2O from N mineralisation	0.1476	0.1211	0.232	0.1903	Gg N_2O	An error in the application of the conversion factor from N_2O-N to N_2O has been corrected.
4E2.3/4(III)	Direct N_2O from N mineralisation	0.7922	0.5244	1.244	0.8318	Gg N_2O	An error in the application of the conversion factor from N_2O-N to N_2O has been corrected.

6.6.8 Category-Specific Planned Improvements

Work on land use vectors for land use change is ongoing, but implementation was postponed to allow the inventory team to focus on the implementation of the new IPCC guidance (2006 AFOLU and 2013 Kyoto Protocol Supplement) and the new CRF reporting software.

6.7 CATEGORY 4F – OTHER LAND

6.7.1 Description

Emissions sources	4F2 Land converted to Other Land in the Overseas Territories and Crown Dependencies
Gases Reported	4F1:None 4F2: CO_2
Methods	Tier 1
Emission Factors	Tier 1
Key Categories	None identified
Key Categories (Qualitative)	None identified
Overseas Territories and Crown Dependencies Reporting	Areas reported under the relevant Sector 4 sub-categories at Tier 1
Completeness	No known omissions- areas are reported for land uses with no associated emissions.
Major improvements since last submission	Revision of the Land Use Change Matrix for the Guernsey. Use of updated agricultural census data for the Falkland Islands.

No emissions or removals are reported in this category in the UK. It is assumed that there are very few areas of land of other types that become bare rock or water bodies, which make up the majority of this type. Therefore the UK rows in Table 4.F. (Other Land) are completed with 'NO' (Not Occurring). A small area of grassland converted to Other Land is reported in the Overseas Territories and Crown Dependencies.

6.7.2 Information on approaches used for representing land areas and on land use databases used for the inventory preparation

The approaches used for representing land use areas in the inventory are described in **Section 6.1.1**

6.7.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

Other Land is defined as areas that do not fall into the other land use categories. For pre-1980 land use matrices Other Land is the sum of the bare rock, sand/shingle, inland water and coastal water land cover types in the Monitoring Landscape Change project (MLC 1986). Post-1980, Other Land contains the inland rock, standing water and canals and rivers and streams broad habitat types in the Countryside Survey (Jackson, 2000). As described in **Section 6.5**, areas of inland water exceeding 1km^2 are included in 4D Wetlands, but water bodies below this threshold would still be included under Other Land.

6.7.4 Category-specific recalculations

Table 6.7 4F Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4E2.3	Carbon stock change in living biomass - losses	0	0.004358	0	0	Gg C	The land use change matrix for Guernsey was revised after reviewing the habitat survey activity data.

6.7.5 Category-specific planned improvements

None planned.

6.8 CATEGORY 4G – HARVESTED WOOD PRODUCTS

6.8.1 Description

Emissions sources	4G Harvested Wood Products
Gases Reported	CO_2
Methods	Tier 3
Emission Factors	Country-specific
Key Categories	4G Harvested Wood Products – CO_2 (L1, L2)
Key Categories (Qualitative)	None identified
Overseas Territories and Crown Dependencies Reporting	Reported under the relevant Sector 4 sub-categories at Tier 3
Completeness	No known omissions
Major improvements since last submission	Revision due to the change to using the latest National Forest Inventory data

HWP stocks result from normal forest management processes (thinning and harvesting) in the Forest Land category and from conversion of Forest Land to Cropland, Grassland or Settlements (deforestation), as recommended by a previous ERT.

6.8.2 Methodological Issues

The UK has elected to use the production approach B2 as set out in the IPCC 2006 Guidelines for estimating HWP. A description of the method is in **Annex 3.4.10**. The carbon accounting model (CARBINE) is used to calculate the net changes in carbon stocks of harvested wood products (at the product type level), in the same way as it is used to estimate carbon stock changes in 4.A. Changes in carbon stocks from HWP arising from deforestation (conversion of Forest Land to Grassland, Cropland or Settlement) are also estimated using CARBINE. Additional data on consumption of wood products in the UK are then used to disaggregate the HWP into either consumed domestically or exported.

6.8.3 Uncertainties and Time-Series Consistency

The uncertainty analysis in **Annex 3.4.13** provides estimates of uncertainty according to IPCC source category and gas. 4G Harvested Wood Products was estimated to have a combined uncertainty of 45% for CO_2. No emissions of methane or nitrous oxide occur from HWP.

Activity data for areas planted and consequently harvested are obtained consistently from the same national forestry sources, which helps ensure time series consistency of estimated removals. Data on the consumption of products is also obtained from national forestry sources, however it is only available from 2002 onwards. The 1990-2001 values are based on the ten year average of the 2002-2011 values.

6.8.4 Category-Specific QA/QC and Verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 6.10**. The timber production predicted has been compared to the national timber production statistics produced by the Forestry Commission based on data from sawmills.

6.8.5 Category-Specific Recalculations

There have been some changes due to revision of the forest activity data to use the NFI dataset, revised small woods areas and improved alignment with wood production statistics. The effect of these changes on the time-series can be seen in **Figure 6.10** and **Table 6.8**.

Figure 6.10 4G Harvested Wood products change in net emissions between the 1990-2014 and 1990-2015 inventories

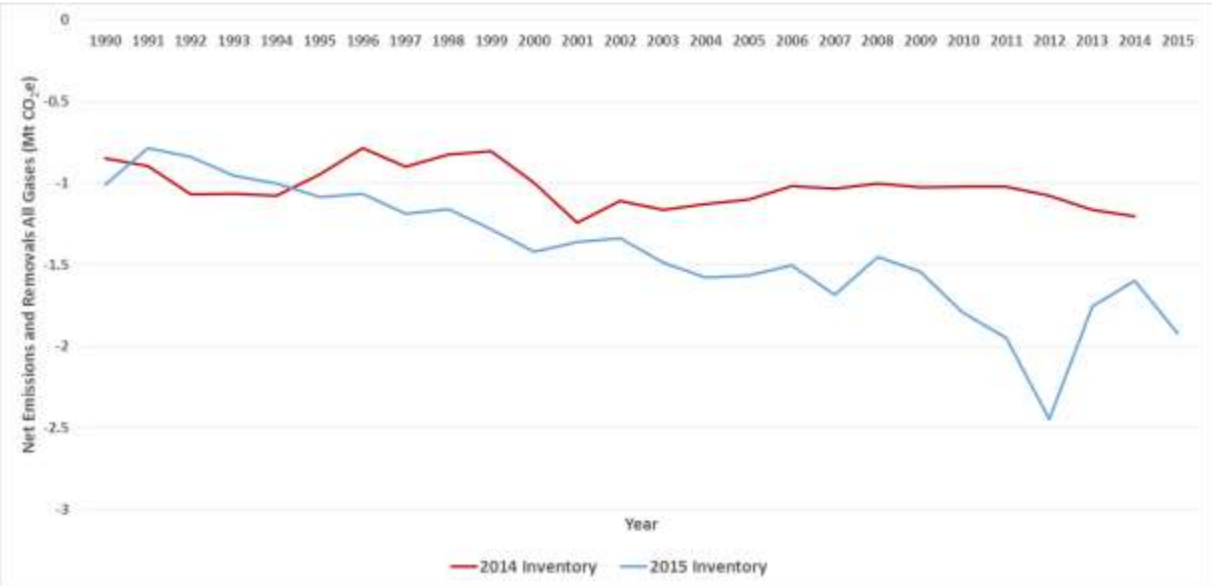


Table 6.8 4G Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2016 Submission		2017 Submission		Units	Comment / Justification
		1990	2014	1990	2014		
4G	Total harvested wood products produced from domestic harvest	-231.9	-328.5	-275.2	-435.9	Gg C	The forest activity data were revised to use the NFI dataset, revised small wood areas and improved alignment with wood production statistics.

6.8.6 Category-Specific Planned Improvements

Work is proceeding to ensure the approach for estimating removals and emissions due to HWP are consistent with methodologies agreed at Cancun and Durban and that underpinning data on UK wood production are reported so as to support implementation of these methodologies.

The most recent UNFCCC review highlighted an inconsistency in the proportions of HWP categorised as sawnwood, panels, pulp and fuel in the HWP predicted by CARBINE and the statistics reported to the FAO. This will be investigated and any improvements made in the next inventory.

6.9 LULUCF EMISSIONS AND REMOVALS IN THE OVERSEAS TERRITORIES AND CROWN DEPENDENCIES

The UK LULUCF inventory includes direct GHG emissions in its GHG Inventory from UK Crown Dependencies (CDs) and Overseas Territories (OTs) which have joined, or are likely to join, the UK's instruments of ratification to the UNFCCC and the Kyoto Protocol. Currently, these are: Guernsey, Jersey, the Isle of Man, the Falkland Islands, the Cayman Islands, and Gibraltar. Bermuda, which is a Party to the Convention but not the 2nd Commitment Period of the Kyoto Protocl, is not included for this reason bu also due to insufficient information on land use and land use change activities. A web search of statistical publications was undertaken for any updates in datasets in 2015. This work builds on an MSc project to calculate LULUCF net emissions/removals for the OTs and CDs (Ruddock 2007). Net emissions and removals from the OTs and CDs are reported under the relevant sub-categories of Sector 4. The estimates have high uncertainty and may not capture all relevant activities, but given the size of the territories any missing sources are likely to be small. **Annex 3.4.11** provides detailed descriptions of the methods and emission factors used.

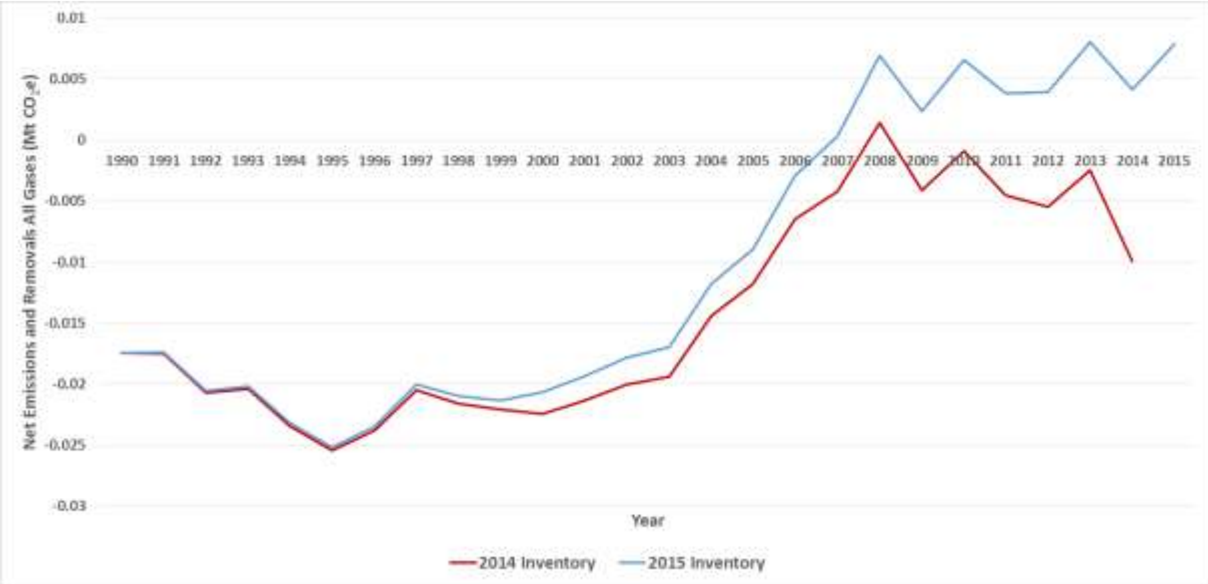
There was sufficient published information to enable estimation of LULUCF emissions and removals from the Isle of Man, Jersey and Guernsey (CDs) and the Falkland Islands (OT). No emissions or removals are estimated or reported for the Cayman Islands due to insufficient information on land use and land use change activities. Gibraltar emissions for this sector are considered to be negligible.

Emissions and removals have mostly been calculated at Tier 1, with a Tier 3 method for forestry in the Isle of Man and Guernsey.

Similar climate and land management parameters are assumed as for the UK. Land areas have been interpolated between land area surveys in some cases. More detailed activity data allowed a Tier 3 method to be applied for forestry in the Isle of Man and Guernsey. The IPCC Tier 1 default factors and GWPs from the 2006 AFOLU Guidelines were implemented: this resulted in the addition of sources of N_2O emissions from land use change, reported in Table 4/4(III). Specific changes to each CD and OT are listed below.

The overall trend in LULUCF emissions from the OTs and CDs moves from an initial net sink in 1990 to a net source from 2007 onwards. From 1998 onwards the sink strength in the 1990-2015 inventory is reduced compared to the 1990-2014 inventory.. These changes are due to correction of the conversion to Settlement in the Falklands post-2005 and revisions to the Land Use Change matrix for. Nitrous oxide emissions from mineralisation due to land conversion to Settlement in the Falklands were included for the first time. Individual graphs are shown for the four reported OTs and CDs below.

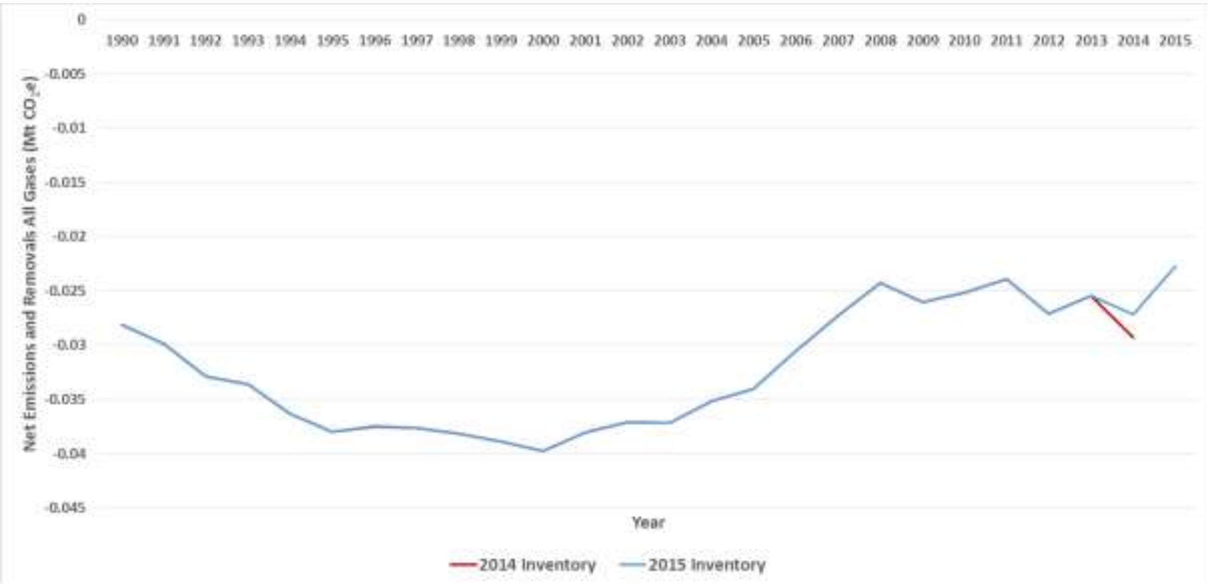
Figure 6.11 LULUCF sector change in net emissions between the 1990-2014 and 1990-2015 inventories for the combined Overseas Territories and Crown Dependencies



Isle of Man

The Isle of Man is estimated to be a small net LULUCF sink, due to its forest area. A total land area of 57.2 kha was used as the 58.2 kha in the 2011 agricultural census (the most recent available) is thought to be a misprint. Agricultural activity data has been updated .The Grassland category is used as the "buffer" category to ensure consistency in total land area. Total LULUCF net emissions for the Isle of Man are shown in **Figure 6.12**.

Figure 6.12 LULUCF sector change in net emissions between the 1990-2014 and 1990-2015 inventories for the Isle of Man

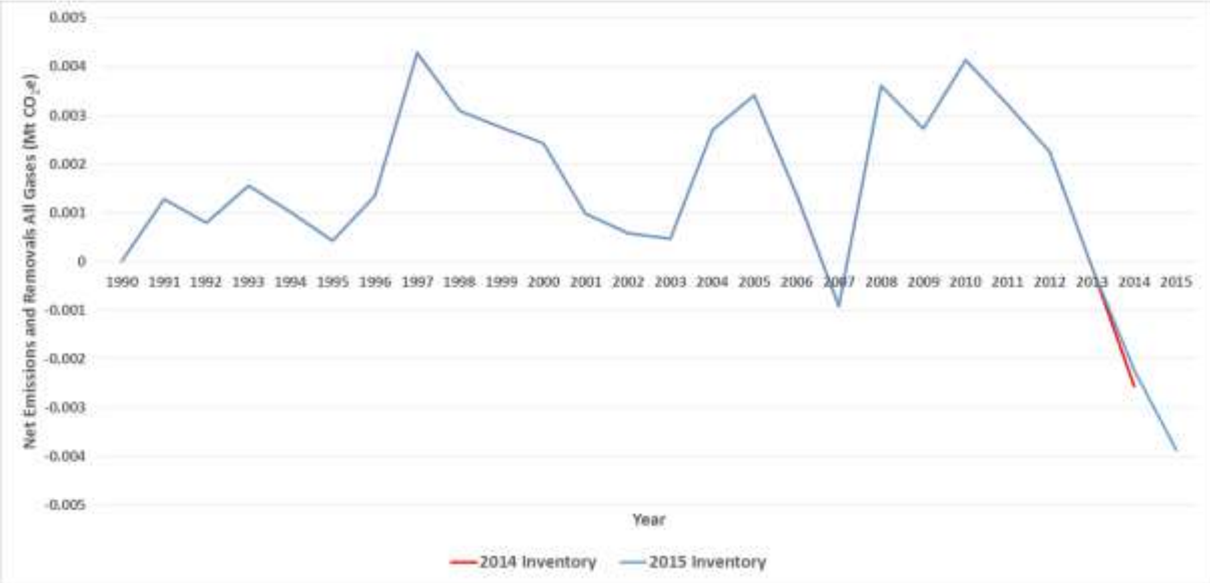


Jersey

Jersey is estimated to be overall a very small net source of LULUCF emissions in most years, although it has been a very small net sink for LULUCF emissions since 2013. The Grassland category is used as the "buffer" category to ensure consistency in total land area. Total

LULUCF net emissions for Jersey are shown in **Figure 6.13.** Agricultural data area for Jersey has been updated.

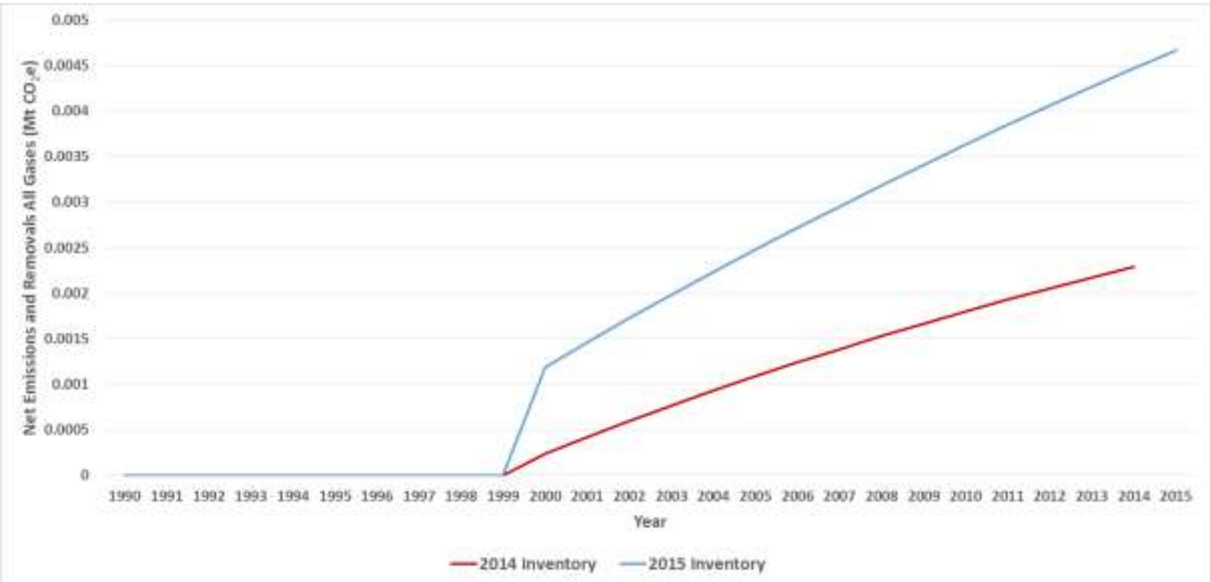
Figure 6.13 LULUCF sector change in net emissions between the 1990-2014 and 1990-2015 inventories for Jersey



Guernsey

Guernsey is estimated to be a small but increasing net source of LULUCF emissions from 1999 onwards. No new land use data were reported for Guernsey. The Settlement category was used as the 'buffer' category as it includes as areas that are not surveyed in the Habitat Surveys used for land category areas. The forest area for 2011 - 2014 was projected using the trend from the 1999 and 2010 habitat surveys rather than being held constant. This is consistent with the approach taken for other land uses. Total LULUCF net emissions for Guernsey are shown in **Figure 6.14**. The primary change in emissions has been due to the revisions to the Land Use Change matrix.

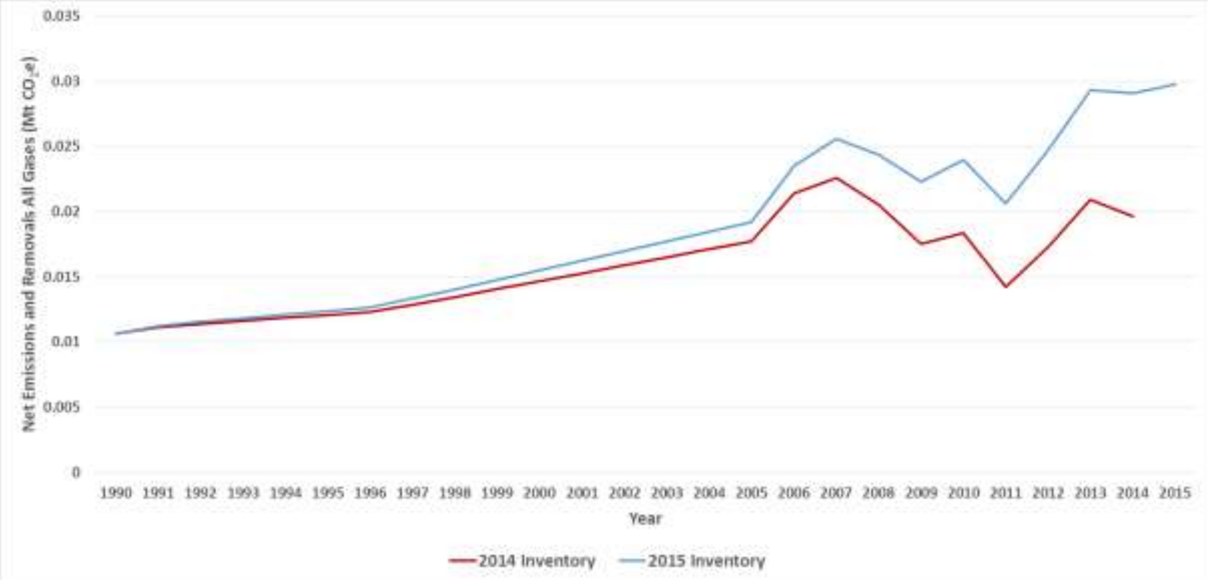
Figure 6.14 LULUCF sector change in net emissions between the 1990-2014 and 1990-2015 inventories for Guernsey



Falkland Islands

The Falkland Islands are estimated to be a small net source of LULUCF emissions. Nitrous oxide emissions from mineralisation due to land conversion to Settlement in the Falklands were included for the first time. The primary change in emissions is due to a correction to the Settlment activity data to extend conversion to Settlement from 2005 to 2015. Total LULUCF net emissions for the Falkland Islands are shown in **Figure 6.15**.

Figure 6.15 LULUCF sector change in net emissions between the 1990-2014 and 1990-2015 inventories for the Falkland Islands



6.10 GENERAL COMMENTS ON QA/QC

CEH has adopted the quality assurance principles set out in the Joint Code of Practice for Research issued by the Biotechnology and Biological Sciences Research Council, the Department for Environment, Food and Rural Affairs, the Food Standards Agency and the Natural Environment Research Council. CEH is accredited to ISO9001, the internationally recognised standard for the quality management of businesses.

Forest Research also carries out its work in accordance with the Joint Code of Practice for Research described above.

In 2009 the LULUCF inventory project was audited by an independent CEH team to confirm compliance with the Joint Code of Practice, where the project was praised for its high standards. In 2015 a review of the QA framework and procedures for the full UK inventory was carried out (Hartley McMaster Ltd, 2015). The reviewers were impressed with the QA/QC plan for LULUCF and made some recommendations for the inventory as a whole which are currently being assessed.

In addition to internal quality assurance procedures the submitted inventory data is also checked by Ricardo Energy & Environment (the national inventory compilers) and the European Commission.

The soil and non-forest biomass carbon stock change models are stored in a version control repository to ensure that all changes to the model code are easily traceable. A Microsoft Access 2007 database is used to compile all the LULUCF inventory numbers and associated data. This database is used to produce consistent outputs for the CRF and other national and international reporting requirements, and for archiving purposes.

Issue management software is used for project management and tracking issues such as requests for data from stakeholders and external parties.

In collaboration with Ricardo Energy & Environment, CEH has been developing a QA/QC plan to standardise and structure the way checks are carried out within the LULUCF inventory. The plan is now being implemented and will be reviewed and updated as required. The QA/QC Plan is embedded into all planning, preparation and management activities of the Inventory. The plan sets out five key Data Quality Objectives (DQOs), covering Transparency, Consistency, Completeness, Comparability and Accuracy, which ensure consistency to the IPCC core QA/QC criteria during inventory preparation and checking.

A major aim of the plan is to ensure appropriate QA/QC responsibilities will be applied to data suppliers, where possible and appropriate through Data Supply Agreements. Arranging these agreements is the next major QA/QC development activity for LULUCF.

7 Waste (CRF Sector 5)

7.1 OVERVIEW OF SECTOR

IPCC Categories Included	5A: Solid Waste Disposal on Land 5B: Biological Treatment of Solid Waste 5C: Waste Incineration 5D: Wastewater Handling
Gases Reported	CO_2, CH_4, N_2O, NO_x, CO, NMVOC, SO_2
Key Categories ('T' or 'L' indicates whether it's been identified in the trend or level assessment respectively and the number indicates which KCA approach it was identified in)	5A: Solid waste disposal - CH_4 (L1, T1, L2, T2) 5B: Biological treatment of solid waste - CH_4 (T1, T2, L2) 5B: Biological treatment of solid waste – N_2O (T2) 5D: Wastewater Handling - N_2O (L2, T2) 5D: Wastewater Handling – CH_4 (L2) 5D: Wastewater treatment and discharge - CH_4 (T1, L1, L2)
Key Categories (Qualitative)	None identified
Overseas Territories and Crown Dependencies Reporting	Emissions from all sectors are included within UK CRF tables.
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.
Major improvements since last submission	5A - The methodology for calculating methane production in landfill sites has been updated. A new source of data on the quantity of commercial and industrial waste landfilled has been identified and used. Assumptions regarding waste decomposition rates have been brought into line with IPCC defaults. Data on Local Authority Collected Waste landfilled, and methane collection and combustion in landfill gas engines and flares have been updated. 5B - New source category in the 2015 inventory. 5D - Updated composting emission factor applied to align with revised 2006 IPCC guidelines. Updated methodology in response to UNFCCC ERT recommendations by applying a country-specific fraction of municipal nitrogen load from unconsumed protein and a fraction of municipal nitrogen load from commercial and industrial sources from the 2006 IPCC guidelines for calculating N_2O emissions from commercial and industrial waste water.

Emissions from the waste sector contributed 3.7% to greenhouse gas emissions in 2015. Emissions consist of CO_2, N_2O and CH_4 from waste incineration, CH_4 from solid waste disposal on land, and both CH_4 and N_2O from wastewater handling and biological treatment of solid waste. Overall emissions from the waste sector have decreased by 72% since 1990. This is mostly due to the implementation of methane recovery systems at UK landfill sites and reductions in the amount of waste disposed of at landfill sites.

Figure 7.1 Breakdown of total GHG emissions from the Waste sector in 2015

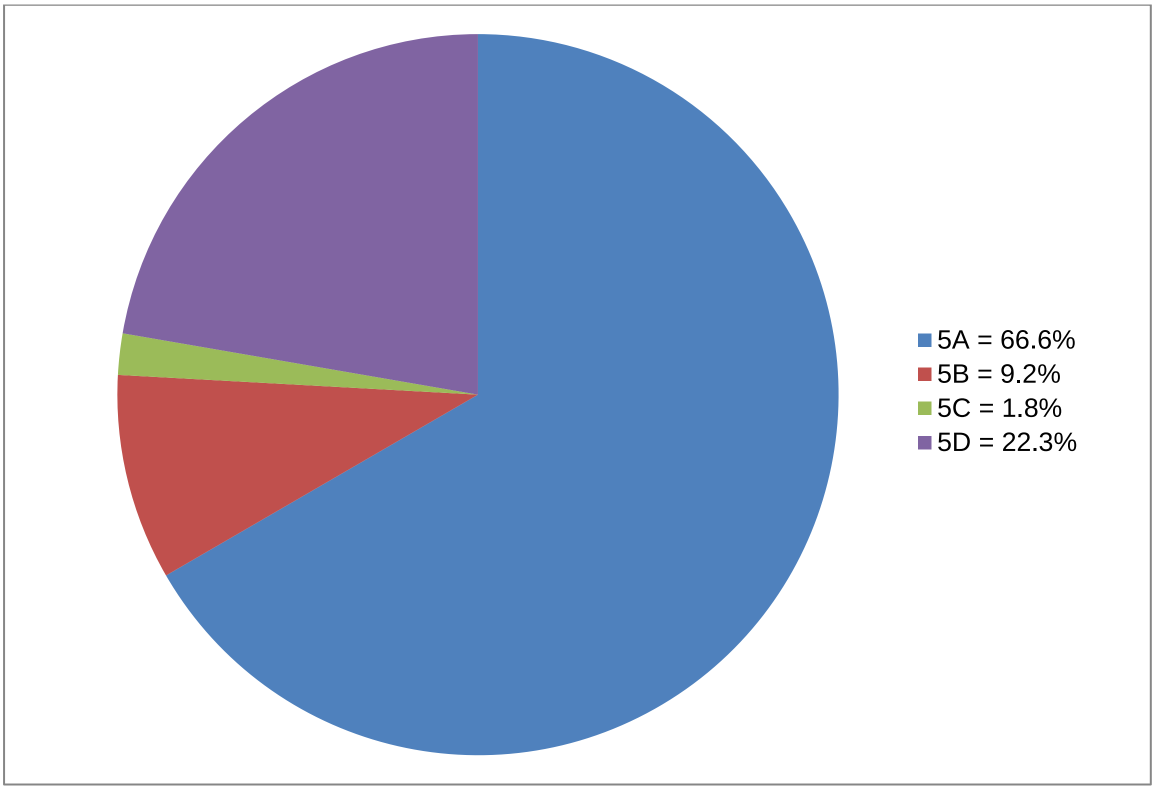
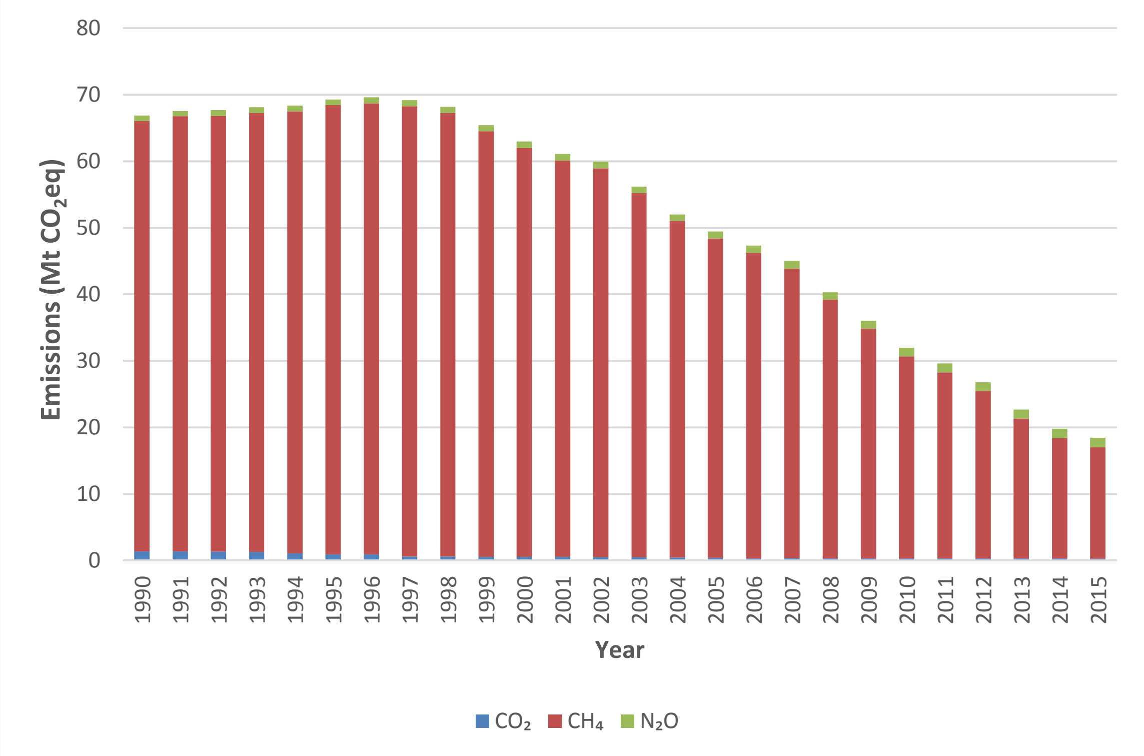


Figure 7.2 Trend in total GHG emissions in the Waste sector



7.2 SOURCE CATEGORY 5A – SOLID WASTE DISPOSAL ON LAND

7.2.1 Source category description

Emissions sources	Sources included	Method	Emission Factors
	5A: Landfill	OTH, T2	CS
Gases Reported	CH_4, NMVOC		
Key Categories	5A: Solid waste disposal - CH_4 (L1, T1, L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	OT & CD emissions for 5A are included as a separate category within 5A.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	The methodology for calculating methane production in landfill sites has been updated. A new source of data on the quantity of commercial and industrial waste landfilled has been identified and used. Assumptions regarding waste decomposition rates have been brought into line with IPCC		

	defaults. Data on Local Authority Collected Waste landfilled, and methane collection and combustion in landfill gas engines and flares have been updated.

The NAEI category "Landfill" maps directly on to IPCC category 5A Solid Waste Disposal for methane emissions. Emissions are reported from Solid Waste Disposal Sites (SWDS – also known as landfills) that started receiving waste in 1980, when legislative changes took effect to improve management of landfill sites, and old unmanaged waste disposal sites that closed prior to 1980.

Estimated emissions from this sector in 2015 were 12.3 Mt CO_2e. Emissions have been on a downward trend since 1996.

In addition to CH_4, anaerobic decomposition also produces an approximately equivalent amount of carbon dioxide and further CO_2 is also produced by aerobic decomposition processes. However, as the decaying organic matter originates from biomass sources derived from contemporary crops and forests, we do not need to consider the greenhouse impacts of this carbon dioxide. Waste also contains fossil-derived organic matter, predominantly in the form of plastics, but these are essentially non-biodegradable under landfill conditions, and so emissions of fossil-derived CO_2 from SWDS are not considered further. Emissions of CO_2 from landfills are not estimated as they are considered to be entirely biogenic in origin and therefore not counted towards the national total as this would introduce a double count with net carbon losses reported in thr LULUCF sector.

Non-methane volatile organic compounds (NMVOCs) are also released by SWDS. These are estimated using an emission factor relating the NMVOC to the amount of CH_4 emitted. An emission factor of 0.0036 kg NMVOC/tonne landfill gas was used (Broomfield et al., 2010).

The 2006 guidelines confirm that nitrous oxide emissions from SWDS are not significant.

The amount of methane emitted from landfills depends primarily on the amount of carbon in biodegradable waste landfilled and how the sites are operated to reduce the escape of the methane produced from such wastes. Policy measures to reduce methane emissions from landfills have focused on both these aspects. Diverting biodegradable waste away from landfill avoids the future formation of methane, but of course landfills continue to produce CH_4 for many years from waste that has already been deposited. Improving the efficiency of gas capture from landfills results in an immediate reduction in emissions, but is by nature an "end of pipe" solution, which does not itself prevent the formation of methane. In practice, a combination of measures based on both reducing the amount of biodegradable waste landfilled and improving the management of sites have, in the UK, provided the foundations for reducing emissions from this source. These two broad approaches are outlined below.

The most important legislative and regulatory measures which have reduced the emissions of methane from UK landfills derive from the 1999 Landfill Directive (1999/31/EC). The requirements of the Directive were transposed into national legislation through the Landfill (England and Wales) Regulations 2002, subsequently amended in 2004 and 2005 to transpose the requirements of Council Decision 2003/33/EC on Waste Acceptance Criteria. The provisions were re-transposed as part of the Environmental Permitting (England and Wales) Regulations 2007, further revoked by the Environmental Permitting (England and Wales) Regulations 2010 SI 675. The regulations were further amended in 2013. In Scotland, the Landfill Directive is implemented through the Landfill (Scotland) Regulations 2003, as amended, and in Northern Ireland, through the Landfill Regulations (Northern Ireland) 2003a. The provisions of the Landfill Directive require reduction of the amount of biodegradable waste landfilled to specific targets and improved landfill design, operation and management in order to reduce release of methane.

The revised EU Waste Framework Directive 2008/98/EC provides the legislative framework for collection, transport, recovery and disposal of waste. The Directive mandates management of waste according to the waste hierarchy – with the first and preferred method being prevention, followed by reuse, recycling, recovery, and lastly disposal. This mandates the movement away from landfilling of waste.

7.2.2 Methodological issues

The UK approach to calculating emissions of methane from landfills uses a "Tier 2" methodology based on national data on waste quantities, composition, properties and disposal practices over several decades. The equations for calculating methane generation use a first-order decay (FOD) methodology (IPCC (2006) p3.6 – 3.12). The IPCC FOD methodology is based on the premise that Dissimilable Degradable Organic Carbon compounds (DDOC)[50] decay under the airless conditions in landfills to form methane, carbon dioxide and a variety of stable decomposition products that remain in the landfill, and represent a sink for carbon. First order means that the rate of reaction is proportional to the amount of reactant (i.e. DDOC) present at any given time. This means that as the reactant is used up, the rate of reaction slows down.

The IPCC Guidelines (IPCC, 2006) define the overall approach for calculating methane emissions from landfill as the amount of methane (CH_4) generated in the waste, minus the amount of methane recovered (for flaring or other combustion process), minus the amount of remaining methane that is oxidised to carbon dioxide.

In the UK model, the various waste types are allocated to three pools (p) of dissimilable degradable organic carbon (DDOC) that decompose according to their characteristic first order rate constant, k_p. This parameter defines the proportion of material decomposing per year in each year following disposal. The three pools are described as Rapidly, Moderately, and Slowly Decomposing Organics (RDO, MDO and SDO, respectively). Allocation of DDOC in waste materials to these pools was described in a report produced by Eunomia Consulting and Research (2011) and updated for the 2013 and 2014 inventories.

The characteristic decay rates for these three pools are difficult to estimate, and have been the subject of recent research (Golder Associates 2014; ESD, 2016). In view of recent research highlighted by ESD, it was considered that there was no longer a strong case for using Country Specific values, and the IPCC default decay rates for a wet boreal and temperate climate zone were used. Fats, sugars and proteins are assigned to the rapidly degrading pool (RDO), lignin to the slowly degrading pool (SDO) and cellulose, hemicelluloses and remaining compounds are allocated to the moderately degrading pool (MDO).

Methane generation is calculated using a methodology adapted from IPCC 2006 Equations 3.1 to 3.6.

The total methane generated in each inventory year is determined by summing the quantity of methane emitted over all waste types, all three decomposition pools, all landfill types, and all years in which the waste is landfilled.

A Methane Correction Factor (MCF) is used as a multiplier on methane formation to reflect the fact that shallow or unmanaged disposal sites do not develop extensive anaerobic conditions typical of modern landfills and hence a proportion of waste decays aerobically and

[50] DDOC is the amount of degradable organic carbon (DOC) that is converted (ie dissimilated) to methane and carbon dioxide under landfill conditions. DDOC = DOC x DOC_F where DOC_F is the fraction of DOC that dissimilates.

does not produce methane. For modern landfills, the MCF term is given the value of 1 (IPCC 2006 Table 3.1), but the Guidelines allow use of a smaller figure for unmanaged dumpsites. All solid waste disposal sites in the UK that have received biodegradable wastes since 1980 have been required to adhere to a number of regulations are classed as landfills and assigned a MCF value of 1. MCF has been assigned a value of 0.6 for old closed landfills that operated up to 1980 (IPCC 2006 Table 3.1).

The molar fraction of methane in landfill gas was assigned the value of 0.5, the default value given in the 2006 IPCC Guidelines.

A model system known as MELMod was used to carry out these calculations from 2008 (Brown et al., 2008). In 2010, the UK government commissioned further work to update the activity data and emission factors for landfill methane (Eunomia Consulting and Research, 2011), which was peer reviewed by independent experts from academia, industry, regulators and consultants in 2010. The principal changes to the input data at that time were summarised in the 2011 NIR submission for the 1990-2009 inventory. Further details on data sources and rationale are given in Eunomia's report.

7.2.3 Activity data

Activity data for 2015 were taken from the following published data sources:

- England: "Quarterly local authority collected waste management statistics," August 2016, Department for Environment, Food and Rural Affairs https://www.gov.uk/government/statistical-data-sets/env19-local-authority-collected-waste-quarterly-tables
- Scotland: Household Waste Interrogator (Source: http://www.environment.scotland.gov.uk/get-interactive/data/household-waste/ accessed August 2016);
- Wales: StatsWales "Waste managed (tonnes) by management method and year" (https://statswales.wales.gov.uk/Catalogue/Environment-and-Countryside/Waste-Management/Local-Authority-Municipal-Waste/Annual/wastemanaged-by-management-year accessed August 2016); and
- Northern Ireland: "Northern Ireland local authority collected municipal waste management statistics 2014/15 annual report" (https://www.daera-ni.gov.uk/publications/northern-ireland-local-authority-collected-municipal-waste-management-statistics-2014) and "Northern Ireland local authority collected municipal waste management statistics January to March 2016 quarterly report," (https://www.daera-ni.gov.uk/publications/northern-ireland-local-authority-collected-municipal-waste-management-statistics-january-march-2016).

Data on Commercial and Industrial waste arising in England up to 1997 were taken from a review carried out for Defra (Eunomia, 2011). Data on C&I waste arisings from 1998 to 2015 were obtained from HMRC published data on landfill tax returns (HMRC, Landfill Tax Bulletin, April 2016, https://www.uktradeinfo.com/Statistics/Pages/TaxAndDutyBulletins). From 2015 onwards, data for Scotland were reported separately (https://www.revenue.scot/about-us/publications/statistics)

Data on waste composition since 2008 was taken from research for the UK Government (Resource Futures for Defra, 2012).

7.2.3.1 Methane recovery from modern landfills

Landfill operators are required under their permit conditions to control the release of landfill gas. For large landfills containing biodegradable wastes, this requires the use of impermeable liners and cover material, and gas extraction systems. These typically consist of a system of gas wells (perforated pipes sunk into the waste) connected to a network of gas collection pipes. Suction is applied to the gas wells, resulting in a slight negative pressure sufficient to draw out the landfill gas but not enough to draw excessive air into the waste. Air ingress is avoided, as it can result in aerobic decomposition of the waste, which produces considerable heat, and may lead to the waste catching fire, as well as shutting off methane formation. The landfill gas collected is normally used to generate electricity on a commercial basis. Where this is not practicable, gas collected can be burnt in flares. In either case, the net effect of the combustion process is to convert the methane to carbon dioxide. The carbon dioxide so produced is not taken into further consideration for inventory purposes as it is considered to be entirely biogenic in origin.

The key factors in determining methane emissions are estimates of the quantity of methane generated, and information on the amount of methane collected, either for utilisation or flaring. Data on utilisation is available and of good quality (see section 7.2.3.2), but recent analysis indicates that data on flaring prior to 2009 is either unavailable or only accessible at disproportionate cost. The current inventory uses operator-provided data on the quantities of gas collected and burnt in landfill gas flares (see section 7.2.3.3). No gas collection is assumed to be carried out at old pre-1980 closed sites. At sites and inventory years for which robust data on landfill gas flaring are not available, it is conservatively assumed that no landfill gas was flared.

Current estimates for methane recovered are given in **Table A 3.5.2**.

A high standard of gas collection and combustion efficiency is achieved by compliance with the Landfill Directive requirements for gas collection, and by implementing national guidance on landfill gas collection. This is enforced via the landfill permitting and regulatory processes. Large-scale passive venting of landfill gas is no longer accepted under permitting conditions and impermeable barriers are required as best practice to prevent the migration of landfill gas off-site.

7.2.3.2 Gas Utilisation

Power generation is currently the dominant use for landfill gas in the UK and good data are available on this from official sources. The method for calculating methane combusted in landfill gas engines is as reported in the 2013 UK NIR. The assumed efficiency of landfill gas engines in these calculations was calculated in accordance with research carried out for the UK Government (Golder Associates, 2014).

Current data on the amount of methane used for power generation in England, Scotland, Wales and Northern Ireland, calculated from the electricity generated from landfill gas as reported in the Digest of UK Energy Statistics (BEIS, 2016), is given in **Table A 3.5.2**.

7.2.3.3 Flaring

Since 2009, operators of landfills in England and Wales permitted under the Integrated Pollution Prevention and Control (IPPC) Directive have been required to report the annual quantity of methane flared at the regulated sites under the terms of their operating permits. As it has been obtained under the terms of IPPC operating permits, this data has documentation and quality control built in via the permitting procedures and operator obligations at an individual site level. The use of this dataset is therefore a robust and appropriate basis on which to evaluate the quantities of methane flared by operators. Based on guidance from the Expert Review of the 2013 GHG Inventory (para 98 of the 2013 Annual Review Report), this dataset was used to estimate the quantity of methane flared at landfill sites in England and Wales in 2008.

Similarly, landfill site operators in Scotland have been required to compile a similar annual report on the quantity of landfill gas flared since 2013. This dataset was used to evaluate the quantity of methane flared by operators at landfill sites in Scotland in 2013.

Further work was commissioned by BEIS (then DECC) to identify all reasonably available data on the quantities of methane flared at landfill sites in England, Scotland and Wales for other years (DECC, 2015). This project identified some additional site-specific data which was also taken into account in compiling the inventory. Additionally, landfill operators voluntarily provided further site-specific data on the quantities of methane flared at older sites without a reporting requirement set in permit conditions for 2010 to 2015.

The landfill methane flaring data provided represents information for approximately 300 individual sites in 2015. Data checking/ validation therefore relies on the regulatory authorities and processes, rather than comprising additional checks on individual operators. The information on landfill gas flaring is provided via under the Environmental Permitting (England/Wales) and Pollution Prevention and Control (Scotland/Northern Ireland) regulatory processes. This information is consequently subject to quality obligations under these regulations, as with any other information reported to the regulatory authorities by regulated process operators under the terms of their operating permits. The data is then forwarded to the compilation agency by each regulatory authority.

At all other sites and inventory years, robust data on landfill gas flaring was not available, and it was conservatively assumed that no landfill gas was flared.

The estimates shown in **Table A 3.5.2** are based on the estimate of methane used for power generation added to the estimated quantity of methane flared. The minor proportion of landfill gas used for non-electricity generation purposes such as direct use and as a vehicle fuel is neglected in these calculations due to a lack of data, and assumed to be emitted to the atmosphere as a conservative assumption.

7.2.3.4 Overseas Territories and Crown Dependencies

The IPCC landfill model is used for all landfill estimates. Where available, country-specific waste generation and composition data have been applied and appropriate defaults chosen e.g. taking into account climatic variation. There are no landfill emissions for Gibraltar as waste is exported. Parameters used in these calculations are shown in **Annex 3.5**.

7.2.4 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type. There are many uncertainties in estimating methane emissions from landfill sites. The model is 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. A recent programme of work has assisted in reducing these uncertainties. The uncertainty estimates in **Annex 2** are intended to reflect the current uncertainties in data and model parameters.

The estimates for all years have been calculated from the MELMod model and thus the methodology is consistent throughout the time series. Estimates of waste composition and quantities have been taken from different sources – prior to 1995 they are from Brown *et al.* (1999), prior to 2000 they are based on the LQM (2003) study and from 1995 to 2009, they are based on information compiled by Eunomia (Eunomia, 2011). Data sources since 2009 are described in **Section 7.2.3.** The new waste to landfill data indicates a significant decrease in the amount of LA-controlled and C&I waste sent to landfill since about 2002 and 2003. Data on local authority collected waste is considered to be sufficiently accurate not to affect the uncertainty in the landfill methane calculations. The source of data on C&I waste was updated for the 2015 inventory to use annual data compiled by HMRC, and is considered to be more robust and consistent than the previous ad-hoc data sources. The approach to calculating DDOC, the main driver behind methane formation, was reviewed and updated in 2011 where endorsed by peer reviewers. Further details are given in **Annex 3**.

Uncertainty in the quantity of methane collected is also an important contributory factor to uncertainty in the calculation of overall landfill methane emissions. Uncertainties in the key components of this calculation are as follows.

- Current and historical combustion of methane in landfill gas engines: Reliable data on methane collected for power generation are available, based on national statistics for energy generated from landfill gas engines (DUKES 2016). The methane to carbon dioxide ratio of gas burnt in landfill gas engines is assumed to be 50:50, following the IPCC default approach. Gas engine efficiency is assumed to be 30% up to 1996, increasing linearly to 36% in 2012 and thereafter, following peer review (Golder Associates, 2014). This is considered to be a reasonably reliable calculation of the quantity of methane combusted in landfill gas engines; and

- Combustion of methane in flares. These data are based on site-specific records where available and are considered to be accurate for the sites where data exist. However, records of the quantity of landfill gas are incomplete, particularly for the years prior to 2008. In cases where records of landfill gas flaring are not available, the quantity of methane flared was assumed to be zero. This means that the landfill methane inventory is subject to greater uncertainty for the years prior to 2008, although because of the conservative approach adopted in respect of landfill gas flaring, it is considered that the inventory represents an over-estimate of methane emissions from landfill sites in the UK, particularly for the years prior to 2008.

Because records of landfill gas flaring are incomplete, it is considered that the inventory represents an over-estimate of methane emissions from landfill sites in the UK, particularly for the years leading up to 2008.

Landfill permit conditions are designed to deliver a high standard of gas collection and combustion efficiency. Requirements to design and operate landfills to minimise gas escape have strengthened considerably since the 1990s. In this context, the calculated collection efficiency of 68% in 2015 derived in this analysis appears reasonable. Lower collection efficiencies in the years between 1990 and 2014 are likely to be more conservative.

Oxidation of methane in the surface layers of landfills is a further source of uncertainty in overall emissions. In the absence of better data, the IPCC oxidation default factor of 10% is applied to the estimated quantity of gas released as a fugitive emission. A recent pilot survey carried out on behalf of the UK Government and Environment Agency included measurements of surface methane oxidation. This study did not support a move away from the IPCC default position. A particular challenge in deciding on oxidation rates for use in a national landfill model is the high level of variability in field measurements, reflecting a wide range of factors such as nature and porosity of the surface layers, moisture content and temperature, along with methane production rates in the underlying waste.

7.2.5 Source-specific QA/QC and verification

The verification of MELMod has been described in the 2008 NIR. The update undertaken by Eunomia (Eunomia, 2011) in 2010 resulted in updating of input data to the model only, with no changes implemented as to calculation methodology other than where indicated. The changes to the model input data recommended by Eunomia were peer reviewed by independent experts from academia, industry, regulators and consultants in late 2010, before their incorporation into the UK inventory. The implementation of the recommended changes within the model has now also been reviewed, and the changes arising from this review were set out in the previous NIR.

MELMod was subject to a further peer review process in 2014 (Golder Associates, 2014). In the light of this peer review, changes were made to the assumed efficiency of landfill gas engines.

7.2.6 Source-specific recalculations

There have been two significant changes to the UK landfill methane inventory for 2015, as follows:

- Change in the source of data used to quantify the amount of C&I waste landfilled; and
- Reversion to IPCC default waste decomposition rates, in the light of new evidence in this area.

The UK inventory of methane emissions from this sector is set out in **Table A 3.5.2**. This table shows the quantity of methane generated, combusted in engines and flares, oxidised by the landfill surface and emitted to the atmosphere.

Emission estimates for the OTs and CDs are now calculated using the IPCC waste model taking into account country-specific data and parameters. Previously, the majority of estimates were made by scaling against historic UK data.

7.2.7 Source-specific planned improvements

Emission factors, model parameters, and activity data will be kept under review. Defra and the environmental regulatory agencies in the UK have carried out a small pilot study to measure methane emissions from a selection of landfills, and a programme of research on closed landfills is now complete (https://www.gov.uk/government/groups/acumen-assessing-capturing-and-utilising-methane-from-expired-and-non-operational-landfills). In the longer term, this may facilitate the production of additional site-specific data on landfill methane releases.

7.3 SOURCE CATEGORY 5B – BIOLOGICAL TREATMENT OF SOLID WASTE

7.3.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	5B:Composting (non-household) Composting (household) Anaerobic digestion (non-agricultural) Mechanical biological treatment	T2 T2 T2 T2	D D D D
Gases Reported	CH_4, N_2O		
Key Categories	5B: Biological treatment of solid waste - CH_4 (T1, T2, L2) 5B: Biological treatment of solid waste – N_2O (T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Estimates have been made for OT and CD emissions from 5B1, composting of municipal solid waste, where data on the total amount of waste composted is available. In these cases 2006 IPCC default EFs are applied. These estimates are included within 5B for CRF reporting.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	New source category in the 2015 inventory.		

7.3.2 Methodological Issues

Emissions of methane and nitrous oxide from composting of MSW (Category 5.B.1) and anaerobic digestion (AD) and Mechanical Biological Treatment (MBT) (Category 5.B.2) were introduced into the inventory for 2013 using a Tier 2 methodology. This was identified as an appropriate approach in view of the scale of emissions from this sector (DECC, 2015b)

The approach to obtaining activity data for composting and anaerobic digestion was changed to reconcile approaches used in the GHG and ammonia inventories. Activity data for composting was derived from Devolved Administrations' data on organic waste fractions. Inputs to household composting were calculated by using population statistics and district level analysis for home composting in the UK (Parfitt, 2009).

Activity data for anaerobic digestion was derived from information on anaerobic digestion processing capacity and "feedstock demand" from two datasets compiled by WRAP and the Biogas Association respectively (Biogas, 2016; WRAP, 2016).

Emissions from the anaerobic digestion of agricultural residues are not considered in the waste sector. These emissions are reported in the agriculture sector, as it is suggested by the IPCC 2006 Guidelines.

Emission factors for source category 5.B.1 and the anaerobic digestion component of 5.B.2 were taken from IPCC (2006) default emission factors. IPCC 2006 Guidelines published an update for the waste sector in July 2015. This update is related to the default CH_4 and N_2O

emission factors proposed for composting and anaerobic digestion, so these new emissions factors have been considered for this Inventory edition, and it has been applied to the complete time series. CO_2, in line with the IPCC methodology, is not included in the Inventory calculation as it comes from a renewable source of organic matter. The emissions factors for the AD component of mechanical biological treatment were assumed to be the same as for anaerobic digestion.

7.3.2.1 Overseas Territories and Crown Dependencies

Emissions from 5.B.1 have been estimated, however due to data availability, only estimates for Guernsey can be derived. Within Guernsey, composting has only occurred on the Island since 2008, due to creation of a new national composting scheme. The total amount of waste composted within this scheme has been supplied by Guenrsey, and IPCC 2006 default emission factors for both CH_4 and N_2O have been applied.

7.3.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

Activity data for industrial activities over the time series were taken from relevant publications, and are considered to provide robust and accurate data. Activity data for home composting is less reliable, but now represents a small proportion (approximately 3%) of total composting activity carried out in the UK.

IPCC Tier 1 default emission factors were used for this analysis. These are considered to be less reliable, and hence subject to greater uncertainty. This is the key source of uncertainty in emissions from the 5.B sector in 2014.

Time series consistency is based on activity data and is considered to be reasonably representative of activity in this sector between 1990 and 2014.

7.3.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**. Additionally, this year, an additional QC process has been carried out in order to develop a consistent activity data series for the composting activity. The data used by CEH for the ammonia emissions estimations have been compared with the activity data used for CH_4 and N_2O emissions estimation. For the 2015 inventory, the data sources used to develop the ammonia inventory have been used to calculate CH_4 and N_2O emissions as they are considered to comprise a more robust, consistent and ongoing time series.

7.3.5 Source Specific Recalculations

The use of new activity data for anaerobic digestion and composting has resulted in changes in calculated emissions throughout the time series.

For information on the magnitude of recalculations, see **Section 10**.

7.3.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

7.4 SOURCE CATEGORY 5C – WASTE INCINERATION

7.4.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	5C1: Incineration: MSW Incineration: sewage sludge Incineration: clinical Incineration: chemical Incineration: animal carcases Crematoria 5C2: Accidental fires: dwellings Accidental fires: other buildings Accidental fires: vehicles Bonfire night Fireworks Small-scale waste burning	T2,T1 T1 T1 T2, T1 T1 CS CS CS CS CS CS CS	CS, D CR, D OTH, D CS, D CS CS OTH OTH OTH OTH OTH OTH
Gases Reported	CO_2, CH_4, N_2O, NO_x, CO, NMVOC, SO_2		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Included in the CRF with the UK MSW incineration, since the same emission factors are applied, apart from 5C2.1b, incineration of waste from small scale burning, where estimates are now made for Guernsey using IPCC default method.		
Completeness	A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements have been made since the last submission.		

This source category covers the incineration of wastes (excluding waste-to-energy facilities). The UK also reports indirect GHG emissions from various other sources including crematoria, small-scale waste burning, accidental fires, and fireworks under 5C2. Methane emission estimates are included for accidental fires.

In the UK, all MSW incineration plants have recovered energy since 1997, and so emissions are reported under CRF source category 1A1a. For the years 1990-1996, at least some MSW was incinerated at plants with no energy recovery, so emissions are split between 1A1a and 5C for those years, in proportion to the waste burnt with and without energy recovery respectively. All incineration of chemical wastes, clinical wastes, sewage sludge and animal carcasses is reported under 5C1, , since we have no information on any recovery of energy from these processes. In-situ burning of agricultural waste e.g. crop residue burning is reported under category 3F.

The numbers of chemical waste, clinical waste and sewage sludge incinerators in the UK are not known with certainty, although that number has almost certainly decreased significantly between 1990 and 2015. A total of 36 incinerators regulated under the Industrial Emissions Directive (IED) have been identified as operating in 2015 - 7 burning sewage sludge, 17 burning clinical wastes, and 12 burning chemical wastes. It is possible that a few very small incinerators, outside the scope of IED, may also exist. Approximately 2600 animal carcass incinerators are believed to be in use (estimated in AEA Technology, 2002). These are typically much smaller than the incinerators used to burn other forms of waste. Numbers of crematoria are slowly increasing in the UK: there were 277 in 2015 compared with 239 in 1999 (based on statistics published by the Cremation Society of Great Britain, website at http://www.cremation.org.uk/).

This source category also includes emissions from the open burning of wood waste in Guernsey.

7.4.2 Methodological Issues

Emissions of CO_2, CO, NO_x, SO_2, and VOC from chemical waste incinerators are estimated based on analysis of emissions data reported to the Pollution Inventory (Environment Agency, 2016), the Welsh Emissions Inventory (NRW, 2016) and the Northern Ireland Pollution Inventory (NIEA, 2016). These data sources cover England, Wales and Northern Ireland respectively. There are not thought to be any plants in Scotland. Emissions data are not available for all pollutants for all sites and so some extrapolation of data from reporting sites to non-reporting sites has been done, using estimates of waste burnt at each site as a basis. The gaps in reported data are usually for smaller plants but the need for extrapolation of data may contribute to significant variations in the quality of the estimates. Emissions of N_2O from chemical waste incinerators are estimated using the 100 g N_2O / t waste default factor for industrial waste incineration given in the IPCC guidelines (2006), Waste tonnages burnt at the largest individual chemical waste incinerators for the period 2006 – 2014 have been obtained from the Environment Agency, but the overall quantity of chemical waste burnt must then be estimated by the Inventory Agency, with estimates for the smaller plant based on their capacity. For the earlier part of the time series, we use the following estimates of total waste burnt:

1993	290,000 tonnes (HMIP, 1995)
2002	284,000 tonnes (Entec, 2003)

The HMIP figure is assumed to also be applicable for 1990-1992, and we interpolate between the HMIP and Entec figures for the years 1994-2001. For the period 2003-2005, we interpolate between the Entec figure of 284,000 tonnes and our estimate for 2006 of 177,000 tonnes. We have been unable to obtain site-specific waste disposal data for 2015, so the waste burnt at each site is assumed to be the same as in 2014. The use of reported emissions data for pollutants other than N_2O avoids the need to rely upon the highly uncertain activity data.

Emissions of CH_4, CO, N_2O, SO_2 and VOC from sewage sludge incineration are estimated using literature-based emission factors, while emissions of NO_x are estimated using Pollution Inventory data. The factor for N_2O is the average of the range of emission factors given in the 2000 IPCC good practice guidance for UK sewage sludge incineration. Emission factors for other pollutants are taken from the EMEP-EEA Emission Inventory Guidebook. The quantity of waste burnt annually is estimated using data from various sources:

1990	RCEP, 1993
1991-1998	Digest of Environmental Statistics (Defra, 2004)
2006-2014	Environment Agency, waste disposal data for individual sites in England
2004-2015	Inventory Agency estimates for Northern Ireland, based on design capacity of incinerator plant at only site.

2013, 2015	Scottish Environment Protection Agency, estimates of total sewage sludge incinerated in Scotland

Interpolation between the various estimates is used to fill the gaps in the activity data time series.

Emissions of CO_2, CH_4, CO, N_2O, NO_x, SO_2, and VOC from clinical waste incineration are estimated using literature-based emission factors. The factors for CO_2 and N_2O are IPCC default factors. Emission factors for other pollutants are largely taken from the EMEP-EEA Emission Inventory Guidebook. The quantity of waste burnt annually is also estimated, these estimates being based on information given in the following sources:

1991	RCEP, 1993
1997	Wenborn *et* al, 1998
2002	Entec, 2003
2006-2014	Environment Agency, waste disposal data for individual sites in England and Wales
2004-2013, 2015	Scottish Environment Protection Agency, estimates of total clinical waste incinerated in Scotland

Interpolation between the various estimates is used to fill the gaps in the activity data time series.

Emission estimates for animal carcass incinerators are taken directly from a Defra-funded study (AEA Technology, 2002) and are based on emissions monitoring carried out at a cross section of incineration plant. No activity data are available and so the emission estimates given in this report are assumed to apply for all years.

Emissions of CO, NO_X, SO_2 and VOC from crematoria are based on literature-based emission factors, expressed as emissions per corpse, and taken from US EPA (2008). Data on the annual number of cremations is available from the Cremation Society of Great Britain (2016).

Emissions from MSW incineration for the period 1990-1996 are reported split between 1A1a and 5C, in proportion to the tonnages of waste burnt with and without waste recovery respectively. The same methodology is used to estimate emissions for both types however.

Estimates for accidental fires are based on statistics from the Fire Service of Great Britain, available from the Department for Communities and Local Government (DCLG, 2014). These statistics give the number and severity of fires in dwellings and other buildings, and the number of fires in road vehicles by type. The statistics have then been converted into masses of material burnt by applying country-specific assumptions for each type of fire e.g. for the many fires in dwellings that are limited to just a single item, the mass of material combusted is assumed to be 1 kg. The total material burnt is then combined with emission factors to obtain emission estimates for methane, CO, NO_X and NMVOC. The methane factors are taken from AP 42 (USEPA, 2014) and relate to open burning of municipal waste (for dwellings and other buildings) and automobile parts (for vehicle fires). Factors for other pollutants are taken from the same source, or from UK-specific literature. The UK is not aware of any source of appropriate emission factors for carbon or nitrous oxide emissions from this source, but emissions of these pollutants from this source are expected to be small.

The tonnage of MSW burnt in incinerators is provided by the Cayman Islands and the Falklands. UK GHGI EFs were then applied to these activity data to estimate emissions from this sector. Emissions from waste incineration in Jersey and the Isle of Man are reported under 1A1a. Data are available for the amount of waste open-burned in Guernsey, so these are used to estimate emissions for 5C2 using IPCC 2006 default EFs. It is assumed that this source is not occurring in the remaining territories.

The inventory also includes estimates for emissions of:

- CO, NO_X & VOC from small-scale burning of domestic and garden waste, for example on domestic grates and on garden bonfires;
- CO from open fires lit as part of 'bonfire night' celebrations; and
- CO from fireworks.

All of these estimates are very uncertain, because of the need for expert judgements and assumptions in order to derive any activity data from waste arising data, and the need, because of a lack of suitable emission factors, to instead use factors that were designed for other types of emission source such as domestic fires.

Activity and emissions data for this sector can be found in **Annex 3**, **Table A 3.5.5** and **Table A 3.5.6**.

7.4.3 Uncertainties and Time-Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and gas.

7.4.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

7.4.5 Source Specific Recalculations

Data on waste burnt during 2014 has become available since the previous inventory and the estimates for that year have been updated to reflect that.

For information on the magnitude of recalculations to Source Category 5C, see **Section 10**.

7.4.6 Source Specific Planned improvements

Emission estimates for chemical waste incineration currently do not include the burning of chemical wastes in flares and it is unclear whether these emissions might be included in the estimates reported in 2B10. As recommended in the 2014 Expert Review and associated report, if data on flaring becomes available within the pollution inventory for chemical waste incineration this data will be included in the GHG inventory. No evidence has been found for any chemical waste incineration processes carried out in Scotland or Northern Ireland, and so emissions in these regions are assumed to be zero. The need to deal with significant gaps in the reported data means that estimates are quite uncertain. Emission estimates for clinical waste, animal carcass and sewage sludge incineration are also quite uncertain and ideally would be improved. However, all incineration processes are relatively minor sources of greenhouse gases and further development of the methodology is not a priority.

7.5 SOURCE CATEGORY 5D – WASTEWATER HANDLING

7.5.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	5D1: Domestic Waste-water treatment 5D2: Industrial Waste-water Treatment	T1, CS T1	CS, D D
Gases Reported	CH_4, N_2O		
Key Categories	5D: Wastewater Handling - N_2O (L2, T2) 5D: Wastewater Handling – CH_4 (L2) 5D: Wastewater treatment and discharge - CH_4 (T1, L1, L2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Emissions from wastewater handling within OTs and CDs are included in 5D1. Estimates are based on 2006 IPCC Guidelines and EFs with country-specific parameters applied, where available.		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	Updated composting emission factor applied to align with revised 2006 IPCC guidelines. Updated methodology in response to UNFCCC ERT recommendations by applying a country-specific fraction of municipal nitrogen load from unconsumed protein and a fraction of municipal nitrogen load from commercial and industrial sources from the 2006 IPCC guidelines for calculating N_2O emissions from commercial and industrial waste water.		

Emissions reported in 5D2 arise from wastewater handling in a number of industry sectors in the UK where organic content of effluent is high. No data are currently available on sludge removal so all water treatment, sludge treatment and disposal emissions are reported as aggregated under 5D2.

Emissions reported in 5D1 arise from wastewater handling, sludge treatment and disposal in the UK's municipal waste-water treatment system and private waste-water management systems. The UK's municipal waste-water treatment system encompasses the treatment of effluent and sludge from residential and commercial sectors as well as trade waste from many industrial sites in the UK.

Methane is released from handling of wastewater and its residual solid by-products (i.e. sludge) under anaerobic conditions, due to the decomposition of organic matter by bacteria.

Nitrous oxide is released from human sewage during waste-water handling due to the release of nitrogenous material from proteins.

7.5.2 Methodological Issues

The emissions from 5D1 and 5D2 are estimated for the following sources in the UK:

- ***5D1 Domestic and Commercial Waste-Water.*** Which consists of 4 main aspects:

- **UK CH_4 emissions from municipal waste-water treatment.** UK-specific method, using activity data for the municipal waste-water treatment volumes, organic content and sludge treatment and disposal routes. Emission factors are derived from water company reported data for recent years, extrapolated back to 1990;
- **UK CH_4 emissions from private waste-water management.** Default IPCC methodology using UK-specific per capita Biochemical Oxygen Demand (BOD) and estimated population using private waste-water management systems;
- ***UK N_2O* emissions.** Default IPCC methodology applied to UK time series of population and protein intake estimates from food surveys;
- ***OT and CD Sewage Treatment.*** For the majority of overseas territories and crown dependencies, wastewater emissions are estimated using UK data and scaled by population. Data specific to Bermuda were provided by the territory and used within the time series, interpolating and extrapolating where necessary.

- ***5D2 Industrial Waste-water Treatment (CH_4).*** Default IPCC methodology applied to UK waste-water estimates of organic load from the food and drink and chemical industries.

7.5.2.1 5D1: UK CH_4 emissions from municipal waste-water treatment

The UK estimates for methane from municipal domestic and commercial waste-water and sewage sludge treatment and disposal are derived from a time series of activity data for (i) total mass of sewage sludge disposed, and (ii) population equivalent of effluent treated in the municipal water treatment systems. These data cover most of the UK water company activity since 1990, which reflects shifts in UK water sector regulation and management.

7.5.2.1.1UK Industry Overview

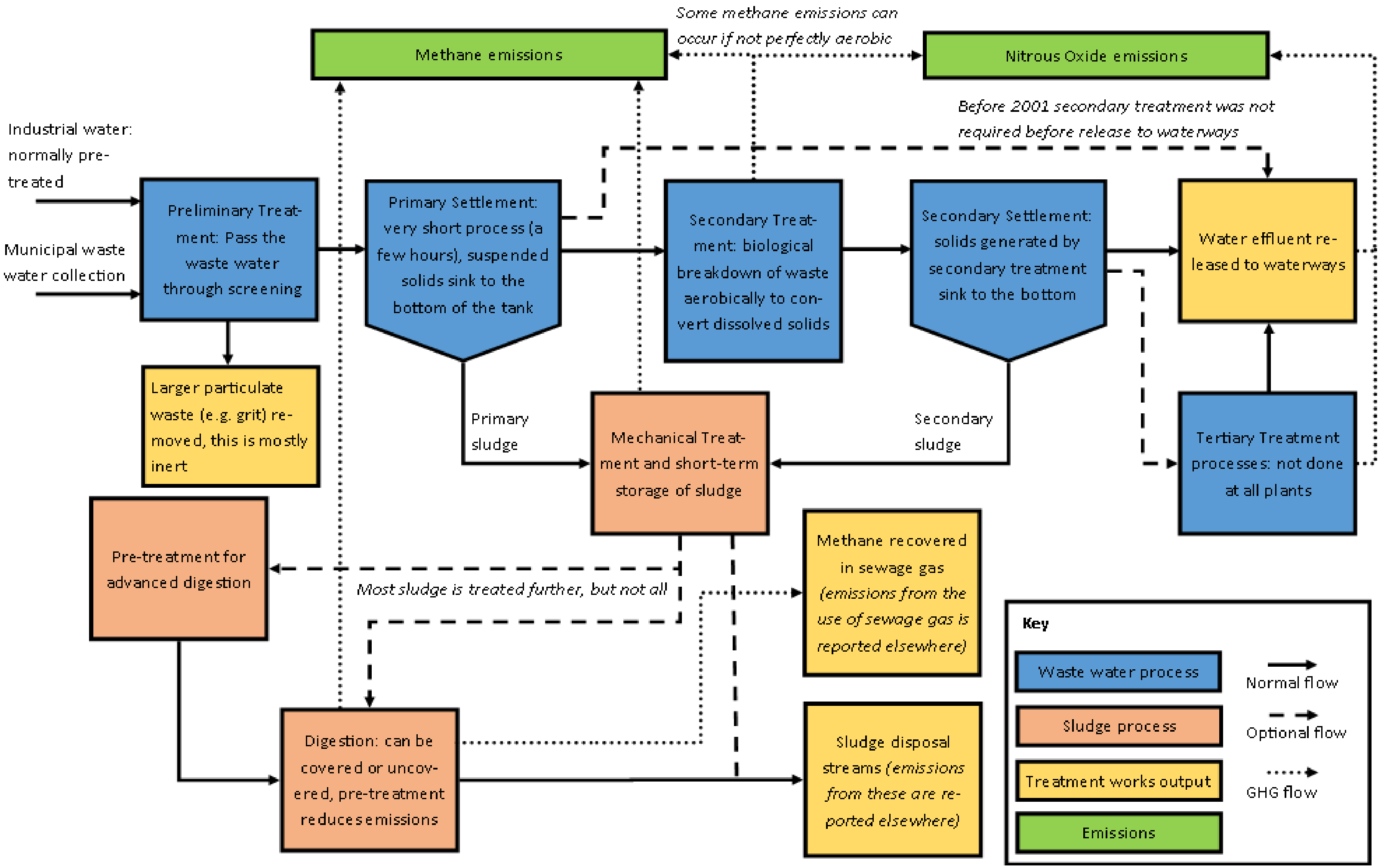
The UK waste water treatment industry is a highly-regulated sector that has undergone a high level of investment in infrastructure and improvement of management practices over several decades in order to deliver a service that achieves high environmental standards and meets key performance indicators (e.g. treatment parameters and volumes, economic and sustainability standards). Even prior to 1990 the UK network of waste water treatment plant were at the fore-front of engineering and technological development globally, and this has been strengthened by the impacts of successive and more stringent regulations in the intervening years, notably the Urban Waste Water Treatment Directive in the late 1990s / early 2000s which banned dumping of sewage to sea.

The UK water sector was previously publicly owned, and is now comprised of around 15 individual companies that operate regional networks and infrastructure. There is a long history of UK-wide research and co-operation across these companies, and in response to the challenge to monitor and report environmental performance, all major UK water companies engage via a central body, UK Water Industry Research, through which common reporting frameworks and systems are researched, developed and updated to reflect latest science and industry practices.

In the UK, a typical Waste Water Treatment Plant (WWTP) involves a number of interrelated processes each of which have different emissive behaviour. The different combinations of treatment options and the local waste water arising characteristics (especially where high volumes of industrial waste are combined and treated together with municipal waste water, altering the waste water input characteristics away from “typical” municipal waste water arisings) lead to a range of performance in the management of organic waste and the emission performance of the treatment works. The UK tools to monitor WWTP performance, estimate the input water characteristics (which in the UK is linked to regulatory and charging regimes for industrial customers, often based on periodic sampling of industrial effluents that pass into the predominantly municipal system), and to estimate the GHG emissions from these activities have been developed through research focussed on the UK waste water sector and the existing infrastructure. This research underpins the UK GHGI estimates of methane emissions, as the country-specific model uses company-reported data via the Carbon Accounting Workbook (CAW) which accounts for plant specific processes using CS emission factors that reflect UK circumstances.

Figure 7.3 provides an overview of the key processes in a typical UK WWTP.

Figure 7.3 Waste water flow diagram



7.5.2.1.1.1 Preliminary Treatment

All waste water is initially filtered for large objects and particulate matter. The filtering process is not emissive and the screened material is largely inert. Any emissions associated with the disposal of non-inert content of the screened waste are included in estimates for other sectors (e.g. landfill in sector 5A).

7.5.2.1.1.2 Settlement (Primary, Secondary and Tertiary)

After preliminary treatment all waste water undergoes primary settlement. Primary settlement involves allowing suspended solids to settle at the bottom of the tank to form a sludge. The sludge can then be extracted for separate sludge treatment. The process is relatively short (a few hours), and hence there is not time for methane generating bacteria to proliferate. Methane emissions from process are therefore insignificant.

During Secondary and Tertiary treatment, the biological processes can lead to the conversion of dissolved solids to suspended solids. When this occurs, additional settlement stages are typically used to extract more solids from the water. The process of secondary and tertiary settlement is otherwise the same as primary settlement.

7.5.2.1.1.3 Secondary Treatment

The standard secondary treatment in the UK is an aerobic treatment which reduces the biological dissolved solids by allowing bacteria to proliferate and process the dissolved solids. The dissolved solids are converted to suspended solids which is separated from the water in the settlement stages.

This process was made compulsory for large WWTP in 2001 under the Urban Waste Water Treatment Directive. Before 2001 this treatment practice was widespread, but was not implemented at all UK WWTP. As a result, the effluent to UK waterways prior to 2001 would typically have had a higher biological load. For this reason, the UK GHGI method applies the IPCC default methodology for waste water disposed to waterways, to account for the increased biological load of this water. The additional biological load is estimated by finding the difference between the sludge generated per capita before and after 2001.

Secondary treatment is a source of nitrous oxide emissions, and a small amount of methane emissions (primarily due to potential disruptions in the process which may allow anaerobic conditions to occur). In the company reported data emissions are reported for nitrous oxide; the Inventory Agency does not use this as we do not have sufficient information to determine what impact this process has on downstream nitrous oxide emissions. Emissions of methane are reported with mechanical treatment and short term storage of sludge in the CAW, and the Inventory Agency uses these values as part of the emissions estimates.

7.5.2.1.1.4 Tertiary Treatment(s)

In many UK WWTPs, there is a requirement for tertiary waste water treatment, in order to meet the regulatory permit conditions and/or to meet water quality criteria for the water-ways receiving the WWTP effluent outflow. There are a number of tertiary processes that can occur depending on what products require removing from the water.

The most common tertiary treatments are nitrification and denitrification which aim to reduce the nitrogen load of effluents. These processes can be a significant source of nitrous oxide within the WWTP, but they also reduce the level of nitrous oxide emissions occurring downstream due to the removal of nitrogen from the effluent. Similar to secondary treatment, the UK cannot estimate nitrous oxide emissions from this source (using the directly-reported emissions from WWTP operators) without introducing a potential double count with downstream emissions, as the data are not available to establish the impact of these tertiary treatments on the residual nitrogen loads in WWTP effluent.

Similar to secondary treatment processes, methane emissions from tertiary treatments do not occur through routine operation and are considered negligible by the UK industry.

7.5.2.1.1.5 Mechanical Treatment and Short Term Storage

All sludge extracted from waste water goes through an initial mechanical treatment and to short term storage. This process thickens, dewaters and homogenises the sludge to reduce the volume of the sludge and prepare it for further treatments. The gravity thickening process and storage of sludge under anaerobic conditions leads to methane emissions which are reported by waste water companies via the CAW, and these data are used to derive the UK inventory estimates.

7.5.2.1.1.6 Digestion

In the UK the vast majority of sludge undergoes anaerobic digestion after mechanical treatment, particularly in recent years. This process allows anaerobic bacteria to process the sludge, reducing the volume of sludge and generating methane. WWTPs collect the generated methane and burn it in engines to generate electricity; this generation of electricity by the industry using sewage gas is reported within the UK energy statistics. Emissions from the burning of sewage gas are reported in the UK inventory within sector 1A1a Power generation, whilst emissions from the disposal of sludge is reported according to the water company reporting of sludge fate, to landfills (5A), incinerators (5C) and agricultural soils (3D).

There is an increasing trend in the UK to pre-treat the sludge before digestion to improve the efficiency of digestion; this is known as **advanced digestion**. There are two main advanced digestion processes; Cambi's patented **Thermal Hydrolysis Process** (CambiTHP™) which involves high pressure steam to improve anaerobic digestion conditions and **Acid Phase Digestion** (ADP) which involves creating two sets of conditions which suits two types of bacteria. These processes allow for a higher biogas yields and greater reductions in sludge volume than conventional digestion.

This is the main source of methane emissions in UK WWTP as methane is intentionally generated but not all methane is collected. The data reported to the UK inventory team by waste water companies via the CAW accounts for the types of digestion occurring and whether or not the digestion is enclosed.

Nitrous oxide emissions from digestion are negligible, due to the lack of oxygen in the system.

7.5.2.1.1.7 Composting

In some cases, UK WWTPs may compost the sludge after mechanical treatment, instead of digestion. This is a source of methane and nitrous oxide emissions. These emissions are reported by waste water companies in the UK through the CAW, the method for which applies default methane and nitrous oxide emission factors for composting from the 2006 IPCC guidelines.

7.5.2.1.2Waste-water Treatment and Sludge Disposal Activity Data

Activity data are available at an aggregated level (across countries: England and Wales, Scotland, Northern Ireland, and with no detail on treatment) for the early part of the time series within EPSIM data published by UK Government (Defra, 2006). More detailed activity data (from each of 12 UK water companies, with details on sludge treatment and fate) most of the recent part of the time-series.

In recent years, each of the UK's 12 water and sewerage companies report annual activity data on water treatment, sewage sludge arising and the ultimate fate of sewage sludge, to UK industry regulators. The activity data reported by each company includes data that are used to estimate company GHG emissions:

- Total volume of sludge disposed (kt total dissolved solids (tds)); and

- Population Equivalent (PE) Served (‘000), this is the estimated resident and non-resident (e.g. tourist) population served which acts as an alternative indicator of sewage load.

In addition, each company provides a detailed split of sewage sludge disposal routes, including data (kt tds per year) for the following activities:

- Incineration;
- Composted;
- Landfill;
- Land reclamation;
- Farmland;
- Disposal at sea (up to the year 2000, when this activity was banned); and
- Other.

For the 2013 inventory cycle the Carbon Accounting Workbook (CAW), developed by UK Water Industry Research (UKWIR), which is the tool used by the water industry for reporting emissions to Defra and OFWAT, was adapted to provide detailed data for the inventory. The inventory team was provided with a methodology report that included a number of the underlying assumptions and emission factors and activity (in PE for secondary treatment, m^3 for biogas use and kt tds otherwise), CH_4 and N_2O emissions was reported for the following:

- Mechanical treatment and short term storage of sludge (activity and CH_4 emissions only);
- Secondary treatment (activity and N_2O emissions only);
- Digestion (activity and CH_4 emissions only);
- Advanced digestion (activity and CH_4 emissions only);
- Composting (activity and CH_4 emissions only);
- Digested sludge to land;
- Advanced digested sludge to land;
- Composted sludge to land;
- Raw and limed sludge to land;
- Raw and composted sludge to landfill (activity and CH_4 emissions only);
- Digested sludge to landfill (activity and CH_4 emissions only);
- Sludge to incineration (activity and N_2O emissions only);
- Biogas used in CHP for energy generation (activity only); and
- Biogas used for combustion other than by CHP (activity only).

From 2000 to 2009, each of the 10 water companies in **England and Wales** reported sludge disposal activity to the industry regulator, OFWAT, broken down across 8 sludge disposal routes: incineration, composting, landfill, land reclamation, farmland untreated, farmland conventional, farmland advanced and other. After 2009 the requirements of data reported to OFWAT changed, and data was no longer publically available. For 2013 onwards company reported data from the CAW has been available.

For 1991 to 2005, the EPSIM data present a breakdown of sewage sludge disposal data across five options: farmland, incineration, landfill, sea disposal and other, and for 1986-2005 this data set gives total estimates sewage sludge arising. No additional information is available, such as the BOD loading of the municipal sewerage system, treatment methods, or the population equivalents treated by UK water companies. The overlap in time-series between the EPSIM data and company reported data confirms that the total and split of disposal methods are largely consistent with each other.

In **Scotland** the same level of detailed activity data as outlined above for companies in England and Wales have been available since 2002 and continues to be published, from the Water Commissioner for Scotland; EPSIM data are used for 1990-2001. The totals reported in the

EPSIM data fit the company reported data very well, but because the disposal split fits very poorly in the overlapping years the company reported split from 2002 is used with the EPSIM total for the earlier part of the time series.

In **Northern Ireland**, data are only available from the water regulator, UREGNI, for 2006-9 and 2012 onwards, with a disposal split only available for 2013. The Defra EPSIM statistics are used to provide activity data for the early part of the time series to 2005, whilst the year gap between the 2 data sets and the 2 year gap in company reported data is interpolated. The EPSIM time-series trend fits well with the company reported trend in later years, as the disposal split is similar in the 2013 reported data and at the end of EPSIM time-series it is reasonable to assume a similar split for the intervening years.

7.5.2.1.3Emission Estimation: Use of UK-specific Factors

The UK GHG inventory mostly follows the UK water industry GHG emission estimation methodology developed by UKWIR for the submission of 2013 data in 2015, and used by all UK water companies to generate their annual emission estimates from all sources / activities. UKWIR have not provided an approach for estimating emissions associated with waste to sea in the 1990s, so to avoid an omission the 2006 IPCC default approach using the Methane Correction Factor (MCF) for sea, river and lake discharge has been used. Discharges would have only been to the cold seas with low organic loadings around the UK, so this is likely to be a very conservative approach for estimating emissions.

Methane emissions from sewage sludge disposed to landfill and incineration are accounted for in 5A and 5C, and hence no estimates are included in 5D1 to avoid a double-count. Waste disposed of via 'other' means has been given a weighted average emission factor based on the emissions from other disposal methods. Where the treatment before disposal isn't specified, the treatment split is estimated based on the profile given in CAW reported data for since 2013; for example it was only after 2013 that the sludge disposed to landfill has been disaggregated based on treatment, this split has been used to estimate the treatment split for the earlier years where none is specified.

UK-specific emission factors are applied to the treatment and disposal methods reported in the CAW, outlined above. Most of these factors are derived from UK water industry emissions data reported to the Inventory Agency, through use of the UKWIR estimation spreadsheet tool that all UK water companies utilise. The UKWIR tool provides emission factors for sub-processes within the industry, enabling water companies to calculate their methane emissions based on their stock of water treatment equipment and effluent inputs to individual water treatment works. From the aggregated industry reported emissions and activity data, implied emission factors for each of the treatment and disposal approaches can be derived. The emission factor for composted sewage sludge treatment is derived from the 2006 IPCC guidelines.

Water company reporting of emissions to the Inventory Agency is not comprehensive; emissions data are only available from 2009 onwards, and only from up to 9 of the 12 UK water companies in any one year before 2013; for example in 2009, emission reporting by water companies was estimated to cover around 53% of total UK water treatment.

During 2013 the Inventory Agency met with all UK water company carbon managers and the authors of the UKWIR reporting tool that all companies use under a voluntary mechanism for GHG emissions reporting. Through this consultation, 9 out of 12 water companies provided 2012 emissions data, covering around 65% of UK water company activities. In addition, a reporting template has been drafted for inclusion within the UKWIR tool, which means that since 2013 we have received data from all 12 of the water companies, covering over 86% of water company activities (2 companies reported lower activity for disposal than treatment, we believed that this meant there was a reporting omission of about 10% of the disposal emissions. This gap was filled by assuming waste was disposed of in similar ways to other companies). In future we should continue to receive this much more comprehensive data from the industry, and therefore have much more confidence in emissions estimates.

Despite limitations to data collection in previous years, there is good consistency across the emission factors derived from the different water companies and the data are based on UK-specific water treatment facilities, effluent inputs and treatment / disposal activities, and therefore are regarded as the best available data upon which to derive inventory estimates.

The implied emission factors are given in **Annex 3.5.3**.

7.5.2.1.4Reporting of Methane Recovery from Sewage Treatment

The methodology report provided by UKWIR for the 2013 version of the CAW provides the emission factor assumed for digestion without capture. Using this factor we calculated what emissions would have been reported had there been no methane capture, then necessarily the difference between reported emissions and this unabated emission estimate would be the amount of methane captured.

Data on the annual amount sewage gas being produced are provided in DUKES (BEIS, 2016). Using this we can establish a link between the DUKES estimate based on energy use and the mass based estimate based on the difference between unabated and reported methane emissions. Assuming that the relationship between energy use and methane captured is consistent throughout the time series, the amount of methane removed can be calculated for all years and removed from the estimate for unabated emissions.

Using this approach it suggests that 6-19% of potential methane emitted during digestion is captured for flaring or energy use, with the highest value being observed in 2015 after a steady increase over a number of years.

7.5.2.2 5D1: UK CH_4 emissions from private waste-water management

An estimate of the number of households that are likely to be using off-grid systems in the UK in 2013 has been made based on data provided by the Environment Agency (EA), the Scottish Environmental Protection Agency (SEPA), the Northern Ireland Department of the Environment (NIEA) and Natural Resources Wales (NRW).

A time series of emissions has been developed using population data. This time series of number of households has been combined with ONS data for average household occupancy and the calculated volume of waste produced per person per year based on water company statistics to produce an estimate of total waste-water being disposed of via off-grid systems.

The emissions are then calculated following the method set out in the 2006 guidelines Volume 5, Chapter 6: Wastewater treatment and discharge. Equation 6.2 in the GLs, reproduced below, calculates the emission factor.

$$\mathrm{EF_j} = \mathrm{B_0} * \mathrm{MCF_j}$$

Where

$\mathrm{EF_j}$= emission factor, kg CH_4/kg BOD (Biochemical Oxygen Demand)

j = each treatment/discharge pathway or system

$\mathrm{B_0}$= maximum CH_4 producing capacity, kg CH_4/kg BOD

$\mathrm{MCF_j}$= methane correction factor (fraction), See Table 6.3 of the GLs.

Table 7.1 lists the parameters which were used and the calculated EF. The MCF of 0.5 was the default factor for septic tanks. The team did not have enough data to establish the activity by waste treatment process. As the vast majority of private waste management systems observed were septic tanks, and the septic tank factor is conservative when compared to other systems that could be used, it was decided that it would be the most appropriate factor to apply.

Table 7.1 New emission factors added as a result of completeness checks

Parameter	Description	Units	Value
B_o	Maximum CH_4 producing capacity	kg CH_4/kg BOD	0.6
MCF	Methane correction factor	Fraction	0.5
EF	**Emission factor**	**kg CH_4/kg BOD**	**0.3**

The emission factor is then combined with total amount of organically degradable material in the waste-water (TOW), expressed as kg BOD/year, which is calculated using Equation 6.3 in the 2006 GLs:

$$TOW = P \bullet BOD \bullet 0.001 \bullet I \bullet 365$$

Where:

TOW = total organics in wastewater in inventory year, kg BOD/yr

P = country population in inventory year, person

BOD = country-specific per capita BOD in inventory year, g/person/day

0.001 = conversion from grams BOD to kg BOD

I = correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00).

The population figure used is for only the proportion of the population using septic tanks. The BOD value is assumed to be similar to the BOD per capita implied by the data provided by the major water companies

7.5.2.3 5D1: UK N_2O emissions from Domestic and Commercial Waste-water

Nitrous oxide emissions from the treatment of human sewage are based on the 2006 IPCC default methodology. The most recent average protein consumption per person is based on the Expenditure and Food Survey (Defra, 2015); see **Table 7.2**. For the purposes of the 2015 estimates within the inventory, the Expenditure and Food Survey 2016 was not available in time, and therefore the data for 2014 has been used as a best estimate. Population estimates are from the Office for National Statistics (ONS, 2016).

In previous years, the protein consumptions used to estimate emissions were “household intakes”. However, Defra now produce a time series of the estimates of the small amount of additional protein from consuming meals eaten outside the home; this intake is called “eating out intakes”. This time series is only available from 2000 onwards. For values between 1990 and 2000 an average of the data available is applied. The sum of the “household intakes” and “eating out intakes” then provides the total protein consumption per year per person.

Table 7.2 Per capita protein consumption in the UK (kg/person/yr), 1990-2015

Year	Protein consumption (kg/person/yr)
1990	27.9
1995	28.6
2000	29.9
2005	29.8
2010	28.7

Year	Protein consumption (kg/person/yr)
2011	28.2
2012	27.7
2013	27.3
2014	27.1
2015*	27.1

*2014 data used, as 2015 data was not published in time for inventory compilation.

Nitrous oxide emissions are calculated by multiplying annual total protein consumption per person by the fraction of nitrogen in protein (0.16kg N/kg protein) by a fraction of municipal nitrogen load from unconsumed protein (1.16; Henze and Comeau, 2008), and from commercial and industrial sources, as per the 2006 IPCC guidelines (1.25).

This derives a total for the UK nitrous oxide emissions from sewage sludge, but not all of those emissions are allocated to 5D1. The nitrous oxide emissions from sludge spread on agricultural land are reported under IPCC source category 3D Agricultural Soils and emissions from waste incineration are included in 5C. Therefore to avoid a double-count in the UK GHG inventory, the emissions reported in 5D1 are the difference between the UK total from the IPCC default method, and the estimates included in 3D and 5C.

Use of UK-Specific Protein Consumption Data instead of FAO Data

The FAO estimate of per capita protein consumption is based on supply balance sheets for all commodity items. For each commodity supply balance sheet, factors are applied to the estimate of supply for human consumption to derive total protein consumption and a per capita figure is obtained by dividing by population statistics. These are summed across the supply balance sheets to derive a total protein consumption estimate for a country.

The FAO estimate is therefore an aggregate calculation based on aggregate commodity supply data. It uses common conversion factors (not specific to any country) to derive food, protein and fat per capita consumption estimates. It also relates to quantities available for consumption and will not be net of any losses (including e.g. fat trimmed from meat) beyond the farm-gate through to retail. These methodological limitations of the FAO estimates are more significant for developed countries such as the UK where a greater proportion of consumption is in the form of processed products.

The UK GHGI estimate of protein consumption is derived from the Expenditure and Food Survey (Defra, 2015). This is a sample household survey in which households record the actual purchases of food they make. UK-specific conversion factors are then applied to these individual food items to estimate consumption of protein and other nutrients. The UK-specific conversion factors are based on a detailed analysis of the individual types of food purchased and contrasts to the more broad-brush factors used by the FAO. The Expenditure and Food Survey estimate is also net of any losses through the food chain through to retail as it is based on actual purchases. The only limitation to the Expenditure and Food Survey is that it may have an element of under-recording due to purchases of some food items not being included in the diary of survey participants, but the Inventory Agency considers that it is more representative of UK protein consumption per capita than the FAO estimate.

7.5.2.4 5D2: Industrial Waste-water Treatment

In the UK, a high proportion of industry trade waste-water is disposed to the municipal sewer system and treated by water companies together with the sewage and effluent from domestic and commercial sectors.

In the data reported by the water companies and used to generate methane emission estimates in 5D1 (see above), some of the annual reporting to water regulators includes explicit data on the BOD from “trade waste” and the total BOD treated (i.e. including domestic and commercial effluent) in the municipal systems. The share of total BOD that is attributable to the industry sector (i.e. “trade waste”, managed via contracts between water companies and industry operators) is variable across the UK and across years. In 2008 (before the economic down-turn) the trade waste share of total BOD treated in the municipal waste-water systems (i.e. emissions from which are reported in 5D2) is estimated to be 13.2%, but from 2009-2012 the figure has been in the range 10.8-11.7%. We are attempting to collect information on the domestic-industrial split in wastewater treatment from water companies in order to have confidence in building a time series that removes this double count.

In addition to the emissions reported in 5D2 due to trade waste disposed to municipal sewers, where large industrial sites that have on-site waste-water treatment plant are regulated under IPPC/EPR, then the annual IPPC/EPR reporting to regulator inventories (PI/SPRI/NIPI) includes the requirement to report any methane emissions from the waste-water effluent plant. The PI/SPRI/NIPI data on methane emissions are used within the UK GHGI, and included within many IPCC source categories, but the lack of source-specific detail in the PI/SPRI/NIPI reporting does not enable the waste-water treatment emission estimates from these industrial facilities to be split out and reported separately in the CRF.

In practice it is not straightforward to ascertain the extent to which emissions from waste-water treatment are consistently included in operator estimates across different industry sectors, as the IPPC/EPR data are not presented “by source”, but rather “by installation”. Within sector-specific guidance to plant operators on pollution inventory data preparation, emissions of methane from wastewater treatment are not highlighted as a common source to be considered, whilst in guidance for several industrial sectors, wastewater treatment is singled out as a potentially significant source of ammonia and nitrous oxide emissions.

Therefore, some industrial waste-water treatment methane emissions are already reported within a range of IPCC source categories, but cannot be quantified explicitly due to the lack of transparency of available source data from UK environmental regulatory reporting systems.

At the 2012 in-country review, the lack of transparency and level of emissions reported in 5D2 (at the time 6B2) led the expert review team to recommend that the UK introduces new separate estimates of emissions of methane from industrial waste-water treatment. Therefore in the 2013 submission the Inventory Agency added a new time series estimates using the IPCC default methodology and available UK activity data from high-BOD-emitting UK industry sources, primarily in the food and drink and chemical production sectors. The UK Inventory Agency considers that this introduces a double count to the inventory, but is a conservative estimate to ensure completeness. The method is retained to the present, as no further evidence has been obtained by the Inventory Agency.

Summary of Estimation method for UK 5D2 Estimates

In developing industrial waste-water methane emission estimates, the following UK industries have been considered, as they are high-BOD-emitting waste-water source sectors in the UK economy:

- Organic Chemicals; and
- Food and Drink, including:
    - milk-processing;
    - manufacture of fruit and vegetable products;
    - potato processing;
    - meat processing;
    - production of alcohol and alcoholic beverages;
    - breweries;
    - manufacture of animal feed from plant products;
    - manufacture of gelatin and of glue from hides, skin and bones

- malt houses; and
- fish processing.

The estimation methodology is based on the following data and assumptions:

- Default values for Chemical Oxygen Demand (COD) and amount of wastewater generated used for organic chemical production from the IPCC 2006 GLs;
- PRODCOM data (supplied by the Office for National Statistics) used for organic chemical production (2009) and scaled using Office for National Statistics Index of Production (IOP) for other years (1997 is earliest year for IOP so 1990-1996 estimates use the 1997 value); and
- Total organic load obtained for food and drink industry sub-sectors in a 2002 paper by Defra[51], scaled across the time series using Office for National Statistics Index of Production data (as above, 1997 data are used for 1990-1996 also).

*[The UK activity data are summarised for selected years across the time series in **Annex 3.5.4**]*

The Inventory Agency considers that these new emission estimates are very conservative, and likely to be over-estimates, noting that:

- There is no information currently available on how much wastewater for the chemical and food and drinks industries are treated on site and how much is included in emissions of wastewater sent to sewers. We have therefore used IPCC default values for the amount of wastewater consumed per tonne of output and amount of COD in the wastewater, and assumed all wastewater is treated on site rather than any of it disposed to municipal sewers;
- There is no information currently available on how much sewage sludge is removed and sent to landfill or applied to agricultural land. Although it is likely that this activity does take place, due to the absence of information, the default value of zero has been used;
- There is no information on the amount of methane recovered, so the default value of zero has been used, although it is likely that this activity also takes place. There is some evidence from the EU ETS dataset that several UK food and industry facilities collect methane from anaerobic digestion systems and use the gas as a fuel source; and
- There is no UK specific information on the split of aerobic and anaerobic industrial wastewater treatment and therefore the IPCC default estimate has been used. It is likely that aerobic treatment systems will be used in many UK facilities.

7.5.2.5 Overseas Territories and Crown Dependencies

Estimates from the OTs and CDs are calculated using the Tier 1 approach from the 2006 IPCC Guidelines and default EFs. Country-specific parameters have been chosen based on information provided through a waste survey (distributed in 2014) and through expert judgement. Per capita protein consumption data were taken from FAOSTAT with data for Bermuda applied to all OTs other than Gibraltar, and data from the UK applied to all CDs and Gibraltar.

7.5.3 Uncertainties and Time-Series Consistency

As outlined in **Section 7.5.2**, the method for deriving methane emission estimates for 5D1 uses activity data from across the time series, and applies emission factors that are derived from reported emissions data from 2009 onwards. The method uses a published national set

[51] http://www.defra.gov.uk/publications/files/pb6655-uk-sewage-treatment-020424.pdf

of activity statistics that reflect the changing fate of sewage sludge treatment and disposal; the UK the water industry has undergone a marked shift in treatment and disposal practices since the Urban Waste-water Treatment Directive of 1999 banned the dumping of sewage to sea and in 2001 the same directive required all large WWTP to conduct secondary treatment; the sludge disposal trends are consistent with this regulatory change.

Not all UK water companies reported their emission estimates in all years since 2009, and the available dataset for deriving country-specific factors is limited in some cases to only around 50% coverage of UK water treatment and sludge treatment / disposal activity. The Inventory Agency has continued to develop working relationships with the 12 UK water companies and in from 2013 onwards obtained activity and emissions data from all of the 12 water companies. Therefore, we have a much more complete, consistent set of activity and emissions data reported from across the UK. This helps to further develop the UK-specific dataset from which estimates can be derived, improving accuracy through accessing more complete, representative data which reflects the range of waste-water quality and the design / stock of waste-water treatment facilities across the UK. The template for UK water company reporting used last year will be sent to the Inventory Agency on an annual basis, and we have negotiated for further detail to be provided to improve other estimates.

The reported emissions and activity by UK water companies since 2013 has been used to derive country-specific emission factors for water treatment, methane capture, sludge treatment and most disposal routes, and these factors are applied to the activity dataset back to 1990. We are therefore using the best available data to estimate the emissions back to 1990. The use of the IPCC default for methane emissions from waste disposal to sea introduces a significant uncertainty to the early part of the time series where the activity is known to have taken place. This is because the IPCC default factor is for a wide range of situations including stagnant lakes with high organic loads in temperate climates, which would have very different emissive behaviour to the cold, low organic load seas around the UK. Furthermore, the limited activity data time series for 5D1 due to changes in data reporting across the time series limits the accuracy and time series consistency of the estimates for the early part of the time series; however it is observed that the overlaps in trend between the data sets typically show strong agreement.

See **Annex 3.5.4** for further details on the activity data, implied emissions factors and emissions estimates, and **Section 7.5.6** below for an insight into the planned improvements for this source method.

7.5.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.2.2.5**.

During the 2016 UK GHGI reviews under the EU Effort Sharing Decision (ESD) and the UNFCCC Expert Review Team (ERT) both of these review teams concluded that the UK should carry out a verification of the methodology by comparing it with a tier 1 default methodology set out in the 2006 IPCC guidelines. Below this comparison is made.

The UK currently already uses a 2006 IPCC default methodology to estimate emissions from waste water disposed to waterways and private waste management systems. The verification calculations below compare the emission estimates using the IPCC 2006 GLs Tier 1 method against the UK's country-specific model for all other waste water sources, i.e. from emission sources at UK WWTP where the 2006 IPCC Guidelines are not directly applied.

As outlined in **Section 7.5.2.1.1.3** the UK uses well-managed centralised aerobic treatment for waste water treatment. The UK also has a well-managed, flowing, closed sewer system. The 2006 IPCC default MCF for these sources is "0", which means that should the UK follow the 2006 IPCC default methodology it would be reporting zero emissions of methane.

We note, however, that the MCF of "0" may be due to a rounding of a small number rather than inferring that zero methane emissions would occur. It is likely that some methane emissions *will* occur. Even at well-managed WWTPs there will be incidences that lead to temporary anaerobic conditions. At an EU Working Group 1 meeting in February 2016 it was flagged that having an MCF of "0" for some sources in the 2006 IPCC guidelines meant that some countries will be under-reporting emissions.

The UK uses a CS factor which accounts for several processes that occur at UK WWTPs including aerobic treatment[52]. Unfortunately, because it includes processes that are not included in the 2006 IPCC guidelines, it is not a like-for-like comparison. **Table 7.3** sets out a comparison of parameters used to estimate methane emissions in the guidance with the most similar parameters in the UK methodology.

While the UK estimate comes out close to the lower estimate of methane emissions based on IPCC default methodology, the higher value is dependent on the assumption that methane emissions are not captured in anaerobic digestion of sludge. This appears to be very conservative when even compared to the Chapter 4 factor (which does account for methane capture), which is more than 2 orders of magnitude smaller and comparable to the UK's CS factors.

Table 7.3 Comparison of IPCC and UK methane parameters by source

Source/Parameter	2006 IPCC Default Parameter	UK Parameter	Comments
Sewage treatment processes (Centralized, aerobic treatment plant)	0 kg per kg BOD	2.7 kg per tonne raw DS	IPCC MCF is 0 for Centralized, aerobic treatment plant. UK factors from the CAW, which additionally includes emissions associated with temporary storage and gravity thickening of sludge.
Flowing sewer (closed)	0 kg per kg BOD	Not Estimated	This is not included in the CAW, and the UK has not investigated further as the IPCC default is 0. While strictly speaking there probably are non-0 emissions from this source it is likely very close to 0 in the UK's well developed, managed, closed and flowing sewer system.
Private waste water management systems	0.3 kg per kg BOD	0.3 kg per kg BOD	UK uses IPCC default methodology for this source.
Sea, river and lake discharge	0.06 kg per kg BOD	0.06 kg per kg BOD	UK uses IPCC default methodology for this source.
Digestion (Chapter 4 of the 2006 IPCC guidelines)	2 kg per tonne dry waste treated	4.46 to 18.1 kg per tonne raw DS	UK factors from the CAW, this accounts for several different methods of digestion. The Chapter 4 IPCC Digestion factor includes the impact of methane recovery, the chapter 5 digestion factor does not. Given that anaerobic digestion is rarely done without methane recovery it is very conservative to assume it does not occur.
Digestion (Chapter 5 of the 2006 IPCC guidelines)	0.48 kg per kg BOD		
Composting	10 kg per tonne dry waste treated	10 kg per tonne raw DS	UK uses IPCC default methodology for this source. This source is included in the CAW, but they additionally used the 2006 IPCC guidelines

52 See the factor in **Table 7.3** for "Sewage treatment processes and the temporary storage and gravity thickening of sludge"

Source/Parameter	2006 IPCC Default Parameter	UK Parameter	Comments
Degradable Organic component - BOD	60 g BOD / capita / day)	60 to 71 g raw DS / capita / day)	This is a parameter that the guidance gives to derive activity data. Value chosen from the IPCC guidelines is in the mix of other Western European countries presented. The UK value presented is the implied factor based on reported data via the CAW and other waste water reporting systems.
Correction factor for industrial BOD discharged in sewers	1.25	Not Estimated	This is a parameter that the guidance gives to derive activity data. The reported data via CAW and other waste water reporting systems should already account for industrial co-discharge.
Total Emissions for 1990	**57 to 174 kt**	**59 kt**	**The range of IPCC Default emissions is dependent on which digestion factor is used, note that the higher value does not account for methane capture, which we know is occurring at UK sites.** **The UK's estimate remains within the range for both 1990 and 2015. The only notable differences between the UK's method and the default method is the use of a non-0 UK factor for well-managed, centralised aerobic treatment, and using specific factors for different methods of anaerobic treatment.**
Total Emissions for 2015	**16 to 594 kt**	**29 kt**	

7.5.5 Source Specific Recalculations

A number of recalculations have been made to the time-series, as a result of methodological improvements to the inventory this year.

- The CH_4 emission factor for composted sewage sludge treatment has been updated to reflect the July 2015 correction to the IPCC 2006 guidelines, resulting in recalculations across the entirety of the methane emissions from sewage sludge decomposition.
- An updated methodology in response to UNFCCC ERT recommendations now applies a fraction of municipal nitrogen load from unconsumed protein (Henze and Comeau, 2008) and a fraction of municipal nitrogen load from commercial and industrial sources from the 2006 IPCC guidelines for calculating N_2O emissions from commercial and industrial waste water. This causes large recalculations to the whole time-series for N_2O emissions from sewage sludge decomposition (equating to an increase in over 50% per year from this source for N_2O).
- Some minor recalculations due to revisions in index of production data and population statistics and more up to date protein data becoming available.

For information on the magnitude of recalculations, see **Section 10**.

7.5.6 Source Specific Planned improvements

It is noted that N_2O emissions from waste-water has been highlighted as a key category, and we are currently using a tier 1 method, it is also noted that the 2006 IPCC GLs do not provide a higher tier method.

8 Other (CRF Sector 6)

8.1 OVERVIEW OF SECTOR

No emissions are reported in Sector 6.

9 Indirect CO_2 and Nitrous Oxide Emissions

9.1 DESCRIPTION OF SOURCES OF INDIRECT EMISSIONS IN GHG INVENTORY

The calculation of indirect CO_2 and N_2O is not mandatory. The UK calculates indirect emissions of N_2O from emissions of NO_X and NH_3 from non-AFOLU sources. These are reported as a memo item.

The methods and data sources for the calculation of NO_X and NH_3 emissions are described in the UK's Informative Inventory Report (IIR), as submitted under the Convention on Long Range Transboundary Air Pollution.

9.2 METHODOLOGICAL ISSUES

Emissions of indirect N_2O are calculated using Equation 7.1 of Volume 1 of IPCC, 2006. EF4 within the equation is the IPCC default of 0.01 kg N_2O-N/kg NH_3-N or NO_X-N emitted.

9.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

No formal uncertainty or trend analysis for indirect N_2O emissions has been carried out. Uncertainties and trends for NO_X and NH_3 are described in the IIR.

9.4 CATEGORY-SPECIFIC QA/QC AND VERIFICATION

Emissions of NO_X reported under the GHG inventory are cross checked with those reported under CLRTAP and are consistent. NH_3 emissions are only reported under CLRTAP and not under the GHG inventory, however, calculated emissions from the UK inventory database have been carefully cross checked with the submitted totals to ensure completeness.

9.5 CATEGORY-SPECIFIC RECALCULATIONS

None.

9.6 CATEGORY-SPECIFIC PLANNED IMPROVEMENTS

Indirect nitrous oxide emissions will change in line with changes made to the NO_X and NH_3 inventories. Air quality pollutants are subject to a separate improvement programme to the GHG inventory, this is described in the IIR.

10 Recalculations and Improvements

This section of the report summarises the recalculations and improvements made to the UK GHG inventory since the 2016 NIR submission (1990-2014 inventory), including responses to reviews of the inventory. It summarises material that has already been presented and discussed in more detail in **Chapter 3** to **Chapter 7**.

Each year the UK greenhouse gas inventory is *updated*, *extended* and may be *expanded*.

Updating often entails revision of emission estimates, most commonly because of revision to the core energy statistics presented in the Digest of UK Energy Statistics (DUKES). The inventory also makes use of other datasets (see **Table 1.4** for a summary) and these too may be revised. Updating also covers adoption of revised methodologies. Updating, particularly involving revised methodologies may affect the whole time series, so estimates of emissions for a given year may differ from estimates of emissions for the same year reported previously. Therefore comparisons between submissions should take account of whether there have been changes to the following:

- the emission estimation methodology, including revisions to assumptions or conversion factors;
- the reporting guidelines under which the submissions are made (i.e. 1996 GLs or 2006 GLs);
- the emission factors applied; and/or
- the activity data.

The time series of the inventory is extended by included a new inventory year. For example, the previous report covered years up to and including 2014. This report gives emission estimates for 2014 and also includes estimates for the year 2015.

The time series of the inventory may also be expanded to include emissions from additional sources if a new source has been identified within the context of the IPCC Guidelines and Good Practice Guidance and there are sufficient activity data and suitable emission factors.

10.1 EXPLANATIONS AND JUSTIFICATIONS FOR RE-CALCULATIONS, INCLUDING IN RESPONSE TO THE REVIEW PROCESS

Table 10.1 to **Table 10.12** summarise the recalculations that have occurred in estimates of CO_2, CH_4, N_2O and F-gases since the 2016 NIR submission (1990-2014 inventory). The changes in emissions are net changes (the sum of any increases and decreases) in the source category, for each GHG in the Base Year (1990) (1995 for F-gases) and latest recalculated year (2014).

Table 10.15 summarises where changes to methodological descriptions have been made and where these descriptions can be found in the main text of this document.

All revisions to source data and methods, and all recalculations that are reported in the latest UK GHG inventory are conducted by the Inventory Agency in agreement with the BEIS GHG inventory management team; all major recalculations and systematic improvements to the UK GHG inventory are approved and managed via the NISC, with new outputs approved through the UK's system for pre-submission review. The inventory improvement process that manages the prioritisation and implementation of revisions to inventory data and methods uses the guiding principles of the 2006 IPCC Guidelines to govern the decisions over whether to implement changes to inventory estimates or not. The most common justifications for implementing changes that lead to recalculations are:

- ✓ Improved **accuracy** of the estimates, e.g. where underlying data from data providers has been revised (e.g. revisions to energy statistics), where less uncertain data are now available (e.g. use of EU ETS activity data to inform energy allocations, in preference to UK energy statistics data sources), or where the inventory agency has applied more representative (ideally UK-specific) EFs in estimation methods (e.g. use of carbon emission factors derived from EU ETS fuel compositional analysis);
- ✓ Improved **transparency** of the inventory estimates, e.g. the restructuring of inventory data reporting to improve the level of detail of the UK inventory (such as the reporting of F-gas estimates by species wherever this is achievable);
- ✓ Improved **comparability** of the inventory estimates, e.g. the restructuring of inventory data reporting to enable UK estimates to align more closely with IPCC GLs and GPGs, (e.g. re-allocations of limestone and dolomite data in the glass sector from 2A3 and 2A4 to 2A7, which was implemented in the 2012 submission to enable more harmonised data reporting across EU Member States).
- ✓ Improved **completeness** of the inventory estimates, e.g. the addition of emission estimates for new sources that come to light in the UK, or where new data for an existing source indicates that the activity data previously used in the method omitted some portion of the source emissions (e.g. use of EU ETS activity data to revise the estimates of emissions from refineries in the UK, where a gap in UK energy data reporting was identified through comparison against EU ETS data for the sector);
- ✓ Improved **consistency** of the inventory estimates, e.g. to implement new or revised methods that deliver estimates based on more consistent underlying data or assumptions across the time series.

Table 10.1 Recalculations to CO_2 in 1990 (kt CO_2)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
Energy					
1.A.1. Energy Industries	235822.84	235424.71	-398.13	-0.17%	Very minor recalculations, information available on request. Removal of Bermuda from the submission under the Kyoto Protocol (the ‘GBK’ submission) inventory contributes a minor recalculation.
1.A.2. Manufacturing Industries and construction	96243.57	95417.51	-826.06	-0.86%	Re-allocation of some emissions from 1A2 to 2B for methanol production. Revised assumptions for carbon emission factor for coal-fired autogeneration, based on later EU ETS data for the plant that dominates fuel use in this sector over the entire time-series. Revisions to the estimated split of gas oil use between 1A2 off-road vehicles & mobile machinery and other sectors. Re-allocation of emissions from waste lubricants used for energy from 2D1 to 1A2.
1.A.3. Transport	114251.38	113999.17	-252.21	-0.22%	Very minor recalculations, information available on request. Removal of Bermuda from the submission under the Kyoto Protocol (the ‘GBK’ submission) inventory contributes a minor recalculation.
1.A.4. Other sectors	109327.65	109315.77	-11.88	-0.01%	Recalculation of kerosene use in overseas territories/Crown Dependencies. Removal of Bermuda from the submission under the Kyoto Protocol (the ‘GBK’ submission) inventory contributes a minor recalculation
Industrial processes and product use					
2.A. Mineral industry	9806.38	9803.78	-2.60	-0.03%	Very minor recalculations, information available on request.
2.B. Chemical Industry	6376.75	6764.97	388.22	6.09%	Revised methodology for methanol production. Carbon stored in methanol product was previous treated as an emission.
2.C.Metal industry	7403.72	7403.74	0.01	0.00%	Very minor recalculations, information available on request.
2.D. Non-energy products from fuels and solvent use	1218.12	553.08	-665.04	-54.60%	Re-allocation of waste lubricants used for energy from 2D1 to 1A2. Within 2D1, there have also been some very trivial recalculations. Removal of Bermuda from the submission under the Kyoto Protocol (the ‘GBK’ submission) inventory contributes a minor recalculation.
3 Agriculture					
3.H. Urea application	250.76	252.19	1.43	0.57%	Updated urea use value

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
3.J. Other	2.73	2.75	0.02	0.64%	Small revisions to agricultural livestock estimates from Crown Dependencies and Overseas Territories & the removal of Bermuda estimates from the submission under the Kyoto Protocol (the ‘GBK’ submission).
4. Land use, land-use change and forestry					
4.A. Forestland	-15796.01	-10540.57	5255.44	-33.27%	Incorporation of new forestry data and new model for soil and litter carbon stock change.
4.B. Cropland	15146.68	15122.71	-23.97	-0.16%	Incorporation of new crop area data
4.C.Grassland	-6770.16	-7750.95	-980.79	14.49%	Revisions to various categories of emissions. Changes include inclusion of more detailed deforestation area data, following UNFCCC review recommendation and a new methodology for calculating biomass carbon stock change from hedges as a result of grassland management.
4.D. Wetlands	486.97	486.95	-0.02	0.00%	Very minor recalculations, information available on request.
4.E. Settlements	6930.40	6913.52	-16.88	-0.24%	Various revisions to figures for deforestation following UNFCCC review recommendation to include more detailed forest area data.
4.G. Harvested wood products	-850.55	-1009.08	-158.53	18.64	Improvements to forest land activity data, particularly improved alignment with annual wood production statistics, have increased the estimated net removals from harvested wood production.

Table 10.2 Recalculations to CO_2 in 2014 (kt CO_2)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
Energy					
1.A.1. Energy Industries	152392.12	152294.62	-97.51	-0.06%	Revisions to UK energy statistics. Numerous minor revisions, with one notable revision to AD for MSW used to generate electricity. Removal of Bermuda from the submission under the Kyoto Protocol (the ‘GBK’ submission) inventory contributes a minor recalculation.

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
1.A.2. Manufacturing Industries and construction	56716.04	55819.88	-896.16	-1.58%	Numerous revisions to UK energy statistics, with decreases in emission estimates for coal and natural gas and increases in those for LPG as a result. Revisions to UK energy statistics for gas oil, plus revisions to the estimated split of gas oil use between 1A2 off-road vehicles & mobile machinery and other sectors, leading to decreased emissions from gas oil. Re-allocation of emissions from use of waste lubricants as fuel from 2D1 to 1A2. The net result of these many changes is a decrease in emissions.
1.A.3. Transport	115174.02	115046.22	-127.79	-0.11%	Minor revisions to off-road fuel use estimates and fuel use in Crown Dependencies impact on fuel estimates for UK road transport. Removal of Bermuda from the inventory submission under the Kyoto Protocol (the ‘GBK’ submission) contributes a minor recalculation.
1.A.4. Other sectors	85570.31	85354.05	-216.27	-0.25%	Revisions to UK energy data, most significantly for gas oil and fuel oil where consumption and therefore emissions are slightly lower. Removal of Bermuda from the submission under the Kyoto Protocol (the ‘GBK’ submission) inventory contributes a minor recalculation
1.B.2. Fugitive Emissions from Fuel: Oil and Natural gas	3911.93	3911.80	-0.13	0.00%	Very minor recalculations, information available on request.
2.Industrial Processes and product use					
2.A. Mineral Industry	6562.53	6562.12	-0.41	-0.01%	Very minor recalculations, information available on request.
2.B. Chemical Industry	4180.62	4183.51	2.88	0.07%	Minor revision to the estimate of use of process off-gases in chemical and petrochemical production
2.C. Metal Industry	4861.06	4859.84	-1.21	-0.02%	Minor revision to dolomite consumption data
2.D. Non-energy products from fuel and solvent use	1274.44	799.80	-474.64	-37.24%	Re-allocation of waste lubricants used for energy from 2D1 to 1A2. Within 2D1, there have also been downward revisions to estimates of emissions from lubricants from non-road transport sectors in order to improve consistency between the UK inventory and UK energy statistics. Removal of Bermuda from the submission under the Kyoto Protocol (the ‘GBK’ submission) inventory contributes a minor recalculation (for lubricant use only)
3.Agriculture					
3.G. Liming	1037.96	786.46	-251.50	-24.23%	Updates to data that was previously provisional
4. Land use, Land-use change and forestry					

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
4.A Forestland	-17370.17	-16554.91	815.26	-4.69%	Incorporation of new forestry data and new model for soil and litter carbon stock change
4.B. Cropland	11860.22	11926.08	65.85	0.56%	Incorporation of new crop area data
4.C. Grassland	-9306.27	-9155.59	150.68	-1.62%	Revisions to various categories of emissions. Changes include inclusion of more detailed deforestation area data, following UNFCCC review recommendation and a new methodology for calculating biomass carbon stock change from hedges as a result of grassland management.
4.D. Wetlands	379.39	268.69	-110.70	-29.18%	Revisions to peat extraction area estimates following review of satellite imagery.
4.E. Settlements	5916.87	6096.34	179.47	3.03%	Various revisions to figures for deforestation following UNFCCC review recommendation to include more detailed forest area data.
4.G. Harvested wood products	-1204.71	-1598.38	-393.66	32.68%	Improvements to forest land activity data, particularly improved alignment with annual wood production statistics, have increased the estimated net removals from harvested wood production.
5. Waste					
5.C. Incineration and open burning of waste	304.86	289.51	-15.36	-5.04%	Minor revision to waste incineration activity data.

Table 10.3 Recalculations to CH_4 in 1990 (kt CH_4)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
Energy					
1.A.1. Energy Industries	201.73	202.73	1.00	0.50%	Revised calorific value for coal
1.A.2. Manufacturing Industries and construction	107.90	112.88	4.99	4.62%	Revisions to calorific value assumptions for wood used as a fuel by industry
1.A.3. Transport	1253.61	1250.51	-3.10	-0.25%	Very minor recalculations, information available on request.
1.A.4. Other sectors	1535.09	1560.46	25.37	1.65%	Revised calorific value for coal
1.B.1. Solid Fuels	21788.35	21826.86	38.50	0.18%	Revised assumptions following UNFCCC ERT review, to increase the AD for open cast mining to account for material lost during washing and coal preparation to generate saleable coal.
1.B.2. Fugitive Emissions from Fuels: Oil and Natural gas	12344.91	12344.96	0.05	0.00%	Very minor recalculations, information available on request.

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
Industrial processes and product use					
2.D. Non-energy products from fuels and solvent use	0.69	NO,IE	-0.69	-100.00%	Re-allocation of waste lubricants used for energy from 2D1 to 1A2.
3 Agriculture					
3.A. Enteric Fermentation	27932.07	28019.46	87.39	0.31%	Added country-specific dairy cow milk yield; updated dairy and beef cow live weights; Updated livestock housing periods.
3.B. Manure Management	4433.39	4444.68	11.30	0.25%	Added country-specific dairy cow milk yield; updated dairy and beef cow live weights; updated poultry numbers; updated AWMS; Updated livestock housing periods; Country-specific FracGasMS values.
3.F. Field burning of agricultural residues	205.48	205.37	-0.11	-0.05%	Updated crop areas
3.J. Other	308.82	275.51	-33.31	-10.79%	Small revisions to the agricultural livestock estimates for crown dependencies and Overseas Territories, including the removal of estimates from Bermuda, who are no longer included in submission under the Kyoto Protocol (the 'GBK' submission).
4. Land use, land-use change and forestry					
4.A. Forestland	3.72	3.24	-0.48	-12.85%	No significant recalculations
4.B. Cropland	0.08	0.09	0.00	4.39%	No significant recalculations
4.C.Grassland	10.46	9.91	-0.55	-5.28%	No significant recalculations
4.E. Settlements	3.84	3.38	-0.46	-11.95%	No significant recalculations
5. Waste					
5.A. Solid Waste disposal	62848.77	60368.00	-2480.78	-3.95%	Improvements in data for commercial and industrial waste sent to landfill in the UK, and a revision of decay rates to align more consistently with IPCC defaults. This leads to small decrease in emissions in the Base Year and slightly higher emissions in later years.

Table 10.4 Recalculations to CH_4 in 2014 (kt CH_4)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
Energy					
1.A.1. Energy Industries	217.31	248.79	31.48	14.49%	Revisions to UK energy statistics and revised assumption for calorific value of wood burnt at power stations.

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
1.A.2. Manufacturing Industries and construction	94.44	96.33	1.90	2.01%	Various individually trivial revisions to UK energy statistics and assumed calorific values for various fuels
1.A.3. Transport	120.36	122.88	2.52	2.09%	Minor revisions to traffic data
1.A.4. Other sectors	876.17	926.22	50.05	5.71%	Revisions to UK energy statistics and revised assumption for calorific value of wood.
1.B.1 Fugitive Emissions from Fuels: Solid Fuels	1665.13	1681.97	16.84	1.01%	Revised assumptions following UNFCCC ERT review, to increase the AD for open cast mining to account for material lost during washing and coal preparation to generate saleable coal.
1.B.2 Fugitive Emissions from Fuels: Oil and Natural gas	5387.76	5302.80	-84.95	-1.58%	New information provided by gas distributors indicates lower leakage emissions in 2014 and other recent years, following a programme of closures of LNG storage facilities.
Industrial processes and product use					
2.D. Non-energy products from fuels and solvent use	0.40	NO,IE	-0.40	-100.00%	Reallocation of waste lubricants used in energy from 2D1 to 1A2
3 Agriculture					
3.A. Enteric Fermentation	23846.01	23981.62	135.62	0.57%	Added country-specific dairy cow milk yield; updated dairy and beef cow live weights; Updated livestock housing periods. Livestock numbers updated for horses
3.B. Manure management	3486.80	3502.51	15.71	0.45%	Added country-specific dairy cow milk yield; updated dairy and beef cow live weights; updated poultry numbers; updated AWMS; Updated livestock housing periods; Country-specific FracGasMS values. Livestock numbers updated for horses
3.J. Other	210.14	198.00	-12.14	-5.77%	Small revisions to the agricultural livestock estimates for crown dependencies and Overseas Territories, including the removal of estimates from Bermuda, who are no longer included in submission under the Kyoto Protocol (the 'GBK' submission).
4. Land use, land-use change and forestry					
4.A. Forest Land	8.36	5.91	-2.45	-29.31%	Inclusion of new forestry data
4.B. Cropland	0.09	0.02	-0.07	-74.51%	No significant recalculations
4.C.Grassland	21.72	22.11	0.39	1.78%	No significant recalculations
4.E. Settlements	1.32	4.45	3.13	236.89%	Inclusion of new forestry data
5. Waste					

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
5.A. Solid Waste disposal	13654.25	13830.38	176.13	1.29%	Improvements in data for commercial and industrial waste sent to landfill in the UK, and a revision of decay rates to align more consistently with IPCC defaults. This leads to small decrease in emissions in the Base Year and slightly higher emissions in later years.
5.B. Biological treatment of solid waste	763.92	994.60	230.68	30.20%	Updates in activity data for anaerobic digestion and composting for 2014 and other recent years.
5.C. Incineration and open burning of waste	9.25	9.07	-0.18	-1.96%	No significant recalculations
5.D. Waste water treatment and discharge	3431.53	3300.74	-130.79	-3.81%	Updated sectoral production data used as a basis for estimating industrial wastewater arisings.

Table 10.5 Recalculations to N_2O in 1990 (kt N_2O)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
Energy					
1.A.1. Energy Industries	1416.70	1387.06	-29.65	-2.09%	Several minor revisions, including a revision to the assumed calorific value of wood burnt in power stations based on new information from energy statisticians.
Industrial processes and product use					
2.D. Non-energy products from fuels and solvent use	1.64	NO,NE,IE	-1.64	-100.00%	Re-allocation of waste lubricants used for energy from 2D1 to 1A2.
2.G. Other product manufacture and use	570.28	593.41	23.12	4.05%	Minor update to activity data to take account of a site that has been identified as operating between 1990 and 2008.
3 Agriculture					
3.B. Manure management	1784.65	1769.05	-15.60	-0.87%	Added country-specific dairy cow milk yield; updated AWMS; Updated livestock housing periods; Country-specific FracGasMS values.
3.D. Agricultural soils	16739.00	16830.49	91.49	0.55%	Updated crop areas; Updated crop production; Updated urea and UAN values; Updated mineralisation data and added direct emissions from cropland management as well as indirect emissions; updated poultry numbers; Country-specific FracGASF, FracGasM and FracLossMS values; Updated AWMS; added country-specific dairy cow milk yield; Updated livestock housing periods.
4. Land use, land-use change and forestry					

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
4.A. Forest Land	48.31	402.43	354.13	733.08%	New sources added to inventory - principally for direct emissions from mineralization/immobilization associated with grassland converted to forest land.
4.B. Cropland	649.03	1019.85	370.82	57.14%	Correction of an error
4.C.Grassland	10.79	10.28	-0.50	-4.66%	No significant recalculations
4.E. Settlements	372.94	583.99	211.05	56.59%	Correction of an error and revisions to figures for deforestation following UNFCCC review recommendation to include more detailed forest area data.
5. Waste					
5.D. Waste water treatment and discharge	783.69	779.72	-3.97	-0.51%	Method improvements to use updated indicators for estimating industrial waste water activity data, and also to apply more representative factors (FNON-CON and FIND-COM) for nitrogen loading of the WW system. Removal of Bermuda from the submission under the Kyoto Protocol (the 'GBK' submission) inventory contributes a minor recalculation.

Table 10.6 Recalculations to N_2O in 2014

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
Energy					
1.A.1. Energy Industries	924.48	977.56	53.08	5.74%	Several minor revisions, including a revision to the assumed calorific value of wood burnt in power stations based on new information from energy statisticians.
1.A.2. Manufacturing Industries and construction	859.58	722.49	-137.10	-15.95%	Revisions to the estimated split of gas oil use between 1A2 off-road vehicles & mobile machinery and other sectors, leading to decreased emissions from gas oil here.
1.A.3. Transport	1082.77	1078.66	-4.10	-0.38%	Minor revisions to traffic data. Removal of Bermuda from the submission under the Kyoto Protocol (the 'GBK' submission) inventory contributes a minor recalculation.
1.B.2 Fugitive emissions from fuels: Oil and Natural gas	31.86	33.69	1.84	5.77%	Minor revisions to offshore flaring data
Industrial processes and product use					
2.D. Non-energy products from fuels and solvent use	0.95	NO,NE,IE	-0.95	-100.00%	Re-allocation of waste lubricants used for energy from 2D1 to 1A2.

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
2.G. Other product manufacture and use	831.01	817.37	-13.64	-1.64%	Update to sectoral activity data used to estimate consumption of whipped cream.
3 Agriculture					
3.B. Manure management	1471.66	1457.66	-14.01	-0.95%	Added country-specific dairy cow milk yield; updated dairy and beef cow live weights; updated poultry numbers; updated AWMS; Updated livestock housing periods; Country-specific FracGasMS values. Livestock numbers updated for horses
3.D. Agricultural soils	14362.53	14618.81	256.28	1.78%	Updated crop areas; Updated crop production; Updated urea and UAN values; Updated mineralisation data and added direct emissions from cropland management as well as indirect emissions; updated poultry numbers; Country-specific FracGASF, FracGasM and FracLossMS values; Updated AWMS; added country-specific dairy cow milk yield; Updated livestock housing periods. Livestock numbers updated for horses
3.J. Other	88.48	90.59	2.10	2.38%	Small revisions to the agricultural livestock estimates for crown dependencies and Overseas Territories, including the removal of estimates from Bermuda, who are no longer included in submission under the Kyoto Protocol (the ‘GBK’ submission).
4. Land use, land-use change and forestry					
4.A. Forest land	52.93	234.28	181.36	342.67%	New sources added to inventory - principally for direct emissions from mineralization/immobilization associated with grassland converted to forest land.
4.B. Cropland	321.69	503.30	181.61	56.46%	Correction of an error
4.C.Grassland	30.49	37.02	6.52	21.39%	Correction of an error and updated forestry data
4.E. Settlements	321.30	513.61	192.31	59.85%	Correction of an error and revisions to figures for deforestation following UNFCCC review recommendation to include more detailed forest area data.
5. Waste					
5.B. Biological treatment of solid waste	517.57	635.15	117.58	22.72%	Revision to estimate for mechanical/biological treatment to reflect change in IPCC Guidelines
5.C. Incineration and open burning of waste	54.66	50.29	-4.37	-7.99%	Minor revision to waste incineration activity data.

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
5.D. Waste water treatment and discharge	708.25	703.22	-5.03	-0.71%	Method improvements to use updated indicators for estimating industrial waste water activity data, and also to apply more representative factors (FNON-CON and FIND-COM) for nitrogen loading of the WW system. Removal of Bermuda from the inventory contributes a minor recalculation.

Table 10.7 Recalculations to SF_6 in base year (CO_2 eq, kt)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
There were no recalculations in SF_6 in the base year					

Table 10.8 Recalculations to SF_6 in 2014 (CO_2 eq, kt)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
2.Industrial processes and product use					
2.G.1. Electrical equipment	228.08	236.45	8.38	3.67	Minor revisions to activity data for electrical switchgear

Table 10.9 Recalculations to HFC in base year (CO_2 eq, kt)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
2.Industrial processes and product use					
2.F.1. Refrigeration and air conditioning	531.27	530.50	-0.77	-0.14	Very minor revisions due to updated model input data.
2.F.2. Foam blowing agents	184.46	184.23	-0.24	-0.13	Very minor revisions due to updated model input data.
2.F.4. Aerosols	663.02	662.34	-0.68	-0.10	No significant recalculations

Table 10.10 Recalculations to HFC in 2014 (CO_2 eq, kt)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
2.Industrial processes and product use					
2.F.2. Foam blowing agents	431.88	380.04	-51.84	-12.00	Minor revisions to UK foams model following consultation with industry and access to new data.
2.F.3. Fire protection	293.28	257.26	-36.03	-12.28	Revisions to GDP data used to estimate UK data from EU-wide statistics. Also minor revisions to stock and decommissioning assumptions.
2.F.4. Aerosols	2191.17	1819.48	-371.69	-16.96	Revised recent time series due to access to new data on non-MDI aerosols from the UK trade association, BAMA.
2.F.5. Solvents	41.54	47.43	5.89	14.19	Revisions to GDP data used to estimate UK data from EU-wide statistics.

Table 10.11 Recalculations to PFC in base year (CO_2 eq, kt)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
There were no recalculations to PFC in the base year					

Table 10.12 Recalculations to PFC in 2014 (CO_2 eq, kt)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
There were no recalculations to PFC in 2014					

Table 10.13 Recalculations to NF_3 in base year (CO_2 eq, kt)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
There were no recalculations to NF_3 in the base year					

Table 10.14 Recalculations to NF_3 in 2014 (CO_2 eq, kt)

IPCC name	Previous submission (CO_2 eq, kt)	Latest submission (CO_2 eq, kt)	Difference (CO_2 eq, kt)	Difference %	Explanation for recalculations
There were no recalculations to NF_3 in 2014					

Table 10.15 Changes in Methodological Descriptions

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
Total (Net Emissions)	Y	Y	
1. Energy	Y	Y	Chapter 3
A. Fuel Combustion (sectoral approach)	Y	Y	Chapter 3
1. Energy industries	Y	Y	Chapter 3
2. Manufacturing industries and construction	Y	Y	Chapter 3
3. Transport	Y	Y	Chapter 3
4. Other sector	Y	Y	Chapter 3
5. Other	Y	Y	Chapter 3
B. Fugitive emissions from fuels	Y	Y	Chapter 3
1. Solid fuels	Y	Y	Chapter 3
2. Oil and natural gas and other emissions from energy production	Y	Y	Chapter 3
C. CO_2 transport and storage	N	N	Chapter 3
2. Industrial processes and product use	Y	Y	Chapter 4
A. Mineral industry	Y	Y	Chapter 4
B. Chemical industry	Y	Y	Chapter 4
C. Metal industry	Y	Y	Chapter 4
D. Non-energy products from fuels and solvent use	Y	Y	Chapter 4
E. Electronic industry	Y	Y	Chapter 4
F. Product uses as substitutes for ODS	Y	Y	Chapter 4
G. Other product manufacture and use	Y	Y	Chapter 4

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
H. Other	Y	Y	Chapter 4
3. Agriculture	Y	Y	Chapter 5
A. Enteric fermentation	Y	Y	Chapter 5
B. Manure management	Y	Y	Chapter 5
C. Rice cultivation	Y	Y	Chapter 5
D. Agricultural soils	Y	Y	Chapter 5
E. Prescribed burning of savannahs	Y	Y	Chapter 5
F. Field burning of agricultural residues	Y	Y	Chapter 5
G. Liming	Y	Y	Chapter 5
H. Urea application	Y	Y	Chapter 5
I. Other carbon containing fertilisers	Y	Y	Chapter 5
J. Other	Y	Y	Chapter 5
4. Land use, land-use change and forestry	Y	Y	Chapter 6
A. Forest land	Y	Y	Chapter 6
B. Cropland	Y	Y	Chapter 6
C. Grassland	Y	Y	Chapter 6
D. Wetlands	Y	Y	Chapter 6
E. Settlements	Y	Y	Chapter 6
F. Other land	Y	Y	Chapter 6
G. Harvested wood products	Y	Y	Chapter 6
H. Other	Y	Y	Chapter 6
5. Waste	Y	Y	Chapter 7
A. Solid waste disposal	Y	Y	Chapter 7

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
B. Biological treatment of solid waste	Y	Y	Chapter 7
C. Incineration and open burning of waste	Y	Y	Chapter 7
D. Wastewater treatment and discharge	Y	Y	Chapter 7
E. Other	N	N	
6. Other (as specified in Summary 1.A)	N	N	
KP LULUCF	Y	Y	Chapter 11
Article 3.3 activities	Y	Y	Chapter 11
Afforestation/reforestation	Y	Y	Chapter 11
Deforestation	Y	Y	Chapter 11
Article 3.4 activities	Y	Y	Chapter 11
Forest management	Y	Y	Chapter 11
Cropland management (if elected)	Y	Y	Chapter 11
Grazing land management (if elected)	Y	Y	Chapter 11
Revegetation (if elected)	Y	Y	Chapter 11
Wetland drainage and rewetting (if elected)	Y	Y	Chapter 11

NIR Chapter	**DESCRIPTION**		**REFERENCE**
Chapter 1.2 Description of national inventory arrangements	N	N	

10.1.1 Removal of Bermuda from the submission under the Kyoto Protocol (the ‘GBK’ submission)

The 2017 submission under the Kyoto Protocol (the ‘GBK’ submission) does not include emissions from Bermuda. As a result, there are a number of recalculations to the inventory.

As expected, the contribution of the Bermudan territory to the inventory is small (0.1% of the total inventory in 2014), but for some sources their contribution is significantly larger than this. According to the 2014 inventory, the largest sources in terms of the percentage contribution to the overall reported figure are domestic aviation (1A3a; 2.5%), domestic waste water treatment (5D1; 1.4%), and motorcycles (1A3biv; 0.8%). Recalculations due to this removal are outlined in **Table 10.1** to **Table 10.14**. Bermuda was not previously reported in the LULUCF sector due to a lack of data, so there are no recalculations in this sector.

10.1.2 KP-LULUCF Activities

Article 3.3 Afforestation

The forest activity data were revised to use the National Forest Inventory dataset and small wood datasets with improved alignment with wood production statistics for the first time in this inventory

Forestry carbon stock change modelling was updated to include the CARBINE-SCA soil and litter model within CARBINE.

N_2O emissions from mineralisation following soil carbon losses have been calculated for the first time (under previous modelling these were gains).

Article 3.3 Deforestation

Post-2000 deforestation areas have been updated with the use of the National Forest Inventory dataset and NFI report “Preliminary estimates of the changes in canopy cover in British Woodlands between 2006 and 2015.”

Improvements have been made to carbon stock change modelling in Cropland Management and Grazing Land Management activities on Deforestation land.

Indirect N_2O emissions from mineralisation have been calculated in addition to direct emissions.

Article 3.4 Forest Management

The forest activity data were revised to use the National Forest Inventory dataset and small wood datasets and improved alignment with wood production statistics.

Forestry carbon stock change modelling was updated to include the CARBINE-SCA soil and litter sub-model within CARBINE.

Article 3.4 Cropland Management

Ongoing emissions from mineral soils as a result of land use change occurring before 1990 and ongoing emissions from organic soils due to pre-1990 drainage have been included.

Indirect N_2O emissions from mineralisation have been calculated in addition to direct emissions.

Article 3.4 Grazing Land Management

Biomass carbon stock change arising from hedge creation and loss has been included for the first time.

Ongoing emissions from mineral soils as a result of land use change occurring before 1990 and ongoing emissions from organic soils due to pre-1990 drainage have been included.

Indirect N_2O emissions from mineralisation have been calculated in addition to direct emissions.

10.2 IMPLICATIONS FOR EMISSION LEVELS

10.2.1 GHG Inventory

Information at sector level is summarised in **Table 10.1** to **Table 10.15** above. The overall impact of all recalculations is an increase in emissions of 1.67 Mt CO_2 equivalent in 1990, and a decrease in emissions of 0.01Mt CO_2 equivalent in 2014.

An overview chart showing the sector level changes is set out below.

Figure 10.1 Time series of changes in GWP emissions between the inventory presented in the current and the previous NIR, according to IPCC source sector.

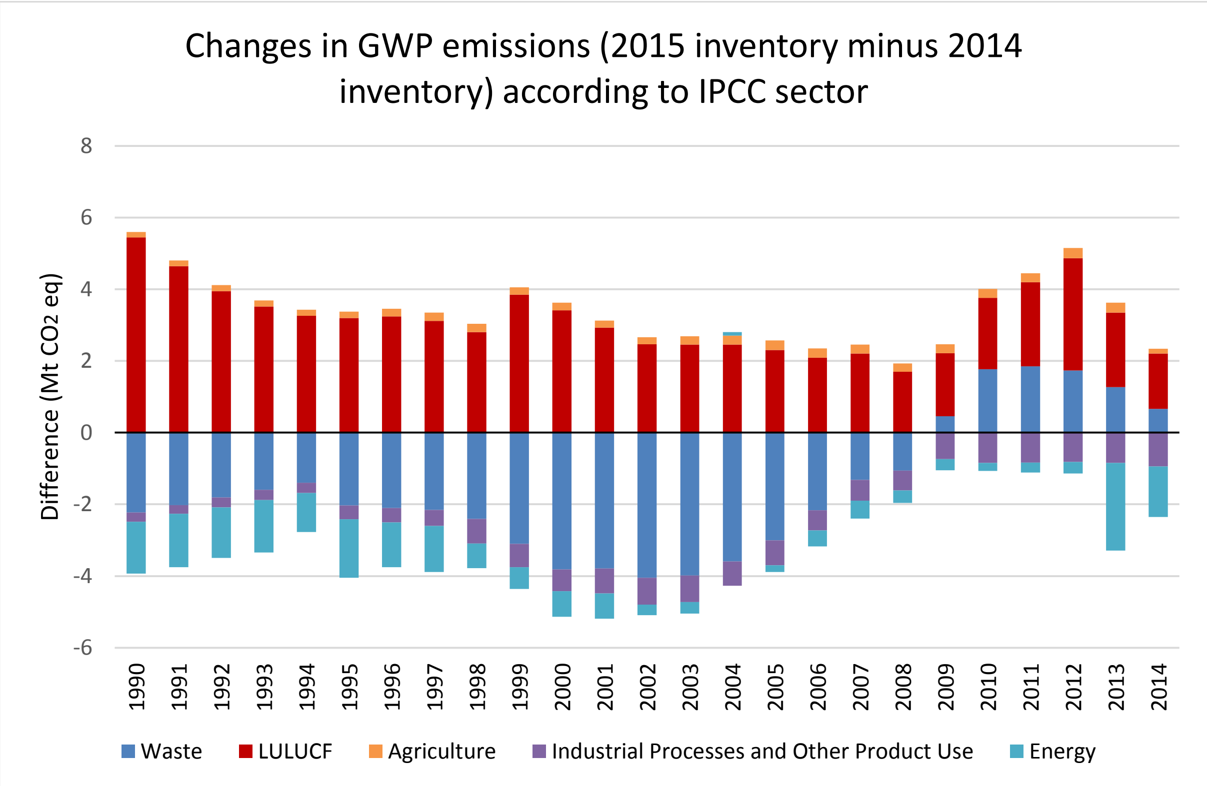
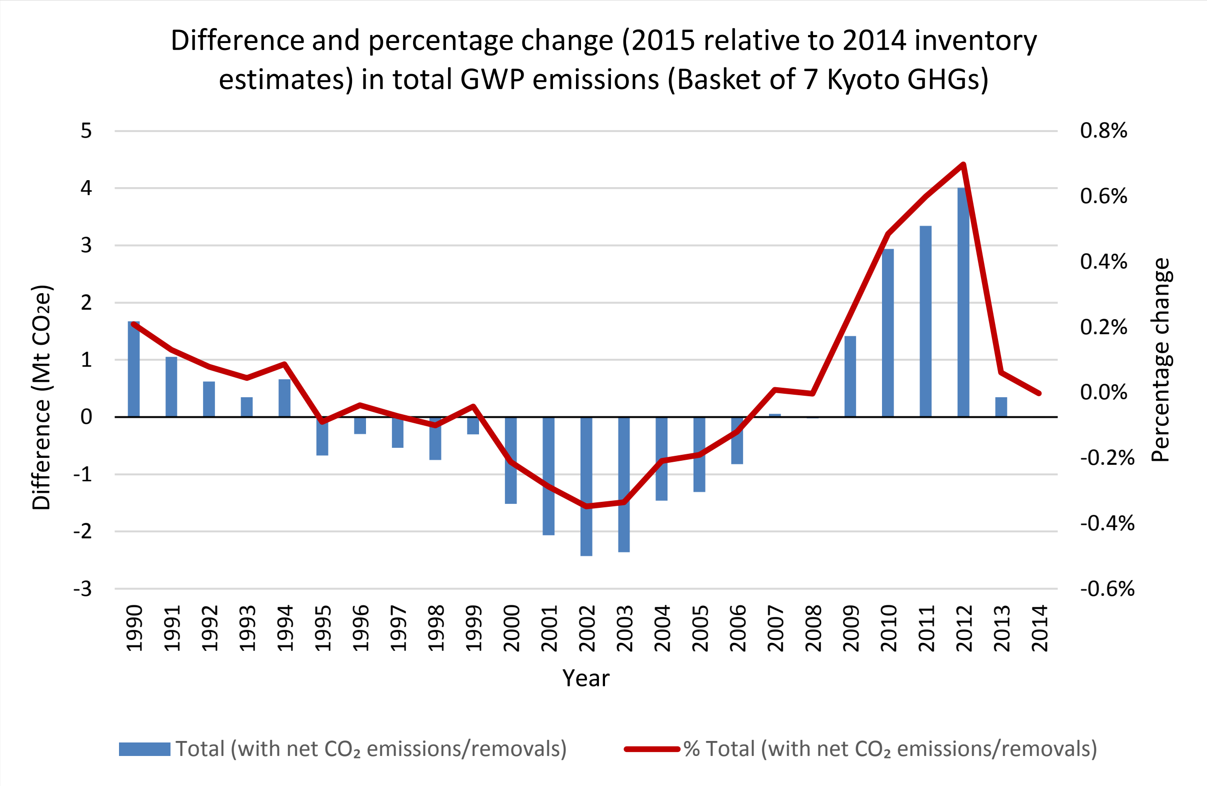


Figure 10.2 shows the net impact of all recalculations in absolute and percentage terms.

Figure 10.2 Time series of changes in total net GWP emissions, and percentage changes in total net GWP emissions, between the inventory presented in the current and the previous NIR.



10.2.2 KP-LULUCF Activities

Information on the reasons for recalculations is included in **Chapter 10** and **Section 11.3.1.4**.

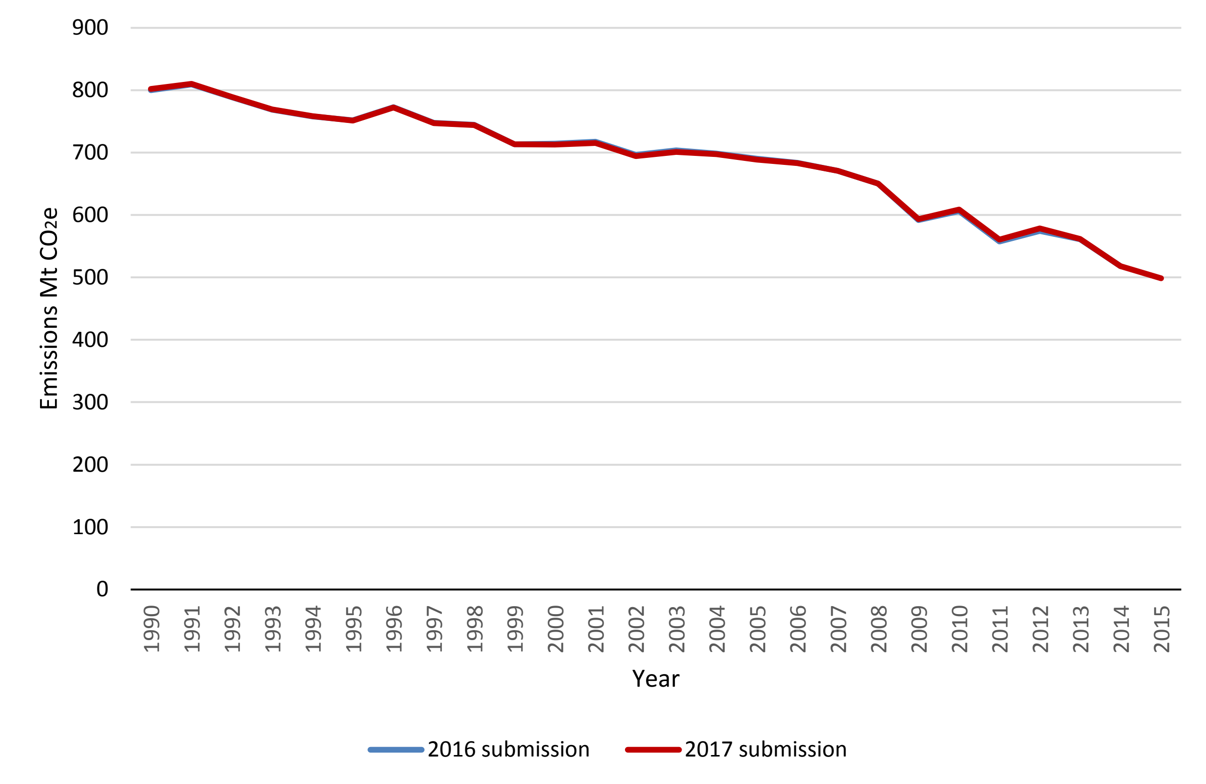
10.3 IMPLICATIONS FOR EMISSION TRENDS, INCLUDING TIME SERIES CONSISTENCY

10.3.1 GHG Inventory

There has been a small change in the reported trend in emissions. The reported trend from 1990 to 2014 in the 2016 inventory submission was a decrease of 35.2%. The recalculated trend from 1990 to 2014, as presented in the 2017 submission is a decrease of 35.4%.

The chart below displays the trend from both the 2016 and 2017 submissions.

Figure 10.3 Reported trends from the current and previous inventory submissions



10.3.2 KP-LULUCF Activities

Information on the reasons for recalculations is included in **Chapter 10** and **Section 11.3.1.4**. As the KP-LULUCF Inventory contains both emissions and removals of GHGs, expressing the change in trend from the base year to 2015 as a percentage difference is inappropriate.

10.4 RECALCULATIONS, INCLUDING IN RESPONSE TO THE REVIEW PROCESS, AND PLANNED IMPROVEMENTS TO THE INVENTORY

All recalculations to the inventory, including those made in response to the review process and other recalculations e.g. due to data revisions are described in detail within chapters 3-8, and are summarised in **Table 10.1** to **Table 10.15.** This section of the report summarises all recommendations from the review process, including where these have led to:

- Recalculations;
- changes in reporting in the NIR;
- changes in reporting in the CRF; and
- planned improvements for future submissions.

The UNFCCC conducted a Centralised Review of the 2014 greenhouse gas inventory submission (2014 NIR) in accordance with decision 22/CMP.1. In accordance with the conclusions of the Subsidiary Body for Implementation at its twenty-seventh session, the focus of the review was on the most recent (2014) submission. The review took place during September 2014 and the review report was published on March 2nd, 2015. Improvements to the 2015 submission were implemented based on comments provided during the review week and also in the Saturday Paper. Further improvements have been made for the 2016 submission, based on the review report.

Due to the delays in the 2015 reporting cycle, no UNFCCC or formal ESD review took place in 2015, and there is no published review report yet from the UNFCCC Centralised Review of the UK inventory in September 2016 of the UK's 2016 submission.

However, an ESD review of the 2016 submission was conducted during spring-summer 2016, with a number of findings that were taken into consideration during the compilation of the 2017 submission. A table detailing responses to the 2014 UNFCCC review and the most recent ESD review which have been conducted in this inventory cycle are provided in **Table 10.16** below.

10.4.1 GHG Inventory

Table 10.16 Brief Details of Improvements to the NIR and the Inventory in response to UNFCCC Reviews in response to the 2014 reviews

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
QA/QC	Describe any changes in the QA/QC procedures in the NIR	ARR 2014 – Paragraph 13	See improvements to QA/QC system, listed under section 1.3 of the short NIR 2017, and section 1.6.2 of the main NIR 2017	Section 1.6.2
QA/QC	Provide a short summary of the pre-submission review outcome in the NIR	ARR 2014 – Paragraph 14	The outcome of the pre submission review will be summarised in the main NIR 2017, to be submitted in March 2017.	Section 1.2 of the 2017 NIR
Transparency	Improve the transparency of the NIR by including sufficient information in the annual submission (e.g. based on the supporting material provided during the review)	ARR 2014 – Paragraph 15	The NIR undergoes improvements annually, aiming to be as transparent as possible. Under the improvement programme, writing guidance has been drafted in order to improve the NIR, including improving transparency. This has been implemented for the Energy chapter (chapter 3), and associated annexes (3, 4). We welcome the ERT’s views on the changes made to the structure of the Energy chapter and supporting Annexes within recent submissions.	All, Chapter 3, Annex 3, 4 of the 2017 NIR
Inventory preparation	Perform a key category analysis following the IPCC good practice guidance at an aggregation level where individual methodologies and EFs are used	ARR 2014 – Paragraph 18	We have reviewed the KCA such that the overall method and level of detail at which calculations are currently performed is fully consistent with the requirements of the IPCC 2006 GLs.	Annex 1 of the 2017 NIR
Inventory preparation	Improve the inventory preparation in terms of prioritizing inventory improvements using the key category analysis	ARR 2014 – Paragraph 19	An additional tool for prioritising inventory improvements using the key category analysis has been developed. The key category ranking table in chapter 1 uses a scoring system to determine the how significant each category is in the different approach 1 key category analyses.	Chapter 1 of the 2017 NIR
Energy overview	Complete the improvements regarding the use of comparable units	ARR 2014 – Paragraph 28	Annex 3 now contains a full list of emission factors on an energy basis, to aid comparability with other Parties.	Annex 3.1 of the 2017 NIR

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Comparison of the reference approach with the sectoral approach and international statistics	Include a summary of information on the possible sources of differences between the approaches for liquid and solid fuels in the NIR	ARR 2014 – Paragraph 31	The differences between the reference approach and sectoral approach have been analysed in more detail. The results of are will be reported in chapter 3 of the main NIR 2017. An initial assessment was included in the Short NIR chapter 3.	Chapter 3 of the 2017 NIR
Comparison of the reference approach with the sectoral approach and international statistics	Investigate the possibility of using disaggregated coal data in the reference approach	ARR 2014 – Paragraph 32	The reference approach now handles data for bituminous coal, coking coal and anthracite separately in the 2017 submission.	Chapter 3 of the 2017 NIR
Comparison of the reference approach with the sectoral approach and international statistics	Implement checks to ensure that all imports of coke oven/gas coke are correctly accounted for	ARR 2014 – Paragraph 32	This has been corrected, and all imports and exports of coke oven/gas coke are accounted for within the 2017 submission. Additional checks have been included within the reference approach to improve accuracy.	Chapter 3 of the 2017 NIR
Comparison of the reference approach with the sectoral approach and international statistics	Review the EFs used in the reference approach	ARR 2014 – Paragraph 32	The application of emission factors within the RA has been reviewed, with several improvements made, including: use of weighted-average coal CEF consistent with the sectoral approach data; application of AD and EFs at a more detailed level for solid fuels, rather than aggregating across steam coal, anthracite, coking coal; update to the EFs applied for gas oil / derv.	Chapter 3 of the 2017 NIR
Comparison of the reference approach with the sectoral approach and international statistics	Apply the relevant IPCC defaults for the fractions of carbon oxidized	ARR 2014 – Paragraph 33	The method for the reference approach has been revised to use the 2006 GLs method, including for carbon oxidation factors.	Chapter 3 of the 2017 NIR
Feedstocks and non-energy use of fuels	Include the carbon content of emissions in the industrial processes sector in the amount of carbon stored in non-energy use of fuels reported in the energy sector in column E of CRF table1.A(d)	ARR 2014 – Paragraph 36	The methodological descriptions for this sector, along with the rest of the energy sector has been reformatted as part of a programme to improve the transparency of the NIR.	Chapter 3 of the 2017 NIR
Stationary combustion: solid, liquid and gaseous fuels – CO_2, CH_4 and N_2O	Implement planned improvements to avoid errors in future CRF tables	ARR 2014 – Paragraph 37	See improvements to QA/QC system, listed under section 1.6.1 of the main NIR.	Section 1.6.1 of the 2017 NIR

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Stationary combustion: solid, liquid and gaseous fuels – CO_2, CH_4 and N_2O	Provide an update on the status of QA/QC improvements in the NIR	ARR 2014 – Paragraph 37	See improvements to QA/QC system, listed under section 1.6.1 of the main NIR.	Section 1.6.1 of the 2017 NIR
Stationary combustion: solid, liquid and gaseous fuels – CO_2, CH_4 and N_2O	Improve the text of the relevant sections of the NIR to better explain the reasons for the low EFs, and justify the extrapolation of these EFs over the entire time series	ARR 2014 – Paragraph 38	Annex 3 describes the approach to calculating the time series of carbon emission factors and how these are used in the inventory. Emission factors for CH_4 and N_2O are largely based on IPCC defaults. All emission factors are listed in Annex 3. Emission factors were also reviewed as part of a bilateral exchange with Denmark, and some changes have been made to N_2O and CH_4 emission factors to use defaults, or more transparently calculated factors from UK literature sources. The method and data selection are described in full in the 2017 NIR.	Annex 3 of the 2017 NIR.
Stationary combustion: solid, liquid and gaseous fuels – CO_2, CH_4 and N_2O	Improve the documentation of country-specific EFs and oxidation factors, including any corrections done, in the NIR	ARR 2014 – Paragraph 39	A description of the 2004 Carbon Factors Review report (Baggott et al., 2004) is included in Annex 3, together with information on how it is used. Country specific oxidation factors that could not be fully justified have been replaced with IPCC defaults. Any revisions to carbon emission factors will be decribed within the 2017 NIR. A summary of methodological improvements, including the most signifiant revisions to selection of EFs is included in the short NIR, section 2.4.	Annex 3, Chapter 10 of the 2017 NIR. Summary in section 2.4 of the short NIR.
Stationary combustion: solid, liquid and gaseous fuels – CO_2, CH_4 and N_2O	Clearly document in the NIR any revision of the EFs to discount carbon unoxidized	ARR 2014 – Paragraph 39	As above	As above

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Road transportation: liquid fuels – CO_2	Review the report on carbon factors in detail and investigate whether the EFs that are currently used are accurate	ARR 2014 – Paragraph 43	Carbon emission factors for all liquid fuels have been reviewed. UKPIA have been consulted and were not able to provide any new data. The existing carbon emission factors are within the range of the default factors in the 2006 IPCC Guidelines for all commonly used fuels. A wider review of carbon emission factors remains on the UK GHGI improvement list, for consideration for future research.	As above
Road transportation: liquid fuels – CO_2	Report the findings of the review in the NIR	ARR 2014 – Paragraph 43	As above.	As above
Oil and natural gas: natural gas – CH_4	Improve the transparency of the description in the NIR of the methodology followed for the estimation of fugitive emissions from natural gas transmission and distribution systems	ARR 2014 – Paragraph 44	The methodological descriptions for this sector, along with the rest of the energy sector has been reformatted as part of a programme to improve the transparency of the NIR.	Chapter 3 of the 2017 NIR
Oil and natural gas: natural gas – CH_4	Complete the update of estimates of the length of pipelines and report the findings	ARR 2014 – Paragraph 45	The requested validation exercise has been carried out, and the results were reported in the 2016 submission.	Chapter 3: MS19 of 2016 submission
Railways: solid fuels – CO_2, CH_4 and N_2O	Improve the time-series consistency of the estimates and consider reallocating the relevant emissions from “other industrial combustion” to railways	ARR 2014 – Paragraph 47	The UK does not have sufficient data to make an informed reallocation, and considers solid fuel combustion by heritage railways to be a source too minor to warrant additional investigation, particularly as it is known that there is no omission.	N/A
Railways: solid fuels – CO_2, CH_4 and N_2O	Use the correct notation key in the CRF tables	ARR 2014 – Paragraph 47	This was corrected in the 2016 submission.	N/A
Industrial processes and solvent and other product use overview	Improve the consistency between what is reported in the NIR and the CRF tables focusing on the numerical descriptions of GHG emissions, including the impact of recalculations, and improve the consistency in the use of units in the NIR tables	ARR 2014 – Paragraph 51	Improvements to the QA/QC process is described in section 1.6 of the main 2017 NIR and were summarised in section 1.3 of the Short NIR.	Section 1.6.2 of the 2017 NIR

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Industrial processes and solvent and other product use overview	Conduct the key category analysis for F-gases at the subcategory level (e.g. HFCs from refrigeration and air conditioning equipment)	ARR 2014 – Paragraph 52	In response to other recommendations to implement the key category analysis at a different aggregation a review of the key category analysis and uncertainties was undertaken. Part of this review included distinguishing F-gases by the second level sector (e.g. 2.B.).	Annex 2 of the 2017 NIR
Nitric acid production – N_2O	Include information on the monitoring standards followed by plant operators in the NIR	ARR 2014 – Paragraph 53	The UK has contacted the operating nitric acid producers to find out more about their monitoring and abatement. Further information for open sites is included in the 2017 NIR submission in section 4.7.	Chapter 4.7 of the 2017 NIR
Nitric acid production – N_2O	Include the reason for the change in the N_2O IEF, together with information on specific abatement measures taken at the two nitric acid production sites in its NIR	ARR 2014 – Paragraph 53	The UK has contacted the operating nitric acid producers to find out more about their monitoring and abatement. Further information for open sites is included in the 2017 NIR submission in section 4.7.. It has not been possible to obtain further information for closed sites.	Chapter 4.7 of the 2017 NIR
Consumption of halocarbons and SF_6 – HFCs, PFCs and SF_6	Incorporate in the NIR information on F-gas regulations and their coverage, and how collection/destruction is accounted for in the models to estimate emissions from consumption of halocarbons and SF_6	ARR 2014 – Paragraph 54	The foams, refrigerant containers and refrigerants models have all been updated as part of the inventory improvement programme, in part to account for the recent changes in F-gas regulations. As a result the applicable sections of the NIR have been updated accordingly.	Chapter 4 of the 2017 NIR
Consumption of halocarbons and SF_6 – HFCs, PFCs and SF_6	Continue to refine the underlying assumptions and methodologies of the models used, together with conducting checks of the consistency of reported AD	ARR 2014 – Paragraph 55	The foams, refrigerant containers and refrigerants models have all been updated as part of the inventory improvement programme.	Chapter 4 of the 2017 NIR
Consumption of halocarbons and SF_6 – HFCs, PFCs and SF_6	Provide more specific explanation of how it has determined the EF(s) for foam blowing and indicate more consistently whether or not the emissions from manufacturing, stocks and disposal are reported separately, or provide clear reasons for why these emissions are aggregated when reporting	ARR 2014 – Paragraph 56	The foams model has been updated as part of the inventory improvement programme, emissions are now reported seperately for manufacture, lifetime and disposal.	Chapter 4 of the 2017 NIR

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Consumption of halocarbons and SF_6 – HFCs, PFCs and SF_6	Improve QC procedures to ensure consistent reporting between the NIR and the CRF tables prior to submission, but in particular to ensure the provision of correct information in the tables of the NIR regarding emissions	ARR 2014 – Paragraph 57	The information reported in the NIR has been reviewed in light of the ERT recommendations. We are continually investigating methods to improve QA/QC and consistency; in particular we have compiled a table in our central database for method and emission factor information key to be used as a reference for both the CRF and NIR.	Chapter 4 of the 2017 NIR
Ammonia production – CO_2	Improve the consistency of its description of issues in the NIR, especially regarding quantitative data, and focus on the consistent use of units	ARR 2014 – Paragraph 60	Ammonia production activity cannot be presented in consistent units with the Energy chapter due to commercial in confidence data. More comparable data can be made available to an ERT.	Chapter 4 of the 2017 NIR
Agriculture overview	Enhance QC procedures so that what is reported in the NIR and CRF tables is fully consistent, but especially with regard to values for emission estimates	ARR 2014 – Paragraph 64	A QA/QC plan has been drafted that is aligned with the overall inventory plan and is being implemented. Consistency between the NIR and CRF tables has been improved by direct link of calculations outputs to tables in the NIR.	Chapter 5 of the 2017 NIR
Enteric fermentation – CH_4	Implement the planned improvement of digestibility of feed (DE) data through the commissioned research projects as explained	ARR 2014 – Paragraph 65	This is ongoing and is been implemented as part of the improvement program for the 1990-2015 timeseries (2018 submission).	N/A
Enteric fermentation – CH_4	Apply a methodology that more closely reflects the country-specific conditions, for instance, by moving to the IPCC tier 2 methodology for the sheep subcategory, in addition to documenting national circumstances leading to methodological choice	ARR 2014 – Paragraph 66	Data to inform a Tier 2 methodology are being derived through ongoing research under the inventory improvement program. Implementation of this method improvement is anticipated for the 2018 submission.	N/A
Manure management – N_2O	Include information on the country-specific methodology for dairy cattle in the form of a summary explanation of how the N excretion values used in the inventory were derived	ARR 2014 – Paragraph 67	These values have been revised and are included in the 2017 submission.	Chapter 5 of the 2017 NIR
LULUCF overview	Incorporate an explanation on changes made from the previous NIR regarding areas allocated to land-use categories in 1990, as reported in the land-use matrix (NIR table 7.1), when appropriate	ARR 2014 – Paragraph 73	Annual land use change matrices are now reported in Table 4.1 of the CRF. The data used for the area of each sub-category has been clarified in the section describing the land use transition matrix.	Section 6.1.1 of the NIR

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Forest land – CO_2	Continue efforts to gather information on the management of privately owned forests and include information on the management prescriptions and rotation ranges in the NIR	ARR 2014 – Paragraph 76	Additional information on management prescriptions and rotations has been included in the annex and reference made to a more detailed document. The UK will continue to look for information on the management of privately owned forest and include information in the NIR when possible.	Annex 3.4.1 of the NIR
Forest land – CO_2	Continue efforts to improve the estimates on soil carbon and related documentation	ARR 2014 – Paragraph 77	A new soil carbon module has been incorporated in the CARBINE forest carbon model to improve modelling of carbon stocks of forests on organic soils.	Section 6.2.4 and Annex 3.4.8 for the 2017 NIR
Cropland and grassland – CO_2	Research again the possibility of generating suitable data and report on the progress to estimate emissions and removals from organic soil, and until additional information becomes available, report using the notation key “NE”	ARR 2014 – Paragraph 80	The 1990 – 2013, 1990-2014 and 1990 - 2015 inventories use new data on the extent of Cropland and improved Grassland on organic soils, and so have improved estimates emissions from these soils. A project to implement the Wetlands Supplement guidance is ongoing. This is due to complete in 2017 and will generate UK-specific emissions factors for carbon stock change of organic soils. It will also improve mapping of organic soils in the UK which will give more accurate estimates of the condition of organic soils and provide updates estimates of areas organic soils under different land uses.	Sections 6.3.4 and 6.4.4 of the 2016 NIR

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Cropland and grassland – CO_2	Assign orchards to cropland and provide documentation on the method used to estimate the carbon stock changes over time, and ensure that changes in the area of orchards over time have been taken into account	ARR 2014 – Paragraph 81	The Countryside Survey (CS) Broad Habitat types shown in Table A3.6.8 are used to assign land use from 1984 onwards. Orchards are included in the Arable and Horticultural Broad Habitat type, and so for years which use CS data orchards are included in Cropland. Prior to 1984 Mapping Landscape Change (MLC) data are used to classify land use. As shown in Table A3.6.7 MLC Orchards have mistakenly been included in Forest Land. This will be amended when improved methodology to assess land use change is implemented. The misclassification of Orchards only applies to years before 1984 use so will only affect emissions from change in soil carbon stocks as a result of historical land use change. Orchards only cover a small area of the UK and the effect of this mis-classification is likely to be small. The 1990 – 2014 and 1990 – 2015 inventories include estimates of the change in the biomass carbon stocks of Croplands as well as change in their soil carbon stock which was estimated in the previous inventory. These estimates have used agricultural survey data to track the area of orchards and the change in biomass carbon stocks resulting from changes in their area.	n/a
Cropland and grassland – CO_2	Report land-use changes from cropland to grassland for 2010 onward	ARR 2014 – Paragraph 82	The error in land use conversion has been corrected for the 2015 and future submissions: extrapolated rather than projected values are now used.	Section 6.3.7 of the NIR

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Settlements	Investigate the internal consistency of the reported changes in carbon stock and more transparently provide information on the methods used	ARR 2014 – Paragraph 83	Carbon stock changes in living biomass following land conversion to Settlement are reported under gains, however the value includes both gains and losses. The notation key IE (instead of NO) is now reported to make this clearer.	N/A
Wetlands	Assess the appropriateness of the use of the notation key “NE” for the carbon stock changes in living biomass in overseas territories for forest land converted to wetlands and the related area and report on it	ARR 2014 – Paragraph 84	This recommendation has been assessed and it has been agreed that the notation key ‘NE’ is not appropriate in this situation. It has been changed to ‘NO’ for the 2015 and future submissions.	For the CRF submission
Waste overview	Improve the QC checks in, and between, the main text of the NIR and the annexes, as well as with the CRF tables	ARR 2014 – Paragraph 87	The UK has addressed the issues flagged by the ERT for the 2017 submission.	Chapter 7 and Annex 3 of the 2017 NIR
Solid waste disposal on land – CH_4	Implement the proposed improvements of emission estimates from solid waste disposal sites in the overseas territories and crown dependencies, by providing further information on methodologies to estimate emissions, and by completing the CRF tables with specific parameters such as AD, MCF and DOC	ARR 2014 – Paragraph 91	The UK has endeavoured to provide more detail where possible for the 2017 submission.	For the CRF submission
Wastewater handling – CH_4	Improve the transparency of the employed EFs by providing a more detailed explanation in the NIR	ARR 2014 – Paragraph 92	Due to changes in the methodology the specific transparency issue raised by the ERT is no longer relevant; however the UK has continued efforts to improve transparency.	Section 7.4 of the NIR
Waste incineration – CO_2, CH_4 and N_2O	Improve the documentation in the NIR, provide a detailed explanation of the methodology used to estimate emissions from accidental fires (vehicle) and standardize the terminology used for waste classification	ARR 2014 – Paragraph 93	The 2017 submission includes a methodology for accidental fires and the terminology has been standardised.	Section 7.3 of the NIR

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Waste incineration – CO_2, CH_4 and N_2O	Implement the improvement plan, and report only on the recovery of emissions that is based on metered data	ARR 2014 – Paragraph 94	The UK re-iterates to the ERT that the emissions from installations including chemical waste incinerators are included within the UK GHGI via the aggregated emission totals from operator-reported data, but due to the fact that operator data are not reported at the source-specific level (but rather at the “installation” level), these emissions are “IE” within IPPU emission estimates, source category 2B10. There are no available statistics in the UK that are gathered to estimate / report the methane flaring volumes or mass at chemical waste incinerators, and therefore the proposed improvement item is impossible to implement at this stage.	N/A
Deforestation – CO_2	Include the explanation that liming on deforested land occurs only in England	ARR 2014 – Paragraph 101	This comment relates to KP-LULUCF tables; liming is no longer reported in the KP-LULUCF tables.	N/A
Forest management – CO_2	Incorporate information on the effect of “windblow” disturbances in its next annual submission	ARR 2014 – Paragraph 103	The UK will be assessing the impacts of natural forest disturbances (including windblow) as part of its reporting in the 2nd commitment period and will report on results as they become available.	N/A

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Cropland and grassland – CO_2	Research again the possibility of generating suitable data and report on the progress to estimate emissions and removals from organic soil, and until additional information becomes available, report using the notation key "NE"	ARR 2014 – Paragraph 80	The 1990 – 2013 and 1990-2014 inventories use new data on the extent of Cropland and improved Grassland on organic soils, and so have improved estimates emissions from these soils. No histosols occur in the Caribbean OTs (Soil Atlas of Latin America, JRC, 2014) or in CDs close to the UK (Soil Atlas of Europe, JRC, 2014). Histosols do occur in the Falkland Islands (Soil Atlas of Latin America, JRC, 2014) but there is no drainage on Grassland, and therefore no emissions from disturbance (disturbance results in conversion to Cropland). Therefore the NO notation key will be retained. Work to implement the Wetlands Supplement is underway which will attempt to further refine these areas including the area of Grassland on organic and organo-mineral soils in the OTs and CDs and to generate estimates for the area of drained organic soils under semi-natural grasslands. The Wetlands Supplement work will also assess whether the T1 emission factors which are currently used to assess CO_2 emissions from organic soils should be replaced with T2 or T3 factors to reflect UK circumstances.	N/A

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Cropland and grassland – CO_2	Assign orchards to cropland and provide documentation on the method used to estimate the carbon stock changes over time, and ensure that changes in the area of orchards over time have been taken into account	ARR 2014 – Paragraph 81	The Countryside Survey (CS) Broad Habitat types shown in Table A3.6.8 are used to assign land use from 1984 onwards. Orchards are included in the Arable and Horticultural Broad Habitat type, and so for years which use CS data orchards are included in Cropland. Prior to 1984 Mapping Landscape Change (MLC) data are used to classify land use. As shown in Table A3.6.7 MLC Orchards have mistakenly been included in Forest Land. This will be amended when an improved methodology to assess land use change is implemented. The misclassification of Orchards only applies to years before 1984 use so will only affect emissions from change in soil carbon stocks as a result of historical land use change. Orchards only cover a small area of the UK and the effect of this mis-classification is likely to be small. The 2016 submission includes estimates of the change in the biomass carbon stocks of Croplands as well as change in their soil carbon stock which was estimated in the previous inventory. These estimates have used agricultural survey data to track the area of orchards and the change in biomass carbon stocks resulting from changes in their area.	N/A

11 KP-LULUCF

11.1 GENERAL INFORMATION

Emissions sources	Forest Management Afforestation and Reforestation Deforestation Cropland Management Grazing Land Management
Gases Reported	CO_2, CH_4, N_2O
Methods	NA
Emission Factors	NA
Key Categories (Quantitative)	Afforestation and Reforestation – CO_2 Deforestation – CO_2 Forest Management – CO_2 Cropland Management – CO_2 Grazing Land Management – CO_2
Key Categories (Qualitative)	Not undertaken
Overseas Territories and Crown Dependencies Reporting	OTs and CDs are included at Tier 1 level
Major improvements since last submission	New forestry activity data and improved soil, litter and management modelling for forests. The inclusion of ongoing emissions from pre-1990 land management and land use change for Cropland Management and Grazing Land Management.

11.1.1 Definition of Forest

The UK uses the following definition of forest which has been agreed with the Forestry Commission:

- Minimum area of 0.1 hectares;
- Minimum width of 20 metres;
- Tree crown cover of at least 20 per cent, or the potential to achieve it;

- Minimum height of 2 metres, or the potential to achieve it.

This definition includes felled areas awaiting restocking and integral open spaces up to 0.5 hectare (Forestry Statistics 2016, Sources chapter).

These single minimum values are used for reporting UK forestry statistics (Forestry Commission, 2015) and the UK's greenhouse gas inventory submitted under the UNFCCC. The definitions are consistent with information provided by the UK to the FAO. If an international enquiry uses a different minimum definition, for example 0.5 ha in the Global Forest Resource Assessment 2010, the UK areas are adjusted to this different definition (FAO, 2010).

A new National Forest Inventory (NFI) has been undertaken in Great Britain (Forestry Commission 2011), as described in section 6.1, and is used for the first time in this inventory submission. The NFI has a minimum area threshold of 0.5 ha, which is the threshold for detecting open areas such as clearings within forests and subtracting them from the forest area. The area of small woods, between 0.1 ha and 0.5 ha, has been derived through a separate analysis and has been included in the 2015 inventory for the first time. The analysis will be published in 2017.Estimates of woodland loss have been assessed, which affect the total estimated woodland area in the GHGI (but are not reflected in the national Forestry Statistics). Improved estimates of woodland loss to settlement have been published since the 2014 inventory and have been included (Forestry Commission, 2016).

The UK does not distinguish between natural and planted forest areas, with the exception of relatively small areas of semi-natural and ancient woodland, which are usually actively managed to conserve their characteristics. All forest areas in the UK can be regarded as managed from the point of view of regulation against deforestation and protection against fire, storms and disease. In general, forest areas are actively managed for landscape, soil protection, habitat conservation, amenity and recreation, which may or may not include active management for wood production.

11.1.2 Elected activities under Article 3, paragraph 4 of the Kyoto Protocol

The UK elected Forest Management (FM) as an activity under Article 3.4 in the first commitment period (2008-2012). For the second commitment period (2013-2020), in addition to FM, the UK has elected Cropland Management (CM), Grazing Land Management (GM) and Wetland Drainage and Rewetting (WDR), as identified in the UK's Initial Report (2016).

The UK's original Forest Management Reference Level (FMRL) during the second commitment period, as identified in the appendix to the annex to Decision 2/CMP.7, was -3.442 Mt CO_2 eq/yr, or -8.268 Mt CO_2 eq/yr when applying first order decay function for harvested wood products. The UK has calculated a technical correction to the FMRL which is -10 811Mt CO_2 eq/yr, or -7 566Mt CO_2 eq/yr when applying first order decay function for harvested wood products..

11.1.3 Description of how the definitions of each activity under Article 3.3 and each mandatory and elected activity under Article 3.4 have been implemented and applied consistently over time

The areas of forest land reported for AR and FM under the Kyoto protocol are the same as the area reported under 4A Forest Land (**Figure 11.1**).

Definitions of forest are consistent with those used in the UNFCCC GHGI. The Afforestation/Reforestation area is land that has been converted to forest land from other land uses since 1990. This area is estimated from the area of forest in the NFI age class that indicates the woodland was replanted or afforested post-1990. The replanted area is estimated based on the wood production information, and the rest is assigned as Afforestation. Areas of forest planting are now reported by calendar year for both 4A Forest Land and AR and FM (previously the source data was reported by financial year (April to March) and was adjusted for KP-LULUCF reporting). The area of forest established since 1990 for 2015 is 654,076 ha in both the UNFCCC GHGI and Article 3.3 Afforestation.

Afforestation and reforestation are considered together and are consistent with the definition of forest given above. New planting can result from planting, seeding or natural colonisation. It is assumed that none of the AR area has been subsequently deforested.

Deforestation since 1990 is the land area permanently converted from forest land to non-forest land uses. Areas of annual forest conversion are reported in the UNFCCC GHGI, and the cumulative total 1990-2015 matches the area reported under Article 3.3 Deforestation (60 695 ha) (Figure 11.2).

Forest Research has collated data from multiple sources: unconditional felling licences granted, differences between the NFI and NIWT maps and the 2006 NFI map and the 2015 NFI map (Forestry Commission 2016) (where it is possible to differentiate permanently deforested land from harvested land that has not yet been replanted), analysis of the forest sub-compartment database, remote sensing of Forest land converted to settlement and information on open habitat restoration. There is an increase in the estimated level of deforestation from 2000. There were policies initiated in 2000 that lead to habitat restoration of forests to heath land, and an increase in deforestation due to windfarm development. There is a paucity of data prior to 1999, but there are no known policies or land use drivers that would significantly change the estimated level of deforestation in the 1990s. From 2000 onward, a low end estimate of deforestation was made based on the areas of woodland permanently converted to another land use from the comparison of the woodland area maps. Estimates of conversion to open habitat and windfarms, and unconditional felling licence data, were then used to supplement this low end estimate to arrive at the current estimates of post-2000 deforestation. New data on permanent Forest land conversion to Settlement between 2006 and 2015, based on remote sensing, were published in 2016 and have been included in the 2015 inventory.

There is an assumption of restocking after harvesting, although open habitat can make up 13-20% of stand area on restocking (so reducing stocking density from its previous level). Thinning is considered to be part of the normal forest management regime. A felling license is required for felling outside the national forest estate; there is a legal requirement to restock under such a license unless an unconditional felling license is granted (in which case this would be formally reported as Deforestation).

The Forest Management area is the area established before the end of 1989 adjusted to reflect losses from deforestation. In the UNFCCC GHGI the Deforestation area is deducted from the 4A1 Forest remaining Forest Land area, and carbon stock changes are adjusted accordingly. The area of KP Forest Management and the area of 4A1 Forest remaining Forest were comparable at the end of 2009, as the area of 4A1 in 2009 will include all forest planting up until 1990 (as activity data reporting is now by calendar year for both).

The area of Cropland Management reported under KP is broadly consistent with that reported as Cropland under UNFCCC (the total area of tillage crops, orchards, fallow and set-aside). Its starting point is the area of cropland recorded in the agricultural census in 1990, whereas the UNFCC methodology uses Countryside Survey data (the land use matrix approach), leading to a 5% difference in total areas across the time series. There are also small differences because (i) a small area of CM activity occurs on Deforested land (<0.15 kha) and therefore this area and associated emissions and removals are reported under Deforestation; (ii) areas of CM land have been converted to Settlement (c. 150 kha). As land cannot leave the KP reporting hierarchy once it has been included, this area has remained in KP CM land, but been included in the Settlement area for UNFCCC reporting (

Figure 11.3).

The area of Grazing Land Management reported under KP is consistent with that reported as Grassland under UNFCCC as all Grassland in the UK is considered to be grazed and managed to some degree and both use the area of grassland in the Countryside Survey in 1990 as the starting point. However, the area of KP-GM land is slightly different from the UNFCCC Grassland area because (i) some KP-GM activity occurs on Deforested land (c. 49 kha) and therefore this area and associated emissions and removals from this are reported under Deforestation; (ii) some KP-GM land has been converted to Settlement (c. 506 kha) -as land cannot leave the KP reporting hierarchy once it has been included, this area has remained in KP-GM land, but been included in the Settlement area for UNFCCC reporting (**Figure 11.4**).

BEIS has commissioned a programme of research and methodological development to compile activity data and UK-specific emission factors for Wetland Drainage and Rewetting (WDR) activities (due to report mid-2017). It is anticipated that the UK will be able to report on WDR activity once this work has been completed and incorporated into the inventory system.

Figure 11.1 Area of forest in Article 3.3 Afforestation and Article 3.4 Forest Management compared with total area of forest in UNFCCC Sector 4A Forest Land

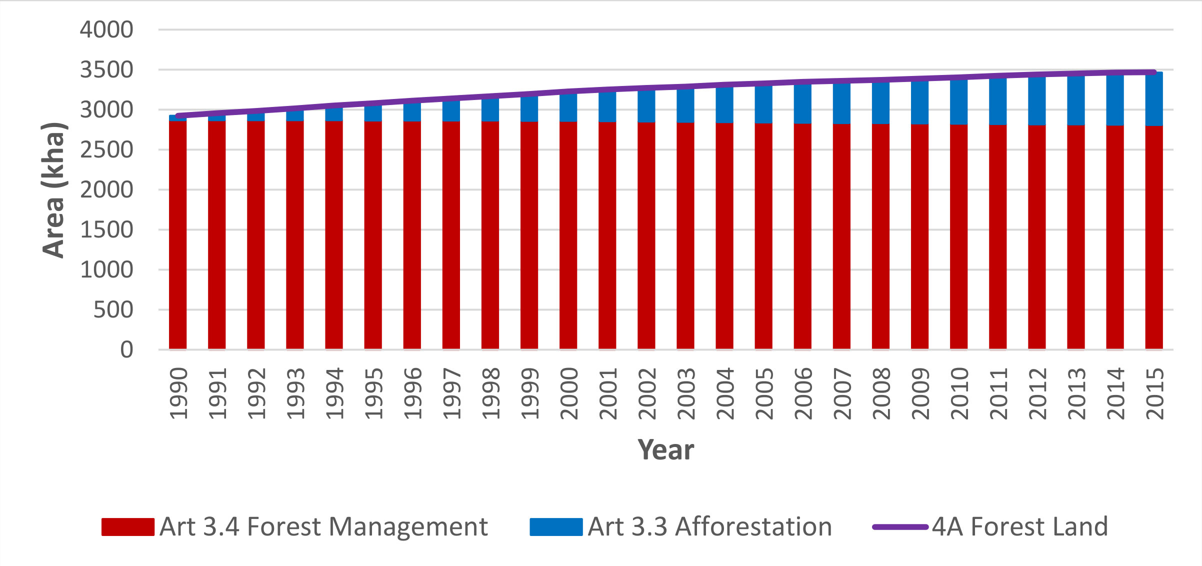


Figure 11.2 Area of Article 3.4 Deforestation (note different scale from other figures)

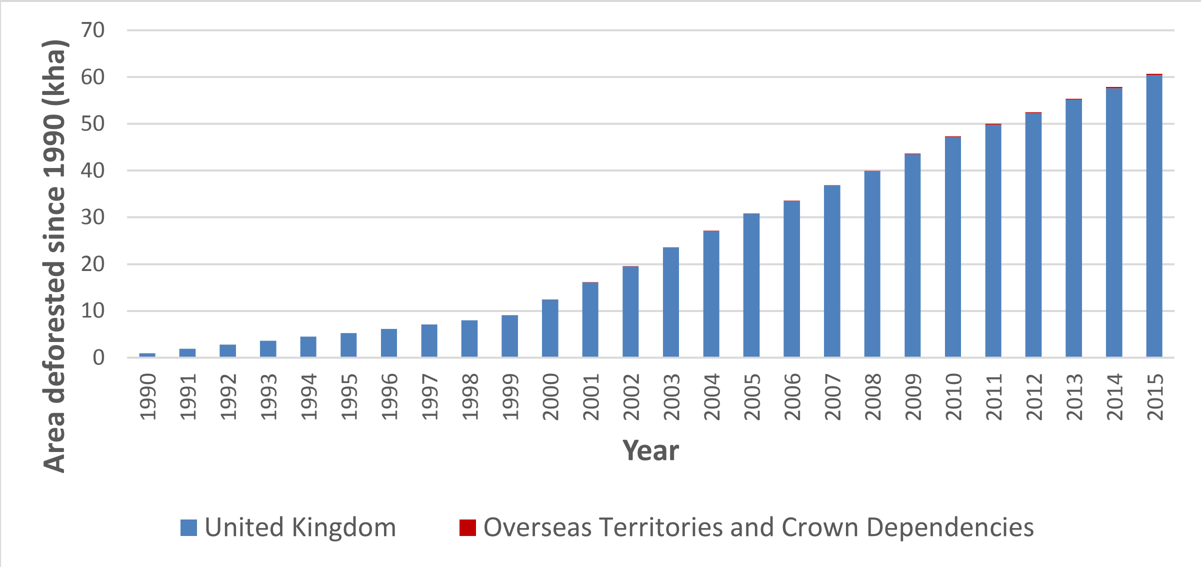


Figure 11.3 Area of Article 3.4 Cropland Management compared with total UNFCCC sector 4B Cropland (note different scale from other figures)

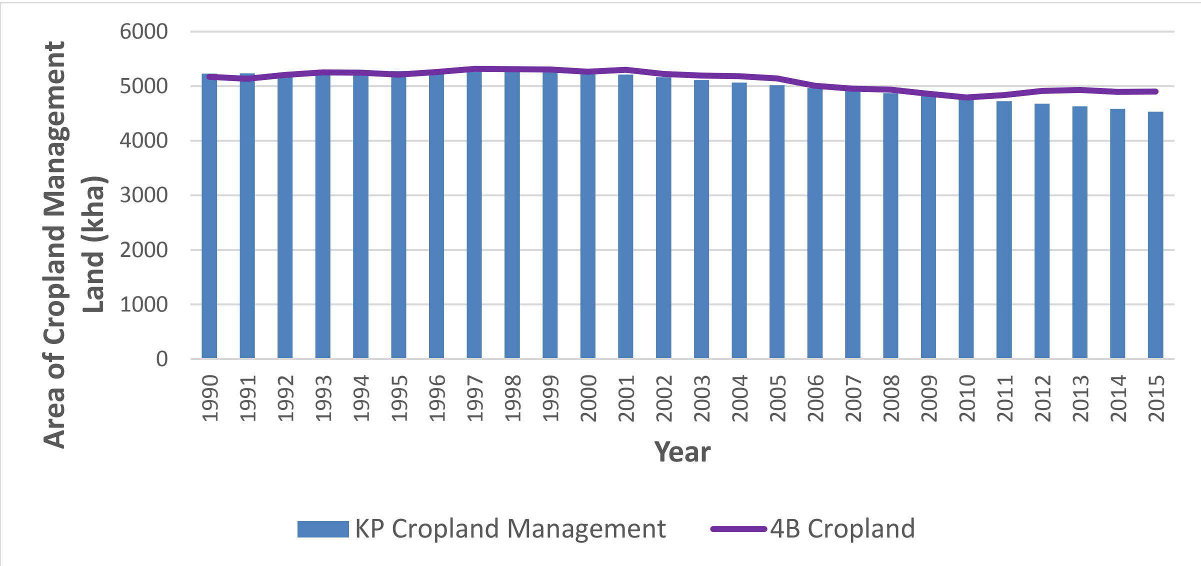
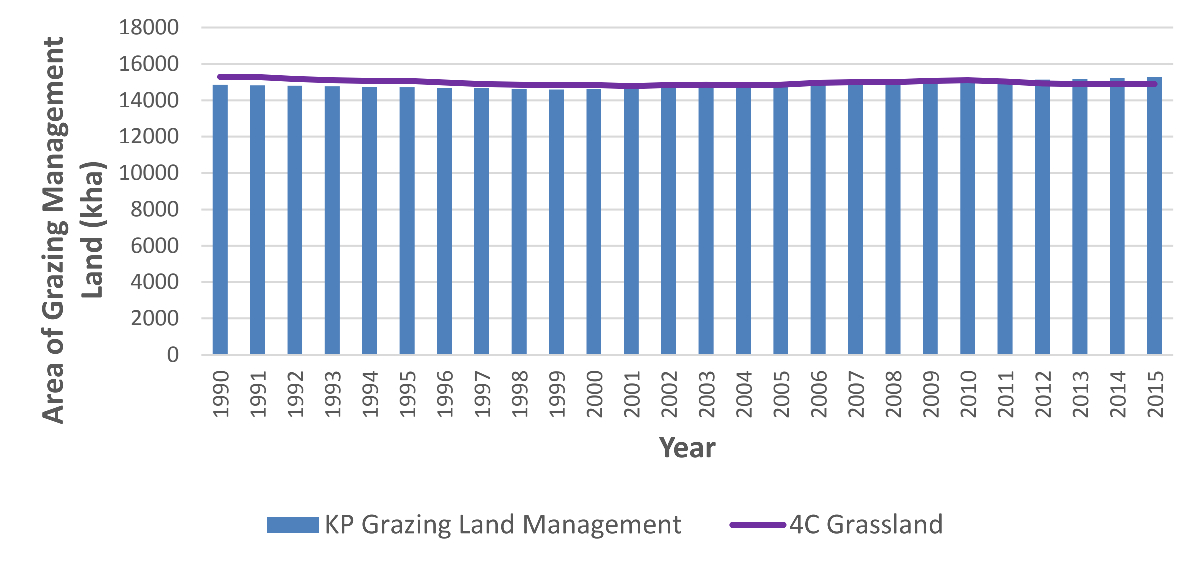


Figure 11.4 Area of Article 3.4 Grazing Land Management compared with total UNFCCC sector 4C Grassland (note different scale from other figures)



11.1.4 Precedence conditions and hierarchy among Art. 3.4 activities

The UK has elected additional activities under Article 3.4 for the second commitment period. There is a programme of research and methodological development underway for the newly elected activities (CM, GM and WDR) and the UK is now able to report some of the emissions and removals for these activities and will be able to account for emissions/removals from these activities by the end of the commitment period. The UK will follow the precedence conditions recommended by the 2013 Kyoto Supplementary Guidance (section 1.2), with Article 3.3 Deforestation highest in the hierarchy, and Article 3.4 WDR lowest. Article 3.4 CM and GM are considered equivalent in the hierarchy: however, in some regions of the UK, rotational management is dominated by crops, with the occasional grass ley, and vice versa in other regions, therefore cropland-grassland land use change is temporary. In the future land undergoing rotational crop/grass management will be specifically allocated to either CM or GM as a sub-category, rather than regularly moving between activities. Development work on land use vectors (see Annex 3.4) may allow the identification and pattern of areas under rotational land use.

There is no double-counting of emissions and removals from Article 3.4 activities under Article 3.3. The UK has consistent records for the land areas in all Article 3.3 and 3.4 activities since 1990, as illustrated by the NIR-2 tables in the CRF, and these are used as the activity data for estimating emissions and removals.

11.2 LAND-RELATED INFORMATION

11.2.1 Spatial assessment unit used for determining the area of the units of land under Article 3.3

The UK uses Reporting Method 1, for Article 3.3 and 3.4 activities. Data sources for tracking areas of afforestation and forest management are spatially explicit, whilst those for deforestation are mostly not. The data sources and methodology can detect a land use change at a resolution consistent with the forest definition in **Section 11.1.1** (0.1ha). Data sources for Article 3.4 activities Cropland Management (CM) and Grazing Land Management (GM) are not spatially explicit at present although the inventory development programme's plans to integrate new datasets for reporting land use change may enable more spatially explicit data to be used in future.

The geographic boundaries used for international reporting are the United Kingdom and the combined area of the UK's Overseas Territories and Crown Dependencies. Disaggregated emissions and removals are estimated at the level of the four countries of the UK (England, Scotland, Wales and Northern Ireland) using both KP and UNFCCC methodology and are reported in an Annexe to the annual report on Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland.

11.2.2 Methodology used to develop the land transition matrix

The land transition matrix is shown in CRF Table NIR 2 (Table 11.1). The same data sources are used for the UNFCCC greenhouse gas inventory (as described in **chapter 5.2** and **Annex 3.4**) and emissions/removals under Articles 3.3 and 3.4.

Forest Research has compiled a forest dataset of estimated forest age from 1500 to the present day. The Foresty Commission, Natural Resources Wales and Forest Service of Northern Ireland have provided national forest planting statistics from 1921 to the present. The age of establishment for pre-1921 forests is estimated using information on the distribution of forest area by age class from forest inventories and an algorithm to assign areas of forest to years based on assumed management and rotation length. Areas planted since 1990 in this dataset are used in Article 3.3 Afforestation/ Reforestation**.**

There is currently no detailed information on the age and type of forests subject to deforestation, so it is assumed that for areas that have been afforested since 1990 very little deforestation will have taken place. Estimates of areas in Article 3.3 Deforestation are collated from multiple sources (see **Annex 3.4.4** for details). Further information on these data sources is in **Chapter 5.2** and a summary is given in **Table 11.2.**

The area of Article 3.4 Forest Management land is the area of forest planted before 1990, adjusted to take account of the area lost through deforestation.

The area of Cropland Management reported under Article 3.4 is estimated by combining annual agricultural census data and Countryside Survey data. The CM area at the start of 1990 is the area of cropland recorded in the agricultural census. The CM area at the end of each year is the sum of the initial cropland area and the area gained by land use change from non-forest land, minus the area of cropland converted to Afforestation land or GM land (calculated using the Countryside Survey LUC matrices, described in Annex 3.4.2). The area of cropland at the start of the subsequent year is equal to the cropland area at the end of the previous year.

The area of Grazing Land Management reported under Article 3.4 is estimated from Countryside Survey data using the assumption that all grassland in the UK is subject to grazing and management to some degree (this area is greater than that reported in the agricultural census). The GM area at the start of 1990 is the area of grassland recorded in the Countryside Survey. The GM area at the end of each year is the sum of the initial grazing land area and the area gained by land use change from non-forest land, minus the area of grazing land converted to Afforestation land or CM land (calculated using the Countryside Survey LUC matrices, described in Annex 3.4.2). The area of grazing land at the start of the subsequent year is equal to the grazing land area at the end of the previous year.

The area of Other Land in CRF table NIR 2 is adjusted so that the total area adds up to the land area reported for the UK and Overseas Territories and is constant for all years.

The UK is not yet in a position to report emissions from land in the Wetland Drainage and Rewetting (WDR) category, although emissions from some WDR practices on land classified under activities higher in the KP hierarchy have been reported in the 2017 inventory. A programme of research and methodological development has started which will enable the full reporting of WDR activities by the end of the commitment period.

Table 11.1 Land area and changes in land areas in 2015 (including area of Overseas Territories and Crown Dependencies)

To current inventory year (2015)			Article 3.3 activities		Article 3.4 activities			Other	Total (beginning of year)
From previous inventory year (2013)			Afforestation and Reforestation	Deforestation	Forest Management	Cropland Management	Grazing Land Management		
Article 3.3 activities	Afforestation and Reforestation	kha	648.52	0.00					648.52
	Deforestation			57.88					57.88
Article 3.4 activities	Forest Management			2.81	2810.72				2813.54
	Cropland Management		0.54			4477.57	104.91		4583.03
	Grazing Land Management		5.30			56.91	15158.92		15221.13
Other			1.06			0.20	10.74	2375.35	2387.35
Total (end of year)			655.42	60.70	2810.72	4534.68	15274.57	2375.35	25711.44

Table 11.2 Data Sources on Afforestation, Reforestation and Deforestation (ARD), Forest Management (FM), Cropland Management (CM), and Grazing Land Management (GM) Activities

Activity	Dataset	Available scale	Time period	Details
AR & FM	Annual planting statistics	UK	1921 - 2015	New planting on previously non-forested land. Updated annually. Categorized into conifer and broadleaved woodland.
AR & FM	Annual restocking statistics	UK	1976 - 2015	Restocking of existing forest. Updated annually. Categorized into conifer and broadleaved forest. Used to estimate the pre-1921 planting years.
AR & FM	Forestry Commission Sub-compartment Database	Every area of forest managed as part of the public forest estate	2015	Contains information on the growth rate and management of every area of forest in the public forest estate. Used to estimate the distribution of tree species, growth rates and management of forests.
AR & FM	Timber production statistics	UK	1970 - 2015	Estimates from the Forestry Commission of timber production by year based on outturns from sawmills Used to estimate the percentage of private sector woodland that is managed (thinned or felled).
D	Forestry Commission Unconditional Felling Licence data	England, Scotland, Wales	England: 1992-2013; Scotland: 1998-2013; Wales: 1996-2013	Unconditional Felling Licences are issued for felling without restocking. Used to estimate deforestation in rural areas (primarily for heathland restoration). Omits felling for development purposes, e.g. construction of wind turbines. Available at http://www.forestry.gov.uk/datadownload
D	National Inventory of Woodland and Trees (NIWT)	Great Britain (not Northern Ireland)	2000	Forest map used to estimate deforestation since 2000.
D	Land Use Change Statistics (survey of land converted to developed uses)	England only	1990-2008 (updated in 2010)	Estimates of the conversion of forest to urban/developed land use. Based on Ordnance Survey map updates, identifying changes through aerial surveys and other reporting, expected to capture most changes within five years. English data are extrapolated to GB scale for pre-2000 areas.

Activity	Dataset	Available scale	Time period	Details
D	Countryside Survey (CS) 1990, 1998, 2007	UK	1990-2007	Estimated areas of woodland converted to other land uses from CS data (1990, 1998, and 2007). The CS over-estimates the extent of woodland conversion compared with the extent estimated by the Forestry Commission. This is due to differences in woodland definitions, amongst other causes. However, the CS data can be used to estimate the relative split of woodland conversion between grassland, cropland and settlements, using other known data to "discount" the CS areas. There is no non-CS data for Northern Ireland so the discount rates for England or Wales are used, depending on availability.
D	Forestry Commission Internal Records	Great Britain (not Northern Ireland)	2000-2015	Update to the deforestation to grassland areas based on data on publicly-owned forest areas converted to non-forest land use from administrative records maintained by Forestry Commission England, Forestry Commission Scotland and Natural Resources Wales.
D	Preliminary estimates of the changes in canopy cover in British woodlands between 2006 and 2015	Great Britain	2006-15	Revised information (remote sensing) on coversion of Forest land to settlement.
AR, FM and D	National Forest Inventory (NFI)	Great Britain (not Northern Ireland)	2009-2013	Species and growth rate by age class, used to estimate AR and FM area. Estimates of permanent woodland loss reported in National Forest Inventory Country Reports.
AR, FM	National Forest Inventory (NFI) - small woods	Great Britain (not Northern Ireland)	2014	Estimates of the area of small woods.

Activity	Dataset	Available scale	Time period	Details
AR, FM, CM, GM	Habitat surveys, agricultural statistics and planting data	Crown Dependencies	1965-2015	Forest planting data for broadleaves and conifers was available for the Isle of Man. Habitat surveys were used to estimate forest, cropland and grassland area for Guernsey and Jersey. There is no forest meeting the forest definition in the Falkland Islands. Agricultural statistics are used for cropland and grassland areas in the Isle of Man and Falklands Islands.
CM, GM	Countryside Survey	UK	1984 – 2007	Land use change to and from Cropland and Grazing Land. Area under different grassland types.
CM	Agricultural census	UK	1866 - 2015	Areas under different crops.
CM	British Survey of Fertiliser Practice	Great Britain (not Northern Ireland)	1992 – 2015	Percentage of crop residues incorporated to soil. Fertiliser and manure inputs to Cropland and Grazing Land.
CM	Farm Practice Survey	England	2010	Percentage of Cropland under conventional, reduced and no tillage regimes.
CM	Scottish Survey of Agricultural Production Methods	Scotland	2010	Percentage of Cropland under conventional, reduced and no tillage regimes.
CM	Scottish Survey of Farm Structure and Methods	Scotland	2013	Percentage of Cropland under conventional, reduced and no tillage regimes.
CM, GM	Spatial extent of cultivated organic (Histosol) soils	UK	2013	Area of drained organic soils under cropland and improved grassland in the UK.
AR, D, FM, CM, GM	Fire and Rescue Service Incidence Reporting System	Great Britain (not Northern Ireland)	2010-2015	Area of wildfires on forest, cropland and grassland.

11.2.3 Maps and database to identify the geographical locations, and the system of identification codes for the geographical locations

The whole area of the United Kingdom and the combined area of the Overseas Territories and Crown Dependencies have been used as the geographical units for reporting (**Figure 11.**). Only the OTs/CDs of Isle of Man, Jersey, Guernsey and the Falkland Islands have sufficient information to allow us to estimate GHG emissions and removals from KP-LULUCF.

Figure 11.10 Geographical areas used for reporting Kyoto Protocol LULUCF activities

11.3 ACTIVITY-SPECIFIC INFORMATION

11.3.1 Methods for carbon stock change and GHG emission and removal estimates

11.3.1.1 Description of the methodologies and the underlying assumptions used

Methods for estimating carbon stock changes in forests for Article 3.3 Afforestation/Reforestation and Article 3.4 Forest Management are the same as those used for the UNFCCC greenhouse gas inventory: details are given in **Annex 3.4.1.** A carbon accounting model, CARBINE, is used to estimate the net change in pools of carbon in living biomass, litter and soil in conifer and broadleaved forests. In the KP CRF tables changes in carbon stock are reported for: above-ground biomass (gains and losses), litter (net changes) and soils (net changes in mineral and organic soils). Carbon stock changes in below-ground biomass and dead wood are reported as Included Elsewhere, because below-ground biomass is calculated as part of the above-ground biomass and dead wood is calculated as part of the litter pool. Additional information on dead wood may be available from the NFI in future and CARBINE will be modified to report dead wood separately.

Annual data on forest planting are provided by the Forestry Commission, at a higher precision than that published in the annual Forestry Statistics. Information on state afforestation is stored in the Forestry Commission Sub-Compartment Database (SCDB): this is the stand management database for state-owned and managed forest, containing information on species, age, yield class and management. Non-state forest information comes from the grant schemes by which the government encourages planting and management of private woodland. These schemes cover almost all private woodland planting since 1995: there is a small amount of non-grant aided woodland (mostly in England) which is assumed to be broadleaved natural regeneration but we have no further information on the management or permanence of this area. Areas included are those for which new planting grants have been paid and the planting has actually been completed. The FC does not pay grants prior to the planting taking place so it is assumed the areas are stocked.Estimates for carbon stock changes as a result of Article 3.3 Deforestation use the same methods as the UNFCCC greenhouse gas inventory (**Annex 3.4.4**). During deforestation, 40% of the above-ground biomass is assumed to be burnt and emissions of CO_2, CH_4 and N_2O are reported in Table 5(KP-II)5. The remaining carbon stock in biomass is assumed to be immediately lost (instantaneous oxidation) (in the UNFCCC this biomass stock is transferred to the harvested wood products pool). This loss (in Gg C) is calculated as:

Carbon stock loss = living biomass loss + dead organic matter loss

where *living biomass loss = biomass density * area * % biomass removed,* and

*dead organic matter loss = DOM density * area * % biomass removed*

and *proportion of biomass removed = 60%*

area = area deforested, ha

biomass density = average forest living biomass density, Gg C /ha

DOM density = average dead organic matter density, Gg C/ha

Carbon stock changes in soils as a result of deforestation are calculated using the dynamic model of carbon stock change discussed in **Annex 3.4**. It is not possible to report changes in mineral and organic soils separately since there are no separate activity data. Estimates of deforestation are made for the UK and for the Crown Dependencies for the first time in this submission. Only Guernsey has any deforestation (the Overseas Territory of the Falkland Islands has no forest).

Carbon stock changes due to Forest Management are estimated using the CARBINE model, as described in **Annex 3.4.1**. It is assumed that all deforestation occurs on Forest Management land, so the area of FM land and carbon stock changes are adjusted to reflect deforestation losses. This was done by running the model with the initial FM land area and calculating the implied carbon stock changes per unit area (as in the CRF tables). The Forest Management land areas were then adjusted to take account of annual deforestation , and the resulting areas multiplied by the implied carbon stock changes per unit area to give total carbon stock changes.

The calculation of the Forest Management Reference Level is briefly described in section 11.3.1.6, and fully in the UK's 2011 submission to the UNFCCC (DECC, 2011). The FMRL has been updated for this inventory submission and is described in **Section 11.5.2.4**.

The UK will take up the natural disturbances provision for forest land in the second commitment period. The background and threshold levels for natural disturbances on Forest Management and Afforestation/Reforestation land in the UK are shown in **Table 11.3**. The methodology used to estimate these background and threshold levels is explained in the United Kingdom's Initial Report under the Second Commitment Period of the Kyoto Protocol (, 2016). No emissions have been excluded as being due to natural disturbances in the 1990-2015 inventory.

Table 11.3 The background emissions estimated for disturbance events over the calibration period for Forest Management and Afforestation and Reforestation

	Background Level ($ktCO_2e/yr$)	Margin ($ktCO_2e/yr$)	Disturbance provision threshold ($ktCO_2e/yr$)
Forest Management	270	112	382
Afforestation and Reforestation	34.9	18.8	54
UNFCCC 4A Forestland	307	132	440

Carbon stock changes in the HWP pool (CRF Table 4(KP-I)C)are calculated on a first-order decay function basis for AR and FM forests and on an instantaneous oxidation basis for deforestation, in accordance with the 2013 Kyoto Protocol Supplementary Guidance (see Annex 3.4 for details). HWP from AR land includes all domestically produced HWP from Afforestation land since 1990. HWP is included in Forest Management in the second commitment period as the UK's FMRL was based on a projection. HWP is only included from 2013 onwards because:

- The UK accounted for FM in the first commitment period, where HWP was assumed to be instantaneously oxidised to the atmosphere; and
- As the UK's FMRL is based on a projection which represents a "business as usual scenario", inherited emissions from HWP before the start of the commitment period (i.e. all HWP from FM land produced 1990-2012) can be excluded as long as there is consistency between the FMRL and the accounting during the commitment period.

Changes in soil carbon and biomass carbon due to land use change under KP-Cropland Management and KP-Grazing Land Management are modelled using a Tier 3 model of dynamic stock change, driven by matrices of change calculated from the Countryside Survey and historical data sources (from 1950 onwards). Soil carbon stock changes are estimated using a database of soil carbon density for the UK (Bradley et al. 2005), and country-specific biomass carbon densities for biomass carbon stock changes. Carbon stock changes resulting from deforestation to cropland or grazing land are reported under KP-Deforestation. The carbon stock change estimates now include ongoing emissions from mineral soils due to land use change occurring before 1990 and ongoing carbon emissions from organic soils due to pre-1990 drainage (**Annex 3.4.6**) (in response to recommendations in the 2016 UNFCCC review). Further description of the model, country-specific soil and biomass carbon densities and rates of change can be found in **Annex 3.4.2**.

Carbon stock changes in biomass as a result of agricultural management activities on cropland are calculated using the areas of different types of crop each year, obtained from agricultural census data. Crops are grouped into six broad types: annual crops, orchards, shrubby perennial crops, perennial grasses grown as biomass fuel, short rotation coppice, and set aside and fallow. The biomass carbon stocks of each of these crop types was estimated from a literature review (Moxley *et al*, 2014b). Full methodology is given in **Annex 3.4.**

Soil carbon stock changes as a result of management activities on cropland are estimated using agricultural census data on crop areas supplemented with data on residue removals and fertiliser and manure inputs from the farm practice surveys (**Annex 3.4.2**). Default stock change factors from the IPCC 2006 Guidelines and a Tier 2 tillage factor were used to estimate stock changes.

Carbon stock changes in biomass as a result of agricultural management activities on grazing land are calculated using shrubby and non-shrubby grassland areas from Countryside Survey data and biomass carbon stocks (Moxley *et al*, 2014b). Carbon stock changes arising from hedgerow creation and loss were included for the first time in the 2017 inventory. This is based on Countryside Survey data on gains and losses in hedgerow length and UK-specific biomass stocks in managed and unmanaged hedges(see **Annex 3.4.2** for details of biomass carbon stock methodology).

The reporting of emissions from Grazing Land soils as a result of management activities is awaiting the outcome of further research in this area. A literature review (Moxley et al, 2014a) suggested that Tier 1 emission factors for emissions and removals as a result of changing soil carbon stocks due to management activities on Grazing Land were not appropriate for the high carbon organo-mineral soils underlying large areas of grazing land in the UK, and a BEIS-funded research project is identifying suitable emission factors for these systems.

Greenhouse gas emissions (rather than carbon stock changes) from LULUCF activities under the Kyoto Protocol are reported in CRF Tables 4(KP-II)1-5.

Table 4(KP-II)1. Direct and indirect N_2O emissions from N fertilization

The method used to estimate emissions is the same as that used in the UNFCCC greenhouse gas inventory and described in **Annex 3.4.1**. It is assumed that nitrogen fertilizer is only applied to newly planted forests on settlement land (i.e. AR land) in the UK (see **Chapter 5.2** for more information). Indirect emissions from leaching and deposition of N fertiliser are calculated using a Tier 1 methdology and are reported for the first time in the 2017 submission.

Table 4(KP-II)2. CH_4 and N_2O emissions from drained and rewetted organic soils

The method used to estimate N_2O emissions from drained forest land is the same as that used in the UNFCCC greenhouse gas inventory and described in **Annex 3.4.1.** Drainage of forest land only occurs on certain soil types in the UK (see **Annex 3.4** for more detail) and is reported for AR and FM land. Carbon emissions from the drainage of forest soils are included with emissions from soils in the carbon stock change tables for AR and FM. There is insufficient information to estimate CH_4 emissions from drainage and non-CO_2 emissions from rewetted soils at this time. The UK has a research programme investigating the implementation of the 2013 Wetlands Supplement Guidance for the UK and will report emissions from this area before the end of the commitment period.

Table 4(KP-II)3. N_2O emissions from N mineralization/immobilization due to carbon loss/gain associated with land-use conversion and management change in mineral soils

Indirect emissions of N_2O from leaching of mineral soils as a result of N mineralization following land use change are calculated (using a Tier 1 methodology) for the first time in the 2017 submission. Direct N_2O following deforestation to Cropland, Grassland and Settlement and with land use change between Cropland, Grazing Land and Settlement in the UK since 1990 are reported. Direct N_2O emissions from N mineralisation on forest land due to land use change are reported for the first time in the 2017 submission as, following methodological changes in the forest soil carbon model (**Annex 3.4.1**), net carbon stock losses rather than gains are now estimated from newly afforested mineral soils. N_2O emissions resulting from the artificial drainage of mineral soils on AR and FM land are also reported in this table, as Table 4(KP-II)2 is for organic soils only.

Table 4(KP-II)4. GHG emissions from biomass burning

The method used to estimate emissions from controlled and wildfire biomass burning is the same as that used in the UNFCCC greenhouse gas inventory and described in **Annex 3.4**. There is no controlled burning of AR or FM forest land in the UK or on managed Cropland. Controlled burning on managed Grazing Land is not included in the inventory at present.

There is insufficient information on the occurrence of wildfires on different forest types so wildfire emissions have been split between Afforestation/Reforestation land and Forest Management land on the basis of their proportion of the whole forest area (a ratio of 0.237 AR/FM for the UK in 2015). As described above, it is assumed that 40% of the standing biomass and DOM undergoes controlled burning during deforestation and emissions from that burning are reported in this table. It is assumed that wildfires that cause deforestation do not occur in the UK, as there is a general commitment to maintaining forest area. However, it is possible for previously deforested land to undergo wildfire (for example on restored heathland). The wildfire activity data are spatially explicit, so it was possible to assess whether there was any co-location of deforested areas (from the unconditional felling licence dataset) and wildfires. There have been three incidences of wildfires on previously deforested land in 2010 (57 ha), 2012 (200 ha) and 2015 (70 ha). Estimated emissions from these events are included in Table 4(KP-II)4.

Emissions from wildfires on grassland and cropland not on Deforested land are reported under Grazing Land Management and Cropland Management, also in Table 4(KP-II)4.

11.3.1.2 Justification for omitting any carbon pool or GHG emissions/removals from activities under Article 3.3 and elected activities under Article 3.4

The UK has elected three additional Article 3.4 activities: Cropland Management, Grazing Land Management and Wetland Drainage and Rewetting. We are not yet in a position to fully report emissions and removals from all of these activities and the relevant tables are filled in with the notation keys NA or NE. The UK has put in place a research and methodological development programme for these activities to enable full reporting by the end of the commitment period.

Table 4(KP-I)A.1.1 Article 3.3 activities: Afforestation and Reforestation. Additional information: emissions and removals from natural disturbance

The UK will use the provision to exclude emissions from natural disturbances with respect to Article 3(3) (Afforestation and Reforestation). The background levels of emissions from natural disturbances and the disturbance provision thresholds are shown in **Table 11.3**. No emissions from natural disturbance above the disturbance provision threshold level have occurred on Afforested and Reforested land in the period covered in the 1990-2015 inventory. The tables have been filled with NA notation keys (Not Applicable) for the current submission.

Table 4(KP-I)A.2 Article 3.3 activities: Deforestation.

A small amount of deforestation in the Overseas Territories and Crown Dependencies on mineral soils was identified and included in the 2017 submission. The limited data only allowed the estimation of carbon stock changes at Tier 1, so biomass carbon stock losses were reported and other carbon stock changes were reported as Not Occurring.

Table 4(KP-I)A.2 Article 3.3 activities: Deforestation. Deforestation land previously reported under afforestation/reforestation and forest management and subject to natural disturbances

No emissions from natural disturbance above the disturbance provision threshold level have occurred in the period covered in the 1990-2015 inventory. The tables have been filled with NA notation keys (Not Applicable) for the current submission.

Table 4(KP-I)A.2 Article 3.3 activities: Deforestation. Information items: Land areas under deforestation by land-use category in the current reporting year

The rows for Forest Land, Wetlands and Other land are filled with the Not Occurring (NO) notation key as only deforestation to Cropland, Grassland or Settlements occurs in the UK.

Table 4(KP-I)B.1 Article 3.4 activities: Forest management. Newly established forest (CEF-ne) and Harvested and converted forest plantations (CEF-hc)

The UK has not elected to report carbon-equivalent forests and therefore the relevant cells are filled with the notation key NA (Not Applicable).

Table 4(KP-I)B.1 Article 3.4 activities: Forest management. Land subject to natural disturbances

The UK will use the provision to exclude emissions from natural disturbances with respect to Article 3(4) (Forest Management). The background levels of emissions from natural disturbances and the disturbance provision thresholds are shown in **Table 11.3**. No emissions from natural disturbance above the disturbance provision threshold level have occurred on Forest Management land in the period covered in the 1990-2015 inventory. The tables have been with filled NO notation keys (Not Occurring) for the current submission.

Table 4(KP-I)B.2. Elected Article 3.4 activities: Cropland Management

Carbon stock changes on cropland in the Overseas Territories and Crown Dependencies are calculated using Tier 1 methodologies, therefore carbon stock changes in below-ground biomass are reported as Not Estimated (no guidance) and litter and dead wood are reported as Not Occurring.

Table 4(KP-I)B.3. Elected Article 3.4 activities: Grazing Land Management

Carbon stock changes on grazing land in the Overseas Territories and Crown Dependencies are calculated using Tier 1 methodologies, therefore carbon stock changes in below-ground biomass are reported as Not Estimated (no guidance) and litter and dead wood are reported as Not Occurring.

Table 4(KP-II)1. Direct N_2O emissions from N fertilization

It is assumed that nitrogen is only applied to newly planted forests on settlement land in the UK, and therefore that no N fertilization occurs on Deforestation or Forest Management land.

Table 4(KP-II)2. CH_4 and N_2O emissions from drained and rewetted organic soils

At present there is insufficient information to allow the estimation of CH_4 fluxes and non-CO_2 fluxes from rewetted soils (reported with the Not Estimated notation key). The UK has a research project to implement the 2013 Wetlands Supplement in the UK context, which will enable reporting in this area by the end of the commitment period.

Table 4(KP-II)4. GHG emissions from biomass burning

There is no controlled burning for management in UK forests, so this is reported as Not Occurring under Afforestation/Reforestation and Forest Management. Controlled burning is prohibited on UK Cropland, so emissions from this are reported using the notation key NO (Not Occurring). Controlled burning does occur on Grazing Land in the UK, particularly on heather moorland, but emissions for this activity have not been estimated and are reported using the notation key NE (Not Estimated).

Wildfires on Deforested land are infrequent and do not occur every year, so are reported using the notation key NO in most years.

11.3.1.3 Information on whether or not indirect and natural GHG emissions and removals have been factored out

The UK inventory approach to estimating forest carbon stock changes is based on modelled growth data rather than national-scale measurements of forest annual volume increments. The CARBINE model is based on yield class tables, and, in principle assumes constant weather and management conditions; therefore 'factoring out' of climate change effects is not required. Work has been undertaken to model the impact of climate, CO_2 and land use change on the carbon balance of terrestrial ecosystems in Great Britain (Levy and Clark 2009) and interaction between these factors. This suggested that interactions are small and the effects of these environmental factors are additive. Nitrogen dynamics were not considered in this work: the extent to which enhanced nitrogen deposition affects forest carbon sequestration remains contentious (Magnani *et al* 2007; Sutton *et al* 2008). Much of the United Kingdom's forest area was established during the 20th century, and forests are still in their first or second rotation.

11.3.1.4 Changes in data and methods since the previous submission (recalculations)

This is the eighth official submission of Article 3.3 and Article 3.4 estimates, and the third in the second Kyoto Protocol commitment period. There have been major methodological and activity data updates to Afforestation and Forest Management and some smaller activities are reported for the first time. Details of recalculations are given in **Table 11.4**.

Table 11.4 Recalculations of 2014 emissions/removals in the 2017 KP-LULUCF submission

IPCC Category	Source Name	2016 Submission 2014	2017 Submission 2014	Units	Comment/Justification
KP.A.1	Afforestation and Reforestation-carbon stock change	-3341.18	-1023.81	Gg CO_2	The incorporation of the National Forest Inventory and small woods (0.1-0.5 ha) datasets and improved alignment with annual wood production statistics has changed the activity data. A new CARBINE soil and litter sub-model has been implemented and transitions between forest management regimes have been improved. The overall impact has been to reduce the AR sink/increase the source, primarily driven by the new soil carbon model predicting soil carbon losses in the first 20 years after planting.
KP.A.1/(KP-II)4	GHG emissions from biomass burning	11.13	15.60	Gg CO_2	Improvements to forest activity data (see above) has changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a wildfire. There are also minor changes to the wildfires areas due to improved activity data.
		0.038	0.055	Gg CH_4	
		0.002	0.003	Gg N_2O	
KP.A.1/(KP-II)1	Direct and indirect N_2O emissions from N fertilization	0.005	0.019	Gg N_2O	Improvements to forest activity data (see above) have changed the area activity data for calculation of forest fertilisation emissions. An error in the application of the conversion factor from N_2O-N to N_2O has also been corrected.
KP.A.1/(KP-II)2	CH_4 and N_2O emissions from drained and rewetted organic soils	0.029	0.046	Gg N_2O	Improvements to forest activity data (see above) have changed the area activity data used to calculate forest drainage emissions.

IPCC Category	Source Name	2016 Submission 2014	2017 Submission 2014	Units	Comment/Justification
KP.A.1/(KP-II)3	N_2O emissions from N mineralization	0.000	0.759	Gg N_2O	Direct and indirect N_2O emissions from mineralisation due to land use change is included here for the first time. The new CARBINE forest soil sub-model estimates a carbon stock loss from mineral soils following afforestation, hence N_2O emissions must be calculated.
KP.C	HWP from AR Land	-26.35	-14.51	Gg CO_2	Improvements to forest activity data (see above), particularly improved alignment with annual wood production statistics, have reduced the estimated net removals from harvested wood production from AR land.
KP.A.2	Deforestation-Carbon stock change	682.45	882.48	Gg CO_2	The area of deforestation has been updated with the improved forest activity data.
KP.A.2/(KP-II)3	N_2O emissions from N mineralization	0.058	0.130	Gg N_2O	The area of deforestation has been updated with the improved forest activity data. Following UNFCCC review comments, indirect emissions from mineralisation have been calculated in addition to the direct emissions.
KP.A.2/(KP-II)4	GHG emissions from biomass burning	208.56	290.68	Gg CO_2	The area of deforestation, and hence controlled burning, has been updated with the improved forest activity data.
		0.625	0.871	Gg CH_4	
		0.035	0.048	Gg N_2O	

IPCC Category	Source Name	2016 Submission 2014	2017 Submission 2014	Units	Comment/Justification
KP.B.1	Forest Management-carbon stock change	-13920.94	-15598.34	Gg CO_2	The incorporation of the National Forest Inventory and small woods (0.1-0.5 ha) datasets and improved alignment with annual wood production statistics has changed the activity data. A new CARBINE soil and litter sub-model has been implemented and transitions between forest management regimes have been improved. The overall effect for FM land varies over the time series. The sink is increased by the additional forest area from the improved activity data, and reduced by the use of the CARBINE forest soil sub-model which predicts a loss in soil carbon for the first twenty years after planting.
KP.B.1/(KP-II)4	GHG emissions from biomass burning	86.34	51.41	Gg CO_2	Improvements to forest activity data (see above) has changed the average biomass density estimates output from the CARBINE forest model, which is used as the activity data for fuel available during a wildfire. There are also minor changes to the wildfires areas due to improved activity data.
		0.296	0.182	Gg CH_4	
		0.016	0.010	Gg N_2O	
KP.B.1/(KP-II)2	CH_4 and N_2O emissions from drained and rewetted organic soils	0.125	0.145	Gg N_2O	Improvements to forest activity data (see above) have changed the area activity data used to calculate forest drainage emissions.
KP.B.1/(KP-II)3	N_2O emissions from N mineralization	0.063	0.089	Gg N_2O	Direct and indirect N_2O emissions from mineralisation due to land use change are included here for the first time. The new CARBINE forest soil sub-model estimates a carbon stock loss from mineral soils following afforestation hence N_2O emissions must also be calculated.

IPCC Category	Source Name	2016 Submission 2014	2017 Submission 2014	Units	Comment/Justification
KP.C	HWP from FM Land	-3265.48	-3840.72	Gg CO_2	Improvements to forest activity data (see above), particularly improved alignment with annual wood production statistics, have increased the estimated net removals from harvested wood production from FM land.
KP.B.2	Cropland Management-carbon stock change	7269.75	12599.66	Gg CO_2	The carbon stock change now includes ongoing emissions on mineral soils due to land use change occurring before 1990 and from organic soils due to pre-1990 drainage (on the recommendation of UNFCCC reviewers).
KP.B.2/(KP-II)3	N_2O emissions from N mineralization	2.216	2.722	Gg N_2O	Indirect emissions from mineralisation have been calculated in addition to the direct emissions, on the recommendation of UNFCCC reviewers. An error in the application of the conversion factor from N_2O-N to N_2O has also been corrected.
KP.B.3	Grazing Land Management-carbon stock change	-2892.18	-6783.47	Gg CO_2	The carbon stock change now includes ongoing emissions on mineral soils due to land use change occurring before 1990 and from organic soils due to pre-1990 drainage (on the recommendation of UNFCCC reviewers). Biomass carbon stock change arising from hedge creation and loss has been included for the first time.
KP.B.3/(KP-II)4	GHG emissions from biomass burning	0.271	0.191	Gg CH_4	Minor changes to the wildfire area, and hence emissions, have arisen due to inclusion of the latest available activity data.
		0.025	0.017	Gg N_2O	
KP.B.3/(KP-II)3	N_2O emissions from N mineralization	0.934	1.156	Gg N_2O	Indirect emissions from mineralisation have been calculated in addition to the direct emissions, on the recommendation of UNFCCC reviewers. An error in the application of the conversion factor from N_2O-N to N_2O has also been corrected.

11.3.1.5 Uncertainty estimates

Uncertainty assessment and quantification of the inventory was undertaken during 2007-2009, with particular focus on the forest carbon modelling components (van Oijen 2007; 2008; 2009; van Oijen and Thomson 2010). This analysis was based on the previously used carbon accounting model used to model carbon pools and fluxes in UK forests, CFlow (Dewar and Cannell 1992), but much of the analysis will also apply to the CARBINE model (described in **Annex 3.4.1** of this report) as they are very similar models, although CARBINE allows wider range of representation of species, growth rates (yield class) and assumed management. The uncertainty arising from the inputs, parameters and model structure of CFlow has been examined, and it has also been compared with a more complex process-based model, BASFOR (van Oijen and Thomson, 2010). This work is described in the 1990-2008 National Inventory Report (see Chapter 11, Section 11.3.1.5).

This work has not yet produced a simple uncertainty estimate for reporting, and work is continuing in this area. Meanwhile, an uncertainty of 40% for Article 3.3 Afforestation/Reforestation and Article 3.4 Forest Management will be used (as estimated for UNFCCC category 4A), an uncertainty of 50% for Article 3.3 Deforestation (based on expert judgement) and an uncertainty of 45% and 50%, respectively, for Article 3.4 Cropland Management and Grazing Land Management (as estimated for the UNFCCC categories 4B and 4C).

Uncertainty from model inputs.

CARBINE requires input data on the afforestation rate (ha yr^{-1}), species, yield class (mean wood volume production at time of maximum mean annual increment, m^3 ha^{-1} yr^{-1}), whether the forest is thinned and felled, the age of harvesting, and whether the forest is clear-felled or not for different forest types and countries in the UK. The management and yield class of private sector woodlands is assumed to be the same as for the public forest estate. Information on the percentage of private sector woodland in production was estimated for each country by comparing the timber production estimated by CARBINE to the timber production statistics for each country.

No measures of statistical uncertainty are associated with the planting statistics because they come from administrative systems (assumed to have total coverage) rather than surveys (Forestry Commission, pers. comm.). This inventory involves the use of data from the National Forest Inventory, which does have estimates of the error associated with the information on the stocked area of woodland, based on the sampling intensity. This is estimated at 1.5% at the 95% confidence interval.

The litter and soil carbon calculations are derived from the new model CARBINE-SCA. Although a new model, CARBINE-SCA has strong association with the litter model ForClim-D (Perruchoud et al., 1999; Liski et al., 2002) and the soil model ECOSSE (Smith et al., 2011). Although some improvements in both the model and its implementation will be needed, sufficient evidence was presented to the LULUCF Inventory Steering Committee from initial validation that the implementation of the new model was recommended. The initial validation has covered 8 relevant data sets over a wide spread of soil types and UK geographical location. Project reviewers have suggested further validation, particularly to greater depth (i.e. to 1m).

11.3.1.6 Information on other methodological issues

Natural disturbances.

The UK has indicated that it will use the provision to exclude emissions from natural disturbances with respect to Article 3(3) (Afforestation and Reforestation) and Article 3(4) Forest Management. The background levels of emissions from natural disturbances and the disturbance provision thresholds are shown in **Table 11.3**. Areas and emissions from wildfires on forest land, cropland and grazing land are included in the KP-LULUCF inventory (see **Chapter 5.2** and **Annex 3.4** for further details). Wildfires are not assumed to result in a permanent change in land use.

Inter-annual variability.

The method used to estimate emissions and removals from AR and FM is based on the CARBINE model. This model is not sensitive to inter-annual variation in environmental conditions so these will not affect the annual growth and decay rates. The area burnt in wildfires does show inter-annual variation and this is included in the emissions methodology.

Deforestation

The method used to estimate emissions and removals from D assumes deforestation is evenly applied to the FM area – which implies that the deforestation has the same age, growth rate and species distribribution as the FM area. It is unknown whether this assumption leads to an under- or over-estimate of emissions due to deforestation. We intend to investigate whether Forestry Commission records can be used to characterise any of the deforestation on the public forest estate to attempt to assess what the effect of this assumption might be.

11.3.1.7 The year of the onset of an activity, if after 2013

In 2014, 14.085 kha of land were afforested and 2.516 kha of forest land were deforested. In 2015, 6.900 kha of land were afforested and 2.814 kha of forest land were deforested.

11.4 ARTICLE 3.3

11.4.1 Information that demonstrates that activities began on or after 1 January 2013 and before 31 December 2020 and are directly human-induced

Under the current methodology, the Forestry Commission, Natural Resources Wales and the Forest Service of Northern Ireland provide annual data on new planting (on land that has not previously been forested). This information is provided for the whole of the UK and the time series extends back before 1990. Information on new planting and restocking are published as separate figures for both state and private woodlands. New planting can be from planting, seeding or natural colonisation. Data come from administrative systems (state forests) and grant schemes (other woodland) (Forestry Statistics, 2015).

Information on deforestation is collated from multiple sources (unconditional felling licences granted, differences between the NFI and NIWT maps, analysis of the forest sub-compartment database, information on open habitat restoration (see **Annex 3.4.4** for details)), and remote sensing, all of which can thereby be shown to be directly human-induced. The time series of activity data is not sufficiently detailed to demonstrate the exact date of deforestation within a year.

11.4.2 Information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from deforestation

The data sources used for estimating Deforestation do not confuse between harvesting or forest disturbance and deforestation. This is because the unconditional felling licences used for the estimation of rural deforestation are only given when no restocking will occur, and the survey of land converted to developed use describes the conversion of forest land to the settlement category, which precludes re-establishment. The Countryside Survey data (used for gap filling) are adjusted in order that deforestation is not over-estimated. New data sources (post-2000) have been used that clearly identify the post-deforestation land use. The issue is further explored in Preliminary estimates of the changes in canopy cover in British woodlands between 2006 and 2015 (Forestry Commission, 2016).

11.4.3 Information on the size and geographical location of forest areas that have lost forest cover but which are not yet classified as deforested

Restocking is assumed for forest areas that have lost forest cover through harvesting or forest disturbance, unless there is deforestation as described above. Information on the size and location of forest areas that have lost forest cover is not explicitly collected on an annual basis. The National Forest Inventory will track areas of clearfelled forest (through satellite imagery and field survey) where canopy cover has been re-established, with any areas remaining unstocked after ten years being classified as confirmed woodland loss (Forestry Commission 2016). A partial assessment of clearfell and restocking in 2012 identified 29 kha of clearfell between 2006 and 2009, of which 18 kha had been restocked by 2012. Further partial assessments are due in 2018 and 2020, which will give a more complete picture of the proportions of clearfelled land awaiting restocking and confirmed deforestation over the second commitment period.

11.4.4 Information related to the natural disturbances provision under Article 3.3

The UK will take up the natural disturbances provision for forest land in the second commitment period. The background, margin and threshold levels for natural disturbances on Forest Management and Afforestation/Reforestation land in the UK are shown in **Table 11.3**. No emissions have been excluded as being due to natural disturbances in the 2017 inventory report.

Forest management in the UK has evolved to cope with disturbance events, notably windstorms, wildfires and extreme weather events with guidance and decision support systems in place. Historical records show that drought, floods and snow and ice are unlikely to cause substantial damage to UK Forests as even events which are extreme for the UK have not caused stand mortality. The UK is not subject to geological disturbance likely to affect Forests.

As disturbance events are generally considered to be part of the forest management cycle in the UK, monitoring mechanisms have not yet been established to provide comprehensive, geo-referenced, data on disturbance events. Background levels and margins for natural disturbances with potential to affect stand mortality have been estimated from historical data sets combined with expert judgement, following the methodology set out in Chapter 2 of the 2013 Kyoto Protocol Supplement of the 2006 IPCC Guidelines.

The timeframes covered by the individual data-sets do not overlap in all cases, with the longest continuous data-set being 2000 to 2013 (for windstorms), which is taken as the calibration period. Where data are not available for individual disturbance categories, data-filling has used the mean over their individual calibration periods. Assumptions concerning salvage logging (see details under individual disturbance categories, below) has allowed emissions associated with salvage-logging to be excluded from the background emissions.

The avoidance of net credits/debits during the accounting period has been achieved through establishing a margin of twice the standard deviation of the sum of emissions resulting from each of the disturbance categories over the calibration period, both for Forest Management and Afforestation and Reforestation, separately. Monitoring of disturbance events in the future will also be more robust than the data-sets over calibration period, ensuring that all disturbances are geo-referenced and excluded from Forest Management, Afforestation or

Reforestation activities for the duration of the Commitment Period, if the disturbance provision is enacted. Emissions resulting from disturbance events (after the exclusion of emissions from salvage-logging) have been estimated on the basis of instantaneous oxidation.

For Forest Management, carbon stocks and thus emissions (per hectare) are estimated on the basis of mean carbon stocks for conifers (295 tCO_2e/ha) and broadleaves (298 tCO_2e/ha), respectively, reported by the National Forest Inventory (Forestry Commission 2015). With the exception of wildfire events (see below) carbon stocks associated with Afforested and Reforested land are assumed to be 20% of those of Forest Managed land, reflecting their younger growth phase.

The annual emissions from wildfire on Forest Management and Afforestation and Reforestation land reported in the UK's LULUCF GHG inventory have been used for the calibration period. 45% of biomass is assumed to be burned, with no distinction made between total carbon stocks on Forest Management and Afforestation and Reforestation land. Wildfire is apportioned to Forest Management and Afforestation and Reforestation on the basis of the ratio between the two forest categories. Salvage-logging is not assumed to occur on land affected by wildfire. The more detailed data recorded by the UK Fire and Rescue Services will be used if the disturbance provision was implemented during the second commitment period.

Data on pest and disease infestations came from Statutory Plant Health Notices (SPHNs) which are issued when felling is required to combat the infestation (published in Forestry Statistics). Restocking is not required following issuance of an SPHN; however it is strongly encouraged, supported by grant-aid and experience to date indicates that more than 99% of the area has been restocked either by planting or natural regeneration. 80% of the SPHN area has been allocated to Forest Management and 20% to Afforestation and Reforestation (expert judgement), with 80% salvage-logging assumed for Forest Management land and 20% for Afforestation and Reforestation land. Further surveillance is provided through the field survey associated with the National Forest Inventory across approximately 3,000 one hectare sample squares per annum.

Data on wind damage came from detailed records which the Forestry Commission holds on the wind throw damage to the 250 kha of land it manages in England which was extrapolated to the UK. It is assumed that Afforestation and Reforestation land is not affected by windstorm due the young age of the forest, with all emissions from Forest Management land. 80% salvage-logging is assumed to have occurred in conifer woodland and 50% in broadleaf woodland, based on experience from a severe windstorm in 1987 (Forestry Commission 1996). Remote sensing is being deployed more extensively to monitor woodlands in the UK as part of the National Forest Inventory. If the disturbance provision was enacted to cover a major windstorm event, these data would be used to provide robust coverage, including geo-referencing across public and private woodlands.

Full details of the methodology used to assess background levels, margins and thresholds for emissions from natural disturbances is in the UK's Initial Report under the Second Commitment Period of the Kyoto Protocol (DECC, 2016).

11.4.5 Information on Harvested Wood Products under Article 3.3

Carbon stock changes in the harvested wood products (HWP) pool (Table 4(KP-I)C) are reported for the first time in the second commitment period. Carbon stock changes in the HWP pool are calculated on a first-order decay function basis for AR and FM forests and on an instantaneous oxidation basis for Deforestation, in accordance with the 2013 Kyoto Protocol Supplementary Guidance (see Annex 3.4 for details). HWP from AR land includes all domestically produced HWP from Afforestation land since 1990.

11.5 ARTICLE 3.4

11.5.1 Information that demonstrates that activities under Article 3.4 have occurred since 1 January 1990 and are human-induced

All managed forests (planted on or before 31st December 1989) are included in Article 3.4 Forest Management because forest management is an on-going activity. The CARBINE model is used to calculate emissions from this forest area after 1990 that have arisen from thinning, harvesting and restocking. The area under Forest Management is adjusted to reflect losses from deforestation, as recorded in **Section 11.1.2**.

Emissions from Article 3.4 Cropland Management after 1990 are calculated using agricultural census data and surveys of farming practices collected from 1990 onwards. Cropland is subject to intensive management interventions, and therefore any changes in carbon stock can be assumed to be human-induced. Emissions from Article 3.4 Grazing Land Management are calculated using Countryside Survey data from 1990 onwards. Grazing land in the UK is all subject to management activity, and therefore it can be assumed that any changes in carbon stocks are human-induced.

11.5.2 Information relating to Forest Management

11.5.2.1 Conversion of natural forest to planted forest

There are assumed to be no emissions arising from the conversion of natural forests to plantation forests. It has been a long-standing and on-going policy in the UK to restore areas of woodland historically converted to plantations back towards semi-natural woodland.

11.5.2.2 Forest Management Reference Level (FMRL)

The UK's Forest Management Reference Level (FMRL) during the second commitment period, as identified in the appendix to the annex to Decision 2/CMP.7, is -3.442 Mt CO_2 eq/yr, or -8.268 Mt CO_2 eq/yr when applying first order decay function for harvested wood products.

The forest management reference level for the UK was estimated using the same methodology as the UNFCCC LULUCF inventory, the Kyoto Protocol LULUCF inventory and national projections of LULUCF emissions and removals to 2020. The methodology is described in **Chapter 6** and **Annex 3**. A technical correction to the FMRL was calculated for the 2016 inventory submission and is described below.

11.5.2.3 Technical Corrections of FMRL

The UK has calculated a technical correction (TC) to the FMRL for the 1990-2015 inventory. The FMRL submitted by the UK in 2011 was based on the 1990-2008 UK greenhouse gas inventory. A technical correction was submitted based on the 1990-2014 inventory, since when the following changes in data and assumptions necessitate a new technical correction for the 2017 submission:

- A new soil and litter model has been implemented to better model the effects of afforestation on soil under UK conditions.
- The National Forest Inventory is used to provide information on the age class distribution of the forest area; this is based on more recent data than the National Inventory of Woodlands and Trees.
- The area of small woods, between 0.1 and 0.5 ha, has been included in the 2015 inventory for the first time.
- Change in tree growth assumptions – the information from the National Inventory of Woodlands and Trees is used to give a better indication of the mix of tree species in

the UK forests and information from data on the national forest estate is used to give a better indication of the growth rate distribution by species.

- Updated information on the rate of deforestation – a new assessment has been made based on comparison of the 2006 and 2015 NFI woodland maps supported by new data on conversion of Forest land to settlement from remote sensing.
- Updated approach to estimating the incidence of emissions from wildfires.

The UK Greenhouse Gas Inventory approach to estimating carbon stock changes uses a carbon accounting model, CARBINE, driven by historical planting data and data on species, management practice and growth rate distributions. It is assumed that current management practices are continued into the future, and no allowance is made in the projection for changes in management practice, e.g. due to increased demand for bioenergy feedstock (which might involve shorter rotations or more intensive management of woodlands) or more widespread use application of continuous cover management (which might involve longer rotations). This also factors out the effects of post-2009 changes to policies affecting forest management.

The following pools and gases are included in the corrected FMRL: carbon stock changes in above and below ground biomass, litter, deadwood, mineral and organic soils and harvested wood products, and CO_2, CH_4 and N_2O emissions from biomass burning in wildfires.Further details are given in **Annex 3.** No pools are omitted from the reference level construction and there is no double counting. The pools included in the reference level are consistent with those reported in the KP and UNFCCC LULUCF inventories. Below-ground biomass is included in the above-ground biomass pool, and deadwood is included in the litter pool.

The area under forest management between 1990 and 2020 was compiled using information of the area of forest in the National Forest Inventory. This area is adjusted upwards to include deforestation since 1990 and then adjusted for each year from 1990 to take account of losses due to deforestation. This is the area reported under Forest Management for article 3.4 of the Kyoto Protocol.

Table 11.5 Area under forest management and emissions/removals from forest management 1990-2020 (based on the 2016 inventory submission)

Year	Area of FM land, kha	Net CO_2 emissions/ removals from carbon stock changes, Gg CO_2	Emissions from wildfire biomass burning, Gg CO_2eq	Emissions/ removals from HWP, Gg CO_2	Net emissions/ removals, Gg CO_2eq
1990	2867	-11090	42	-974	-12022
1991	2866	-12508	71	-753	-13189
1992	2865	-13314	18	-809	-14105
1993	2864	-13754	32	-922	-14644
1994	2863	-14191	25	-971	-15136
1995	2863	-14567	201	-1053	-15419
1996	2862	-15238	105	-1030	-16163
1997	2861	-15497	138	-1148	-16506
1998	2860	-16174	78	-1123	-17220
1999	2859	-16362	12	-1237	-17587
2000	2855	-16823	43	-1259	-18039
2001	2852	-17435	59	-1177	-18553
2002	2849	-17761	50	-1171	-18882
2003	2846	-17642	43	-1277	-18877
2004	2843	-17480	55	-1399	-18824
2005	2840	-17575	103	-1373	-18845
2006	2838	-17674	102	-1367	-18940

Year	Area of FM land, kha	Net CO_2 emissions/ removals from carbon stock changes, Gg CO_2	Emissions from wildfire biomass burning, Gg CO_2eq	Emissions/ removals from HWP, Gg CO_2	Net emissions/ removals, Gg CO_2eq
2007	2835	-17245	90	-1512	-18667
2008	2832	-17747	84	-1286	-18950
2009	2829	-17480	73	-1336	-18743
2010	2826	-16816	35	-1585	-18366
2011	2823	-15905	46	-1813	-17673
2012	2820	-14170	218	-2316	-16268
2013	2817	-15523	52	-1597	-17069
2014	2814	-15583	59	-1464	-16988
2015	2811	-14504	0	-1766	-16270
2016	2809	-14785	64	-1497	-16218
2017	2807	-14192	64	-1574	-15702
2018	2805	-13664	64	-1609	-15209
2019	2803	-13261	64	-1589	-14786
2020	2801	-12943	64	-1551	-14431

Historical and projected emissions and removals from 1990 to 2020 are also shown in **Table 11.5**. These are consistent with the national GHGI in the 2016 submission, as they are based on the same activity data and use the same methods. Wildfire emissions are also shown, both historical and projected, as described in **Chapter 6** and **Annex 3**. Projections are based upon business as usual assumptions and are consistent with the approach taken in calculating the original FMRL. Projected estimates rely on the same methodology as that used for estimating historical emissions and removals.

It is assumed for the business-as-usual projection that historical management (rotation lengths and thinning regime and felling regimes) will continue in to the future, with the effect that harvesting rates are largely driven by historical planting rates. The pre-2010 policies included are the same as for the original FMRL submission. The projections used for the forest management reference level are based on the methodology used for the 1990-2015 inventory. The pre-1990 woodland area is based on the National Forest Inventory, which assessed the state of the woodland for a base year of 2011. It is assumed that there were no significant effects from post-2009 policies in the area and age distribution. Standard management regimes are rolled forward and do not take account of any policies implemented after mid-2009.

The corrected FMRL was calculated from the average of the Business as Usual projection for the period 2013-2020 (**Table 11.5**). The Technical Correction was calculated as $FMRL_{corr}$ - $FMRL_{orig}$ and is shown in **Table 11.6**.

Table 11.6: Forest Management Reference Levels and Technical Correction for the period 2013-2020.

	Assuming instantaneous Oxidation, Gg CO_2eq	With emissions/removals from HWP using first order decay functions, Gg CO_2eq
Submitted FMRL ($FMRL_{orig}$)	-3442	-8268
Corrected FMRL ($FMRL_{corr}$)	-14253	--15834
Technical Correction	-10811	-7566

11.5.2.4 Information related to the natural disturbances provision under Article 3.4

Data sources used to assess the background, margin and trigger levels for natural disturbance on Forest Management land are the same as those detailed in section 1.4.4 for assessing natural disturbance values for Afforested and Reforested land.

11.5.2.5 Information on Harvested Wood Products under Article 3.4

Carbon stock changes in the harvested wood products (HWP) pool (Table 4(KP-I)C) are reported for the first time in the second commitment period. Carbon stock changes in the HWP pool are calculated on a first-order decay function basis for AR and FM forests and on an instantaneous oxidation basis for Deforestation (since 1990), in accordance with the 2013 Kyoto Protocol Supplementary Guidance (see **Annex 3.4** for details).

HWP are included in Forest Management in the second commitment period as the UK's FMRL was based on a projection. HWP is only included from 2013 onwards because:

- The UK accounted for FM in the first commitment period, where HWP was assumed to be instantaneously oxidised to the atmosphere; and
- As the UK's FMRL is based on a projection which represents a "business as usual scenario", inherited emissions from HWP before the start of the commitment period (i.e. all HWP from FM land produced 1990-2012) can be excluded as long as there is consistency between the FMRL and the accounting during the commitment period.

Carbon stocks in Harvested Wood Products are estimated by CARBINE according to the time of planting and yield table assigned. All areas of forest in the UK are assigned an assumed afforestation year – i.e. a year when the forest was originally planted. For land that is assumed to have been forest for a long time, this is nominally two rotations before the current year in the inventory. In-forest logs are generated by CARBINE each time the assigned management regime indicates a harvesting event took place – either thinning of felling of the forest. Based on the classification of the size of these logs (tips, roundwood or sawlogs) they are assigned to the final HWP classes (fuel, pulp, panels and sawnwood). These HWP are then decayed according to the IPCC default half lives.

HWPs are thus generated for all woodland that was in existence in 1990 from the time of afforestation (nominally back to 1500 for the earliest afforestation) up to the reporting year. HWPs for land deforested before 1990 are not modelled and therefore not included, HWPs for land deforested since 1990 are accounted for on the basis of instantaneous oxidation.

11.5.3 Information relating to Cropland Management, Grazing Land Management and Revegetation, Wetland Drainage and Rewetting, if elected, for the base year

The UK has elected three additional Article 3.4 activities: Cropland Management, Grazing Land Management and Wetland Drainage and Rewetting. Emissions and removals from Cropland soils and biomass as a result of land use change, management activities and wildfires are reported for both Cropland Management and Grazing Land Management.

The UK is not yet in a position to report emissions and removals from soils as a result of grassland management or from drainage of semi-natural Grazing Land on organic soils. Nor is it yet able to report on emissions and removals from other Wetland Drainage and Rewetting activities. The UK has put in place a research and methodological development programme for these activities to enable full reporting by the end of the commitment period.

11.6 OTHER INFORMATION

11.6.1 Key category analysis for Article 3.3 activities and any elected activities under Article 3.4

Five categories are considered to be key: Article 3.3 Afforestation and Reforestation (CO_2), Article 3.3 Deforestation (CO_2), Article 3.4 Forest Management (CO_2), Article 3.4 Cropland Management (CO_2), and Article 3.4 Grazing Land Management (CO_2). These have been assessed according to the IPCC 2013 Kyoto Protocol Supplement Section 2.3.6. The numbers have been compared with key category analysis for the latest reported year (2015) based on level of emissions (including LULUCF).

Article 3.3 Afforestation and Reforestation (CO_2): The associated UNFCCC category 4A (-15 980 Gg CO_2e) is a key category and the AR component (forest planted since 1990) is key on its own (i.e. its category contribution (-1 253 Gg CO_2e) is greater than the smallest UNFCCC key category (5B Biological treatment of solid waste). Removals from this category are also predicted to increase over time as a result of tree planting schemes partially focussed on climate change mitigation.

Article 3.3 Deforestation (CO_2): The associated UNFCCC categories (4B, 4C and 4E) are key categories (11 783, -9 144 and 6 081 Gg CO_2e respectively), and the Deforestation category contribution (1 382 Gg CO_2e) is key on its own.

Article 3.4 Forest Management (CO_2): The associated UNFCCC category 4A is a key category (-15 980 Gg CO_2e). The Forest Management category contribution (-18 662 Gg CO_2e) is also greater than other categories in the UNFCCC key category analysis.

Article 3.4 Cropland Management (CO_2): The associated UNFCCC category 4B is a key category (11 783 Gg CO_2e). The Cropland Management category contribution (13 292 Gg CO_2e) is also greater than the smallest UNFCCC key category.

Article 3.4 Grazing Land Management (CO_2): The associated UNFCCC category 4C is a key category (-9 144 Gg CO_2e). The Grazing Land Management category contribution (-6 492 Gg CO_2e) is also greater than the smallest UNFCCC key category.

11.6.2 Information relating to Article 6

Not applicable in the United Kingdom.

12 Information on Accounting of Kyoto Units

12.1 BACKGROUND INFORMATION

The UK's Standard Electronic Format report for 2016 containing the information required in paragraph 11 of the annex to decision 15/CMP.1 and adhering to the guidelines of the SEF has been submitted to the UNFCCC Secretariat electronically – RREG1_GB_2016_2_1.xls for commitment period 2.

12.2 SUMMARY OF INFORMATION REPORTED IN THE SEF TABLES

Commitment Period 2

At the end of 2016, the total CP2 holdings for the UK Registry were 2,825,417 CERs, of which 362,188 were in the voluntary cancellation account.

In total for 2016, the UK Registry received 17,657,991 CERs. Conversely, 16,342,737 CERs were externally transferred to other national registries. No other CP2 units were transferred or acquired.

319,927 CERs were cancelled.

Full details are available in the SEF tables.

Information on legal entities authorised to participate in mechanisms under Articles 6, 12 and 17 of the Kyoto Protocol can be found on the UK Emissions Registry website in the Kyoto Protocol Public Reports area at

https://ets-registry.webgate.ec.europa.eu/euregistry/GB/public/reports/publicReports.xhtml

Annual Submission Item	Reporting Guidance
15/CMP.1 annex I.E paragraph 11: **Standard electronic format (SEF)**	UK's Standard Electronic Format report for 2016 containing the information required in paragraph 11 of the annex to decision 15/CMP.1 and adhering to the guidelines of the SEF has been submitted to the UNFCCC Secretariat electronically. SEF_RREG1_GB_2016_2_1.xlsx (Commitment Period 2 only). The contents of the SEF report (R1) can also be found in Annex 6 of this document.

12.3 DISCREPANCIES AND NOTIFICATIONS

Annual Submission Item	Reporting Guidance
15/CMP.1 annex I.E paragraph 12: **List of discrepant transactions**	No discrepant transactions occurred in 2016. This is confirmed in the table named “R2” in the Excel file included, SIAR Reports 2016-GB v1.0.xls The contents of the Report R2 can also be found in Annex 6 of this document.
15/CMP.1 annex I.E paragraph 13 & 14: **List of CDM notifications**	No CDM notifications occurred in 2016. Refer to Separate Electronic Attachment “SIAR Reports 2016-GB v1.0.xls” Worksheet R3. The contents of the Report R3 can also be found in Annex 6 of this document.
15/CMP.1 annex I.E paragraph 15: **List of non-replacements**	No non-replacements occurred in 2016. Refer to Separate Electronic Attachment “SIAR Reports 2016-GB v1.0.xls” Worksheet R4. The contents of the Report R4 can also be found in Annex 6 of this document.
15/CMP.1 annex I.E paragraph 16: **List of invalid units**	No invalid units exist as at 31 December 2016. Refer to Separate Electronic Attachment “SIAR Reports 2016-GB v1.0.xls” Worksheet R5. The contents of the Report R5 can also be found in Annex 6 of this document.
15/CMP.1 annex I.E paragraph 17 **Actions and changes to address discrepancies**	Actions and changes are addressed in Chapter 14: Information on Changes to National Register under section Change of discrepancies procedures.

12.4 PUBLICLY ACCESSIBLE INFORMATION

Annual Submission Item	Reporting Guidance
15/CMP.1 annex I.E	The following information is deemed publicly accessible and as such is usually available via the homepage of the UK registry via the Kyoto Protocol Public Reports link at https://ets-registry.webgate.ec.europa.eu/euregistry/GB/public/reports/publicReports.xhtml

Annual Submission Item	Reporting Guidance
Publicly accessible information	In accordance with the requirements of Annex E to Decision 13/CMP.1, all required information for a Party with an active Kyoto registry is provided with the exceptions as outlined below.
	Account Information (Paragraph 45) In line with the data protection requirements of Regulation (EC) No 45/2001 and Directive 95/46/EC and in accordance with Article 110 and Annex XIV of Commission Regulation (EU) no 389/2013, the information on account representatives, account holdings, account numbers, all transactions made and carbon unit identifiers, held in the EUTL, the Union Registry and any other KP registry (required by paragraph 45) is considered confidential. JI projects in UK (Paragraph 46) Note that no Article 6 (Joint Implementation) project is reported as conversion to an ERU under an Article 6 project, as this did not occur in the specified period. The United Kingdom has taken the decision not to host any domestic JI projects, clarification of which is on our registry public reports page https://ets-registry.webgate.ec.europa.eu/euregistry/GB/public/reports/publicReports.xhtml Paragraph 47 a/d/f - Holding and transaction information of units Holding and transaction information is provided on a holding type level, due to more detailed information being declared confidential by EU Regulation. Article 110 of Commission Regulation (EU) 389/2013, provides that "Information, including the holdings of all accounts, all transactions made, the unique unit identification code of the allowances and the unique numeric value of the unit serial number of the Kyoto units held or affected by a transaction, held in the EUTL, the Union Registry and any other KP registry shall be considered confidential except as otherwise required by Union law, or by provisions of national law that pursue a legitimate objective compatible with this Regulation and are proportionate.." Paragraph 47c The United Kingdom is not hosting domestic JI projects as per paragraph 46 above.
	Paragraph 47e The United Kingdom is currently not participating in any LULUCF projects for 2016. Paragraph 47g No ERUs, CERs, AAUs and RMUs have been cancelled on the basis of activities under Article 3, paragraphs 3 and 4 to date. Paragraph 47h No ERUs, CERs, AAUs and RMUs have been cancelled following determination by the Compliance Committee that the Party is not in compliance with its commitment under Article 3, paragraph 1 to date. Paragraph 47j No ERUs, CERs, AAUs and RMUs have been retired in 2016 for CP2. Paragraph 47k

Annual Submission Item	Reporting Guidance
	Although we have now entered a new commitment period, no previous commitment period carry over transactions have yet taken place. This will be completed as part of the true up process. <u>Account holders authorised to hold Kyoto units in their account (Paragraph 48)</u> In line with the data protection requirements of Regulation (EC) No 45/2001 and Directive 95/46/EC and in accordance with Article 110 and Annex III of the Commission Regulation (EU) no 389/2013, the legal entity contact information (required by paragraph 48) is considered confidential.

12.5 CALCULATION OF THE COMMITMENT PERIOD RESERVE (CPR)

15/CMP.1 annex I.E paragraph 18 **CPR Calculation**	The Annex to Decision 11/CMP.1 (paragraph 6) specifies that: '*each Party included in Annex I shall maintain, in its national registry, a commitment period reserve which should not drop below 90 per cent of the Party's assigned amount calculated pursuant to Article 3, paragraphs 7 and 8 of the Kyoto Protocol, or 100 per cent of five times its most recently reviewed inventory, **whichever is lowest***'. Therefore the **UK's commitment period reserve** is calculated as: Either UK's Adjusted Assigned Amount **x** 90% 2,744,937,332 **x** 0.90 = 2,470,443,599 assigned amount units Or 2014 Total Emissions* **x** Total years of the second commitment period 527,500,751 **x** 8 = 4,220,006,008 assigned amount units *Emissions total is taken from Table 10s1 of the CRF and are shown in tonnes CO_2 equivalent. The lower of the two numbers is that calculated as 90 per cent of the UK's assigned amount. The UK's Commitment Period Reserve is therefore **2,470,443,599 tonnes of CO_2 equivalent (or assigned amount units).**

13 Information on Changes to the National System

13.1 CHANGES TO THE NATIONAL SYSTEM

The UK Department of Energy & Climate Change (DECC) was previously the Single National Entity responsible for the compilation of the UK's GHG Inventory. In July 2016 DECC was replaced by the Department of Business, Energy & Industrial Strategy (BEIS), which has taken over all of DECC's responsibilities with regards to the UK's GHG Inventory. BEIS is now the Single National Entity for the UK's National Inventory System.

The inventory agency has changed its trading name from Ricardo-AEA to Ricardo Energy & Environment.

In October 2016 a new 3-year contract was established for the UK Inventory Agency following a competitive tendering exercise. Ricardo Energy & Environment will continue to lead a consortium responsible for compiling the UK's Inventory, under contract to BEIS. This contract differs from the previous one in that it incorporates production of LULUCF and KP-LULUCF emissions estimates by the Centre for Ecology and Hydrology, where previously this was contracted separately. Agriculture estimates continue to be produced by Rothamsted Research, under contract to the Department of Environment, Food & Rural Affairs.

Key roles within the National Inventory System are shown in the Introduction.

14 Information on Changes to the National Registry

The following changes to the national registry of United Kingdom have therefore occurred in 2016.

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(a) Change of name or contact	None
15/CMP.1 annex II.E paragraph 32.(b) Change regarding cooperation arrangement	No change of cooperation arrangement occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(c) Change to database structure or the capacity of national registry	New tables were added to the CSEUR database for the implementation of the CP2 SEF functionality. Versions of the CSEUR released after 6.7.3 (the production version at the time of the last Chapter 14 submission) introduced other minor changes in the structure of the database. These changes were limited and only affected EU ETS functionality. No change was required to the database and application backup plan or to the disaster recovery plan. The database model, including the new tables, is provided in Annex A. No change to the capacity of the national registry occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(d) Change regarding conformance to technical standards	Changes introduced since version 6.7.3 of the national registry are listed in Annex B. Each release of the registry is subject to both regression testing and tests related to new functionality. These tests also include thorough testing against the DES and were successfully carried out prior to the relevant major release of the version to Production (see Annex B). Annex H testing was completed in January 2017 and the test report will provided at a later date. No other change in the registry's conformance to the technical standards occurred for the reported period.

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(e) Change to discrepancies procedures	No change of discrepancies procedures occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(f) Change regarding security	The mandatory use of hard tokens for authentication and signature was introduced for registry administrators.
15/CMP.1 annex II.E paragraph 32.(g) Change to list of publicly available information	No change to the list of publicly available information occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(h) Change of Internet address	No change of the registry internet address occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(i) Change regarding data integrity measures	No change of data integrity measures occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(j) Change regarding test results	Changes introduced since version 6.7.3 of the national registry are listed in Annex B. Both regression testing and tests on the new functionality were successfully carried out prior to release of the version to Production. The site acceptance test was carried out by quality assurance consultants on behalf of and assisted by the European Commission; the report is attached as Annex B. Annex H testing was carried out in January 2017 and the test report will be provided at a later date.

15 Information on minimization of adverse impacts in accordance with Article 3, paragraph 14

15.1 GENERAL OVERVIEW

The UK is committed to action aimed at minimising the impacts on developing countries from climate change, including any adverse impacts resulting from action taken to mitigate climate change as outlined in Article 3, paragraph 14 of the Kyoto Protocol.

The Paris Agreement reached at the 21st UNFCCC Conference fo Parties in Paris in December 2015 takes a significant step towards reducing, on a global scale, the emissions that cause climate change. The UK fully supports the Paris Agreement and played an integral role, alongside the EU and its Member States, in the negotiations. In addition to driving forward efforts to keep average global temperature rise to well below 2°C and to pursue efforts to 1.5°C, the Agreement also sets a long term goal of net zero emissions in the second half of the century.

Integral to the agreement is the recognition of the role of both developed and emerging economies in helping the poorest and most vulnerable to curb emissions whilst developing, and protecting themselves from the worst effects of climate change. The Agreement establishes a new long term goal to strengthen adaptation and resilience and reduce vulnerability to climate change. The UK, through deployment of the International Climate Fund (ICF), drives sustainable economic development and helps millions of the poorest and most vulnerable in developing countries build resilience and cope with the increased risk of floods and droughts

The Paris Agreement sends a clear signal to businesses and investors that the shift to the low carbon economy is global and irreversible and gives confidence to drive the scale of investment needed. Low carbon opportunities can unlock markets in countries around the world and support poorer and more vulnerable countries to develop sustainably, but we must also be alert to any negative impacts of this transition and make efforts to prevent adverse effects and improve the exchange of evidence-based information to inform our understanding of the effects.

The UK continues to pursue climate initiatives that have been mentioned in previous inventory reports and national communications and this chapter is not an exhaustive list but instead outlines recent examples of what the UK is doing to support developing countries to adapt to climate change, build capacity to curb their emissions and develop sustainably as well as those efforts aimed at understanding the impacts of mitigation action on developing countries and how to minimise any adverse impacts.

This chapter has been updated for the 2016 NIR submission. Changes include:

- An update on EU activities in 15.2.2;
- An update on the International Climate Fund in 15.2.4
- An update on Mission Innovation in 15.2.6
- An update on new research programmes in 15.2.1

15.2 UNDERSTANDING IMPACTS OF RESPONSE MEASURES

Understanding the impacts of response measures is a key step to be able to minimize the adverse impacts. The UK continues to undertake assessments, reviews and analysis projects to better understand the impacts its policies could have on developing countries, and how they could be addressed. Consequently, the UK takes these findings and seeks to apply them in UK and within the EU community in order to minimize adverse impacts in accordance with article 3, paragraph 14. Recent examples of areas where ongoing research and action is taking place are outlined below.

15.2.1 UK research, reports and analysis

The UK has undertaken research to determine the extent of impacts of response measures and uses this information to implement policies in a way that takes into account the impacts of response measures on all developing countries. Examples of ongoing work are listed below.

- A scoping study commissioned by BEIS to review the available scientific literature on the co-benefits and possible adverse side effects of climate change mitigation. This research will identify knowledge gaps and make recommendations for areas of future research.
- BEIS have recently funded two major programmes of research on 1.5 degree pathways and the limitations and possible impacts of 1.5 degree consistent mitigation options (for example widespread deployment Bioenergy, Carbon Capture and Storage).

To support the UK 2050 Pathways Analysis DECC developed a 2050 Energy and Emissions Calculator model. The Calculator is a tool that helps strengthen the level of debate on energy issues in the UK. Over the last four years, the Department for Business, Energy and Industrial Strategy has supported countries around the world to develop their own calculators to explore their options to reduce greenhouse gas emissions and help tackle energy challenges.

- An International Climate Fund programme has directly supported teams in India, Indonesia, Brazil, Mexico, Colombia, Nigeria, South Africa, Vietnam, Thailand and Bangladesh. These ten countries have now published finished calculators online. Many other countries, both developed and developing, have also adopted the model, for example China, Japan and Austria.
- There is evidence that they are starting to have a policy impact. For example, four countries (India, Colombia, Vietnam and Nigeria) used their calculators to help develop their Intended Nationally-Determined Contributions (INDCs) for the UNFCCC conference in Paris, and India is using it to develop their new national energy policy. Many countries are also keen to use their calculators to communicate with stakeholders and the general public. For example, the South African Government has developed a simplified version for use in schools, and is providing training to teachers on how to use it.
- DECC, working in collaboration with a number of other organisations, has built a Global Calculator, which enables users to explore the options for reducing global emissions, and the impact of climate change associated with them. Please see the Global Calculator website for more information on the project (www.globalcalculator.org). Since its launch in January 2015, the website has had over 90,000 hits, and the tool itself over 29,000.

The UK Department of Transport has and continues to lead work into understanding Indirect Land Use Change (ILUC) impacts from biofuels. Examples include:

- A study in 2011 which considered the potential for regional (i.e. sub-national, national and supranational) approaches to avoid ILUC from biofuels production. This work highlighted potential actions that may reduce ILUC, and assessed the potential to measure and monitor any such regional level actions to avoid ILUC[53].
- In 2013 the Department of Transport published a report on the sustainability of feedstock[54].

The UK Department for the Environment, Food and Rural Affairs (Defra) has funded and continues to fund research looking at embedded emissions and sustainable production and consumption, in particular:

- The development of an embedded carbon emissions indicator. The aim of this project is to monitor greenhouse gas emissions associated with UK consumption, including those relating to trade flows. This work will provide a high level analysis of the UK national "carbon footprint", and in particular will assess the emissions which are embedded in products which the UK imports and exports[55].

This year's output from the monitoring, which is published in the Official Statistics Release, can be found online[56].

15.2.2. Within the EU

The UK has been an active participant within EU climate policy and the EU itself has played a leading role in securing a strong Paris Agreement with a mechanism to ensure global climate ambition into the future. In June 2016, the people of the United Kingdom voted in the EU referendum to leave the EU. Until exit negotiations are concluded, the UK remains a full member of the EU and all the rights and obligations of EU membership remain in force. During this period the Government will continue to negotiate, implement and apply EU legislation.

Existing EU policies and measures for limiting emissions include the following:

- The EU Emissions Trading System (EU ETS) is the EU's main vehicle for reducing CO_2 emissions from the power, industrial and aviation sectors. The UK is a leading proponent of reform of the EU ETS. The UK was influential in securing a strengthening of the European Commission's proposal for a Market Stability Reserve (MSR). We also continue to promote and promoting wider changes to the system post-2020, to ensure that the system can continue to deliver emissions reductions as cost effectively as possible;
- The EU Effort Sharing Decision (ESD) set targets for 2020 for emissions reductions or growth limits in those sectors of Member States' economies not covered by the EU ETS (excluding Land Use, Land Use Change and Forestry, LULUCF). For the UK, the target to reduce emissions in the non-ETS is 16% below 2005 levels by 2020. For the EU as whole, the 2020 reduction target is 10%; and
- The EU energy efficiency framework includes a number of directives spanning all sectors of the economy. The directives include the Energy Performance of Buildings

53 http://www.dft.gov.uk/publications/regional-level-actions-to-avoid-iluc

54 https://www.gov.uk/government/publications/biofuel-research

55 http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=17729&FromSearch=Y&Publisher=1&SearchText=emissions&GridPage=7&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

56 http://www.defra.gov.uk/statistics/environment/green-economy/scptb01-ems/

Directive, Energy Efficiency Directive, Ecodesign and Energy Labelling directives, as well as vehicle emission performance standards. These legislative requirements drive progress towards the EU's non-binding target to reduce primary energy consumption by 20% by 2020 which was agreed as part of the EU2020 package. The UK is currently on track to over-achieve against the 2020 target and the supplementary targets established by the Energy Efficiency Directive.

The EU2030 climate and energy framework was agreed by EU leaders in October 2014. It sets the EU a binding target of at least 40% domestic reduction in greenhouse gas (GHG) emissions by 2030 compared to 1990. This target formed the basis of the EU's contribution for the Paris Agreement under the UNFCCC. EU legislation to implement the EU2030 GHG target - through reforms to the EU ETS and the introduction of an Effort Share Regulation (ESR) and a Land Use, Land Use Change and Forestry (LULUCF) Regulation – is currently being negotiated.

The EU 2030 climate and energy framework also contains a 27% renewables target, which is binding at the EU level, and an indicative EU level energy efficiency target of 27%. Implementation of this framework (including proposals to make the energy efficiency target binding at the EU level) will be taken forward through legislative proposals on energy efficiency, renewable energy and governance of the Energy Union in the "Clean Energy for all Europeans" package published in November 2016 and currently subject to negotiation.

15.2.3 Actions to minimize adverse impacts in accordance with Article 3, paragraph 14

The UK Government supports the historic agreement reached in the 21st UNFCCC Conference of Parties in Paris in December 2015. The Paris Agreement is a significant step forward on our path to limiting global temperature rises to below 2°C, and agrees to pursue efforts towards 1.5°C. The Agreement also recognises the role of both developed and emerging economies in helping the poorest and most vulnerable to curb emissions whilst developing, and protect themselves from the worst effects of climate change. The transition to a low carbon world requires support to developing countries in their domestic efforts to mitigate and adapt to climate change and to develop their own low carbon economies.

The UK has taken action to minimize adverse impacts in accordance with article 3, paragraph 14 through its International Climate Fund (ICF), which is providing £3.87bn of climate finance from 2011 to 2016. This funding is focused on helping the poorest people adapt to the effects of climate change, helping to encourage low carbon development, and protecting the world's forests and the livelihoods of the people who depend on them.

In September 2015, the Prime Minister announced that the UK will significantly increase our climate finance (to at least £5.8 billion) over the next five years, so that in 2020 the UK's annual climate finance will be double that in 2014. This commitment and the ICF demonstrates the UK's commitment, alongside other developed countries, to jointly mobilise $100bn of public and private finance a year by 2020.

15.2.4 The International Climate Fund

The ICF aims to demonstrate that building low carbon, climate resilient growth at scale is feasible and desirable. Additionally, it is intended to support climate negotiations, particularly through providing support for adaptation in poor countries, supporting developing countries in international climate talks and building an effective international architecture. The ICF also recognises that climate change offers real opportunities to drive innovation and new ideas for action, and create new partnerships especially with the private sector to support low carbon climate resilient growth. Detailed information on the ICF, including on the projects that it is supporting, can be found through our website[57]. Some examples of the types of projects that are supported by the fund follow.

In 2015, DECC launched UK Climate Investments, a joint venture with the UK Green Investment Bank. UK Climate Investments will invest up to £200m of UK climate finance over three years in renewable energy and energy efficiency projects in developing countries. It will target three regions; East Africa, South Africa and India. It will make transformational deals with the private sector, increasing the energy supply and security in those countries through clean technology. We estimate it will make carbon savings of 32Mt CO_2e, create around 3000 jobs and lever £360m of private investment.

Through the Climate Public Private Partnership (CP3), the UK acts as an anchor investor helped to establish two commercially run private equity funds, IFC Catalyst Fund and Asia Climate Partners, which invest in low-carbon development sub-funds and projects in developing countries. The IFC AMC Catalyst Fund reached a final fund size of US$417.75 million in June 2014. By September 2016, it had invested in ten smaller funds, with its capital invested in a total of 58 specialist companies. The UK is an $80m anchor investor. Asia Climate Partners is expected to achieve first close in May 2017 and will invest in India, China and the rest of developing Asia. The fund will make largely direct investments in resource efficiency sectors (energy, water, transport, technology, agribusiness), but may also make some fund investments.

The UK is providing £75m into Green Mini-Grids Africa (GMGs), this programme aims to increase energy access in Africa through creating expanding deployment of clean energy mini-grids[58]. There are 3 main projects within this programme: GMGs Kenya; GMGs Tanzania; and a GMGs Africa Regional Facility. The impact is to transform the green mini-grids (GMGs) sector in Africa in line with International Energy Agency projections that 40% of universal electricity access by 2030 will be most economically delivered in this way. The outcome is creating a critical mass of experience and evidence of GMGs success in two countries, couple with improved policy and market conditions for investment in mini-grids regionally. It is expected that the 135 GMGs in operation will provide 44MW of installed capacity create 500 new jobs and deliver increased public and private capital flows into GMGs in Africa.

A £15m grant over 2012-2018 will support the growth of Silvopastoral Systems (SPS) in Colombia to reduce greenhouse gas emissions, improve the livelihood of farmers, protect local forests and increase biodiversity. Agriculture is one of the biggest sources of greenhouse gas emissions in Colombia and many other developing countries, and a key driver of deforestation. Addressing this fact, the UK and partners are working with cattle ranchers to improve degraded grazing land by using SPS. This means managing the land in a different way: planting trees, shrubs, fodder crops and living fences and conserving existing forest. Participating small farmers, the majority of whom are living in conditions of rural poverty, are able to raise more, healthier cattle on their existing land using SPS, increasing their income and reducing the need to clear forest. This project aims to convert 35,000 hectares of grazing land to SPS, saving around 5.7MtCO_2e over an 8 year period (with 2MtCO_2e attributable to the UK), and create a strategy for increasing the use of SPS in Colombia and beyond.

[57] https://www.gov.uk/government/publications/international-climate-fund/international-climate-fund

[58] Mini-Grids are village or district level electrical distribution networks serving the needs of communities too distant and dispersed to be economically connected to the grid in the near to medium term - but densely populated enough to offer economies of scale in power delivery compared with individual home systems. Green Mini-grids (GMGs) are mini-grids powered by either fully renewable or hybrid (mixed renewable and fossil fuel) generation.

To date the UK has contributed £2 billion to the Climate Investment Funds, over £1.2bn of which has come from the ICF. These funds include 4 key programmes that help 72 developing countries pilot low-emission and climate resilient development. The Clean Technology Fund (CTF) is an example of one of these programmes, which is supporting large scale low carbon investment plans in 19 developing countries. The CTF will also deliver significant development benefits, such as increased energy security, reduced local air pollution, and job opportunities. This is demonstrated in South Africa[59], where the Kaxu concentrated solar power plant, the first such plant to be built in a developing country, went online in 2015. The plant is now providing power to 80,000 people in South Africa. Concentrated Solar Power (CSP) has huge and currently underexploited potential – it could deliver 11% of global electricity by 2050 – and this is just one of a number of CTF investments (underway and planned) in this technology. $1.2 billion from the CTF will contribute to development of over 1.2 GW of concentrated solar power across MENA (Middle East and North Africa), Chile, India and South Africa - around a third of the total global installed capacity of CSP.

The Green Climate Fund (GCF) is set to become the world's principal multilateral climate fund, with a mandate to make 'an ambitious contribution to the global efforts towards attaining the goals set by the international community to combat climate change'. Total pledges to the GCF stand at $10.3bn, of which the UK has committed £720m. In its first year of programming, the GCF Board has approved $1.5bn of projects that support mitigation and adaptation activities in developing countries, many with a private sector focus. The GCF is expected to achieve transformational on-the-ground results and develop a portfolio of low carbon programmes, which the UK expect to reduce emissions by generating and expanding access to low-emission energy. The GCF will aim to balance resources between mitigation and adaptation, with a 'significant allocation' to the private sector facility. The GCF will aim to allocate at least half of its resources for adaptation to particularly vulnerable countries, including Small Island Developing States (SIDS), Least Developed Countries (LDCs) and Africa. Adaptation programmes will focus on increasing the resilience of those most vulnerable to the impacts of climate change. It is estimated that the UK contribution will help at least 7 million people to cope with the impacts of climate change.

The UK has committed up to £60 million of finance from the ICF to support developing countries to develop both the technical and institutional knowledge necessary to enable the deployment of CCS technologies. The UK has agreed to fund £35m and £25m respectively to Asian Development Bank and World Bank Trust Funds to support CCS capacity building projects. Financial support would be channelled toward a range of projects in China, South Africa, Indonesia and Mexico with the aim of ensuring sufficient political support is created to pave the way for full scale demonstration and ultimately the deployment of CCS.

The Nationally Appropriate Mitigation Actions (NAMA) Facility was launched by the UK and German governments in December 2012. The UK has committed £100 million to the NAMA Facility[60] with the German government matching the UK's contribution. The Facility is funding the most transformational parts of NAMA plans. NAMAs are concrete projects, policies, or programmes that shift a technology or sector in a country onto a low-carbon development trajectory. This project will focus on those parts of the projects that are stretching and aspirational, that are pushing to do much more than business as usual to mitigate the impacts of climate change. The NAMA Facility is currently supporting 14 projects across a range of sectors and geographies. For example in Costa Rica the facility is supporting a 'low carbon

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59 https://www.climateinvestmentfunds.org/cif/sites/climateinvestmentfunds.org/files/CTF_TFC.12_6_Update_of_CTF_Investment_Plan_for_South_Africa_.pdf

60 The European Commission (€15m) and Denmark (€10m) are also donors to the NAMA Facility

coffee' project that will contribute to the empowerment of farmers and millers to develop sustainable livelihoods, will maintain employment for up to 150,000 jobs during the harvest period and may create a positive impact on the standard of living of more than 400,000 people.

15.2.5 Knowledge transfer

Knowledge transfer can help accelerate the development and deployment of low-carbon and climate resilient technologies to help developing countries mitigate and adapt to climate change.

The UK supports the Technology Mechanism (TM), as agreed at COP16 in Cancun 2010, and is already involved with several knowledge transfer initiatives. In addition to the UK's long standing involvement in initiatives such as the Climate Technology Initiative, recent actions in this area include:

- The UK is providing £24m of support for Climate Innovation Centres (CICs) in developing countries. These centres support local SMEs to innovate and deploy locally-relevant climate technologies that help reduce/avoid greenhouse gas emissions; and improve the resilience of the population. Services provided by CICs include business advisory and training, market intelligence, access to facilities, seed financing and government advisory. ICF funding is supporting CICs in Kenya, Ethiopia and Vietnam as well as the design of up to 11 new CICs and the establishment of a global network to facilitate cross-learning and to make individual CICs more interconnected and efficient;
- Climate and Development Knowledge Network (CDKN) provides approximately £119m from the ICF to developing countries to share knowledge and build the capacity building of developing country decision-makers to design and deliver climate compatible development policies and programmes. The CDKN does this by providing access to high quality, demand-led technical assistance, and channelling the best available knowledge on climate change and development to support policy and implementation processes at the country and regional level. CDKN has four priority thematic areas which helps prioritise its work across its three focus regions (Africa, Asia and Latin America). These are:
    - Climate compatible development (CCD) strategies and plans;
    - Improving developing countries access to climate finance;
    - Strengthening resilience through climate-related disaster risk management (DRM); and
    - Supporting climate negotiators from the Least Developed Countries.
- The UK has good monitoring and evaluation systems in place, as recognized in the Independent Commission for Aid Impact review of the ICF. We are seeking to strengthen these and to place learning and transfer of knowledge at the heart of the ICF through an ICF Monitoring, Evaluation and Learning (MEL) programme. The MEL will support the generation and use of evidence and knowledge from across the ICF. It will produce practical data-gathering tools where none exist; results and evidence of ICF achievements and effectiveness; learning and knowledge to support continual improvements in project selection and design, and to help inform the design of future funds and programmes, for example, the Green Climate Fund.

15.2.6 Research collaboration

Enhancing global collaboration on research, development and demonstration (RD&D) will be essential to ensure innovation and take-up of climate technologies in developing countries. The UK is cooperating in the technological development of non-energy uses of fossil fuels, and doing so in partnership and supporting developing countries. We are exploring opportunities to support RD&D ‘gap-filling’ activity on climate technologies (both for mitigation/low carbon development and adaptation activities).

The UK will continue to play a leading role in international research efforts to reduce the costs of low carbon energy, working with other countries to strengthen collaboration and transparency in clean energy research, development, and demonstration. To demonstrate this commitment, at the COP21 climate change conference in Paris, the UK joined Mission Innovation.

Mission Innovation is an international initiative which aims to accelerate clean energy investment and innovation in order to provide reliable and affordable energy for all. In line with the Mission Innovation pledge, the Government committed to double the UK’s energy innovation spend, such that by 2021 it will have doubled to over £400m per year.

The UK is participating in all seven of Mission Innovation “Innovation Challenges”. These challenges are aimed at catalyzing global research efforts in areas that could provide significant benefits in reducing greenhouse gas emissions, increasing energy security, and creating new opportunities for clean economic growth.

Further examples of the UK’s commitment to collaborative research are 2010-2011 projects on low carbon technology transfer to China and India that the Department of Energy and Climate Change supported. The main focus of the studies was to provide new empirical evidence to low carbon innovation in developing countries to inform international policy development. Both studies featured a range of low carbon technologies and examined the factors that influence innovation and technology transfer, including technological capacity, access to intellectual property rights and the role of policy frameworks.

The Department of Energy and Climate Change (DECC) in collaboration with Department for International Development (DFID) and the Engineering and Physical Sciences Research Council (EPSRC), on behalf of the Research Councils UK (RCUK) are jointly funding a programme of research in the field of energy and international development. Understanding Sustainable Energy Solutions in Developing Countries (USES) is the first major joint call between DFID, DECC and EPSRC. With a focus on research that will improve our understanding of the opportunities and challenges associated with scaling up sustainable access to modern energy services in developing countries, the Programme has been established to help build the evidence base that supports how the UK will spend its International Climate Fund (ICF).

The programme is supporting 12 projects between UK and developing country institutions. It is hoped that this will deliver high quality research that addresses key development challenges in one or more of the following five areas: bioenergy; solar; decentralised generation; urban and transport; and energy efficiency.

International engagement is a significant part of the Avoiding Dangerous Climate Change Research Programme (AVOID). For example the first phase of the programme investigated technology options for reducing CO_2 emissions from the energy sector in India and China in order to meet a national 2050 emissions target consistent with limiting global temperature rise to below 2°C, and shared these results with Indian and Chinese officials at international workshops. The second phase of AVOID was commissioned in early 2014 and will involve a 2-year work programme including extensive engagement with international researchers and officials on a range of issues including regional climate impacts, feasibility of energy sector decarbonisation and the potential role of land-use in both mitigating and contributing to climate change.

The UK is playing a key role on promoting knowledge sharing and capacity building in developing countries on Carbon Capture & Storage (CCS). The UK has committed up to £60 million of finance from the International Climate Fund (ICF) to raise the level of understanding of CCS within emerging economies – including China, South Africa, Indonesia and Mexico –

leading to the establishment of necessary policy frameworks, technical know-how and incentive structures to support CCS demonstration and ultimately accelerate the deployment of CCS. The UK will support a range of capacity building projects, including: i) preparation and implementation of early-stage full scale integrated CCS pilot demonstration projects by financing CCS planning & pre-investment, capital costs for CCS units and components, and CCS related post-completion & operation activities; ii) development of geological site characterisation intended for integrated full scale CCS projects, both at the pilot and commercial demonstration scales to maximise knowledge on both near-term and future storage capacities; and iii) pilot and demonstration activities aimed at reducing the cost of the technology application across the CCS chain. It is expected that the UK's funding will lead to full scale demonstration projects in developing countries, and ultimately accelerate the deployment of CCS.

The UK continues to jointly lead with Australia the Carbon Capture Usage or Storage (CCUS) initiative under the Clean Energy Ministerial, involving governments of both developed and developing nations. The UK is active in a number of multilateral organisations such as the Carbon Sequestration Leadership Forum (CSLF) which aims to promote the deployment of CCS worldwide in both developed and developing countries. In addition, in April 2013 the UK co-hosted the third 4 Kingdoms Initiative workshop with the government of Norway, bringing together representatives of four oil-producing countries to drive efforts to reduce the economic losses of CCS through alternative uses for CO_2.

The UK provided £35m in 2015/16 to the CGIAR consortium of 15 agriculture research centres. Research conducted by the CGIAR has underpinned global agriculture development since the green revolution. Over 60% of modern plant varieties grown in developing countries have CGIAR ancestry and 30% of global yield growth between 1965 and 1998 can be attributed to plant genetic improvement by the CGIAR. A significant part of the UK support to the CGIAR will develop the next generation of agricultural technology which has the potential to lead to further increases in agricultural productivity, improve the resilience of small-holder agriculture and improve the nutrition and food security of poor people in developing countries.

15.2.7 Capacity Building projects on Renewable Energy & Energy Efficiency

The UK is cooperating in the development, diffusion and transfer of less greenhouse-gas emitting advanced fossil-fuel technologies, and/or technologies relating to fossil fuels that capture and store greenhouse gases, and encouraging their wider use; and through capacity building projects is facilitating the participation of the least developed countries.

The UK is supporting the development of low carbon technology and the increased use of renewable energy to ensure that developing countries can move to a low carbon future that supports economic growth. The UK is a signatory to the International Renewable Energy Agency (IRENA) which is an intergovernmental treaty organisation set up in 2009 to promote a rapid transition to the widespread and sustainable use of renewable energy technologies internationally. The UK has been playing an active part in IRENA, for example by chairing its Policy and Strategy Committee to help develop the agency's work programme for 2012 (which includes activities on Policy Advisory Services and Capacity Building) and its mid-term strategy. Similarly, the UK (both DFID and DECC) contributions to the Climate Investment Funds also support capacity building in these areas.

The UK is working within the International Partnership for Energy Efficiency Co-operation (IPEEC) with key developed and developing countries to share experience and learn from each other's policy successes and failures, and identify opportunities for collaborative work to address issues of mutual interest or concern, where such international action can add value to domestic efforts/expertise. A work programme has been developed encompassing a range of activities including appliance standards and labels, sustainable buildings, financing, data collection and indicators, energy management, transport, and capacity building activities. Much of this work is also being taken forward within the G20's Energy Efficiency Leading programme which IPEEC is co-ordinating.

It is important to tackle both the supply and the demand side to achieve sustainable low carbon energy. The UK has recently been involved with multi-lateral partnerships such as the Renewable Energy and Energy Efficiency Partnership, which has the objective of accelerating the deployment of renewable energy and energy efficiency technologies in developing countries as a means of reducing carbon emissions, increasing energy security, and improving access to sustainable energy. It does so primarily through funding small scale capacity building projects, and to date it has funded 150 projects.

15.2.8 Capacity building projects on adapting to climate change

The UK Government is working to ensure that UK climate support addresses both the causes and effects of climate change. The world's poorest people are hit hardest by the impacts of climate change with crops lost to floods and drought, homes damaged by floods and threatened by rising sea levels, and lives lost to extreme weather events. They are the most vulnerable and least able to adapt. The UK is providing practical help to the most vulnerable and assisting the development of local capacity.

Examples include:

- Building Resilience and Adaptation to Climate Extremes and Disasters (BRACED) is a £140m programme to support countries that are at most risk of climate extremes (e.g. droughts, storms, floods and landslides), will focuses on the Sahel – Senegal, Burkina Faso, Chad, Mali, Mauritania and Niger - and DFID focal countries identified as at most risk, including: Burma, Nepal Ethiopia, South Sudan, Sudan, Uganda, and Kenya. £30m of the programme is dedicated to developing capacity on response to climate related disasters and improve policies and institutions on DRR, and climate adaptation;
- African Risk Capacity (ARC) – The ARC is a sovereign insurance pool to which the UK has provided an initial tranche of £30m. The ARC offers parametric insurance (where payouts are made as soon as a pre-agreed trigger occurs signifying an insured extreme weather event)[61] to enable countries to respond quickly after extreme weather events and scale up social safety nets and other assistance so that people are not without food or having to sell assets. The insurance currently covers droughts, and is expected to expand to floods, tropical cyclones and other hazards. Mauritania, Niger, Senegal and Kenya have purchased insurance and are members, with more countries expected to join in coming years. ARC insurance policies currently cover 1.9 million men and women who are guaranteed an early response in the event of a drought. The UK has set aside a further £60m to scale up ARC to provide cover to more people and for more climate risks, alongside a £10m package of support designed to assist countries to participate in ARC; and
- £10m Climate Development for Africa (ClimDev) is designed to build capacity and expertise to tackle climate change. ClimDev is Africa's first regional climate information services programme, with ICF support focused on the establishment and operations of the Africa Climate Policy Centre based at the UN Economic Commission for Africa (UNECA) in Addis Ababa. In addition ICF country programmes all have capacity building components to help developing countries effectively plan and implement

[61] The value of ARC payouts is linked to the estimated/modelled response costs required for that level of event.

climate strategies. For example the £15 million Strategic Climate Institutions Programme (SCIP) builds organisational capacity within the Ethiopian Government, civil society and the private sector to strengthen Ethiopia's capacity to manage climate risks and opportunities. In Nepal the £25m Climate Change Support Programme (NCCSP) provide capacity building support to central ministries and has a particular focus on strengthening local government capacity, as key implementers of climate change adaptation responses.

15.2.9 Energy Market Reforms – responding to energy market imperfections

Launched under the last Government, Electricity Market Reform (EMR) introduced two key mechanisms – Contracts for Difference (CFD) and the Capacity Market, designed to incentivise the investment required in the UK's energy infrastructure and deliver low carbon energy and reliable supplies, while minimising costs to consumers

The Energy Act 2013 received Royal Assent in December 2013. The Energy Act includes the provisions for EMR:

- **Contracts for Difference (CfDs)** – long-term contracts to provide stable and predictable incentives for companies to invest in low-carbon electricity generation;
- **Capacity Market** – to provide security of electricity supply, by ensuring sufficient reliable capacity is available, including provisions to allow Electricity Demand Reduction to be delivered;
- **Conflicts of interest** and **contingency arrangements** – to ensure the institutions which deliver these schemes are fit for purpose;
- **Investment Contracts** – a form of early CfD entered into by the Secretary of State, designed to enable early investment in advance of the CfD regime coming into force;
- **Transitional arrangements for renewables** – to ensure that existing investments under the Renewables Obligation (RO) remain stable; and
- **An Emissions Performance Standard (EPS)** – to limit the carbon emissions from the most polluting fossil fuel power stations, i.e. unabated coal.

The UK Government is currently consulting on plans to close all unabated coal power stations by 2025.

16 Other Information

There is no additional information to include in this chapter.

17 References

References for the main chapters and the annexes are listed here and are organised by chapter and annex. During 2008 the BERR energy team and the Defra climate teams formed the Department of Energy and Climate Change (DECC). In July 2016 DECC was replaced by the Department of Business, Energy & Industrial Strategy (BEIS), which has taken over all of DECC's responsibilities with regards to the UK's GHG Inventory. BEIS is now the Single National Entity for the UK's National Inventory System. References in this document refer to correct name at the time of original publication.

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17.4 ANNEX 3, SECTOR 3

See references under **Chapter 6**

17.5 ANNEX 3, SECTOR 4

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17.8 ANNEX 6 [VERIFICATION]

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17.9 ANNEX 7 [ANALYSIS OF EU ETS DATA]

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18 Acknowledgements

We are grateful for the contributions, advice and support from the following people listed in **Table 18.1** during the compilation of this National Inventory Report (NIR). The Key Data Providers are listed in **Table 18.2.**

Table 18.1 Contributors to this National Inventory Report and the CRF

Person	Technical work area and responsibility
Main authors	
Broomfield, Mark	Sector expert for solid waste disposal on land. Author of landfill, biological treatment of waste, and sections within Annex 3.
Brown, Peter	Lead Author. Project Manager for the UK Greenhouse Gas Inventory with overall responsibility for the NIR and the CRF[62]. Author of uncertainty and key category analysis annexes and the reference approach section. Reviewed waste water and f-gas sections
Cardenas, Laura[63]	Sector expert for agriculture; author of all sections on agriculture. Compilation of Sector 3 of the CRF.
Choudrie, Sarah	Author of Cpt 1, 8, 9, and 13, and parts of Cpt 3, Annex 3, and Annex 5. Reviewer of the overall document.
Kilroy, Eleanor	Report manager and author of sector overviews and Cpt 2.
Jones, Luke	Contributor to Cpt 3, 4, 7, 10, Annex 3, 8. Author of Annex 4 and Annex 9. Reviewer of Executive Summary.
Murrells, Tim	NAEI transport manager. Technical Director of NAEI Programme. Contributing author to all sections on transport
Passant, Neil	Author of most sections on energy and industry and waste incineration; contributions to most chapters. Co-author of Annex 3 and 7
Thomson, Amanda[64]	Sector expert for LULUCF and KP-LULUCF. Main author of LULUCF Cpt 6 and Cpt 11, Annex 3.5. Contributor to compilation of Sector 4.
Wakeling, Daniel	Author of road transport, off-road machinery, shipping and fishing. Compiled attached emission factors tables,
Contributors	

62 The UK greenhouse gas inventory is part of the UK National Atmospheric Emissions Inventory contract. The UK National Atmospheric Emissions Inventory is funded by the UK Department for Environment, Food & Rural Affairs and the Department of Energy and Climate Change and is contracted to a consortium led by Ricardo Energy & Environment.

63 Rothamsted Research

64 Centre for Ecology & Hydrology

Person	Technical work area and responsibility
Buys, Gwen[64]	Data and QA/QC manager for LULUCF and KP-LULUCF sectors. Author of sections in Cpt 1 and Cpt 2. Compilation of Sector 4 of the CRF.
Forden, Stephen	Review of the draft NIR and contributions regarding National Inventory System. Author of Chapter 15.
Gilhespy, Sarah[63]	Contributions to agriculture inventory compilation and text
Glendining, Margaret	Contributions to agriculture inventory compilation and text
Gluckman, Ray[65]	Author of the section on f-gases in chapter 4.
Henshall, Paul[67]	CARBINE modelling for LULUCF inventory for 4A Forestry, 4G Harvested Wood Products and KP, contributions to text for sections in Cpt 6, Cpt 11 and Annex 3.5.
Hobson, Melanie[68]	Compilation of rail emissions estimates and text for this sector
MacCarthy, Joanna	Author of executive summary and co-author of Annex 9 and checker for sector overviews.
Malcolm, Heath[64]	Land Use and Ecosystem Modelling Group Leader, CEH. Contribution to LULUCF data analysis
Manning, Alistair[66]	Verification of the UK greenhouse gas inventory (Annex 6)
Matthews, Robert[67]	CARBINE modelling for LULUCF inventory for 4A Forestry, 4G Harvested Wood Products and KP, contributions to text sections in Cpt 6, Cpt 11 and Annex 3.5
Milne, Alice	Contributions to agriculture inventory compilation and text
Misselbrook, Tom[63]	Contributions to agriculture inventory compilation and text
Moxley, Janet[64]	LULUCF contributing author for Cpt 6 and Annex 3.5. Contributor to compilation of sector 4.
Pearson, Ben	Methodological development of the Monte Carlo model
Salisbury, Emma[68]	Responsible for compilation of emission estimates for the OTs and CDs, and report text relating to this
Sussams, Julia	Review of the draft NIR and contributions regarding National Inventory System.
Thistlethwaite, Glen	Inventory QA/QC manager. Author of QA/QC section.
Walker, Charles	Sector expert for aviation in the NAEI. Author of aviation sections.
Webb, Nicola	Reviewed Chapter 2 data.
Additional assistance	
Aston, Clare	Data acquisition, report printing
National Inventory Steering Committee	Suggestions and improvements to draft versions of the NIR

Table 18.2 Key Data Providers to the Greenhouse Gas Inventory

Organisation	Summary of Data Provided
BEIS (formerly DECC)	Energy statistics (DUKES) including fuel activity and GCVs; Oil and gas production, flaring and venting statistics; Upstream oil and gas emissions data (EEMS).

65 Gluckman Consulting

66 The Met Office

67 Forest Research

68 Aether

Organisation	Summary of Data Provided
Defra	Solid waste disposal / fate statistics; Waste-water treatment activity data; Food and protein survey data; Agricultural survey data, activity statistics (livestock, crops).
DfT	Road traffic statistics; Marine transport statistics; Rail activity and emission estimates (REM); Aviation movement statistics.
ONS	PRODCOM statistics (industrial production data); Housing and population data; Economic activity statistics (GDP, GVA);
Environment Agency SEPA NIEA NRW	Industrial activity and emissions data (EU ETS); Industrial emissions data from IPPC/EPR regulation; Waste management and disposal statistics, including incineration data;
UKPIA	Refinery emissions data by source; Oil products characteristics (RVP, sulphur content)
Mineral Products Association	Mineral processing activity and emissions data; fuel quality data;
UK Gas Distribution Networks	Natural gas compositional analysis (annual for each LDZ); Gas leakage estimates from transmission and distribution network;
ISSB	Iron and steel production statistics, by technology; Iron and steel fuel use, by fuel, by source;
Tata Steel SSI Steel	Iron and steel facility emissions by source for integrated works; Fuel quality data and other raw material parameters;
Rio Tinto Alcan	Aluminium production data, facility emissions data, supporting data on plant performance and controls.
British Glass	Glass production data.
Ineos BP Chemicals Kemira GrowHow SABIC Shell	Facility emissions data by source, aligned to specific inventory reporting requirements.