

UK Greenhouse Gas Inventory, 1990 to 2017

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 2019 to the United Nations Framework Convention on Climate Change (UNFCCC). It contains national greenhouse gas emission estimates for the period 1990-2017, and descriptions of the methods used to produce the estimates. The report is prepared in accordance with decision 24/CP.19¹ 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 for 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 the Intergovernmental Panel on Climate Change (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>

²http://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 Potential (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 CO₂ equivalent

Gg (of GHG) * GWP = Gg CO₂ 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 ₂ O	Nitrous oxide
Direct	HFCs	Hydrofluorocarbons
Direct	PFCs	Perfluorocarbons
Direct	NF ₃	Nitrogen trifluoride
Direct	SF ₆	Sulphur hexafluoride
Indirect	CO	Carbon monoxide
Indirect	NM VOC	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, NF₃ and SF₆ 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

Common Abbreviations

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

Common Abbreviations

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 ₂ O 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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ES 1 BACKGROUND INFORMATION

ES 1.1 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 (CDs) and Overseas Territories (OTs) for whom the ratification is extended.

The Climate Change Act³ 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 and 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 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 2019 to the UNFCCC and covering both the UK's submission under the Kyoto Protocol and the Convention. It contains national greenhouse gas emission estimates for the period 1990-2017, 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.19⁴ 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 (DAs) 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 (NF₃ was included under the Doha Amendment). These are as follows:

- Carbon dioxide (CO₂);
- Methane (CH₄);
- Nitrous oxide (N₂O);
- Hydrofluorocarbons (HFCs);
- Perfluorocarbons (PFCs);
- Sulphur hexafluoride (SF₆); and
- Nitrogen trifluoride (NF₃).

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 SO₂).

Emissions of indirect N₂O from emissions of NO_x and NH₃ 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.

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 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, this submission includes the UK plus:
 - 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 1 to Table ES 2** show CO₂ and the direct greenhouse gases, disaggregated by gas and by sector for geographical Coverage 4. Table ES 4 and Table ES 5 show emissions for the Kyoto basket based on Coverage 2 and 3, respectively.

Table ES 8 has data on indirect greenhouse gas emissions, for geographical coverage 4.

ES 1.3 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 1 Emissions of GHGs in terms of carbon dioxide equivalent emissions including all estimated GHG emissions from the Crown Dependencies and relevant Overseas Territories, 1990-2017. (Mt CO₂ Equivalent)

	Mt CO ₂ Equivalent											% change
	1990	1995	2000	2005	2009	2010	2013	2014	2015	2016	2017	1990 - 2017
CO ₂ (Inc. net LULUCF)	599.5	563.4	561.9	561.5	484.5	502.0	467.6	428.5	411.9	389.3	376.8	-37%
CO ₂ (Exc. net LULUCF)	601.5	567.4	567.9	570.5	494.9	512.7	478.5	439.6	423.1	400.6	388.1	-35%
CH ₄ (Inc. net LULUCF)	133.0	126.4	108.9	87.4	69.0	64.3	55.9	53.7	53.1	51.5	51.9	-61%
CH ₄ (Exc. net LULUCF)	133.0	126.4	108.9	87.4	69.0	64.3	55.9	53.7	53.1	51.5	51.9	-61%
N ₂ O (Inc. net LULUCF)	48.4	38.7	28.6	24.5	21.2	21.5	20.4	20.9	20.4	20.3	20.7	-57%
N ₂ O (Exc. net LULUCF)	46.1	36.5	26.6	22.7	19.6	19.9	18.9	19.5	19.0	18.9	19.3	-58%
HFCs	14.4	19.1	9.9	13.1	15.6	16.5	15.8	16.0	16.0	15.2	14.2	-1%
PFCs	1.7	0.6	0.6	0.4	0.2	0.3	0.3	0.3	0.3	0.4	0.4	-78%
SF ₆	1.3	1.3	1.8	1.1	0.6	0.7	0.5	0.5	0.5	0.5	0.5	-60%
NF ₃	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28%
Total (Inc. net LULUCF)	798.2	749.6	711.8	688.1	591.1	605.3	560.6	519.9	502.3	477.2	464.5	-42%
Total (Exc. net LULUCF)	797.9	751.3	715.7	695.2	599.9	614.4	569.9	529.5	512.0	487.0	474.3	-41%

1. One Mt equals one Tg, which is 10¹² 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 included in the scope of the UK's ratification of the UNFCCC

Table ES 1 presents the UK Greenhouse Gas Inventory totals by gas, including and excluding net emissions from LULUCF. The largest contribution to total emissions is CO₂, which contributed 81% to total net emissions in 2017. Methane emissions account for the next largest share (11%), and N₂O emissions make up a further 4%. Emissions of all of these gases have decreased since 1990, contributing to an overall decrease of 42%.

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 include carbon stock changes in the Harvested Wood Products pool.

Table ES 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 KP- LULUCF activities (Mt CO₂e)

	Base Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Article 3.3	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	0.9	1.0	1.5	1.6
Article 3.7	0.2												
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	14.4	14.4	14.5	14.5	14.7	14.8	15.2	15.2	15.3	15.4	15.5	15.4	15.2
Article 3.4 Grazing Land Management	-6.8	-6.8	-6.6	-6.5	-6.3	-6.2	-6.1	-6.0	-5.9	-5.8	-5.0	-5.0	-5.0
Article 3.4 Wetland Drainage and Rewetting	*	*	*	*	*	*	*	*	*	*	*	*	*

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Article 3.3	1.6	1.7	1.5	1.6	1.2	1.2	1.1	1.0	0.9	0.5	0.3
Article 3.7											
Article 3.4 FMRL _{submitted}											

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	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
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	14.9	14.6	14.5	14.1	14.0	13.7	13.6	13.7	13.4	13.3	13.2
Article 3.4 Grazing Land Management	-5.0	-5.0	-5.1	-5.2	-5.2	-5.2	-5.3	-5.3	-5.4	-5.4	-5.5
Article 3.4 Wetland Drainage and Rewetting	*	*	*	*	*	*	*	*	*	*	*

	2013	2014	2015	2016	2017
Article 3.3	0.0	-0.2	-0.6	-0.5	-1.0
Article 3.7					
Article 3.4 FMRL _{submitted}	-8.3	-8.3	-8.3	-8.3	-8.3
Article 3.4 Technical Correction to FMRL	-9.4	-9.4	-9.4	-9.4	-9.4
Article 3.4 Forest Management removals compared to FMRL and Technical Correction (capped)	-1.4	-1.0	-0.6	-0.3	0.2
Article 3.4 Cropland Management	13.0	12.8	12.7	12.6	12.6
Article 3.4 Grazing Land Management	-5.6	-5.6	-5.7	-5.7	-5.8
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 to 2013 onwards. Similarly 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 current 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 details total net emissions of GHGs, aggregated by IPCC sector.

Table ES 3 Aggregated emission trends per source category, including all estimated GHG emissions from the Crown Dependencies and selected relevant Overseas Territories (Mt CO₂ equivalent).

Source Category	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017
1. Energy	615.3	573.0	566.0	562.5	491.6	484.1	471.5	432.3	416.1	394.6
2. Industrial Processes and Product Use	66.6	60.9	40.6	39.7	32.8	32.4	34.5	34.2	33.7	30.9
3. Agriculture	49.2	48.0	45.9	43.6	40.8	40.6	40.4	41.8	41.2	41.2
4. LULUCF	0.3	-1.7	-3.9	-7.1	-8.8	-9.0	-9.3	-9.6	-9.7	-9.8
5. Waste	66.9	69.5	63.2	49.4	34.7	26.5	23.5	21.2	21.0	20.4
Total (net emissions)	798.2	749.6	711.8	688.1	591.1	574.6	560.6	519.9	502.3	477.2

Footnotes: Geographical coverage of this table includes the Crown Dependencies and the Overseas Territories which are included in the scope of the UK's ratification of the UNFCCC

The largest contribution to greenhouse gas emissions is from the energy sector. In 2017 this contributed 82% to the total emissions. Emissions of CO₂, CH₄ and N₂O all arise from this sector. Since 1990, emissions from the energy sector have declined by 38%.

The second largest source of greenhouse gases is the agricultural sector. Emissions from this sector are mostly CH₄ and N₂O, with a small amount of CO₂. Since 1990, emissions from this sector have declined by 16%.

Industrial processes and product use make up the third largest sector for greenhouse gas emissions in the UK, contributing 7% to the national total in 2017. 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 CO₂ emissions. LULUCF was a net sink in 2017. Emissions from this sector occur for CO₂, N₂O and CH₄.

The remaining sector that contributes to direct greenhouse gas totals is waste. In 2017 this contributed 4% to the national total. This sector leads to emissions of CO₂, CH₄ and N₂O, with emissions occurring from waste incineration, solid waste disposal on land and wastewater handling. Emissions from this sector have declined and in 2017 were 69% below 1990 levels.

Total net emissions have decreased by 42% since 1990.

ES 3.2 KP Basket and KP-LULUCF Activities

Table ES 4 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 5 presents the same information as Table ES 4 using MMR geographical coverage.

Table ES 6 presents the base year, and 2013 to 2017 emissions calculated from the 2019 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 2019 inventory submission (1990 – 2017).

- The base year emissions are made up of 1990 emissions for CO₂, CH₄ and N₂O, and 1995 for the F-Gases
- Emissions are presented as Mt CO₂ 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 included in the scope for the second commitment period of the Kyoto Protocol. These are the Cayman Islands, Falkland Islands, and Gibraltar.

Table ES 7 presents the same information as **Table ES 6** using MMR geographical coverage.

Table ES 4 **Kyoto basket of emissions, and emissions associated with Articles 3.3, 3.4 and 3.7 for the first commitment period (in Mt CO₂ 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 ₂ O		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 CO₂ 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 5 Kyoto basket of emissions, and emissions associated with Articles 3.3, 3.4 and 3.7 for the first commitment period (in Mt CO₂ equivalent) – MMR Coverage.

	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 ₂ O		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 ES 4** for full footnotes.
- The geographical coverage of this table is UK and Gibraltar only.

Table ES 6 Kyoto basket of emissions, and emissions associated with Articles 3.3, 3.4 and 3.7 for the second commitment period (in Mt CO₂ equivalent) - KP2 coverage

	Base year (current inventory)	2013	2014	2015	2016	2017	Base Year - 2017
CO ₂	600.8	477.8	438.9	422.4	399.8	387.4	-36%
CH ₄	132.9	55.8	53.7	53.1	51.5	51.8	-61%
N ₂ O	46.1	18.9	19.4	19.0	18.9	19.3	-58%
HFCs	19.1	15.8	16.0	16.0	15.2	14.2	-26%
PFCs	0.6	0.3	0.3	0.3	0.4	0.4	-38%
SF ₆	1.3	0.5	0.5	0.5	0.5	0.5	-60%
NF ₃	0.0	0.0	0.0	0.0	0.0	0.0	-36%
Grand Total	800.8	569.1	528.7	511.2	486.3	473.6	-41%
Article 3.3		0.0	-0.2	-0.6	-0.5	-1.0	

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	Base year (current inventory)	2013	2014	2015	2016	2017	Base Year - 2017
Article 3.4 Forest Management removals and HWP compared to FMRL and Technical Correction to FMRL (capped)		-1.4	-1.0	-0.6	-0.3	0.2	
Article 3.4 Cropland Management		13.0	12.8	12.8	12.7	12.6	
Article 3.4 Grazing Land Management		-5.6	-5.6	-5.7	-5.7	-5.8	
Article 3.7	0.2						
Kyoto Protocol Total	800.8	575.2	534.8	517.1	492.3	479.5	-40%

Footnotes:

- The data in this table are all taken from the 2019 inventory submission (1990 – 2017).
- The base year emissions are made up of 1990 emissions for CO₂, CH₄ and N₂O, and 1995 for the F-Gases
- Emissions are presented as Mt CO₂ 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.
- Geographical coverage of this table includes the Crown Dependencies Jersey, Guernsey and the Isle of Man, and the Overseas Territories which are included in the scope for the second commitment period of the Kyoto Protocol. These are the Cayman Islands, Falkland Islands, and Gibraltar.

Table ES 7 Kyoto basket of emissions, and emissions associated with Articles 3.3, 3.4 and 3.7 for the second commitment period (in Mt CO₂ equivalent) – MMR Coverage

	Base year (current inventory)	2013	2014	2015	2016	2017	Base Year - 2017
CO ₂	598.6	475.2	436.3	419.9	397.5	384.9	-36%
CH ₄	132.4	55.4	53.2	52.7	51.1	51.5	-61%
N ₂ O	46.0	18.8	19.3	18.9	18.8	19.1	-58%
HFCs	19.1	15.7	15.9	15.9	15.1	14.1	-26%
PFCs	0.6	0.3	0.3	0.3	0.4	0.4	-38%
SF ₆	1.3	0.5	0.5	0.5	0.5	0.5	-60%
NF ₃	0.0	0.0	0.0	0.0	0.0	0.0	-36%
Grand Total	798.0	565.9	525.5	508.1	483.3	470.5	-41%
Article 3.3		0.0	-0.2	-0.6	-0.5	-1.0	
Article 3.4 Forest Management removals and HWP compared to FMRL and Technical Correction to FMRL (capped)		-1.4	-1.0	-0.6	-0.3	0.2	
Article 3.4 Cropland Management		13.0	12.8	12.7	12.6	12.6	
Article 3.4 Grazing Land Management		-5.6	-5.6	-5.7	-5.7	-5.8	
Article 3.7	0.2						

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	Base year (current inventory)	2013	2014	2015	2016	2017	Base Year - 2017
Kyoto Protocol Total	798.2	572.0	531.6	514.0	489.3	476.5	-40%

Footnotes:

- See **Table ES 6** for full footnotes.
- The geographical coverage of this table is UK and Gibraltar only.

ES 4 OTHER INFORMATION

Table ES 8 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 8 Emissions of Indirect Greenhouse Gases in the UK, 1990-2017 (in kt).

Gas	1990	1995	2000	2005	2009	2010	2011	2014	2015	2016	2017
NO _x	3093	2542	1991	1754	1275	1247	1161	1055	1018	918	889
CO	7371	6128	4191	3053	2131	2048	1869	1759	1705	1581	1559
NMVOC	2841	2242	1591	1165	905	880	861	814	815	801	809
SO ₂	3782	2467	1301	781	438	455	420	326	255	179	177

Footnotes:

Geographical coverage of the emissions in the table includes emissions from the Crown Dependencies and Overseas Territories that are included in the UK's ratification of the UNFCCC.

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 SO₂, over 80% of emissions arise from activities within this sector. For NMVOC, 55% 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 for 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.beis.gov.uk/>

1 Introduction

This is the UK's 2019 National Inventory Report (NIR). From 2008 onwards, the NIR contains information required for reporting under the Kyoto Protocol as set out in decision 15/CMP.1⁵.

The National Inventory Report (NIR) is one element of the annual greenhouse gas (GHG) inventory that is compulsory to submit 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.19⁶.

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 must report supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol⁷, 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 (the Doha Amendment) runs 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). This Kyoto target covers the UK, and the relevant Crown Dependencies and Overseas Territories to whom

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>

ratification has been extended. The UK and the EU formally ratified the Doha Amendment on 17th November 2017, and 21st December 2017, respectively.

The Climate Change Act⁸ 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 and 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.19⁹ 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 2017. 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

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 1990-2017, 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 (AD) 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, 2018). 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.

Activity data estimates for individual OTs and CDs are provided by their respective government departments, through direct communications with the inventory agency or with BEIS. These data are used to supplement UK national statistics (such as DUKES) in order to compile and report a complete inventory for all territories.

1.1.2.3 Greenhouse Gases Reported in the UK Inventory

The greenhouse gases reported are:

Direct greenhouse gases

- Carbon dioxide (CO₂);
- Methane (CH₄);
- Nitrous oxide (N₂O);
- Hydrofluorocarbons (HFCs);
- Perfluorocarbons (PFCs);
- Sulphur hexafluoride (SF₆); and,
- Nitrogen trifluoride (NF₃).

Indirect greenhouse gases

- Nitrogen oxides (NO_x, as NO₂);
- Carbon monoxide (CO);
- Non-Methane Volatile Organic Compounds (NMVOC); and,
- Sulphur dioxide (SO₂).

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 N₂O resulting from NO_x and NH₃ 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 CO₂. 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 ₂ O	298
Hydrofluorocarbons		
HFC-23	CHF ₃	14,800

Gas		GWP
HFC-32	CH ₂ F ₂	675
HFC-41	CH ₃ F	92
HFC-43-10mee	CF ₃ CHFCHFCF ₂ CF ₃	1,640
HFC-125	C ₂ H ₅ F	3,500
HFC-134	C ₂ H ₂ F ₄	1,100
HFC-134a	C ₂ H ₂ F ₄	1,430
HFC-143	C ₂ H ₃ F ₃	353
HFC-143a	C ₂ H ₃ F ₃	4,470
HFC-152	CH ₂ FCH ₂ F	53
HFC-152a	C ₂ H ₄ F ₂	124
HFC-161	CH ₃ CH ₂ F	12
HFC-227ea	C ₃ H ₇ F ₇	3,220
HFC-236cb	CH ₂ FCF ₂ CF ₃	1,340
HFC-236ea	CHF ₂ CHFCF ₃	1,370
HFC-236fa	C ₃ H ₂ F ₆	9,810
HFC-245ca	C ₃ H ₃ F ₅	693
HFC-245fa	CHF ₂ CH ₂ CF ₃	1030
HFC-365mfc	CH ₃ CF ₂ CH ₂ CF ₃	794
Perfluorocarbons		
Perfluoromethane	PFC-14 - CF ₄	7,390
Perfluoroethane	PFC-116 - C ₂ F ₆	12,200
Perfluoropropane	PFC-218 - C ₃ F ₈	8,830
Perfluorobutane	PFC-3-1-10 - C ₄ F ₁₀	8,860
Perfluorocyclobutane	PFC-318 - c-C ₄ F ₈	10,300
Perfluoropentane	PFC-4-1-12 - C ₅ F ₁₂	9,160
Perfluorohexane	PFC-5-1-14 - C ₆ F ₁₄	9,300
Perfluorodecalin	PFC-9-1-18b - C ₁₀ F ₁₈	>7,500
Perfluorocyclopropanec	c-C ₃ F 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 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 11.1 . 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. 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.7¹²) 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/EC¹³ the UK was required to have in place its NIS by 31st December 2005. **Figure 1.1** 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 1.1 Key organisational structure of the UK National Inventory System

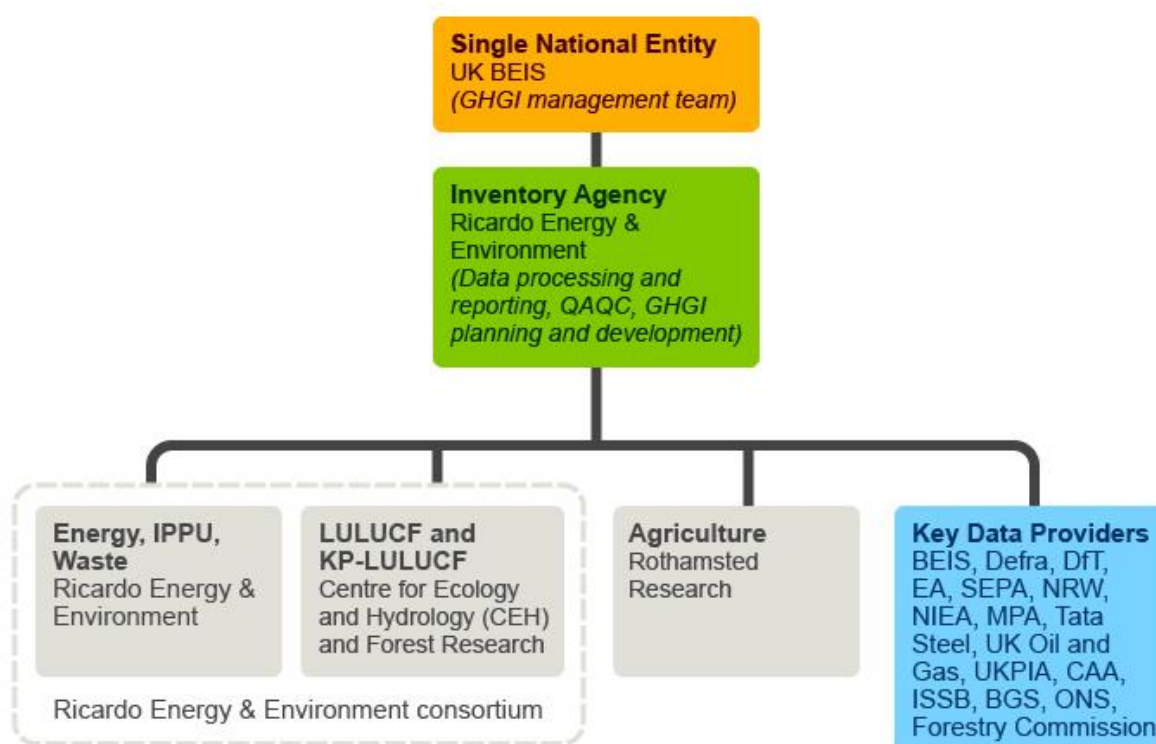


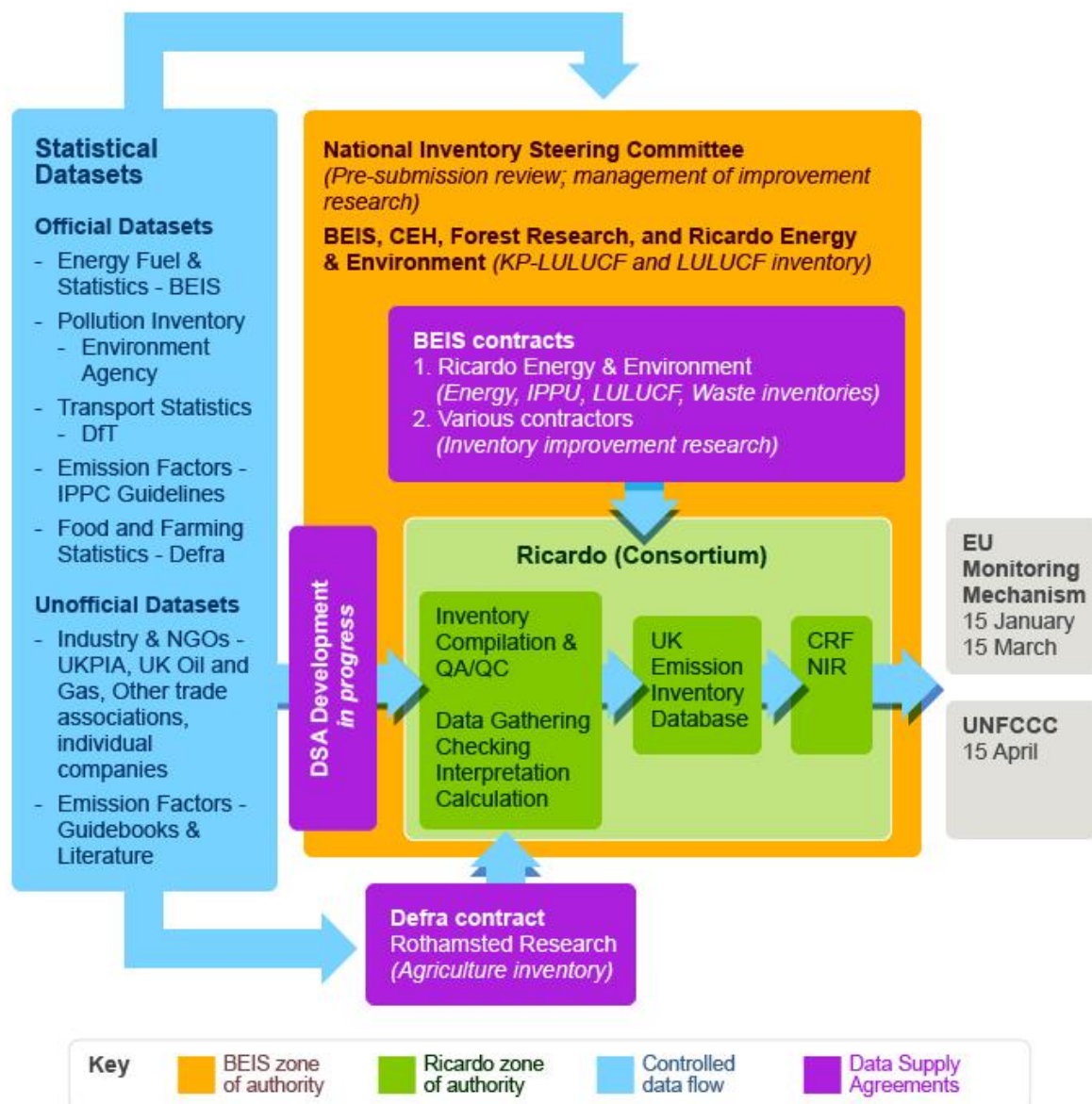
Figure 1.2 shows the main elements of the UK National Inventory System, including provision of data to the European Union under the terms of the Monitoring Mechanism Regulation. BEIS is the **Single National Entity** responsible for submitting the UK's GHGI to the UNFCCC. The

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>

Inventory Agency compiles the GHGI on behalf of BEIS, and produces disaggregated estimates for the DAs within the UK.

Figure 1.2 Main elements for the preparation of the UK greenhouse gas inventory



No significant changes have been made to the UK's National Inventory System since the previous inventory submission.

As part of the functioning of the National Inventory Steering Committee, there are now also bi-annual meetings (teleconferences) between BEIS and the devolved Governments of Scotland, Wales and Northern Ireland, around a month in advance of each NISC. These additional meetings have been established to facilitate discussion and agreement between inventory stakeholders at the UK and sub-national level, regarding: (i) priorities for inventory improvements in future cycles, and (ii) communication of changes to inventory data, including from improvements implemented in the latest national inventory dataset. These new meetings reflect the continued development of GHG mitigation targets by the devolved Governments, the different policy and evidence priorities at different spatial scales within the UK, and the increased scrutiny on both UK and sub-UK GHG emissions data.

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 2005¹⁴. 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. This legislation was updated in 2014 (The Greenhouse Gas Emissions Trading Scheme (Amendment) Regulations 2014¹⁵). 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 (DAs) (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 Science and Innovation for Climate and Energy (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.

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

¹⁵ <http://www.legislation.gov.uk/uksi/2014/3075/contents/made>

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.

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 OTs and CDs; and DA inventories.
- Ray Gluckman Consulting – contributions to the F-gas inventory.
- Hartley McMaster – provide independent QAQC of the system of inventory models

Ricardo Energy & Environment together with the project partners prepares the 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, United Nations Economic Commission for Europe 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 1.6** 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 (PI);
- Natural Resources Wales's (NRW) Emissions Inventory for Wales (WEI);
- The Scottish Environment Protection Agency's (SEPA) Scottish Pollutant Release Inventory (SPRI);
- The Northern Ireland Environment Agency's (NIEA) Northern Ireland Pollution Inventory (NIPI); and
- The BEIS Offshore Petroleum Regulator for Environment & Decommissioning (BEIS OPRED) Environmental and Emissions Monitoring System (EEMS)

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 (ETS), from detailed annual operator returns to the UK regulators of EU ETS (EA, SEPA, NRW, NIEA, BEIS OPRED). 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, DAs 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.

Following the NISC meeting in the autumn, any changes to the inventory methodology are signed off by the Director of Science and Innovation for Climate and Energy (SICE), who is the Senior Responsible Officer in BEIS.

Final technical sign-off of inventory outputs rests with the Inventory Agency, as part of the governance procedures agreed with BEIS as Single National Entity:

- Any outputs relating to financial mechanisms are signed off by the Senior Responsible Officer at the Inventory Agency, as evidence that all quality control has been conducted on these outputs
- National inventory outputs and technical delivery sign-off (e.g. on improvement projects) are signed off by either the inventory Senior Analyst or Technical Director at the Inventory Agency

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:

- UK government departments – including BEIS, the Department for Environment, Food and Rural Affairs (Defra), and Department for Transport (DfT)
- DAs in Scotland, Wales and Northern Ireland
- Inventory contractors (who compile data for the Inventory among other tasks)
- Government agencies (e.g. environmental regulators)
- Industry bodies or associations
- 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 GHGI 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 Effort Sharing Decision (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 – Science and Innovation for Climate and Energy (SICE) Directorate	<ul style="list-style-type: none"> • GHG inventory manager • Manager of GHG research contracts • BEIS annual climate change statistics and indicators 	<ul style="list-style-type: none"> • 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)	<ul style="list-style-type: none"> • Air quality (AQ) inventory manager • Manager of AQ research contracts 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Liaison between Defra and NISC 	<ul style="list-style-type: none"> • Provide an analytical overview of all relevant Defra sectors • Provide link with Defra climate change mitigation team
BEIS – Carbon Budgets	<ul style="list-style-type: none"> • UK Climate Change Programme • Climate Change Act • Carbon budgets 	<ul style="list-style-type: none"> • Inform NISC of UK programme developments • Explore links between inventory and carbon budgets and potential requirements for either area

Organisation	Role in relation to NISC	Key NISC responsibilities
BEIS – National Climate Change, Carbon Markets	<ul style="list-style-type: none"> • EU Emissions Trading System (ETS) • EU ETS Registry • EC Effort Sharing Decision 	<ul style="list-style-type: none"> • 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
BEIS – International Climate and Energy (ICE)	<ul style="list-style-type: none"> • International negotiations • MMR • UNFCCC 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • LULUCF Inventory manager 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Agriculture Inventory Manager 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Waste-water 	<ul style="list-style-type: none"> • To provide water policy expertise to the inventory • To assist in improving waste-water data quality

Organisation	Role in relation to NISC	Key NISC responsibilities
Defra – Waste	<ul style="list-style-type: none"> Waste 	<ul style="list-style-type: none"> To provide waste policy expertise to the inventory, including landfill waste To assist in improving landfill waste data quality
BEIS – Energy Statistics (DUKES)	<ul style="list-style-type: none"> Energy statistics 	<ul style="list-style-type: none"> Annual publication of Digest of UK Energy Statistics (DUKES) Providing energy statistics to inform the UK inventory
Regulators: <ul style="list-style-type: none"> Environment Agency for England Natural Resources Wales Scottish Environment Protection Agency Northern Ireland Environment Agency 	<ul style="list-style-type: none"> Pollution inventory EU ETS Registry 	<ul style="list-style-type: none"> Management, compilation, QA/QC and reporting of pollutant emission inventories/registers under Intergovernmental Panel on Climate Change (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 OPRED	<ul style="list-style-type: none"> Offshore oil and gas regulator (EEMS, EU ETS) and technical expertise 	<ul style="list-style-type: none"> 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

Organisation	Role in relation to NISC	Key NISC responsibilities
Ministry for Housing, Communities and Local Government (MHCLG)	<ul style="list-style-type: none"> Housing statistics Local Government issues 	<ul style="list-style-type: none"> 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)	<ul style="list-style-type: none"> Transport 	<ul style="list-style-type: none"> Publication of transport statistics each year Providing transport statistics to inform the UK inventory
Devolved Administrations	<ul style="list-style-type: none"> Inventories for Devolved Administrations Devolved administration climate change legislation and statutory carbon targets 	<ul style="list-style-type: none"> General review function for completeness and accuracy of UK inventory from a devolved perspective, including ensuring the integration of local datasets and specific research where appropriate. Aid NISC in understanding the implications of the UK inventory for the devolved administration inventories, legislation, carbon targets and other relevant context.
GHG inventory contractor (Ricardo Energy & Environment)	<ul style="list-style-type: none"> UK greenhouse gas inventory compilation and development 	<ul style="list-style-type: none"> Contractor responsible for the UK GHG inventory; activity data, methods, emission factors, emissions estimation, reporting and archiving Deliver annual National Inventory Report (NIR) and Common Reporting Format (CRF) submission to the UN and EU Participate in sectoral expert panels as required
GHG inventory project partners (Aether)	<ul style="list-style-type: none"> Inputs to GHG inventory compilation and development 	<ul style="list-style-type: none"> 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

Organisation	Role in relation to NISC	Key NISC responsibilities
GHG inventory project partners (CEH)	<ul style="list-style-type: none"> LULUCF inventory Kyoto Protocol LULUCF inventory 	<ul style="list-style-type: none"> 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)	<ul style="list-style-type: none"> Agriculture Inventory compilation and development 	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Energy modelling and projections 	<ul style="list-style-type: none"> Produce UK CO₂ 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	<ul style="list-style-type: none"> Atmospheric measurements and interpretation at Mace Head, Ireland and other tall tower sites. 	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Representation of industries, industry organisations and independent experts in the development of the national inventory 	<ul style="list-style-type: none"> Other experts or representatives may be asked to participate in sectoral expert panels or to review key sources or sources where significant changes

Organisation	Role in relation to NISC	Key NISC responsibilities
		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 of 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 Agriculture inventory improvements

The UK GHG agricultural inventory has recently undergone a major improvement program resulting in the adoption of a new coded (C#) inventory model with finer spatial, temporal and sectoral resolution in underlying calculations, implementation of a number of country-specific emission factors and improvements to activity data.

Further planned improvements are more modest, but include:

1. Review UK livestock feed data and revise inventory parameters according to outcomes of Defra project SCF0203.
2. 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 users¹⁶.
- 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 1990-2017 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.

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).

¹⁶ Terms and Conditions at <http://emissionsregistry.environment-agency.gov.uk/Default.aspx>

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 1.6**. Additional details of QA/QC in the LULUCF and Agriculture sectors can be found in **Chapter 6, Section 6.10** and **Chapter 5, Section 5.8.6** 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	<ul style="list-style-type: none"> Basic combustion module (fuel use * emission factor); Transport models (see MS 6 to MS 15); and, Carbon balance approach (See MS 4).

CRF sector	Comments on methods
1B	<ul style="list-style-type: none"> Carbon Balance approach (See MS 4); BEIS EEMS inventory (See Annex 3.1.2.3); and, Gas leakage data from network operators (See MS 19).
2A	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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 CH₄ from ethylene oxide, acrylonitrile, carbon black in years where no environmental regulators' inventories data available; and, Use of IPCC default factor for CO₂ from ethylene dichloride across full time-series.
2C	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Spreadsheet models to estimate emissions of F-gases.
2G	<ul style="list-style-type: none"> Spreadsheet models to estimate emissions of F-gases; NHS research into anaesthetic use; Pollution inventory data for other uses of N₂O; and, Statistics on cream consumption and Danish inventory assumptions for N₂O as a propellant for whipped cream.
3A	<ul style="list-style-type: none"> Emissions calculated based on animal population data and appropriate EFs.
3B	<ul style="list-style-type: none"> Emissions calculated based on animal population data and appropriate EFs.
3D	<ul style="list-style-type: none"> Emissions calculated based on animal population data, fertilizer data and appropriate EFs.
3F	<ul style="list-style-type: none"> Emissions calculated based on IPCC methodologies and USEPA EFs.
3G	<ul style="list-style-type: none"> Tier 1 approach for liming.

CRF sector	Comments on methods
4	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> The Methane Emissions from Landfill model (MELmod).
5B	<ul style="list-style-type: none"> UK waste activity data and IPCC default emission factors.
5C	<ul style="list-style-type: none"> Country specific emission factors, partially based on Pollution Inventory data.
5D	<ul style="list-style-type: none"> IPCC default method using country specific activity data for all N₂O and CH₄ 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) <i>Short name</i>	Relevant activity data contained in the source
Digest of UK Energy Statistics (UK Department for Business, Energy and Industrial Strategy) <i>DUKES</i>	<ul style="list-style-type: none"> 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 for Business, Energy and Industrial Strategy) <i>EU ETS</i>	<ul style="list-style-type: none"> 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) <i>TSGB</i>	<ul style="list-style-type: none"> 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) <i>Short name</i>	Relevant activity data contained in the source
Northern Ireland Statistics: Inventory of Statutory Releases, transport data (NI Department of Agriculture, the Environment and Rural Affairs, NI Department for Regional Development) <i>ISR</i>	<ul style="list-style-type: none"> • Traffic count and vehicle km data for Northern Ireland; and, • Information on regulated processes in NI.
Civil Aviation Authority <i>CAA</i>	<ul style="list-style-type: none"> • Detailed domestic and international civil aviation aircraft km flown.
Pollution Inventory (Environment Agency and Natural Resources Wales) <i>PI</i>	<ul style="list-style-type: none"> • Information on emissions from regulated processes in England and Wales.
Scottish Pollutant Release Inventory (Scottish Environment Protection Agency) <i>SPRI</i>	<ul style="list-style-type: none"> • Information on regulated processes in Scotland.
United Kingdom Petroleum Industry Association <i>UKPIA</i>	<ul style="list-style-type: none"> • Refinery emissions; and • Lead and sulphur contents of fuels, benzene content of petrol, RVP of petrol.
Environmental Emissions Monitoring System (EEMS) (BEIS OPRED) <i>EEMS</i>	<ul style="list-style-type: none"> • Detailed inventory of oil and gas emissions.
UK Iron and Steel Industry Annual Statistics (International Steel Statistics Bureau) <i>ISSB</i>	<ul style="list-style-type: none"> • 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) <i>UKMY</i>	<ul style="list-style-type: none"> • Statistical data on minerals production, consumption and trade.

Source (and publisher) <i>Short name</i>	Relevant activity data contained in the source
Department for Transport <i>ANPR</i>	<ul style="list-style-type: none"> 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 Scarborough et al., 2017). 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 CO₂ 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	Category	Greenhouse Gas	Identification Criteria
1A	(Stationary) Oil	CO ₂	L2, T2
1A	Coal	CO ₂	L2, T2
1A	Natural Gas	CO ₂	L2, T2
1A	Other (waste)	CO ₂	T2
1A1	Energy industries: gaseous fuels	CO ₂	L1, T1

IPCC Code	Category	Greenhouse Gas	Identification Criteria
1A1	Energy industries: liquid fuels	CO ₂	L1, T1
1A1	Energy industries: other fuels	CO ₂	L1, T1
1A1	Energy industries: solid fuels	CO ₂	L1, T1
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	N ₂ O	L2
1A2	Manufacturing industries and construction: gaseous fuels	CO ₂	L1, T1
1A2	Manufacturing industries and construction: liquid fuels	CO ₂	L1, T1
1A2	Manufacturing industries and construction: solid fuels	CO ₂	L1, T1
1A3b	DERV	CO ₂	L2, T2
1A3b	DERV	N ₂ O	L2, T2
1A3b	Gasoline/ LPG	CO ₂	L2
1A3b	Road transportation: liquid fuels	CO ₂	L1, T1
1A3c	Railways: liquid fuels	CO ₂	L1, T1
1A3d	Domestic Navigation: liquid fuels	CO ₂	L1, T1
1A3d	Marine fuel	CO ₂	L2
1A4	Other sectors: gaseous fuels	CO ₂	L1, T1
1A4	Other sectors: liquid fuels	CO ₂	L1, T1
1A4	Other sectors: solid fuels	CO ₂	L1, T1
1A5	Other: liquid fuels	CO ₂	T1
1B1	Coal Mining	CH ₄	T1, T2
1B2	Oil and gas extraction	CH ₄	L1, T1
1B2	Oil and gas extraction	CO ₂	L1
2A1	Cement production	CO ₂	L1
2B	Chemical industries	CO ₂	L2
2B	Chemical industry	HFCs	T2
2B2	Nitric acid production	N ₂ O	T1
2B3	Adipic Acid Production	N ₂ O	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
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 ₂ O	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
3B1	Manure management from Cattle	CH ₄	L1, T1
3B2	Manure management from Sheep	N ₂ O	L1
3D	Agricultural Soils	N ₂ O	L1, T1, L2
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
4G	Other Activities	CO ₂	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 ₂ O	T2

IPCC Code	Category	Greenhouse Gas	Identification Criteria
5C	Waste Incineration	CO ₂	T2
5D	Wastewater Handling	CH ₄	L1, L2
5D	Wastewater Handling	N ₂ O	L2, T2

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

IPCC Code	Category	Greenhouse Gas	Identification Criteria
1A	(Stationary) Oil	CO ₂	L2
1A	Coal	CO ₂	L2
1A	Natural Gas	CO ₂	L2
1A1	Energy industries: gaseous fuels	CO ₂	L1
1A1	Energy industries: liquid fuels	CO ₂	L1
1A1	Energy industries: solid fuels	CO ₂	L1
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	N ₂ O	L2
1A2	Manufacturing industries and construction: gaseous fuels	CO ₂	L1
1A2	Manufacturing industries and construction: liquid fuels	CO ₂	L1
1A2	Manufacturing industries and construction: solid fuels	CO ₂	L1
1A3b	Gasoline/ LPG	CO ₂	L2
1A3b	Gasoline/ LPG	CH ₄	L2
1A3b	Road transportation: liquid fuels	CO ₂	L1
1A3d	Domestic Navigation: liquid fuels	CO ₂	L1
1A3d	Marine fuel	CO ₂	L2
1A4	Other sectors: gaseous fuels	CO ₂	L1
1A4	Other sectors: liquid fuels	CO ₂	L1
1A4	Other sectors: solid fuels	CO ₂	L1
1A5	Other: liquid fuels	CO ₂	L1
1B1	Coal Mining	CH ₄	L1, L2
1B2	Natural Gas Transmission	CH ₄	L2
1B2	Oil and gas extraction	CH ₄	L1
1B2	Oil and gas extraction	CO ₂	L1
2A1	Cement production	CO ₂	L1
2B	Chemical industries	CO ₂	L2
2B	Chemical industry	HFCs	L2
2B3	Adipic Acid Production	N ₂ O	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
3B1	Manure management from Cattle	CH ₄	L1
3D	Agricultural Soils	N ₂ O	L1, L2
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
5C	Waste Incineration	CO ₂	L2
5D	Wastewater Handling	CH ₄	L1, L2
5D	Wastewater Handling	N ₂ O	L2

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

IPCC Code	Category	Greenhouse Gas	Identification Criteria
1A	(Stationary) Oil	CO ₂	L2, T2
1A	Coal	CO ₂	L2, T2
1A	Natural Gas	CO ₂	L2, T2
1A	Other (waste)	CO ₂	L2, T2
1A1	Energy industries: gaseous fuels	CO ₂	L1, T1
1A1	Energy industries: liquid fuels	CO ₂	L1, T1
1A1	Energy industries: other fuels	CO ₂	L1, T1
1A1	Energy industries: solid fuels	CO ₂	L1, T1
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	CH ₄	L2
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	N ₂ O	L2
1A2	Manufacturing industries and construction: gaseous fuels	CO ₂	L1, T1
1A2	Manufacturing industries and construction: liquid fuels	CO ₂	L1, T1
1A2	Manufacturing industries and construction: solid fuels	CO ₂	L1, T1
1A3a	Domestic aviation: liquid fuels	CO ₂	L1
1A3b	DERV	CO ₂	L2, T2
1A3b	DERV	N ₂ O	L2, T2
1A3b	Gasoline/ LPG	CO ₂	L2
1A3b	Road transportation: liquid fuels	CO ₂	L1, T1
1A3c	Railways: liquid fuels	CO ₂	L1, T1
1A3d	Domestic Navigation: liquid fuels	CO ₂	L1
1A3d	Marine fuel	CO ₂	L2
1A4	Other sectors: gaseous fuels	CO ₂	L1, T1
1A4	Other sectors: liquid fuels	CO ₂	L1, T1
1A4	Other sectors: solid fuels	CO ₂	L1, T1
1A5	Other: liquid fuels	CO ₂	T1
1B1	Coal Mining	CH ₄	T1, T2
1B2	Natural Gas Transmission	CH ₄	L2
1B2	Oil and gas extraction	CO ₂	L1
1B2	Oil and gas extraction	CH ₄	L1, T1
2A1	Cement production	CO ₂	L1
2B	Chemical industries	CO ₂	L2
2B	Chemical industry	HFCs	T2
2B2	Nitric acid production	N ₂ O	T1
2B3	Adipic Acid Production	N ₂ O	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
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 ₂ O	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
3B1	Manure management from Cattle	CH ₄	L1, T1
3B2	Manure management from Sheep	N ₂ O	L1
3D	Agricultural Soils	N ₂ O	L1, T1, 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 ₂ O	L2, T2

IPCC Code	Category	Greenhouse Gas	Identification Criteria
5C	Waste Incineration	CO ₂	L2, T2
5D	Wastewater Handling	CH ₄	L1, L2
5D	Wastewater Handling	N ₂ O	L2, T2

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

IPCC Code	Category	Greenhouse Gas	Identification Criteria
1A	(Stationary) Oil	CO ₂	L2
1A	Coal	CO ₂	L2
1A	Natural Gas	CO ₂	L2
1A1	Energy industries: gaseous fuels	CO ₂	L1
1A1	Energy industries: liquid fuels	CO ₂	L1
1A1	Energy industries: solid fuels	CO ₂	L1
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	N ₂ O	L2
1A2	Manufacturing industries and construction: gaseous fuels	CO ₂	L1
1A2	Manufacturing industries and construction: liquid fuels	CO ₂	L1
1A2	Manufacturing industries and construction: solid fuels	CO ₂	L1
1A3b	Gasoline/ LPG	CO ₂	L2
1A3b	Road transportation: liquid fuels	CO ₂	L1
1A3d	Domestic Navigation: liquid fuels	CO ₂	L1
1A3d	Marine fuel	CO ₂	L2
1A4	Other sectors: gaseous fuels	CO ₂	L1
1A4	Other sectors: liquid fuels	CO ₂	L1
1A4	Other sectors: solid fuels	CO ₂	L1
1A5	Other: liquid fuels	CO ₂	L1
1B1	Coal Mining	CH ₄	L1, L2
1B2	Natural Gas Transmission	CH ₄	L2
1B2	Oil and gas extraction	CO ₂	L1
1B2	Oil and gas extraction	CH ₄	L1
2A1	Cement production	CO ₂	L1
2B	Chemical industries	CO ₂	L2
2B	Chemical industry	HFCs	L2
2B3	Adipic Acid Production	N ₂ O	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
3B1	Manure management from Cattle	CH ₄	L1
3D	Agricultural Soils	N ₂ O	L1, L2
5A	Solid Waste Disposal	CH ₄	L1, L2
5C	Waste Incineration	CO ₂	L2
5D	Wastewater Handling	CH ₄	L1, L2
5D	Wastewater Handling	N ₂ O	L2

Table 1.11 Key category ranking

KCA rank (KCs only)	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	1A1	Energy industries: gaseous fuels	CO ₂

KCA rank (KCs only)	IPCC Code	IPCC Category	Greenhouse Gas
6	1A2	Manufacturing industries and construction: gaseous fuels	CO ₂
7	1A1	Energy industries: liquid fuels	CO ₂
8	1A2	Manufacturing industries and construction: solid fuels	CO ₂
9	3A1	Enteric fermentation from Cattle	CH ₄
10	1A2	Manufacturing industries and construction: liquid fuels	CO ₂
11	4A	Forest land	CO ₂
12	1A4	Other sectors: liquid fuels	CO ₂
13	3D	Agricultural soils	N ₂ O
14	4B	Cropland	CO ₂
15	1A4	Other sectors: solid fuels	CO ₂
16	1B2	Oil and gas extraction	CH ₄
17	4E	Settlements	CO ₂
18	1B1	Coal mining and handling	CH ₄
19	4C	Grassland	CO ₂
20	1A3d	Domestic Navigation: liquid fuels	CO ₂
21	2F1	Refrigeration and air conditioning	HFCs, PFCs, SF ₆ and NF ₃
22	3B1	Manure management from Cattle	CH ₄
23	1B2	Oil and gas extraction	CO ₂
24	3A2	Enteric fermentation from Sheep	CH ₄
25	1A5	Other: liquid fuels	CO ₂
26	5D	Wastewater treatment and discharge	CH ₄
27	2C1	Iron and steel production	CO ₂
28	2B9	Fluorochemical production	HFCs, PFCs, SF ₆ and NF ₃
29	3B2	Manure management from Sheep	N ₂ O
30	1A3c	Railways: liquid fuels	CO ₂
31	1A1	Energy industries: other fuels	CO ₂
32	1A3a	Domestic aviation: liquid fuels	CO ₂
33	2A1	Cement production	CO ₂
34	2F4	Aerosols	HFCs, PFCs, SF ₆ and NF ₃
35	2B8	Petrochemical and carbon black production	CO ₂
36	4G	Harvested wood products	CO ₂
37	2B2	Nitric acid production	N ₂ O
38	2B3	Adipic acid production	N ₂ O
39	5B	Biological treatment of solid waste	CH ₄

1.5.2 KP-LULUCF analysis

A separate uncertainty analysis has been completed for the Key Categories for LULUCF 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, CO₂;
- Deforestation, Conversion to Grassland, Conversion to Settlements, CO₂;
- Forest Management, Forest Land, CO₂;
- Cropland Management, Cropland, CO₂; and,
- Grazing Land Management, Grassland, CO₂.

1.6 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

This section presents the QA/QC system for the UK greenhouse gas inventory (GHGI), including the approaches used for verification and treatment of confidentiality issues. QA/QC activities comprise:

- **Quality Control** (e.g. raw data checks, calculation checks, output checks) to minimise the risk of errors within the available resources to deliver the inventory.
- **Quality Assurance** (e.g. peer reviews, bilateral reviews, expert reviews) whereby independent experts periodically review all or part of the inventory to identify potential areas for improvement.
- **Verification** where alternate independent datasets are available to compare against inventory data and trends

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 ISO 9001:2015 and ISO 14001: 2015 (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 NAEI 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:

- Rothamsted Research manages the compilation of emission estimates for the agriculture sector under contract to Defra, working with a team of contractors that are agriculture sector experts from a number of other organisations: ADAS, Cranfield University and the Centre for Ecology and Hydrology (CEH);
- the Centre for Ecology and Hydrology (CEH) and Forest Research (FR) together compile the Land Use, Land-Use Change and Forestry (LULUCF) sector, both under sub-contract to Ricardo Energy & Environment.

Many of the statistical datasets received by Ricardo Energy & Environment, CEH, FR and Rothamsted Research for the UK GHGI compilation come from data provider organisations that are UK government departments, agencies, research establishments or consultants working on behalf of UK government or for trade associations. Several of these data provider organisations (e.g. BEIS, the Department for Transport, Defra, the Office of National Statistics and British Geological Survey) qualify as UK National Statistical Agencies (as defined in UN Guidance¹⁷) and abide by strict statistical QA/QC standards.

¹⁷ See: <https://unstats.un.org/unsd/methods/statorg/>

Other organisations (e.g. the UK environmental regulatory agencies that provide installation-level emissions data) supply important datasets for the UK inventory and have their own QA/QC systems that govern data quality. Regulatory agencies for industry and commerce have developed data QA/QC systems to support their specific regulatory functions, including to regulate operator environmental performance (such as to underpin atmospheric emissions reporting under EU ETS or the Industrial Emissions Directive) and to regulate other activity performance that is relevant for the national inventory (such as annual reporting against industry performance standards for water companies, gas suppliers, electricity suppliers). In some cases, data for the national inventory are provided by individual companies or organisations (e.g. trade associations) and in those instances the inventory agency requests information annually regarding QA/QC systems that underpin the data, as well as seeking information on estimated uncertainties of the data provided.

Ricardo Energy & Environment is responsible for co-ordinating inventory-wide QA/QC activities relating to inventory submissions, across all inventory stakeholders. In addition, Ricardo Energy & Environment works 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, through stakeholder consultation meetings, annual information requests, and via the National Inventory Steering Committee (NISC - *more details are provided below*).

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.

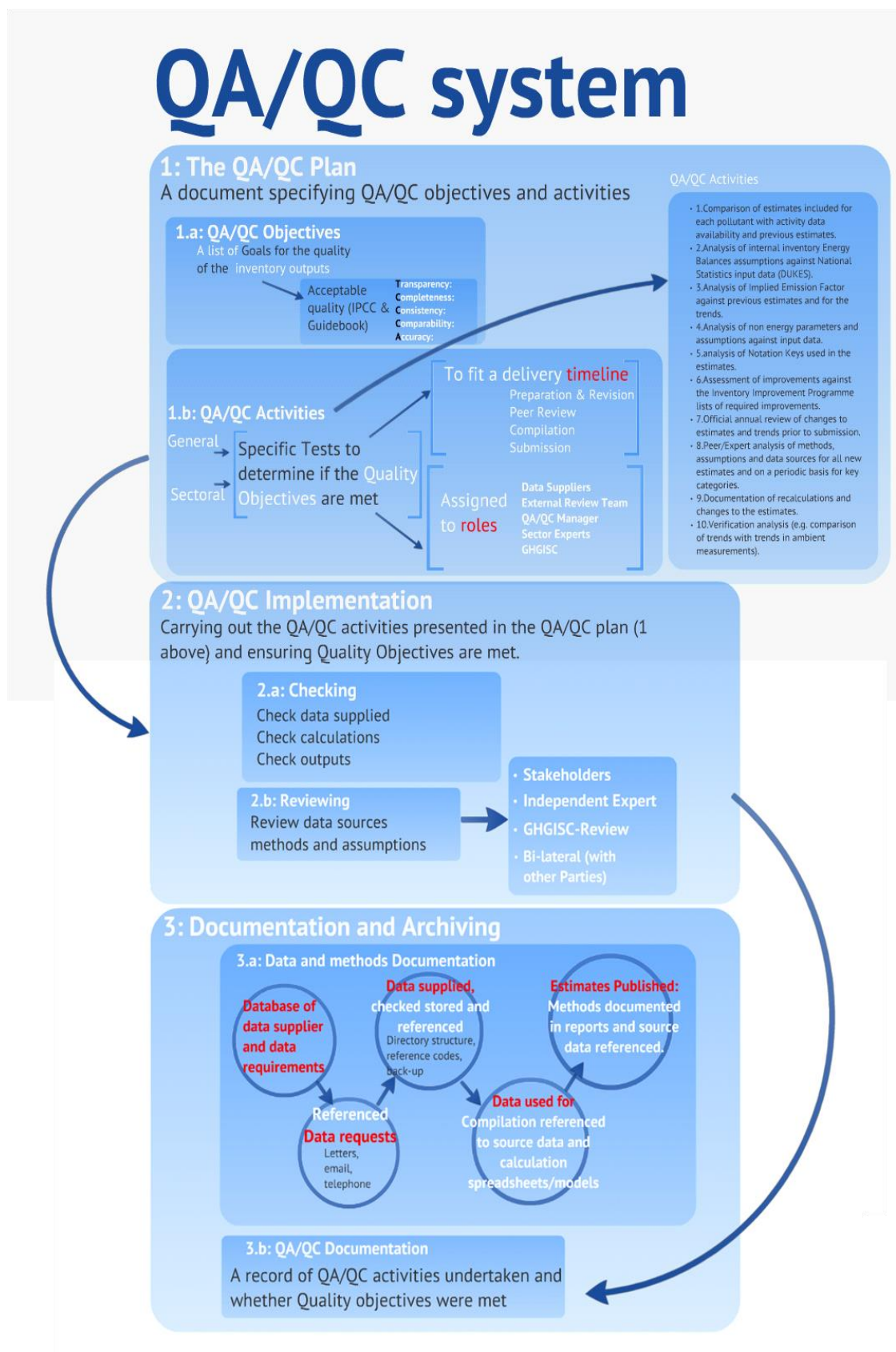
1.6.1.1 Overview of the UK QA/QC system

An overview of the UK's GHGI QA/QC system is illustrated in **Figure 1.3** 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 1.3 QA/QC system used within UK greenhouse gas inventory



Box 1.1: ISO 9001:20 and ISO 14001: 2015 Accreditation

In addition to the UK's GHGI-specific QA/QC system, through Ricardo Energy & Environment, the Inventory has been subject to ISO 9000 since 1994 and is now subject to ISO 9001:2015. 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 five occasions in the last 14 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. As part of the Ricardo Group certification, Ricardo Energy & Environment is currently accredited to ISO 9001:2015. Lloyds Register Quality Assurance carried out a three-yearly recertification audit of Ricardo Energy & Environment which was completed in September 2017. Ricardo Energy & Environment successfully passed the recertification, with no major non-compliances, and a new Ricardo Group certificate was issued in December 2017. Under the Ricardo Group certification, Ricardo Energy & Environment is currently certificated for the Quality Assurance ISO 9001:2015, Environmental Management System ISO 14001: 2015 and Health & Safety OHSAS 18001 standards.

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 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 (HM), 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 Book¹⁸). Further to this review, BEIS commissioned in late 2016 a review of a further sample of NAEI models by Cambridge Architectural Research (CAR). During 2016, HM also reviewed a representative sample of the models operated by Forest Research (FR) and CEH to generate the LULUCF estimates, and during 2017 HM reviewed a sample of models used to process point source data for the national inventory. The findings of these reviews have underpinned QA system improvements in the 1990-2017 inventory compilation cycle, and further model-specific QA improvements may be considered for future work.

The following is a list of the main improvements made to the inventory QA/QC system during the 2019 submission cycle:

- Further improvement of pollutant-specific checking templates that facilitate a more consistent checking procedure for inventory activity data and for the inventories for

¹⁸ <https://www.gov.uk/government/publications/the-aqua-book-guidance-on-producing-quality-analysis-for-government>

GHGs and air quality pollutants, and to collect information on recalculations and reported trends in a systematic, prioritised way. The pollutant-specific checking models were updated to automatically pull forward activity data checking comments to improve speed, consistency and efficiency of the quality checking, and of the analysis of reasons for changes and reasons for trends across pollutants;

- Further improvement to the model developed to convert and manage the derivation of emission factors (often from literature defaults) into units applied in the UK emissions inventory database. This model, developed and first used in the 2018 submission, converts emission factors from energy to mass units, and ensures that a consistent approach is taken (e.g. in selection of the most appropriate default factor for a specific UK emission source, where several may be presented in the literature). In the 2019 submission, the scope of this model has been extended to include more pollutants (such as PAHs), and the selection and use of Net Calorific Values (NCVs) has been simplified to directly use published NCVs (that are now more routinely published by BEIS within the Digest of UK Energy Statistics) rather than to use GCVs and gross-net conversion factors;
- Development and use of new CRF checking systems, using data visualisation checks to help spot outliers and potential inconsistencies;
- Continued upgrading of the LULUCF models, including verification of model calculations and expansion of model quality checks.
- Continued development of agriculture inventory quality systems, to reflect the major methodological changes that were implemented (mostly in the 2018 submission) across the sector. Rothamsted Research has worked closely with Ricardo Energy & Environment and the team of other agriculture sector experts that have developed the new UK inventory methods: ADAS, CEH and Cranfield University. During the 2019 submission cycle, improvements have been made to develop better documentation of the new inventory methods, to use standard forms to improve consistency of the documentation and communication between project partners, including for model issues logs and source-level data validation checks.
- Revision to the agriculture sector data structure used in the central NAEI database that is used to manage and report the GHG inventory data. The new agriculture sector models enable the data to be reported at a greater level of resolution (e.g. by DA, by livestock sub-type, age) than was previously possible (or necessary) when applying lower-Tier methods. In the first year of use of the new methods (i.e. for the 2018 submission), an interim step of data processing was needed to convert the outputs from the new agriculture model to fit the input requirements of the NAEI database. For the 2019 submission, the data structures (source-activity combinations) within the NAEI database have been overhauled to remove the need for the interim data processing step (thereby reducing the risk of data processing errors), and also to enable reporting from the NAEI database to reflect the new, more detailed level of data resolution available from the development of higher-Tier methods.

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 United Nations Economic Commission for Europe (UNECE) and UNFCCC, as set out within national inventory reporting guidance from the IPCC¹⁹ and European Environment Agency (EEA)²⁰. The inventory data quality objectives

¹⁹ 2006 IPCC Guidelines for National Greenhouse Gas Inventories: <http://www.ipcc-nggip.iges.or.jp/public/2006gl/>

²⁰ 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 Air Pollutant Inventory (API) estimates contain many 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**: Lead all key management activities including management of the project finances, commercial issues, liaison with BEIS and Defra, manage and attend project meetings, communicating project tasks and requirements to the team and oversee the day-to-day running of the project. 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 QA/QC improvements by sharing best practice and engaging in team communication activities; and,
- **External Review experts**: Provide expert/peer review of projections for specific sectors, identify key findings and inventory improvement recommendations, 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

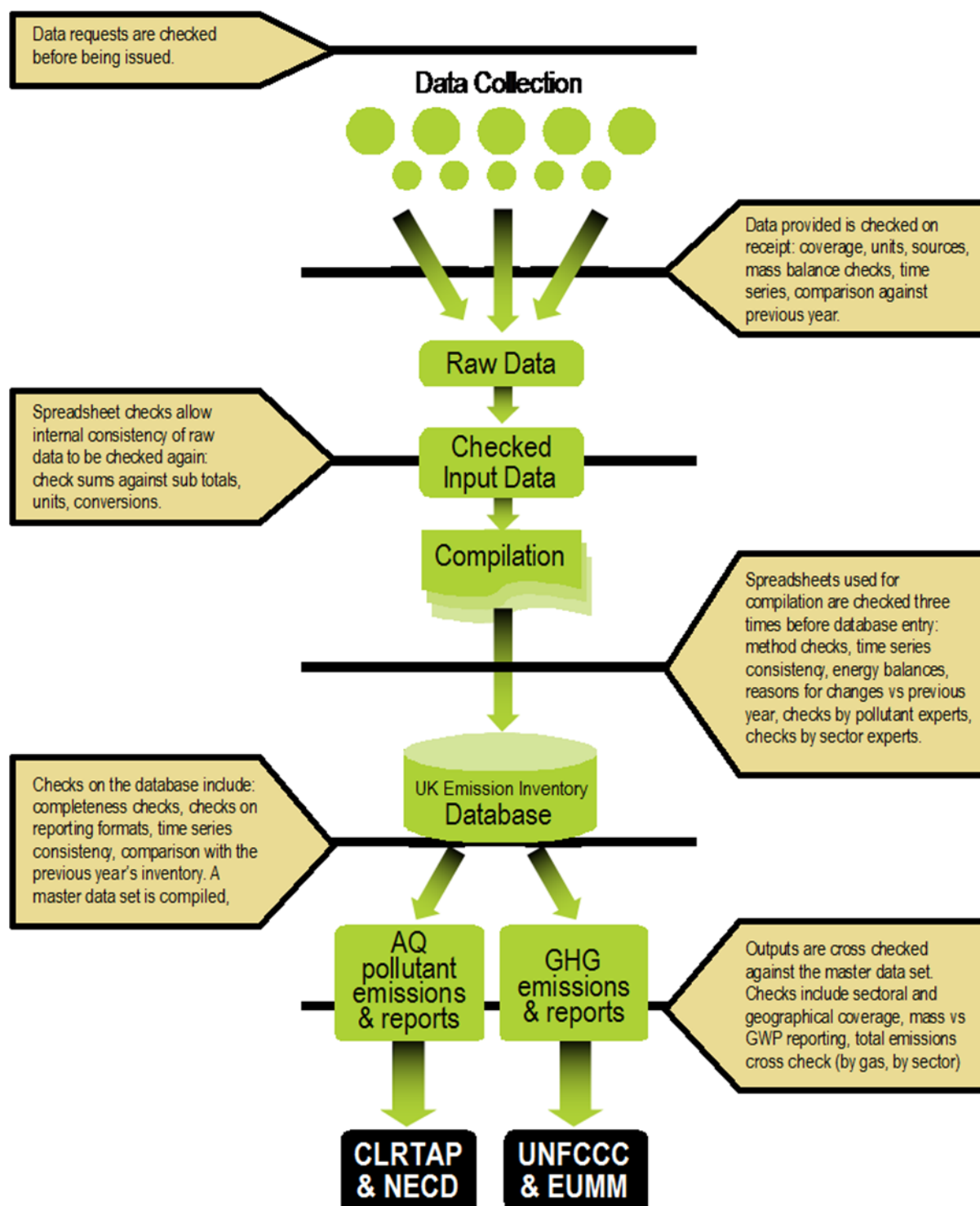
The UK’s GHGI Quality Control (checking, documentation and archiving) occurs throughout the data gathering, compilation and reporting cycle. **Figure 1.4** illustrates the process of data checks used within the UK greenhouse gas inventory. The horizontal bars symbolise ‘gates’ through which data does not pass until it meets the quality criteria and the appropriate checks have been performed. The key activities that are undertaken and documented to check the estimates include:

1. **Checking of input data for scope, completeness, consistency with data for recent years and (where available) verification against other independent datasets.** Compilers check the incoming data from data providers to assess whether the data are complete and consistent with data for recent years. In some cases, checks are performed to compare data between individual operators (e.g. gas composition data from multiple UK

gas transporters) and between different reporting mechanisms (such as comparisons of operator-reported activity and emissions data between IED/PRTR and EU ETS). For several sources, production-based emission estimates can be compared with other data (e.g. sales data, plant capacity data) to check that the trends and values are reasonable.

2. **Analysis of internal inventory energy and mass balances** and other statistics assumptions against National Statistics input data (e.g. DUKES and ONS). Mass or energy balances are performed for each major fuel in the UK economy and any deviations from UK energy statistics are checked and documented. Several sector methods for key categories also have Tier 2 checks to assess internal consistency, such as carbon balance checks for the carbon flows through integrated iron and steel works.
3. **Completeness checks.** The database is checked for completeness and consistency of entry across the different pollutants and gases. For example, combustion sources are checked for inclusion of all relevant pollutants and the database checked for any missing estimates and appropriate use of notation keys.
4. **Recalculation checks.** The latest inventory dataset is compared against the previous inventory submission. Any recalculations are documented by inventory compilers and signed off by checkers. Reasons for the recalculations are documented, e.g. method improvements, revisions to input data or assumptions. These recalculation notes are referenced within the inventory database to facilitate reporting and transparency of recalculations.
5. **Time series checks and benchmarking checks.** The time series of emissions are checked for step changes, trends and any outlier data (e.g. outlier EFs or peaks/dips in activity data trends). Any unusual features are checked and explained, with reasons for significant trends and outliers documented in the method sections of the NIR. Implied Emission Factors (IEFs) are checked against previous estimates and for key categories against defaults (from IPCC guidance) to identify any notable UK-specific EF outliers.
6. **Method implementation checks.** A range of common checks are performed across inventory calculation models, such as: checking that units are correct for input parameters; checking that selection of NCVs or default EFs is consistent across years / pollutants; checking for either new emission estimates (e.g. due to new UK data or new methodological guidance or new EFs within the IPCC guidance) or for any missing emission sources compared to previous submissions.
7. **Reporting checks.** Inventory submissions are checked to ensure correct allocation into the CRF categories. Emission totals at national and sub-category level are checked against the “master” dataset derived from the UK inventory database outputs, to minimise risks of data transcription errors into reporting templates.

Figure 1.4 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 inventory. 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. **Individual data processing tools** 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 models (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 data are referenced 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. **A core database (NAEI database) of AD and EFs** with embedded tier 1 QC routines and data source and data processing referencing. The database provides the quality assured dataset of UK emissions and removals used for EU, UNFCCC and Kyoto Protocol (KP) reporting (including CRF population), responding to ad-hoc queries or deriving other downstream estimates (e.g. emissions by Devolved Government and emissions by Local Authority). The detailed Activity Data and Emission Factor components for each source or sink category estimate are held within the NAEI database and include all sources, activities, gases/pollutants (GHGI and API), territories and years. The majority of data in the database are imported directly from the individual data processing models (as described above). To ensure data source transparency, all data points in the database carry a reference to 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 models 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 are embedded within the database that facilitate annual QC activities, as defined in the QA/QC Plan, including:
 - a. Checks with previous submissions for changes due to recalculations or errors at a detailed level, by source-activity-pollutants (a designated auditor identifies

- sources where there have been significant changes or new sources. Inventory compilers are then required to explain these changes to satisfy the auditor)²¹;
- b. Assessment of trends and time series consistency for selected key sources, including QC of activity data and emissions of high priority pollutants;
 - c. Mass balance checks for all major fuels to ensure that the total fuel consumptions in the GHG inventory are in accordance with those published in energy National Statistics from BEIS, and that any exceptions or deviations are documented and understood;
 - d. Input-output checks for key UK models to conduct “implementation” checks on the processing of data from upstream models for LULUCF, agriculture and F-gases;
 - e. Industry-specific checks, to compare UK inventory output data against operator-reported data via other mechanisms, such as EU ETS, Industrial Emissions Directive (IED). These checks enable high-level checks on the data consistency for high-emitting source categories (e.g. power stations, refineries, cement kilns, Iron and steel works) for priority pollutants (e.g. CO₂, NO_x);
 - f. Other activity data checks (e.g. production and consumption with National Statistics);
 - g. Implied Emission Factor checks (assessing trends in IEF and comparison with previous submissions);
 - h. A consistency check between IPCC output and EMEP/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, online manuals, electronic source data, records of communications, paper source data, output files representing all calculations for the whole time series are frozen and archived on a central server. Electronic information is stored on secure and separately located servers (with one acting purely as back-up) that are regularly backed up. Paper information is archived in a Roller Racking system with a simple electronic database of all items referenced 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.

²¹ 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.

- 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 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.

1.6.2.5.2 Stakeholder 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 during the compilation of the 1990-2017 inventory include:

Department for Business, Energy & Industrial Strategy

- The Inventory Agency met with the BEIS energy statistics team that produces DUKES to discuss changes (to both activity and methodology) in the 2018 publication of the statistics, in order to ensure correct interpretation of the new statistics in the 2019 submission. The inventory agency has regular contact with the DUKES team and works to ensure that any revisions in the DUKES data are reflected accurately in the inventory, and where necessary that time series recalculations are made in consultation with the DUKES team. There were very few notable changes in the 2018 DUKES publication; a small number of minor data inconsistencies were addressed, including updates to improve the accuracy of the inventory time series for petroleum waxes.

- Consultation with the BEIS OPRED to request clarifications on the scope and completeness of Environmental and Emissions Monitoring System (EEMS) reported data for several individual installations, to ensure correct interpretation of the available data. This was especially significant in 2018 due to a change in the software system used by BEIS to collect and report EEMS data, and the resultant data output to the inventory agency had multiple duplications and also a small number of apparent reporting gaps which were identified through the inventory agency's initial data checking routines. The finalisation of the dataset for the 2019 submission was achieved via several exchanges of data, emails and phone calls, in order to assure completeness and accuracy for the offshore oil and gas sector estimates.

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. In some instances, this has led to corrections to previous estimates.
- As in previous years we have contacted environmental regulators to clarify discrepancies between data reported in the regulator inventories used for IED/PRTR reporting (PI, SPRI, WEI and NIPI), EU ETS, and other data sources. Through consultation with regulators, the Inventory Agency has been able to access supplementary data to provide more complete understanding of activity data and emissions where operators are allowed by UK regulators to apply the fall-back approach to EU ETS reporting.

Other data providers

- Consultation with steelworks operators, leading to the provision of more complete industry emissions data for recent years, leading to improvements in emission estimates for integrated steelworks.
- Consultation with the Iron and Steel Statistics Bureau (ISSB) to check on the validity of reported trends in carbonate usage in the sector, which were identified as outliers in initial data checks, leading to provision of a corrected dataset.
- Consultation with representatives of the petroleum supply sector and biofuel sector, including the UK Petroleum Industry Association and Energy Power Resources Limited, in order to research the available data on energy and fossil carbon content of biofuels in the UK market.
- Consultation with National Grid, the operators of the upstream gas supply infrastructure, leading to the provision of a more complete, accurate recent time series of estimates of gas releases from the transmission system, storage venting and LNG terminals.
- Consultation with numerous trade associations that represent sectors that use solvents and contribute significant emissions of indirect GHGs and Air Quality pollutants, including: British Adhesives and Sealants Association (adhesives & sealants); British Aerosol Manufacturers Association (aerosols); Federation of Bakers, Campden BRI (food and drink), Chemical Industries Association (chemicals manufacture), British Coatings Federation (manufacture of paints and inks), European Solvents Industry Group (solvent manufacture and use). New data from these trade bodies led to revisions mainly to the UK NMVOC inventory.

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 UK's 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 Expert, Peer and Bilateral review activities

Review description	Summary
2006 - 2018: 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, nor in 2018 due to limited UNFCCC funds for conducting reviews.
2018: Bilateral review with France of LULUCF	The UK hosted the French lead on LULUCF for a bilateral review in London during autumn 2018. The findings of the review will feed into plans for improvements for the 2020 submission.
2018: Expert review of the agriculture sector	In the absence of a formal UNFCCC review during 2018, and noting that a major change in the UK methodology for most agriculture sources was implemented in the 2018 submission, to move to higher-tier methods, the UK invited experienced UNFCCC reviewer Bernard Hyde of the Republic of Ireland, to conduct a focussed expert review of the new UK methods. This was conducted during autumn 2018 and the findings from the review will feed into plans for improvements for the 2020 submission.
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,	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

Review description	Summary
Netherlands, Denmark, on QAQC.	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 KP- 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.
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 (2F1) with Industry experts; SKM EnviroS	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 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. Knowledge sharing on emissions inventory compilation methods with Moscow State Government officials.
2. Study tour by representatives of the Israeli Ministry of Environmental Protection and Central Bureau of Statistics, who compile the GHG inventory for Israel.
3. Knowledge sharing with Chinese energy statisticians on GHG emissions trading and statistics.
4. Capacity building activities in South Africa in the agricultural sector.
5. Knowledge sharing with the Romanian GHG inventory team during December 2011 to support the improvement of energy sector reporting.
6. 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.
7. Capacity building in Spain – invited presentation of the UK agricultural inventory improvements and further conversations with Spanish government representatives.
8. Knowledge sharing with Russian and French inventory teams.
9. CEH participation in annual yearly knowledge sharing with European LULUCF inventory compilers at EU Joint Research Council LULUCF meetings.
10. Knowledge sharing with the Vietnam inventory team.
11. Capacity building workshop with Balkan EU accession countries on National System development.
12. 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.
13. Knowledge sharing between CEH LULUCF inventory compilers and Maltese LULUCF inventory compilers in 2016.
14. In 2018 the UK inventory team collaborated with peers from the EU Working Group 1 to draft a note for circulation to all Member States regarding the fossil carbon content of road transport biofuels, based on our research with the UK fuel supply chain;
15. The UK experts on inventory verification and the InTEM model, from BEIS and the Met Office, have engaged with verification experts from other countries and across other research institutes through the IG3IS symposium and user summit in November 2018 in Geneva, Switzerland, in order to share knowledge and experience from the UK programme and explore options for further development of these techniques to underpin emissions inventory verification at a range of spatial scales, and/or targeted at specific industries / sources.

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.

The work was 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 replaced in 2015 by a site at Bilsdale in the north of England. The data from these additional sites have resulted in significant increases in the spatial and temporal resolution of the InTEM emission estimates, and hence, an improvement in the 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) 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 and online²².

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 SF₆, 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 publicly 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 publicly 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.

²² www.metoffice.gov.uk/atmospheric-trends

The inventory agency manages confidential data on a password-protected secure server that has limited access rights, to limit access to the inventory compilers and checkers that are required to use the data, and the confidential data are not permitted for use on any research or reporting output for non-national-inventory work programme purposes. Access to the raw data, e.g. from regulators of EU ETS data, is managed via BEIS and using encrypted files and separate email communication of passwords.

The UK National Inventory Reports from the 1999 NIR onwards, and estimates of emissions of GHGs, are all publicly available on the web²³.

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 2017. The trend in the total GWP weighted emissions expressed as the fall between 1990 and 2017 is -42%, with a 95% confidence interval of between -39% and -45%.

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**.

²³ <http://naei.beis.gov.uk/>

2 Trends in Greenhouse Gas Emissions

Figure 2.1 Total GWP weighted emissions by sector²⁴

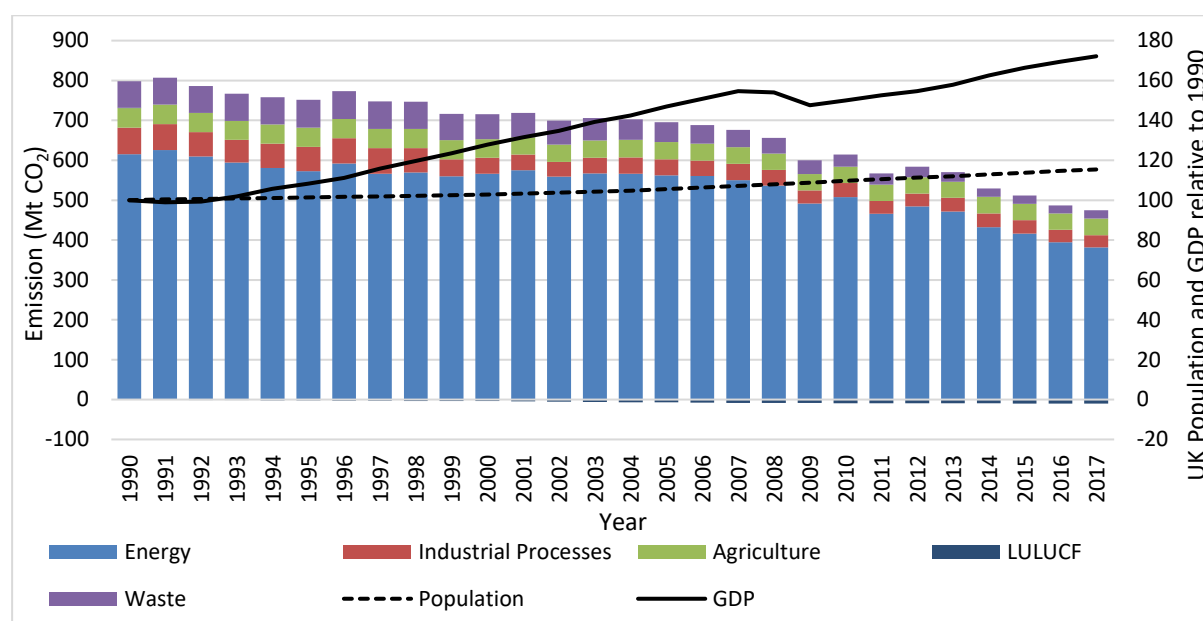
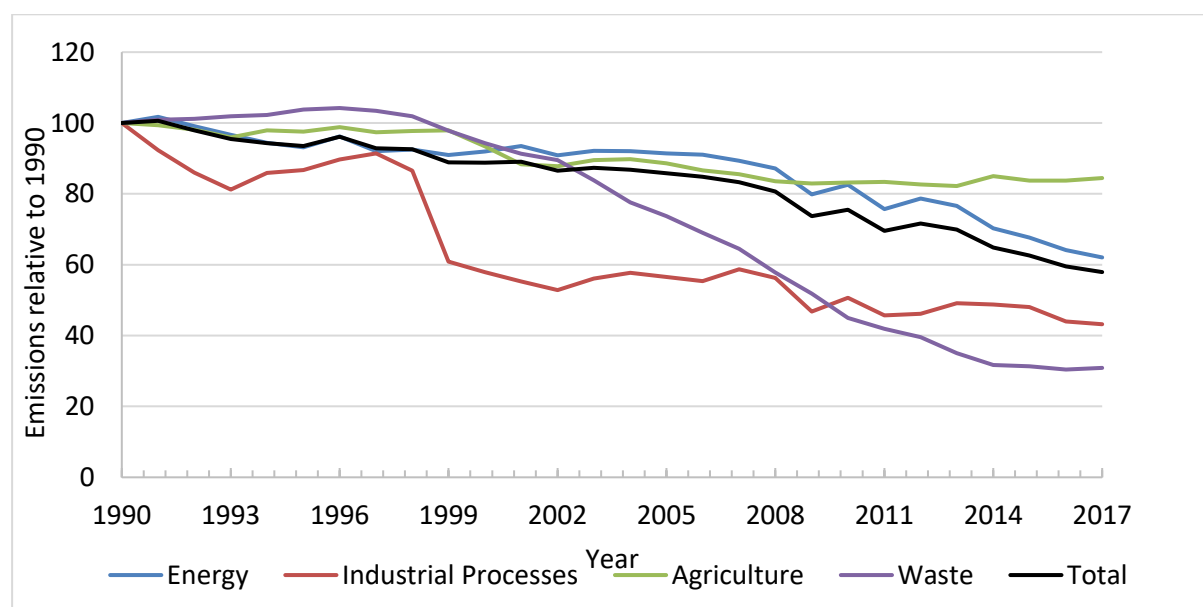


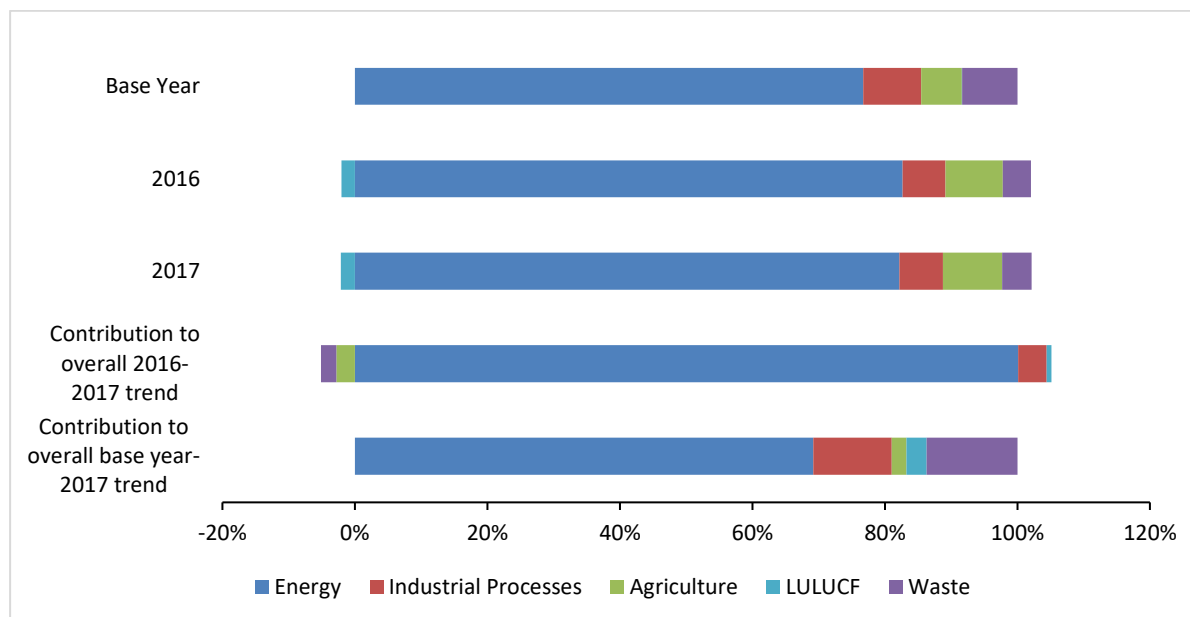
Figure 2.2 Trends in emissions by sector relative to 1990²⁵



²⁴ Note that LULUCF is a net sink in most years, so appears below the x-axis.

²⁵ LULUCF omitted from graph as it is a combination of sinks and sources of emissions; this makes it challenging to representatively present in this format.

Figure 2.3 Contribution to National totals in the selected years and to overall trends between selected years by sector²⁶

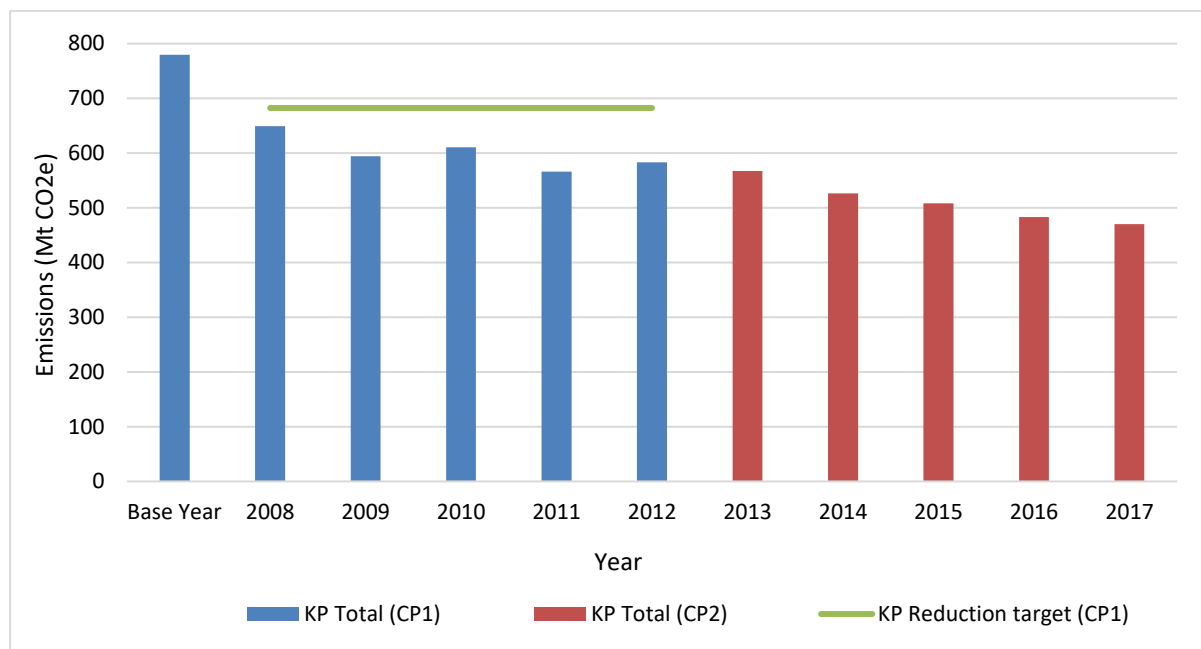


As shown in **Figure 2.1** and **Figure 2.2**, total emissions of direct GHGs have decreased since 1990. **Figure 2.3** illustrates that this decline is driven predominantly by a decrease in emissions from the energy sector – particularly from power stations. The decline between 2016 and 2017 is primarily due to a significant switching from coal use to other, less carbon intensive fuels and renewables (see **Section 2.1**). Total emissions are dominated by the energy sector across the time series. Emissions from all sectors have declined, with the largest decline in percentage terms from Land Use, Land-use Change and Forestry (LULUCF). In addition to being a source of emissions, the LULUCF sector has become a carbon sink of increased magnitude since 1990, i.e. it provides a mechanism by which atmospheric carbon is captured and sequestered. In absolute terms, the largest overall decline is in the energy sector.

Unless otherwise indicated, percentages quoted relate to net emissions (i.e. accounting for carbon sinks in the LULUCF sector). The geographical coverage of the inventory is the UK and the Crown Dependencies and Overseas Territories to whom the UK's ratification of the UNFCCC has been extended.

The percentage changes presented in this chapter are calculated from original emission estimates within the inventory database. They may, therefore, differ slightly from those that could be calculated from rounded figures in this report.

²⁶ 'Base year' refers to 1990 for CO₂, CH₄ and N₂O, or 1995 for F-gases²⁸.

Figure 2.4 GHG emission reductions progress against Kyoto Protocol (KP) Commitment Periods (CP1 and CP2)²⁷

A summary of the contribution of each GHG to the emission trends is provided below. The subsequent sections of this chapter provide an interpretation of emission trends, primarily focusing on the trends by source sector.

²⁷ Note that:

- KP Emissions totals differ from those reported under the UNFCCC due to a difference in the agreed accounting approach for LULUCF
- The reduction target is for average emissions over the commitment period
- The KP CP2 target is not presented, as this is for the EU as a whole, which is devolved to member states in a combination of the EU Emissions Trading Scheme and member state-specific targets to reducing non-traded emissions

Figure 2.5 Trends in emissions by gas relative to 1990²⁸

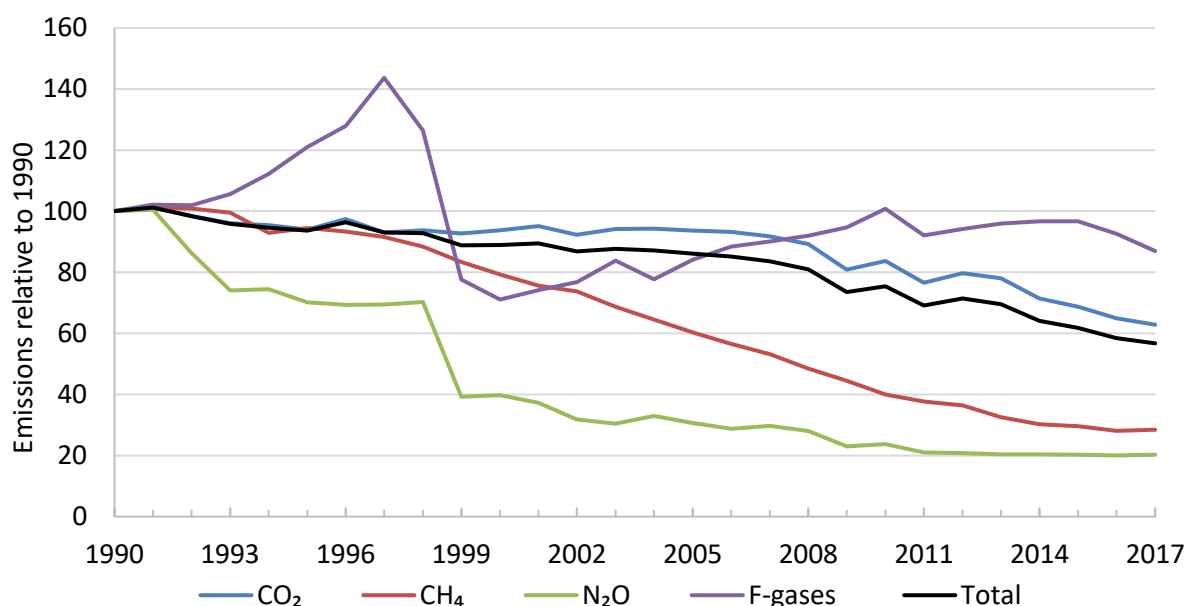


Figure 2.6 Contribution to National totals in the selected years and to overall trends between selected years by gas

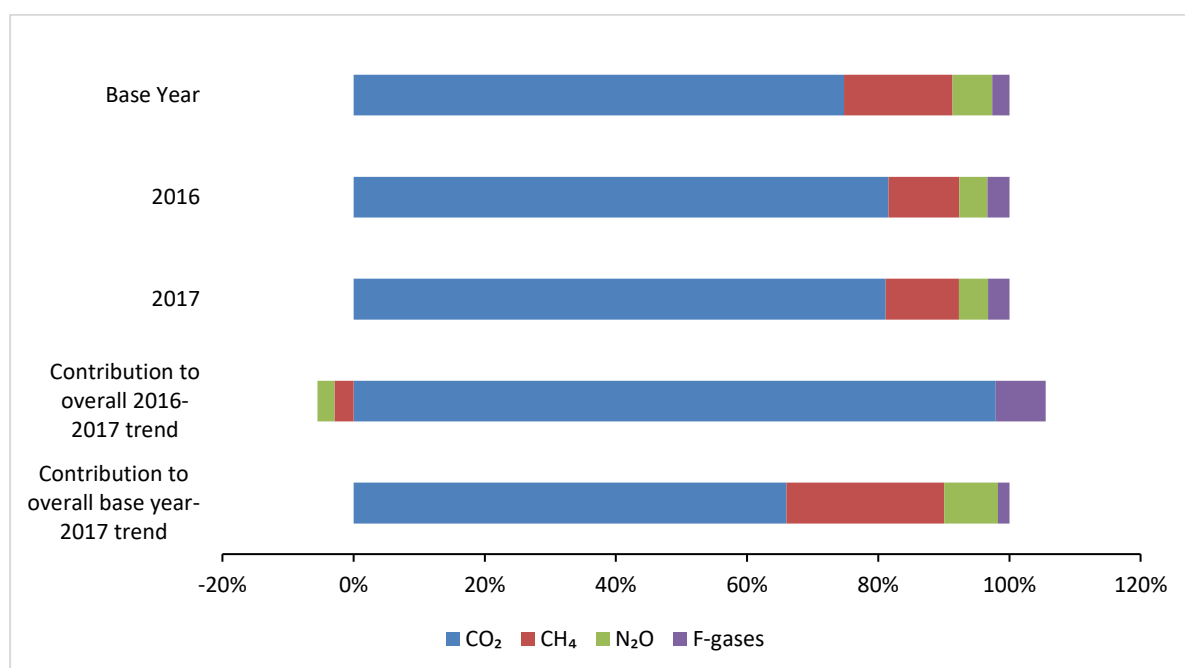


Figure 2.4 presents the contribution of each GHG to the UK emissions trend:

- Emissions of **CO₂** are by far the largest component of total GHG emissions, of which the largest source is from power generation. Emissions have reduced across the time series due to fuel switching, structural change and improvements in end-use efficiency.

²⁸ F-gases are fluorine containing compounds which are potent greenhouse gases, including: Sulphur Hexafluoride (SF₆), Nitrogen Trifluoride (NF₃), Perfluorocarbons (PFCs) and Hydrofluorocarbons (HFCs).

The strong link between power generation and CO₂ emissions means that short term trends can be dominated by UK temperatures. In cold years like 1996 and 2010 there was an increase in demand for power for heating and in warm years like 2011 and 2014 there was a decrease.

- The second most important source of greenhouse gases is **methane (CH₄)**. Annual emissions of CH₄ have reduced by over half since 1990. The main sources of CH₄ are agriculture, waste disposal, leakage from the gas distribution system and coal mining. Reductions in CH₄ emissions in the UK are driven by the increased utilisation of methane from landfills, a large decline in UK coal mining, investment in improvements to the natural gas supply infrastructure to reduce leakage and a reduction in livestock numbers.
- Emissions of **nitrous oxide (N₂O)** have also reduced by over two thirds since 1990. Most N₂O emissions are generated from the agriculture sector, Agriculture sector N₂O emissions have decreased primarily due to reduced emissions from synthetic fertiliser application. N₂O is also released during the production of nitric and adipic acid, a significant source in 1990 contributing to approximately half of all N₂O emissions. Due to a decline in production together with the installation of abatement equipment, industrial sources now only contribute around 0.1 % of N₂O emissions.
- The smallest percentage reduction in emissions across the time series is for the **F-gases**: HFCs, PFCs, NF₃ and SF₆. All F-gas emissions are accounted for under the Industrial Processes and Other Product Use (IPPU) sector. F-gas emissions have decreased since 1995, due mainly to the fall in F-gas manufacture in the UK and the installation of abatement equipment at two of the three UK manufacturers. These emission reductions have been largely offset by the increases in the use of HFCs as substitutes for ozone depleting substances, particularly in refrigeration and air conditioning.

2.1 ENERGY

2.1.1 Overview

Figure 2.7 Total GWP weighted emissions in the energy sector compared to primary energy demand

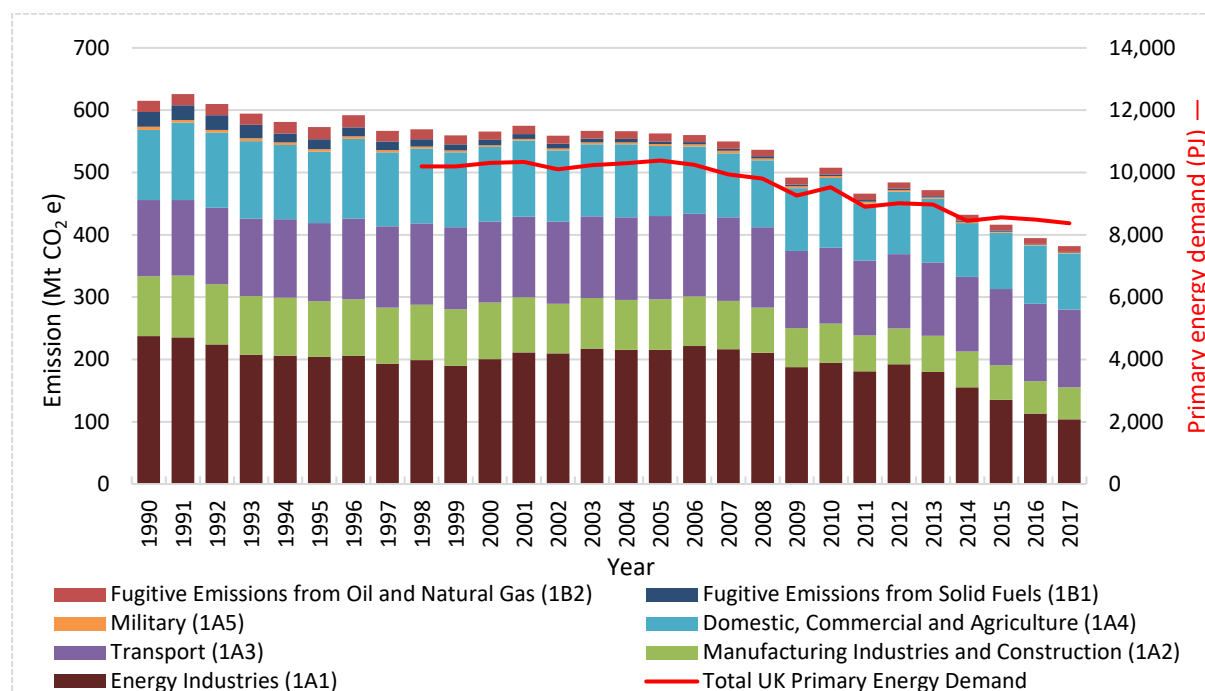


Figure 2.8 Trends in Energy emissions by sub-sector relative to 1990

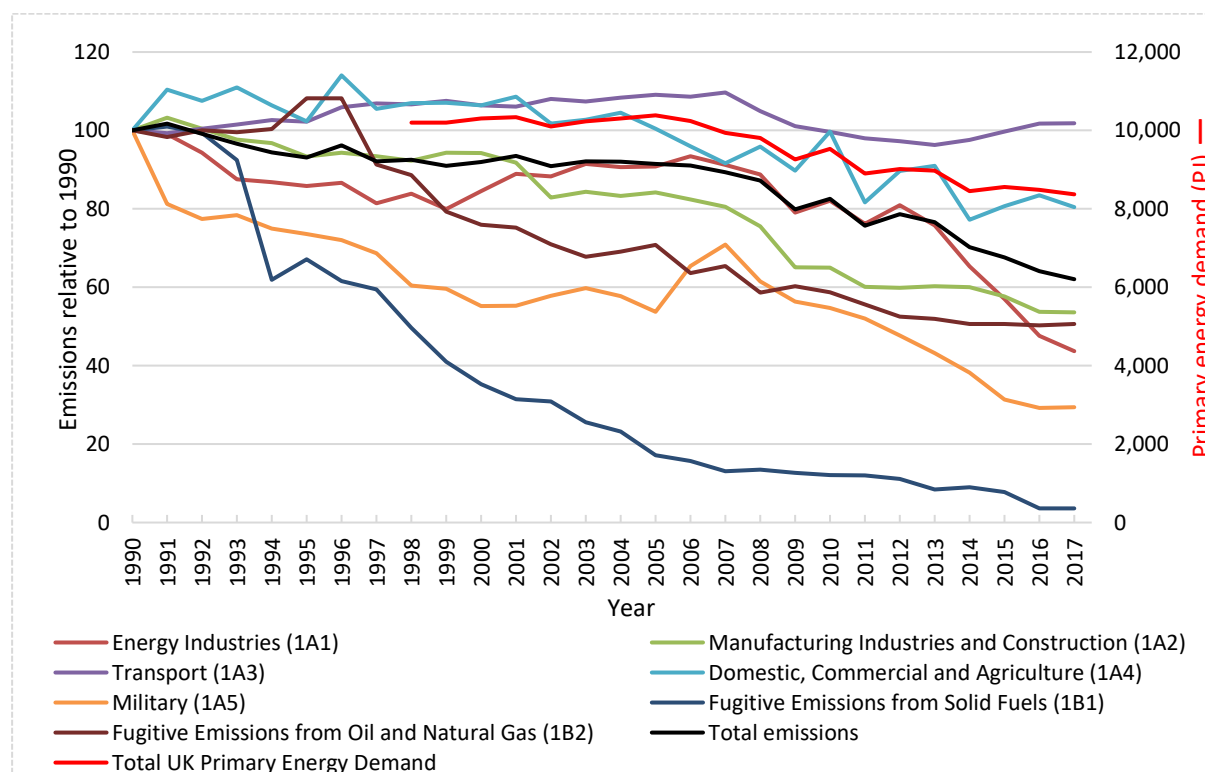
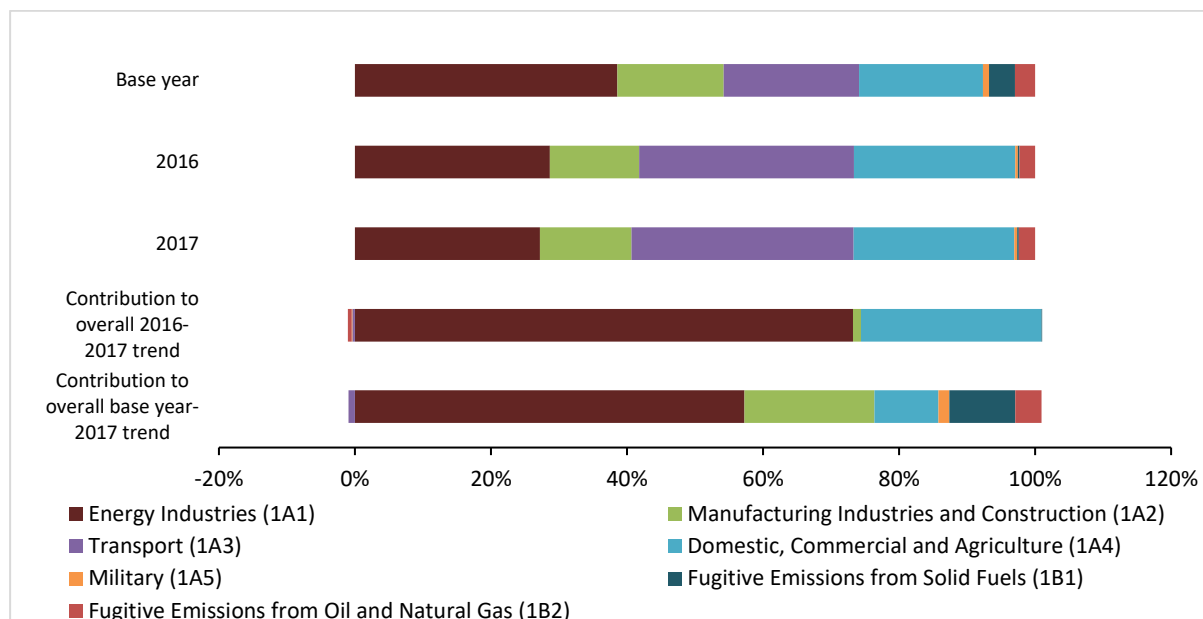


Figure 2.9 Contribution to totals in the selected years and to overall sectoral trends between selected years by sub-sector for Energy



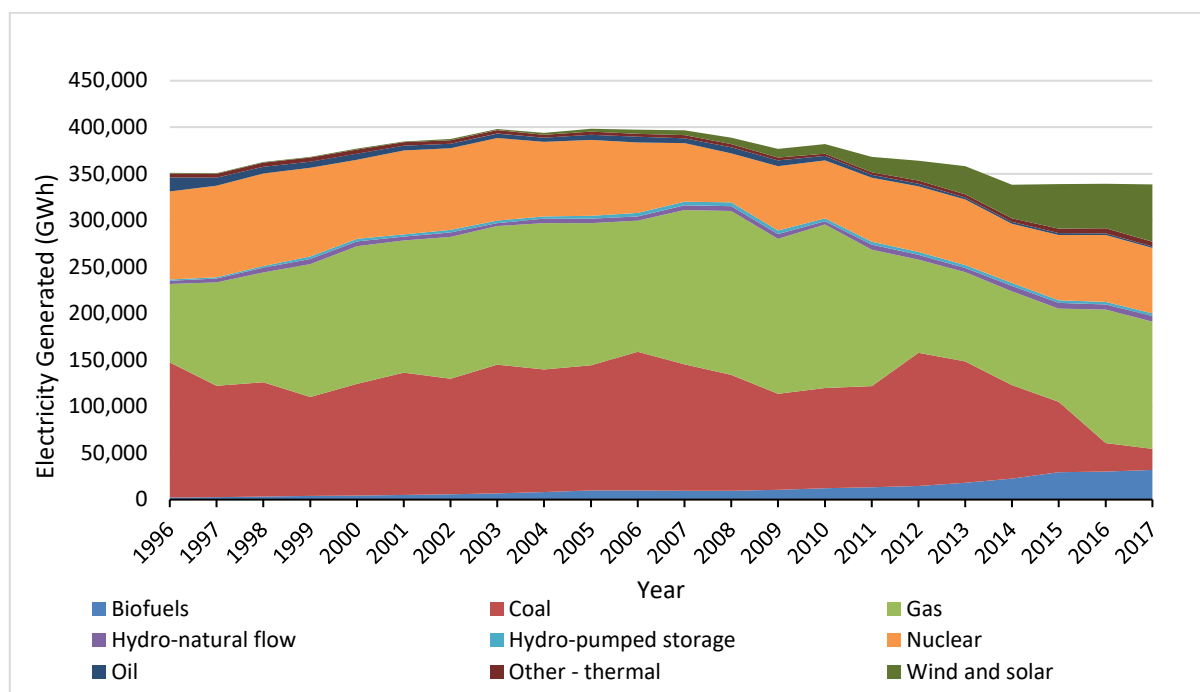
The energy sector GHG emissions are primarily CO₂ from fossil fuel combustion in power generation, transport, manufacturing and construction, and other stationary and mobile fuel combustion. The supply of fossil fuels also leads to significant emissions of CH₄ from fugitive emission sources, such as from coal mining, oil and gas extraction and from the natural gas transmission and distribution system.

Figure 2.8 shows that energy sector emissions have declined since 1990. Emission reductions are due primarily to improvements in energy efficiency, and economy-wide fuel-switching from carbon-intensive fossil fuels such as coal, to greater use of natural gas, nuclear power and renewables. There have also been large reductions in fugitive CH₄ emissions due to a large decline in coal mining, with the last large UK deep mine closing in 2015, and the reduction in leakage from the natural gas distribution network through a UK-wide programme of infrastructure improvements.

2.1.2 Emission trends in Energy sub-sectors

2.1.2.1 Electricity generation

Figure 2.10 Fuel mix of energy generation



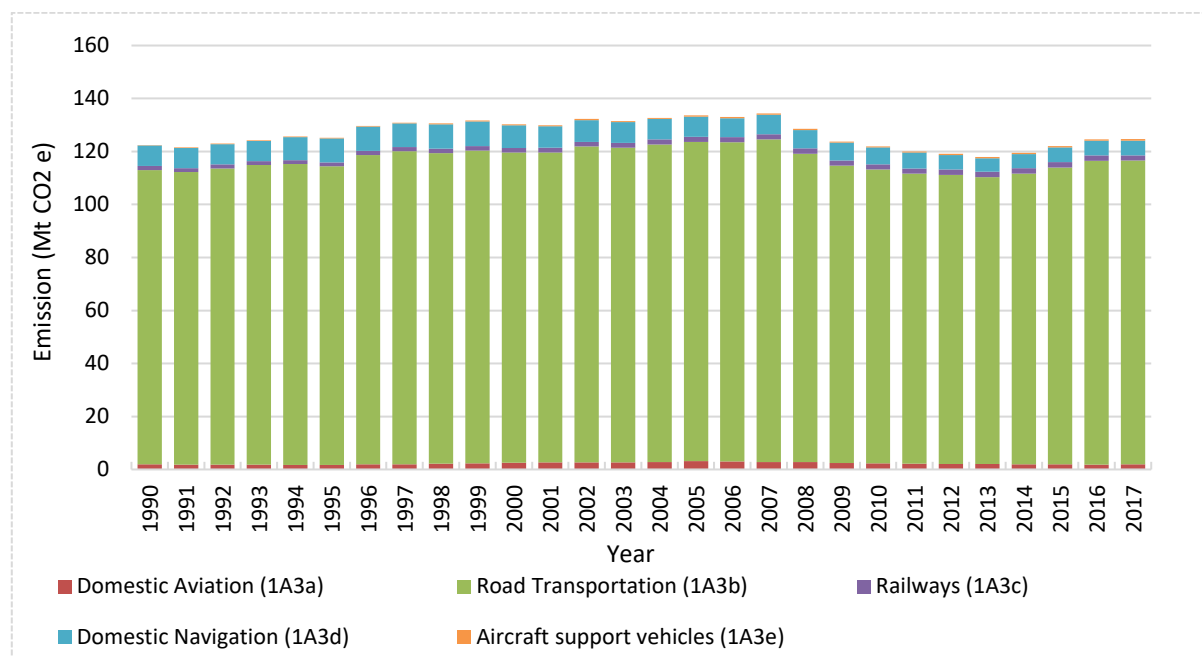
There are several reasons for the decline in emissions from the power generation sector since 1990, including:

- the UK power sector fuel mix has shifted 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 2017 they operated on average at 48.7% efficiency, whilst coal-fired stations operated on average at 34.9% efficiency;
- the shift in fuel mix away from more carbon-intensive fuels such as coal and oils, to less carbon-intensive fuels such as natural gas; the calorific value of natural gas per unit mass carbon is higher than that of coal and oil;
- there has been an increase in electricity generated from non-fossil fuel energy sources, due to increased use of wastes and renewable energy sources.

2.1.2.2 Manufacturing Industries and Construction

Since 1990, emissions from Manufacturing Industries and Construction fuel combustion have declined, with lower fuel use and emissions reported across all sub-sectors including: iron and steel, non-ferrous metals, chemicals, food and drink, paper and pulp, minerals and from mobile machinery. This reflects the general decline in UK manufacturing output (e.g. of steel, aluminium) as well as a shift away from carbon-intensive fuels such as coal and oils to greater use of natural gas, as well as waste-derived and renewable fuels.

Reductions in emissions from unclassified industrial combustion also made a large contribution to the overall trend in emissions from the Manufacturing Industries and Construction sector. Emissions have declined by a third since 1990. This is largely a result of reduced consumption of gas oil, fuel oil, coal and natural gas, partly offset by increases in burning oil and LPG within the sector.

2.1.2.3 Transport**Figure 2.11 Transport emissions by sub-sector**

Emissions from the Transport sector are dominated by road transport, which peaked in 2007, but have declined since 2007, and by 2017 are back almost exactly to 1990 levels. This is driven by a number of factors, including:

- Increases in vehicle kilometres in most years, except for a few years after 2007;
- Improvements in the fuel efficiency of engines in the UK fleet;
- Increases in the typical weight of passenger cars, increasing the energy needed to propel them;
- Increase in energy requirement for additional applications, like air conditioning;
- Fuel switching from petrol to diesel, improving fuel efficiency, but in some cases resulting in higher N₂O emissions due to NO_x abatement technology;
- Increasing sizes of heavy goods vehicles; and,
- The increasing displacement of fossil fuels by biofuels across the time series, since 2002, as CO₂ emissions from the consumption of biofuels are not included in the UK totals²⁹.

Emissions from domestic aviation increased between 1990 and 2005 but have since decreased to levels comparable to 1990. This is because of a move to use more fuel-efficient aircraft in 2006 and a lower number of air miles being flown.

Shipping emissions in the UK peaked in the late 1990s and have decreased in recent years. The reductions are driven by lower shipping activity in several key sectors, notably the support vessels to the offshore oil and gas sector and oil tanker movements.

2.1.2.4 Domestic, Commercial and Agriculture

Emissions from domestic fuel combustion dominates emissions from the Domestic, Commercial and Agriculture sector. Emissions from this sector changed little between 1990 and 2009 but have declined more recently. The effect of annual temperatures can produce

²⁹ Carbon of biogenic origin are accounted for in the carbon stock calculations in the Land Use, Land Use Change and Forestry Sector, see **Section 2.4**.

large inter-annual variations. 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.

2.1.2.5 Fugitives (Energy exploration, production and distribution)

Fugitive energy sector emissions mostly consist of methane released from coal mining, oil and gas extraction and natural gas distribution. In 1990, the majority of these emissions came from the production of solid fuels; however, these emissions have decreased significantly, due to the closure of all UK deep coal mines (by 2015). Another notable trend arises from the reductions in leakage of methane from the natural gas distribution network. Over the time series, the UK gas transporters have invested significantly in replenishment of the gas pipeline infrastructure, replacing leakier cast iron pipe-work with low-leakage plastic pipelines. The fugitive emissions from upstream oil and gas exploration and production have tracked UK production, declining since a peak in 2004.

2.2 INDUSTRIAL PROCESSES AND PRODUCT USE

2.2.1 Overview

Figure 2.12 Total GWP weighted emissions in the Industrial Process and Product Use sector

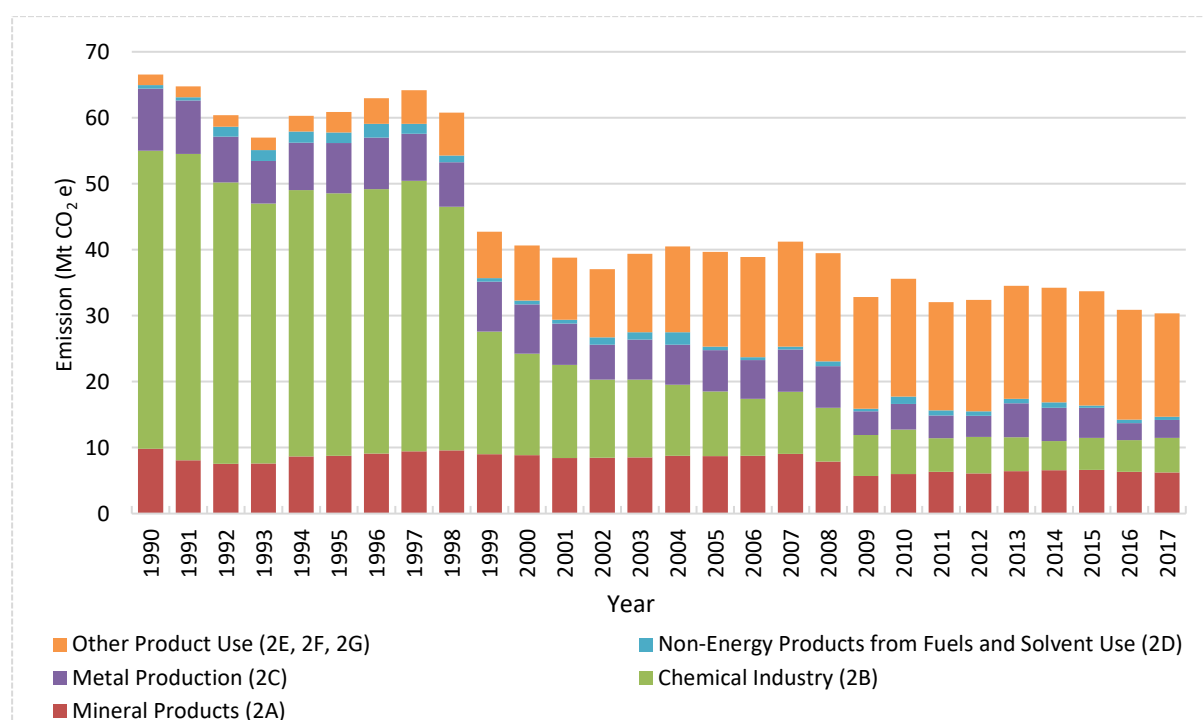


Figure 2.13 Trends in emissions from Industrial Processes and Product Use by sub-sector, relative to 1990³⁰

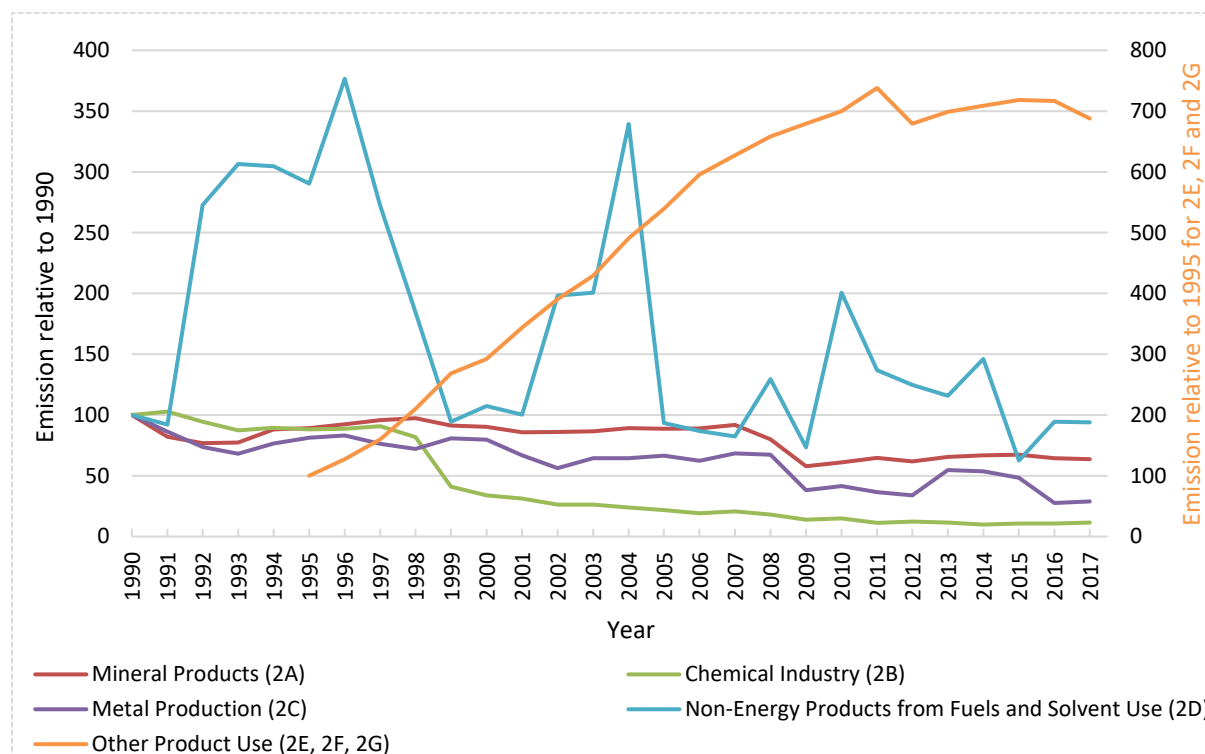
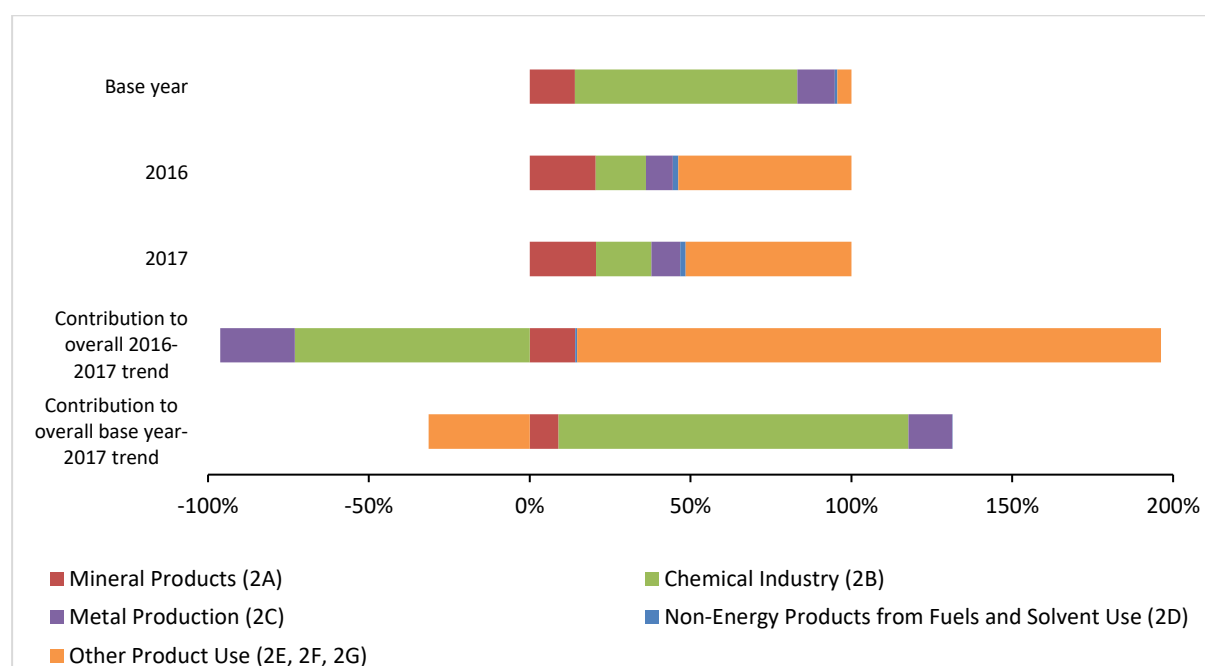


Figure 2.14 Contribution to totals in the selected years and to overall sectoral trends between selected years by sub-sector for Industrial Processes and Product Use



³⁰ Emissions from sectors 2E, 2F, and 2G are dominated by F-gas emissions, whose base year is 1995. See Section 2.1.2.1 for information on the driver of this trend.

The Industrial Processes and Product Use (IPPU) sector accounts for all GHG emissions from industrial sources³¹ and product use including solvents. Just under half of IPPU emissions are now CO₂, although this only contributes to small proportion of total CO₂ emissions. All F-gas emissions are generated from IPPU sources, and there are small quantities of CH₄ and N₂O emissions.

The number of industrial processes in the UK have been declining since 1990 (see **Figure 2.15 - Figure 2.17**). The declining trend in IPPU emissions in the UK (see **Figure 2.12**) is partly due to the closure of numerous UK installations, including several integrated steelworks, primary aluminium works, chemical production sites and cement kilns, as well as the installation of abatement equipment, for example at adipic and nitric acid plant and by F-gas manufacturers. The declining trend in emissions is also a reflection of decreasing production of many industrial materials in the UK, most notably in the chemicals and steel sectors. 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. The large step-change in chemical sector emissions in 1998-1999 was due to the fitting of N₂O abatement equipment at a major adipic acid manufacturing facility, which has subsequently closed.

2.2.2 Emission trends in IPPU sub-sectors

2.2.2.1 Refrigeration, Air-Conditioning and Heat Pumps (RACHP)

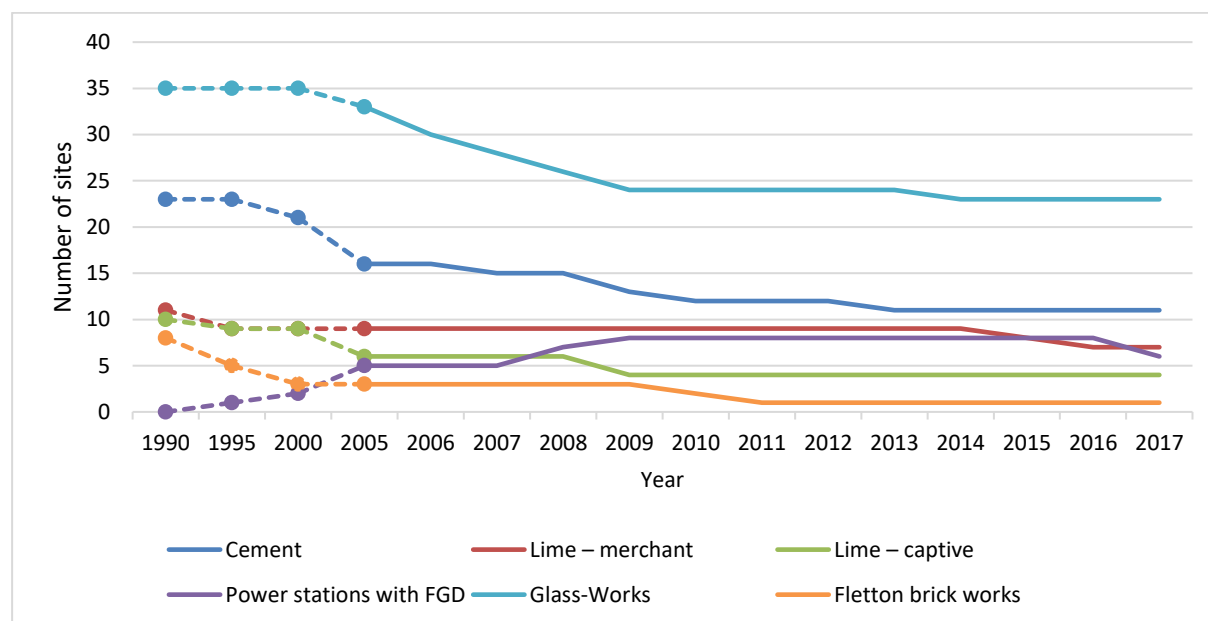
Until the early 1990s, Ozone Depleting Substances (ODS) were used as refrigerants for RACHP applications, but in response to the Montreal Protocol these products were phased out in the UK in favour of products with no ozone depleting potential. The main substitutes for ODS were hydrofluorocarbons (HFCs), which has similar properties, but are still potent greenhouse gases. As a result of this there is a steep increase in HFC use since the mid-90s, plateauing in recent years as almost all ODS-based systems are thought to have been retired or retrofitted.

Since 2008 an increasing number of applications have been restricted from using higher GWP HFCs by EU regulation of F-gases. EU regulation has also become more stringent regarding the management of HFCs and HFC-using systems, and since 2015 a quota system was introduced, limiting the total HFC (on a GWP basis) allowed to be sold on the EU market.. All of these actions are believed to have brought forward the plateaux in HFC emissions and the downturn since 2014.

The 2010 peak and 2011 dip are due to a combination of factors, including:

- Market anticipation of the EU HFC phase-down causing an increase in retrofitting to lower GWP refrigerants;
- Early HFC-based systems starting to reach the end of life for some applications, meaning more emissive decommissioning activities are required; and,
- EU regulation of operational management of some larger refrigeration systems coming into force.

³¹ Note that emissions from fuel combustion for energy is allocated to the energy sector (1A2). For more information, see: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_1_Ch1_Introduction.pdf

2.2.2.2 Mineral Industry**Figure 2.15 Trends in the number of mineral process sites³²**

Annual CO₂ emissions from cement manufacture comprise over 70% of total mineral sector CO₂ emissions in 2017, and have fallen by 40% since 1990 due to the closure of many kilns and decreasing UK clinker production. Emissions fell to a low point of 3.7 MtCO₂ in 2009 due to the impact of the recession in 2008-2009, and then increased again and have stabilised in recent years at around 4.0 to 4.5 MtCO₂.

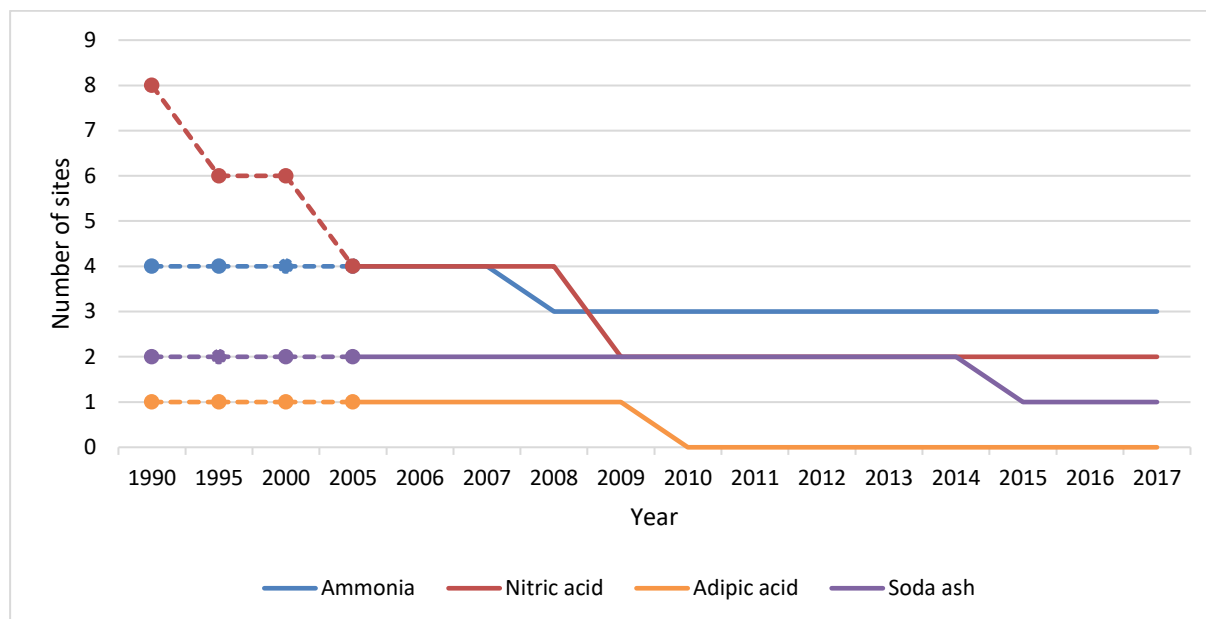
Other mineral source categories don't have a significant impact on the UK GHG trends; lime production and CO₂ emissions has reduced by around 28% since 1990, glass production emissions are down by around 9%; brick manufacturing emissions are down by 51%. Emissions from other product uses of carbonates have increased slightly since 1990, but are still less than 2% of total mineral sector CO₂ emissions in 2017.

³² Merchant refers to sites selling lime and emitting CO₂, captive refers to sites using lime and CO₂ in-situ so in theory no emissions result.

FGD is an abbreviation of Flue Gas Desulphurisation

Excludes very small glassworks producing lead crystal glass, frits etc.

Some early site numbers are estimates

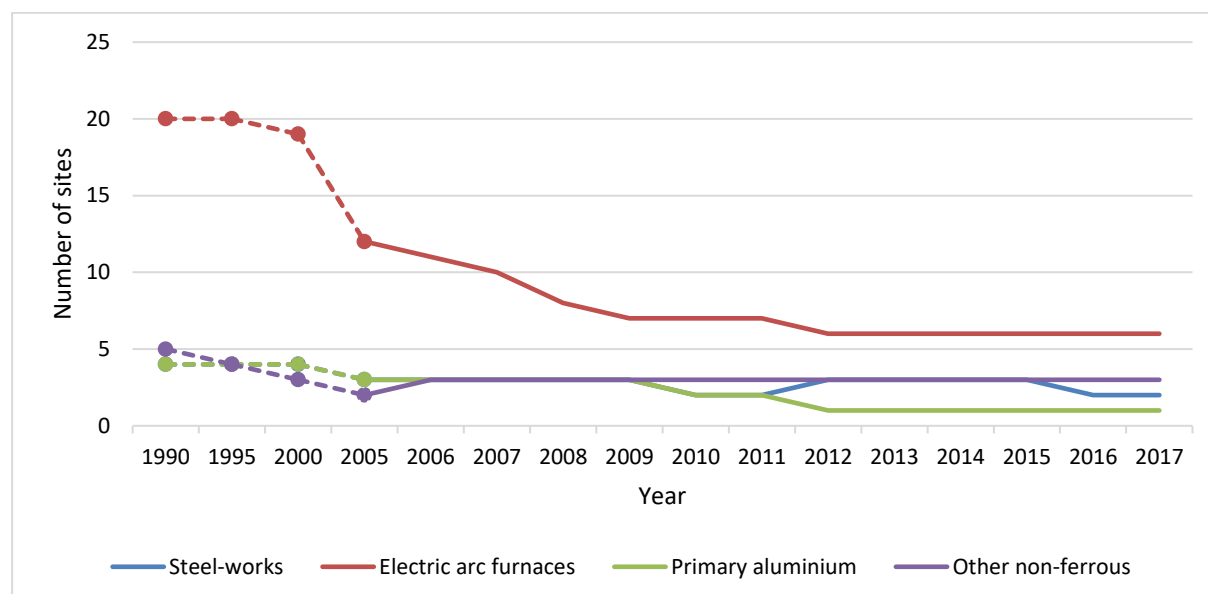
2.2.2.3 Chemical Industry**Figure 2.16 Trends in the number of chemical process sites**

Emissions from adipic acid manufacture were reduced significantly in 1999, approximately half of the total fall in chemical sector emissions in that year, due to the retrofitting of an emissions abatement system to the only adipic acid plant in the UK, which subsequently closed in April 2009.

By-product emissions from the manufacture of HFCs and HCFCs have decreased to zero since 1990, due to plant closures and the installation of abatement equipment. Approximately half of the fall in chemical sector emissions in 1999 emissions was due to the installation of a thermal oxidiser at the UK's only HCFC-22 plant in that year, with emissions in 2000 falling again due to a full year of operation with the new abatement technology. Due to the phase out of HCFC-22 for many applications, production and emissions at this site has fallen and after a closure and reopening in 2010 and 2013 respectively, the plant permanently closed in 2016 ending emissions from this process.

N₂O 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.

Aside from these specific examples of emissions abatement, there has also been an underlying shrinkage in the UK chemical production sector over the time series, with many chemical and petrochemical installations closing since the 1990s. For example, all UK manufacturing of methanol ceased in 2001, whilst the installations producing carbon black and ethylene oxide closed in 2009.

2.2.2.4 Metal Production**Figure 2.17 Trends in the number of metal process sites³³**

GHG emissions from across the UK metal production sector have fallen by around 65% since 1990, with every sector showing a marked reduction in production levels and emissions over the time series. The largest contributor to the UK trends is the closure of several large integrated steelworks and a decline in UK steel output, leading to Iron & Steel (I&S) sector IPPU CO₂ emissions down by 55% (across 2C1a-2C1d), which accounts for 64% of the total UK metal production sector CO₂ reductions since 1990. Emission trends in the sector in recent years reflect the volatility of UK steel production since the economic down-turn from 2008, including a 46% reduction in CO₂ emissions in 2008-2009 followed by several years of uncertainty regarding plant investments and possible closures; the sector increased production and emissions during 2013 to 2015 but the closure of the Redcar steelworks in 2015 and closures of coke ovens and lower production across UK sites led to a 45% decline in CO₂ emissions in 2015-2016, with total IPPU emissions (2c1a-2C1d) around 2.4 to 2.5 MtCO₂ in 2016 and 2017.

The production of primary aluminium has also declined significantly across the time series, with CO₂ emissions down by 84% and only one smelter now remaining in operation in Lochaber, Scotland. In recent years a large step-down in emissions in 2011-2012 reflects the closure of the large Lynemouth smelter in March 2012, with sector emissions relatively stable since at around 0.07 MtCO₂.

Other Non-Ferrous Metal (NFM) sectors have ceased production in the UK completely, with the closure of a large zinc and lead smelter complex in 2003; this one site closure accounts for over a quarter of total metal sector IPPU CO₂ emission reductions in the UK since 1990.

³³'Other non-ferrous' includes primary production of non-ferrous metals other than aluminium, or large-scale secondary smelting of lead only

2.3 AGRICULTURE

2.3.1 Overview

Figure 2.18 Total GWP weighted emissions in the Agriculture sector³⁴

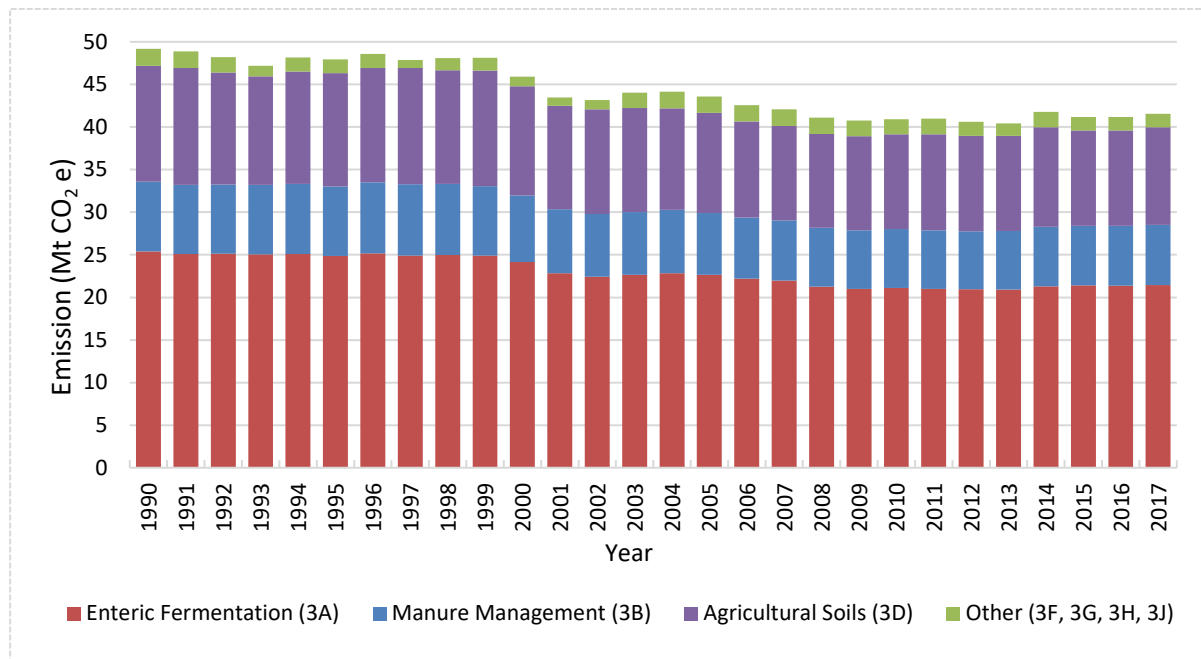
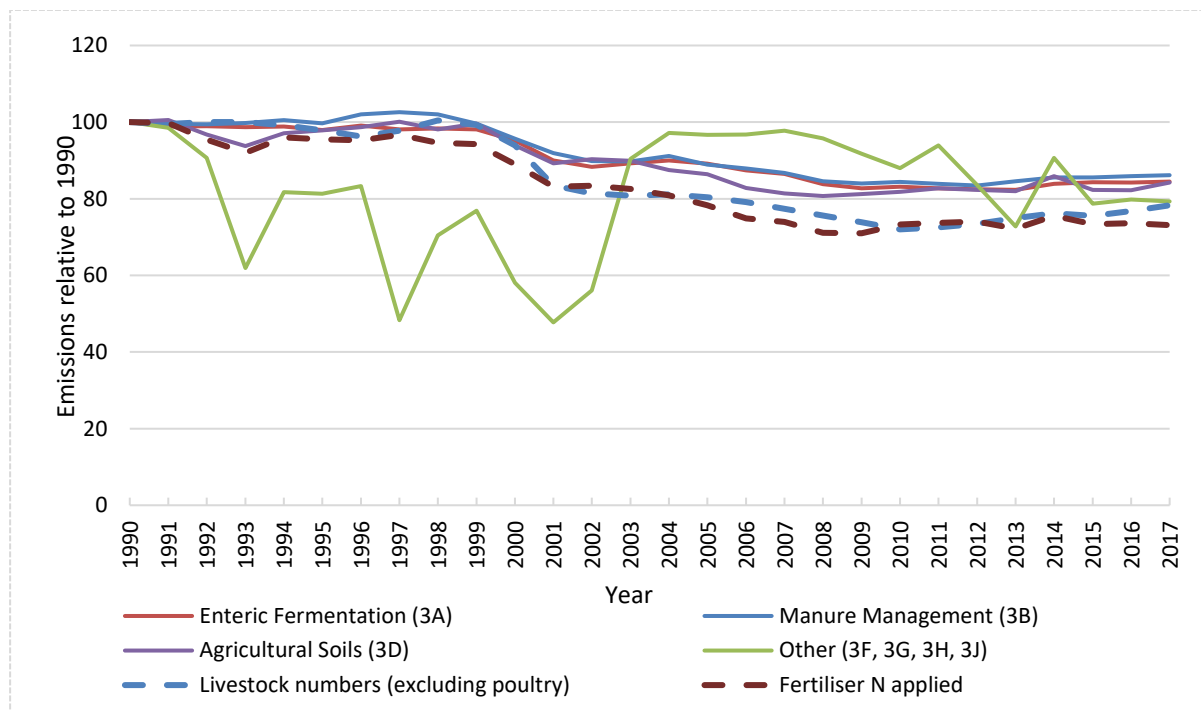
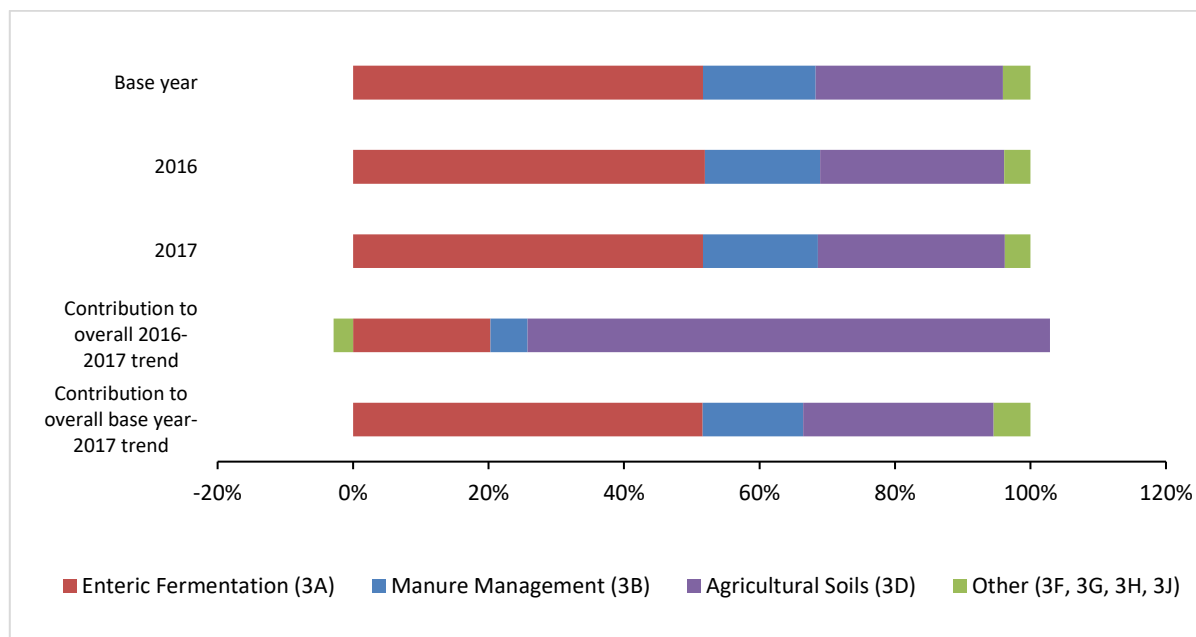


Figure 2.19 Trends in emissions from Agriculture by sub-sector, relative to 1990³⁴



³⁴ 'Other' refers to the following IPCC sectors: Field Burning of Agricultural Wastes (3F), Liming (3G), Urea Application (3H), and Overseas Territory and Crown Dependency Agriculture Emissions (3J)

Figure 2.20 Contribution to totals in the selected years and to overall sectoral trends between selected years by sub-sector for Agriculture³⁴



In the UK, the Agriculture sector is dominated by CH₄ emissions from livestock generated through enteric fermentation (animal digestion processes), and from N₂O emissions from manure management and fertiliser application. The emissions from this sector have shown an overall decrease since 1990, reflecting trends in livestock numbers and emissions from fertiliser application.

2.3.2 Emission trends in Agriculture sub-sectors

2.3.2.1 Livestock: Enteric fermentation and Manure Management

Emissions from livestock have declined over the time series primarily due to a decline in emissions from enteric fermentation (CH₄) and manure (N₂O) from cattle. This is, in turn, due to decreased cattle numbers.

2.3.2.2 Agricultural Soils

Annual emissions from fertiliser use have declined by since 1990, this is driven by a reduction in synthetic fertiliser application, particularly to grasslands.

2.4 LAND USE, LAND USE CHANGE AND FORESTRY

2.4.1 Overview

Figure 2.21 Total GWP weighted emissions in the LULUCF sector

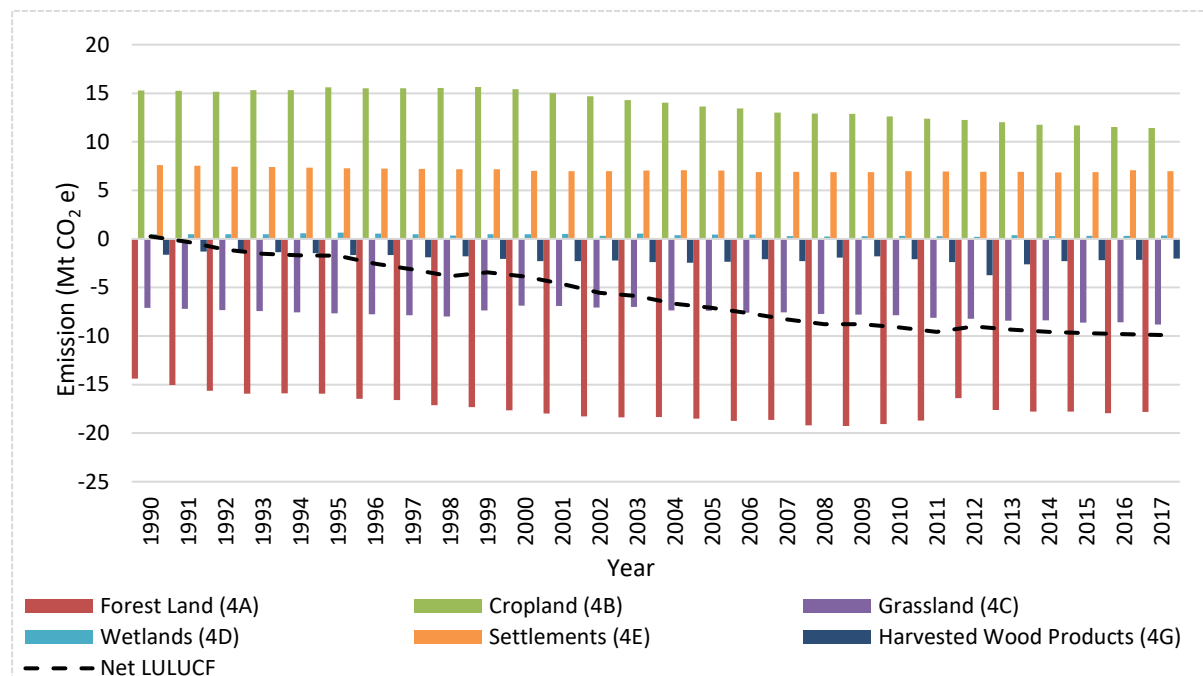
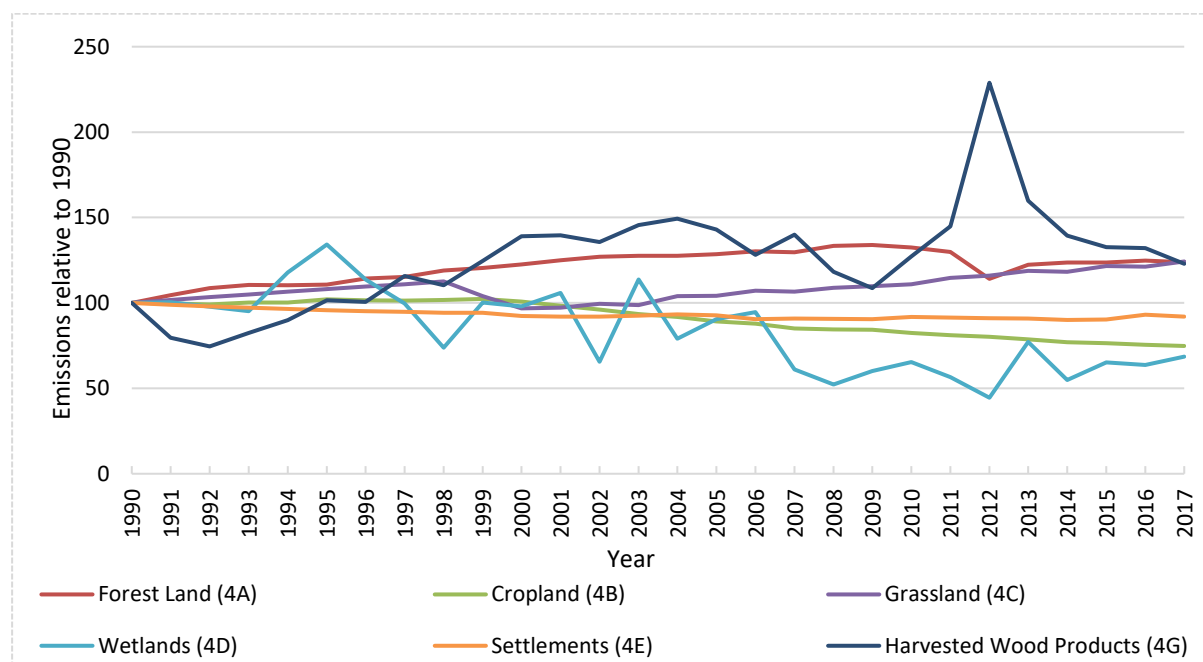


Figure 2.22 Trends in net emissions/sinks from LULUCF by sub-sector, relative to 1990³⁵



The Land Use, Land Use Change and Forestry (LULUCF) sector is the only sector within the national GHG inventory to report net removals. The net sink is provided by removals from

³⁵ Some of these are trends in the size of the net sink rather than net emissions.

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 LULUCF sector is a source of CH₄ and N₂O, but these are small in relation to carbon fluxes which are accounted for as CO₂ equivalent.

The LULUCF sector covers emissions and removals of direct and indirect GHGs under eight land use categories, of which Forest Land, Grassland and Harvested Wood Products are net sinks, and Cropland, Wetlands, and Settlements are net sources (**Figure 2.21**). The UK does not report any emissions or removals from the Other Land and Other categories. 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).

2.4.2 Emission trends in LULUCF sub-sectors

2.4.2.1 Forest land

The size of the Forest land sink increased significantly between 1990 and 2010 but has levelled off in recent years. The variation in the net sink is driven by afforestation in earlier decades and the effect on the age structure of the present forest area, particularly conifer plantations. High levels of conifer afforestation between 1950 and 1990 resulted in increasing carbon stocks (and CO₂ removals) up to 2010 but these forests are now reaching harvesting age, with associated carbon losses and transfer to the Harvested Wood Products category. Harvested areas are replanted but the replacement young trees have also much lower rates of carbon stock increase. As a result there is a progressively decreasing stock in tree biomass and litter, offset by an increasing carbon stock in soils (BEIS 2019). Afforestation rates have also reduced substantially since 1990.

2.4.2.2 Cropland & grassland

Annual emissions from cropland have decreased significantly since 1990. This is due to lower rates of land use conversion to cropland since 2000, compared to rates of conversion before 2000 (based on Countryside Surveys in 1990, 1998 and 2007).

2.4.2.3 Harvested wood products

Annual removals due to harvested wood products have increased significantly in relative terms since 1990 due to increased harvesting rates as the substantial areas of afforestation reach the age to be felled, but the removals are still low in absolute terms (see **Figure 2.21**). The large percentage jump in removals in 2012 is an artefact of the modelling approach and is small in absolute terms. No adjustment was made to ensure complete consistency between carbon losses from Forest Land due to harvest and the carbon gains in the harvested wood products pools.

2.5 WASTE

2.5.1 Overview

Figure 2.23 Total GWP weighted emissions in the Waste sector

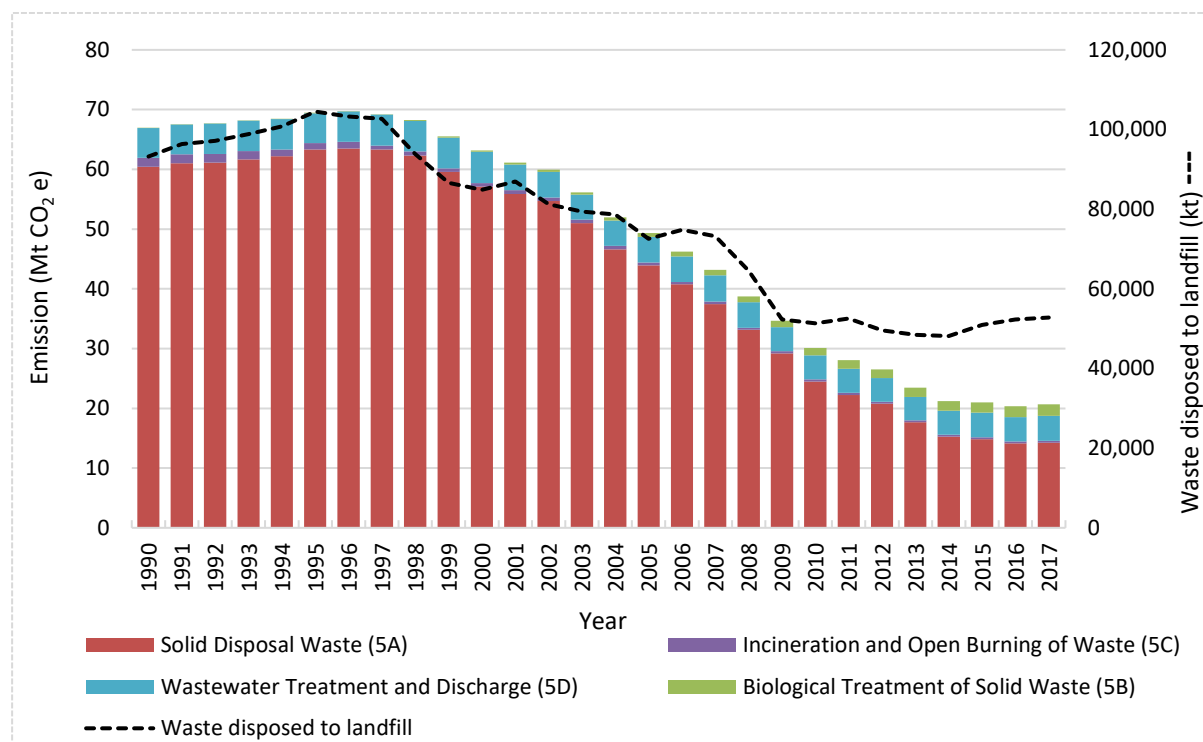


Figure 2.24 Trends in emissions from Waste by sub-sector, relative to 1990

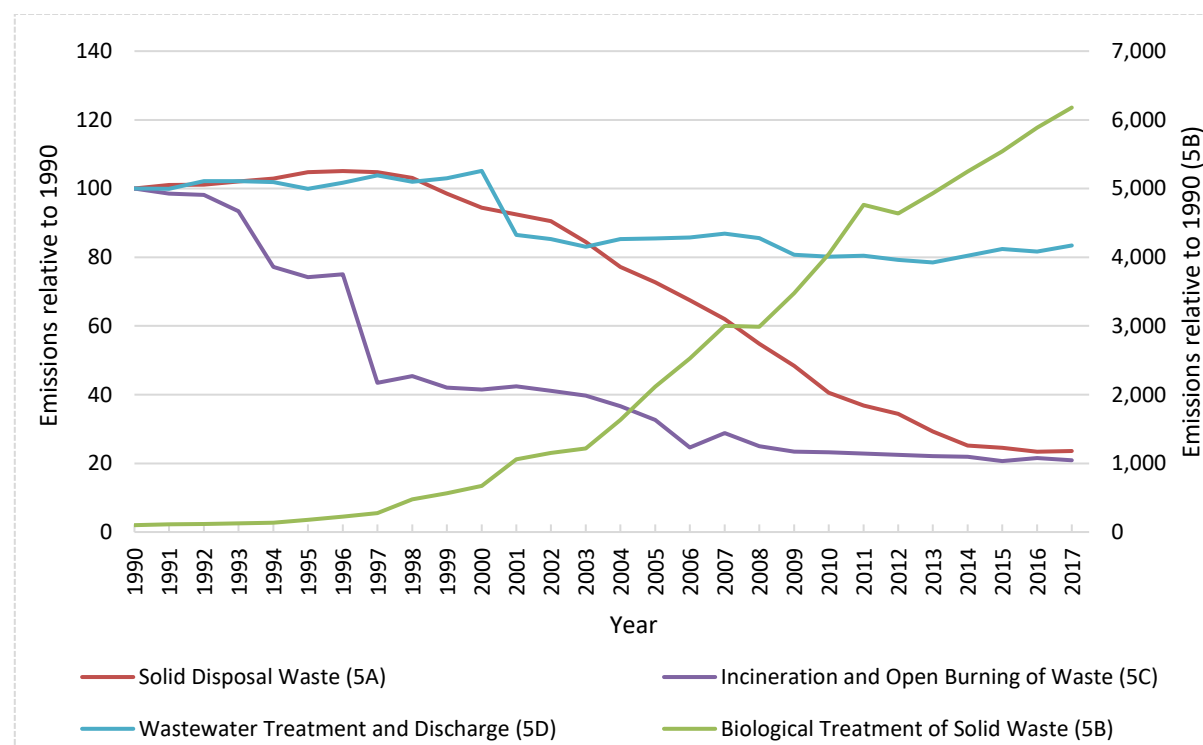
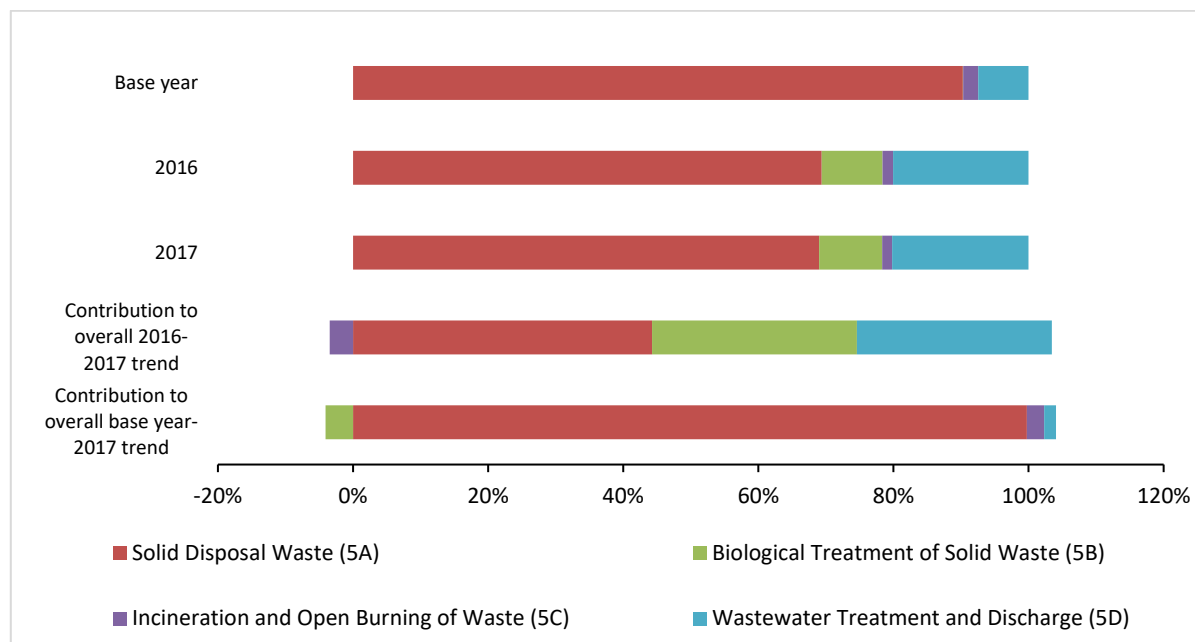


Figure 2.25 Contribution to totals in the selected years and to overall sectoral trends between selected years by sub-sector for Waste



The Waste sector accounts for all emissions generated from waste treatment and disposal. Emissions generated from energy recovery from waste are accounted for in the Energy sector. In the UK, emissions from the waste sector are dominated by CH₄ emissions from landfill sites.

Overall, annual emissions from the waste sector have decreased significantly since 1990, but have flattened out in recent years (**Figure 2.24**).

2.5.2 Emission trends in Waste Management sub-sectors

2.5.2.1 Solid waste disposal

Almost all of the reduction in UK GHG emissions across the Waste sector is due to a decline in CH₄ emissions from landfill. Emissions estimates from landfill are derived from the amount of biodegradable wastes disposed of to landfill, and the method takes account of the recovery of landfill gas for energy generation or in flares

Since 1990, CH₄ emissions from landfill have declined significantly due to the implementation of landfill gas recovery systems, flares and also due to the reduction in biodegradable wastes disposed to UK landfills through greater regulation and an increase in recycling and composting rates. Landfill gas capture rates have plateaued in recent years, which is a key driver of the recent flattening out of emissions from waste.

2.5.2.2 Waste water treatment

The UK activity and GHG emissions from industrial waste water treatment (5D2) shows no significant trend across the time series. For municipal waste water treatment (5D1), however, a major change in regulation, with the introduction of the EU Urban Waste Water Treatment Directive, led to a ban on disposal of untreated sewage to the waterways. This led to the step-change in estimated emissions between 2000 and 2001. Since then, there has been a slight decline in emissions, but in recent years the emission estimates have levelled off.

2.5.2.3 Waste incineration

Waste incineration is a minor source of GHG emissions in the UK. The emissions from clinical and chemical waste incineration show a gradual decline across the time series, partly driven

by the decline in the UK chemical industry, and partly through improvements in waste management practices.

The most notable impact on the UK GHGI trend arises from the ban on the incineration of MSW without energy recovery in 1996; this regulatory change led to all UK MSW incinerators either closing or re-fitting boilers to raise electricity, and therefore from 1997 onwards all “energy from waste” plant emissions from the incineration of MSW are reported in the power generation sector of the inventory, in 1A1a.

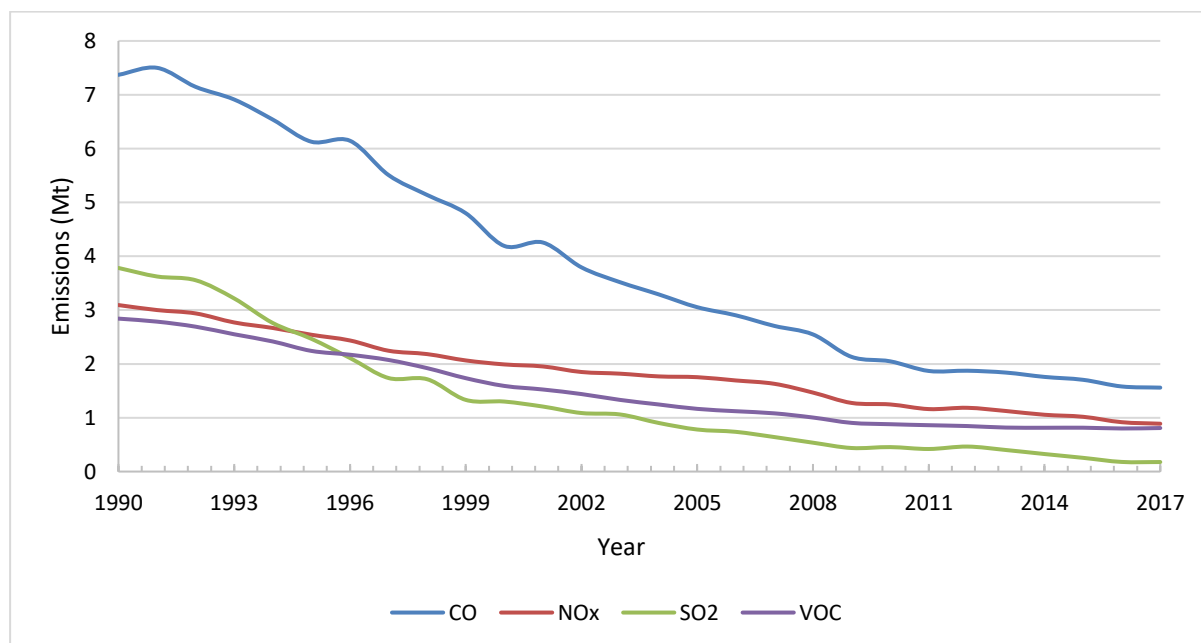
2.5.2.4 Biological treatment of solid waste

Since 1990 emissions from the biological treatment of waste sector has sharply grown from almost exclusively small-scale composting to a widespread and large-scale alternative practice for the treatment of biodegradable wastes, the generation of energy and the efficient generation of biogas as an alternative fuel. The continued increase in emissions from this source is part of the reason why emissions from the waste sector have flattened out in recent years.

2.6 EMISSION TRENDS FOR INDIRECT GREENHOUSE GASES AND SO₂

The indirect greenhouse gases in the UK consist of Carbon Monoxide (CO), Nitrogen Oxides (NO_x), Non-Methane Volatile Organic Compounds (NMVOC) and Sulphur dioxide (SO₂). Of these, NO_x, CO and NMVOC can increase tropospheric ozone concentration and hence radiative forcing. SO₂ 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 2.26**. Significant reductions of all indirect GHGs and SO₂ have occurred since 1990.

Figure 2.26 UK Emissions of Indirect Greenhouse Gases



2.6.1 Carbon Monoxide

Annual emissions of CO have decreased significantly since 1990. Over three quarters of UK emissions of CO are from the energy sector, with a quarter of the latter from transport in recent years. Since 1990, annual emissions from transport have declined dramatically, 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.

Another large source of CO emissions in the UK is from manufacturing and construction which contributes one fifth of total CO emissions. Emissions from within this category mostly come from biomass combustion and off-road vehicles used in manufacturing and construction.

2.6.2 Nitrogen Oxides

As for CO, a large decrease in the annual emissions of NO_x has occurred since 1990. Almost all NO_x emissions in the UK now come from the energy sector, of which road transport is the main source. The reduction in NO_x emissions is primarily due to abatement measures on power stations, three-way catalysts fitted to cars and stricter emission regulations on heavy duty vehicles.

Emissions from the energy industries contributes to almost a quarter of total NO_x emissions in the UK. Since 1990, annual emissions from this sector have decreased by over three-quarters mainly due to a decrease in emissions from public electricity and heat production. 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 have also fallen since 1990. 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.

2.6.3 Non-Methane Volatile Organic Compounds

Emissions of NMVOC have also declined since 1990. Approximately half of NMVOC emissions are from industrial processes and other product use. Three-quarters of these emissions are currently from the Non-energy Products from Fuels and Solvent Use sector whose emissions have halved since 1990. Most of the remaining NMVOC emissions in the industrial processes and other product use sector are from the food and drink and chemicals industries.

Approximately one third of NMVOC emissions originate from the energy sector. Of these, the largest contribution arises from the fugitive emissions of oil and natural gas. This includes emissions from gas leakage, which comprise around half of the total for the energy sector, the remaining emissions arise from oil transportation, refining, storage and offshore. Emissions from transport now contribute around 5% to overall emissions of NMVOC in the UK, but emissions from this sector have decreased by approximately 95% since 1990.

2.6.4 Sulphur Dioxide

Since 1990, total annual emissions of SO₂ have reduced dramatically. Almost all SO₂ emissions originate from energy sector, with the greatest contribution from energy industries. Since 1990, emissions from power stations have declined to a fraction of 1990 levels. 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 SO₂ emissions.

Emissions from Manufacturing, Industry and Construction are currently responsible for approximately a fifth of UK SO₂ emissions. Since 1990, emissions from this category have declined significantly. 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.

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 1990-2017 and 2016-2017. A description of the trends and the main drivers behind these can be found in **Chapter 2**.

Table 3.1 Energy Sector Overview

Energy	KCA Rank	Uncertainty	2017 emissions total (Mt CO ₂ e)	1990-2017 trend	2016-2017 trend	Recalculation: 2016	Recalculation: 1990	Methodology reference (NIR Section)
Greenhouse Gas Source and Sink Categories								
Total Energy			382	-38%	-3%	0%	0%	
A. Fuel combustion activities (sectoral approach)			372	-35%	-3%	0%	0%	
1. Energy industries			104	-56%	-8%	1%	0%	
a. Public electricity and heat production	2, 5, 7, 31	2%	74	-64%	-12%	1%	0%	MS 1
b. Petroleum refining	2, 5, 7, 31	15%	14	-24%	0%	0%	0%	MS 1
c. Manufacture of solid fuels and other energy industries	2, 5, 7, 31	3%	16	11%	4%	2%	0%	MS1, MS 2
2. Manufacturing industries and construction			52	-46%	0%	-1%	-1%	
a. Iron and steel	6, 8, 10	9%	9	-57%	-6%	-1%	0%	MS 4
b. Non-ferrous metals	6, 8, 10	5%	1	-83%	3%	40%	0%	MS 3
c. Chemicals	6, 8, 10	5%	5	-56%	8%	-2%	0%	MS 3
d. Pulp, paper and print	6, 8, 10	6%	1	-69%	-4%	-31%	0%	MS 3
e. Food processing, beverages and tobacco	6, 8, 10	5%	4	-46%	3%	-7%	0%	MS 3
f. Non-metallic minerals	6, 8, 10	12%	3	-64%	-2%	0%	0%	MS 3
g. Other (please specify)	6, 8, 10	5%	28	-28%	0%	2%	-2%	MS 3, MS 6
3. Transport			125	2%	0%	0%	0%	
a. Domestic aviation	32	20%	2	1%	2%	2%	3%	MS 7
b. Road transportation	1	2%	115	3%	0%	0%	0%	MS 8
c. Railways	30	18%	2	36%	-1%	0%	0%	MS 9
d. Domestic navigation	20	18%	6	-28%	-1%	1%	0%	MS 10, MS 11, MS 12
e. Other transportation		19%	1	151%	3%	-4%	-10%	MS 6
4. Other sectors			90	-20%	-4%	0%	0%	

Energy	KCA Rank	Uncertainty	2017 emissions total (Mt CO ₂ e)	1990-2017 trend	2016-2017 trend	Recalculation: 2016	Recalculation: 1990	Methodology reference (NIR Section)
Greenhouse Gas Source and Sink Categories								
a. Commercial / institutional	3, 12, 15	3%	19	-25%	-3%	0%	0%	MS 5
b. Residential	3, 12, 15	4%	66	-18%	-4%	0%	0%	MS 5, MS 6
c. Agriculture / forestry / fishing	3, 12, 15	29%	5	-16%	2%	-2%	-4%	MS 5, MS 6, MS 10
5. Other (as specified in table 1.A(a) sheet 4)			2	-71%	1%	0%	0%	
a. Stationary	N/A	N/A	IE	N/A	N/A	#DIV/0!	N/A	
b. Mobile	25	8%	2	-71%	1%	0%	0%	MS 14, MS 15
B. Fugitive emissions from fuels			10	-76%	1%	1%	0%	
1. Solid fuels		11%	1	-96%	-1%	0%	0%	
a. Coal mining and handling	18		0	-98%	-4%	0%	0%	MS 16
b. Solid fuel transformation	18		0	-79%	3%	0%	0%	MS 4
c. Other (as specified in table 1.B.1)	N/A	N/A	NO	N/A	N/A	#DIV/0!	N/A	
2. Oil and natural gas and other emissions from energy production		33%	9	-49%	1%	1%	0%	
a. Oil	16, 23		0	-76%	2%	1%	0%	MS 5
b. Natural gas	16, 23		4	-64%	-5%	2%	0%	MS 5, MS 19
c. Venting and flaring	16, 23		5	-13%	6%	1%	0%	MS 5
d. Other (as specified in table 1.B.2)	N/A	N/A	NO	N/A	N/A	#DIV/0!	N/A	
C. CO ₂ Transport and storage	N/A	N/A	NO	N/A	N/A	#DIV/0!	N/A	
1. Transport of CO ₂	N/A	N/A	NO	N/A	N/A	#DIV/0!	N/A	
2. Injection and storage	N/A	N/A	NO	N/A	N/A	#DIV/0!	N/A	
3. Other	N/A	N/A	NO	N/A	N/A	#DIV/0!	N/A	
Memo items:(1)	N/A	N/A	46	86%	1%	-2%	-1%	
International bunkers	N/A	N/A	46	86%	1%	-2%	-1%	
Aviation	N/A	N/A	35	125%	4%	-1%	0%	MS 7
Navigation	N/A	N/A	11	19%	-6%	-5%	-3%	MS 13
Multilateral operations	N/A	N/A	NE	N/A	N/A	N/A	N/A	
CO ₂ emissions from biomass	N/A	N/A	44	972%	6%	10%	35%	MS 1, MS 3, MS 6, MS 8
CO ₂ captured	N/A	N/A	NO	N/A	N/A	N/A	N/A	

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 CO₂ emissions described in **Section 3.4**. The Reference Approach is a 'top down' approach for estimating energy CO₂ 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 have 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) CO₂ estimates for the UK typically range between **1.8% lower** to **3.6% 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.

Statistical Differences in Energy Balance Data

The SA is based on the demand side of the national energy statistics, which in 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.

Application 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 means 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.

Fuels 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.

Treatment 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.

Deviations 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.

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

Table 3.3 shows the percentage differences in CO₂ 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	1.015	0.959	0.985	1.7%	1.025	0.973	1.002	1.0%
Solid Fuels	0.949	0.835	0.911	8.9%	1.058	0.969	1.011	1.6%
Gaseous Fuels	1.027	0.997	1.009	0.9%	1.007	0.995	1.001	0.2%
Total	0.982	0.964	0.974	2.6%	1.012	0.994	1.003	0.5%

^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 1.7%³⁶) than the sectoral approach; there are some years with larger deviations, the highest being a 2.7% deviation in 1997. In the adjusted RA the values are closer to the SA (on average 1.0% lower), and the extreme deviations are curtailed so that the greatest deviation is 2.5% in 1997. 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. The most significant differences between the adjusted and non-adjusted RA are our estimate of the impact of the difference in carbon between crude oil and derived petroleum fuels, and the accounting for fuel oil and gas oil consumption in the shipping sector considered additional to DUKES as indicated by the new bottom-up estimates integrated into the inventory for the first time this year.

For solid fuels the RA is 5.1-16.5% 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 0.1-1.1% 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 0.2% 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 2.7% lower than the SA estimates. However, once the RA is amended for known differences, the comparison is much closer with a range of 1.2% higher (in 2015) to 0.6% lower (in 1996) than the SA; the adjusted RA is on average 0.3% higher than the SA.

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

³⁶ Note that the average deviation (in this case 1.7%) 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 CO₂)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Sectoral Approach 1A (Mt CO ₂)	566.6	577.2	561.5	547.8	541.3	530.9	551.2	529.7	535.5	529.6	538.1	548.5	533.4
Reference Approach (Mt CO ₂)	547.5	562.5	551.7	533.7	525.6	516.1	533.2	510.8	519.4	515.8	527.7	534.0	519.7
Reference Approach (Amended for known differences) (Mt CO ₂)	531.2	546.3	536.8	521.0	508.5	501.4	518.5	493.8	504.0	496.9	512.2	519.3	503.8
RA/SA %	-3.4%	-2.5%	-1.8%	-2.6%	-2.9%	-2.8%	-3.3%	-3.6%	-3.0%	-2.6%	-1.9%	-2.7%	-2.6%
RA/SA (amended) %	-0.5%	0.3%	0.9%	-0.2%	0.3%	0.0%	-0.6%	-0.4%	-0.1%	0.9%	0.9%	0.0%	0.4%

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Sectoral Approach 1A (Mt CO ₂)	543.1	543.3	540.7	540.2	530.0	518.1	473.3	489.7	448.7	467.3	455.4	416.3	400.2	380.0	367.1
Reference Approach (Mt CO ₂)	527.2	528.6	529.8	527.5	515.2	505.0	460.2	477.5	434.1	455.7	444.0	403.6	391.1	372.1	360.5
Reference Approach (Amended for known differences) (Mt CO ₂)	509.3	513.0	514.8	512.0	498.9	489.1	446.0	465.5	421.0	443.3	429.7	387.8	377.3	360.6	350.9
RA/SA %	-2.9%	-2.7%	-2.0%	-2.3%	-2.8%	-2.5%	-2.8%	-2.5%	-3.3%	-2.5%	-2.5%	-3.0%	-2.3%	-2.1%	-1.8%
RA/SA (amended) %	0.4%	0.2%	0.7%	0.5%	0.3%	0.5%	0.2%	0.0%	-0.3%	0.2%	0.7%	0.8%	1.2%	0.9%	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 Tier 3 method adopted for aviation and described in **MS 7** and the revised Tier 3 method adopted for shipping as described in **MS 13**. 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 bottom up analysis from the BEIS shipping inventory (Scarborough et al., 2017). This leads to a different total 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, 2018) 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, if inventory estimates lead to more conservative emission estimates. In 2013, the Inventory Agency carried out research into non-energy uses of fuels; this was followed up by the DECC (now BEIS as of 2016) 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, which 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 from literature sources on the estimated split of stored to emitted carbon related to use of chemical feedstocks, 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, petroleum coke for residential use was not recorded in the national energy data, nor was industrial use prior to 2008, and so use has been made of other data for both industrial and domestic sector consumption. Evidence from environmental reporting and from 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), and that petroleum coke is supplied as a fuel for the residential market.

In the reporting of emissions from NEU of fuels, and the comparison of the RA and SA, the ERT noted (2017 ARR item E.13) that the CRF tables 1.A(b) and 1.A(d) include blank cells where “NO” should be reported for other liquid fossil fuels, other gaseous fuels and other fossil fuels. The functioning of the CRF reporting software means that to resolve these Notation Key issues in all cases (including here in Energy, also sectors 2E-2G in IPPU) is very resource-intensive, and disproportionate to the improvement in report quality. Therefore we state here that the emissions from other liquid fossil fuels, other gaseous fuels and other fossil fuels are all “Not Occurring” in the UK inventory.

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, 2018a), 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 may exhibit very different combustion characteristics (for non-CO₂ gases) 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 alternative data suggesting higher fuel consumption are available from other sources, which we use in preference. *For example, the EU Emissions Trading System indicates higher fuel use 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 typically 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 may be too low, 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, 2018b), 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 OPRED, 2018) and from data supplied by the UK Mineral Products Association (MPA, 2018), 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, and these are presented in the inventory reported across a number of source sectors (including: 1A1a, 1A2g, 1A3b, 1A4b and 1A4c). The underlying energy data are not wholly consistent with the needs of inventory reporting, and it is likely that biofuels consumption for industry (reported in 1A2g) will include some consumption within 1A2d, 1A2e and 1A4a and, to a lesser extent, other sectors as well, but the inventory agency does not have sufficient data on which to base estimates at this greater level of sector resolution.

Greenhouse gas emissions including CO₂ are estimated for these fuels and presented in the relevant sections of the CRF. The CO₂ emissions from biomass are, however, not added to the total UK emissions from fuel combustion and are instead recorded as a memo item. The exception to this approach is that there is a fossil-carbon component of some liquid biofuels (e.g. the methyl group in FAME is derived from fossil feedstock), and the CO₂ derived from that fossil component of the biofuels is reported in the UK inventory, predominantly in 1A3b where liquid biofuels are used most widely.

Emissions of N₂O and CH₄ 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 CO₂ 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 that 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	
			2016	1.8% ^b	
			2017	1.6% ^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 except in 2005 and 2016 where no information is available for one site.

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

3.3 CO₂ TRANSPORT AND STORAGE

Currently in the UK, CO₂ 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 (<i>including emissions from flaring at refineries</i>) 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, <i>Memo item</i>	Aviation, International aviation
MS 8	1A3b	Road Transport
MS 9	1A3c	Railways
MS 10	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	<i>Memo item</i>	International shipping

MS number	IPCC categories	Source categories
MS 14	1A5b	Naval Shipping
MS 15	1A5b	Military aircraft
Fugitive sources (<i>Except 1B1b – see MS 4</i>)		
MS 16	1B1ai, 1B1aai, 1B1a2i	Coal mining and handling (excluding closed coal mines)
MS 17	1B1a1iii	Closed coal mines
MS 18	1B2	1B2 excluding: Natural gas distribution (1B2biv to v). <i>Note that emissions from Natural Gas Production (1B2b2) are reported as 'IE', and aggregated in reporting under Natural Gas Processing (1B2b3). Note also that emissions from refinery flaring are included under 1A1b, see MS1.</i>
MS 19	1B2biv, 1B2bv	Natural 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

CO₂, CH₄, N₂O

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 emissions reported under 1A1b include those from flaring at refineries. The operator-reported emissions from refineries include both combustion and flaring sources; it is not possible to disaggregate the data accurately for all installations and years. Hence the UK does not include any emissions from refinery flaring under 1B2c.

[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 peaked in 2012 but has decreased slightly since then. The share of total UK electricity generated in 2017 was 7.8% from coal and 43% from gas, compared with 10% from

coal and 45% from gas in 2016. The decreasing significance of coal continues the trend of recent years as a number of coal-fired stations have been closed in 2015 and 2016. Nuclear stations generated a further 24%, and almost all of the remaining 24% was generated from renewables (6%) or non-thermal sources such as wind and hydro (18%).

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. CO₂ emissions associated with biofuel combustion are estimated and reported as memo items, but not included in the energy sector; 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	44	8	12	1	2	0	Unknown ^a	19
1995	23	8	13	18	4	2	Unknown ^a	16
2000	21	5	11	37	15	4	267	15
2005	17	3	13	49	20	5	461	13
2010	17	3	13	56	24	8	554	10
2012	16	2	13	57	26	9	565	10
2013	15	2	13	51	28	11	621	10
2014	13	1	13	50	34	12	628	10
2015	13	1	13	51	35	14	633	9
2016	12	0	13	52	39	15	642	9
2017	9	0	13	55	41	15	658	9

^aNumber 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 2017, 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 large crude oil refinery 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
1990-1996	11	4
1997-1998	10	4
1999	9	4
2000-2009	9	3
2010-2012	8	3
2013	7	3
2014	7	2
2015-2017	6	2

Some 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** and **MS 18**. Coal is extracted in the UK from deep mines and open-cast sites. The production of coal has been in rapid decline in the UK and levels of UK activity are far lower in recent years than in 1990. The last large UK deep mine closed in 2015 and so production of deep-mined coal was negligible in 2016-2017. Emissions from combustion at UK collieries are covered in this MS. Fugitive emission estimates from these mining and extraction activities are included in **MS 16** and **MS 17**.

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-CO₂ EFs are predominantly IPCC defaults (IPCC, 2006).

*An accompanying spreadsheet “Energy_background_data_uk_2019.xlsx” lists all emission factors used in the energy sector, including a full list of references³⁷. 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**.*

³⁷ 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.

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:

$$\text{UK Emissions} = \text{EF} \times \text{AD}$$

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_2019.xlsx*”. The activity data are taken from DUKES, noting the exceptions set out under Assumptions & observations, below. **Annex 4** describes 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;
- **Coal-fired 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 almost all also report 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 2017 the lowest OF reported is around 96.8%, whereas most stations report 98-99%. The factors presented in “*Energy_background_data_uk_2019.xlsx*” 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 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 non-biodegradable (fossil) and biodegradable wastes and we apply IPCC default carbon factors for each type of waste.
- **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, potential under-reports were identified in the UK energy balance data for the refinery sector from 2004 onwards, although not in all years. The Inventory Agency takes the conservative approach of using the higher fuel consumption data for each year. The estimates for 2004 in the UK GHGI are therefore based on data supplied directly to the Inventory Agency by the UK Petroleum Industry Agency (UKPIA) data, whilst the data for 2006-2011 and 2013-2017 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 2015-2017. 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:

- Some relatively minor re-allocations to the early part of the time-series for MSW use. The split between MSW burnt with energy recovery and MSW incineration previously included an error for 1990-1995 which led to too much MSW being allocated to 5C1 and not enough being allocated to 1A1a. This has now been rectified.
- Emissions from the Ferrybridge Multifuel site are reported as energy from waste in this submission; previously emissions were reported as wood-fired power generation. The site burns both household waste and recovered wood, but the former is now understood to be the main fuel.
- Revisions to DUKES have been incorporated, but these have a small impact on emissions.

For emission factors:

- The inventory agency has revised the method for calculating CO₂ emissions from MSW incineration and Energy from Waste plant. The previous method applied UK-specific factors that were derived from a small dataset of infrequent waste compositional analysis datasets, which exhibited a large range of fossil carbon contents across the small number of surveys. The uncertainty associated with the data was regarded as high, and no new survey data are evident in the UK in recent years. Therefore, as this is a small component of UK emissions the inventory agency has reverted to applying IPCC default factors. This method change leads sometimes to small decreases and more often to small increases in emission estimates.

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 *Code of Practice for Statistics*³⁸. 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 data directly from EU ETS or trade association (UKPIA) 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, 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.

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 CO₂ emissions accurately. Non-CO₂ 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.

³⁸ Available from <https://www.statisticsauthority.gov.uk/code-of-practice>

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

CO₂, CH₄, N₂O

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, 2018), with some supplementary data from the EU ETS and EEMS data sets (both from BEIS OPRED, 2018).

Emission Factors: Carbon factors for natural gas are derived from operator-reporting to EU ETS and EEMS (both from BEIS OPRED, 2018), 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_2019.xlsx” lists all emission factors used in the energy sector, including a full list of references³⁷. Table 1.6 gives additional information for common activity data sources.

Method approach

Fuel consumption data for this source are predominantly taken from DUKES, with the exceptions noted below. Note that in the UK there are different regulatory mechanisms that govern the activities of: (i) offshore oil & gas exploration and production, and (ii) onshore conventional oil & gas exploration and production, including onshore terminals. These different regulatory systems define the data that is available for upstream oil and gas activities, which impacts on the best available method for each sector of the inventory; for example, the data available for offshore rigs is more detailed (source-specific) than for onshore terminals (where only some resolution of emissions by source is feasible).

It is important to note however that despite these different methods and data availability, the UK inventory agency does report in a **time series consistent** manner for each source, and that **the UK inventory is complete for all emission sources in this Method Statement**. For upstream oil & gas combustion, the inventory agency has access to complete reporting of emissions to at least one regulatory mechanism for all installations; for onshore terminals, data are available from EU ETS to provide resolution of activity and emissions data separately for combustion and flaring sources.

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.

Emission factors for N₂O for 1A1cii are higher than the IPCC default range, and this issue has been noted by previous UNFCCC expert review teams. The factors applied in the UK inventory are based on operator-reported data from predominantly offshore oil & gas facilities using fuel gas, which is mainly natural gas or associated gas from oil production. These operator data are considered to be more representative of combustion emissions at UK installations than the IPCC defaults.

Recalculations

There have been no method changes but the 2016 emission estimates have been recalculated and are around 0.23 MtCO₂e higher than the previous submission. These recalculations are due to revisions in the UK energy balance for natural gas use by the upstream oil and gas industry, and also the addition of emission estimates for one new installation that operated from 2016, the Shetland Gas Plant, where process gases (OPG) are used as fuel. The impact of changes is set out in **Section 10**.

Improvements (completed and planned)

Emission factors and activity data remain under review.

The data capture mechanism (the Petroleum Producers Reporting System) used to compile DUKES has not been changed to address the reporting gap for LPG and OPG use at terminals, for which EU ETS data are used by the inventory agency (as noted above in the method description). Hence this issue of inconsistency with the national statistics cannot be resolved. We note however that this does not impact upon the completeness nor the accuracy of the UK inventory submission; it is merely an issue of relevance for the national energy balance, and not the national emissions inventory total.

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.
- comparisons on total emissions data reported by each onshore oil and gas installation via the Pollution Inventory/Scottish Pollutant Release Inventory/Welsh Emissions Inventory to assess time-series consistency and completeness of reporting, comparing CO₂ emissions data against those presented in EU ETS.

The energy AD used in these estimates that come from DUKES are subject to the UK Statistics Authority's *Code of Practice for Statistics*³⁸. 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 CO₂ emissions accurately. Non-CO₂ 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), Autogeneration - exported to grid (coal), Autogenerators (coal)
- 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 (gas), Autogenerators (gas)

Relevant Gases

CO₂, CH₄, N₂O

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, 2018), cement sector fuel use estimates (MPA, 2018) and, installation-specific activity data from EU ETS e.g. for lime kilns (EA, SEPA, NRW, NIEA, all 2018).

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-CO₂ gases are derived from IPCC (IPCC 2006).

*An accompanying document "Energy_background_data_uk_2019.xlsx" 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 CO₂ (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 maximise 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 2008-2017, 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.

In the case of coal-fired autogeneration, EU ETS-based factors are available for 2005-2011. This sector was dominated by a single plant that supplied electricity to a large aluminium smelter until 2012. Originally, the UK inventory used a combination of EU ETS factors for 2005 onwards, and factors from Baggott *et al*, 2004 for earlier years but this resulted in a large step change in the emission factor between 2003 and 2005. The inventory agency reviewed the EU ETS data for the one installation (Lynemouth smelter), which exhibits a very stable CEF across all reported years (2005 to 2011) and concluded that it was very unlikely that this plant would have used significantly different quality coal in 2003 from that used in 2005. Therefore, to improve the inventory time series consistency, the inventory agency now extrapolates CEFs from the EU ETS back to 1990, and applies the 2011 value for subsequent years.

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_2019.xlsx” lists all emission factors used in the energy sector, including a full list of references³⁷

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 until 2013, 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 that site is now allocated to 1A1a. The coal use by autogenerators since 2013 is very low (only 0.2% of total UK coal demand in 2017) compared with earlier years, because of the re-allocation of this one site, but emissions are still reported in 1A2b, in the absence of any information on the nature of the remaining small users.
- The large change in the quantity of coal burnt by autogenerators between 2012 (when consumption was over 1,000,000 tonnes) to 2013 (33,000 tonnes) and then 2014 onwards (less than 20,000 tonnes) has a marked impact on the time-series for the CH₄ IEF reported for 1A2b in the CRF. Since the factors applied for autogeneration and non-autogeneration use of coal are quite different, there are large step changes in the time-series over the 2012-2015 period as a result.

Recalculations

The following summarises the recalculations in 1A2:

- DUKES data revisions have affected data in later years, particularly for natural gas (2015-2016). However, the overall change across 1A2a-f, gviii (i.e. all stationary combustion in 1A2) is very low, with overall changes in 2015 and 2016 around 0.2MtCO₂e; the main recalculations in 2015, 2016 are re-allocations in energy use across 1A2a-f, gviii, with changes to natural gas allocations in DUKES the main driver, with lower gas allocations to 1A2c,d,e and higher gas allocations to 1A2gviii;
- DUKES has also included some revisions to the quantities of plant-based biomass burnt by the agricultural and industrial sectors, with higher estimates now for industrial combustion of biomass, leading to higher emissions of non-CO₂ GHGs. These revisions to UK energy statistics were based on recent fuel use survey data that indicate a higher level of industry use of biomass than was previously reported; the changes to energy data were only made for recent years, due to the statistical revisions policy of the energy statistics, and would have led to a marked step-change in activity data and emissions for 1A2. Therefore to improve time series consistency, the Inventory Agency has re-allocated biomass use from 1A4c to 1A2gviii across the rest 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 *Code of Practice for Statistics*³⁸.

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. The inventory agency seeks to identify and address any inconsistencies in the inventory time series, such as those arising from revisions to the energy balance data that may be implemented by BEIS DUKES for recent years only, through meetings with the key data providers. The use of carbon EFs derived from the EU ETS, which are available only from 2005 onwards, is considered the best available data for recent years in many source categories; the carbon EF data prior to 2005 were also derived from analysis of UK fuels, either from data submissions from fuel users or fuel suppliers, and so the method is consistent across all years noting that the level of detail, frequency of reporting and QA/QC underpinning the data prior to EU ETS is generally lower than from 2005 onwards, and hence the uncertainty of estimates in the earlier years is higher than for recent years.

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 CO₂ emissions accurately. Non-CO₂ 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

CO₂, CH₄, N₂O

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 existed until closure at the end of 2014. The Teesside steelworks was closed in September 2015 and one of the two coke ovens at Scunthorpe steelworks was closed in early 2016 so, at the end of 2016, there were two coke ovens left in the UK, both at steelworks. Four other coke ovens were in existence in 1990 but closed in the years up to 2005 due to closure of two integrated steelworks and 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
1990-1992	10	5	Unknown
1993-1996	9	4	20
1997-2000	9	4	19
2001	9	4	18
2002	9	3	16
2003	7	3	14
2004-2005	6	3	12
2006	6	3	11
2007	6	3	10
2008	6	3	8
2009-2010	6	3	7
2011	6	2	7
2012-2014	6	3	6
2015	3 ^a	2 ^a	6
2016	2 ^a	2 ^a	6

^a Figures at year end

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 CO₂ 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, 2018), ISSB annual statistics (ISSB, 2018), installation-specific activity data from EU ETS (EA, NRW, both 2018), 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-CO₂ gases are predominantly IPCC defaults (IPCC 2006), Baggott et al., 2004.

*An accompanying spreadsheet “Energy_background_data_uk_2019.xlsx” lists all emission factors used in the energy sector, including a full list of references³⁷. **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

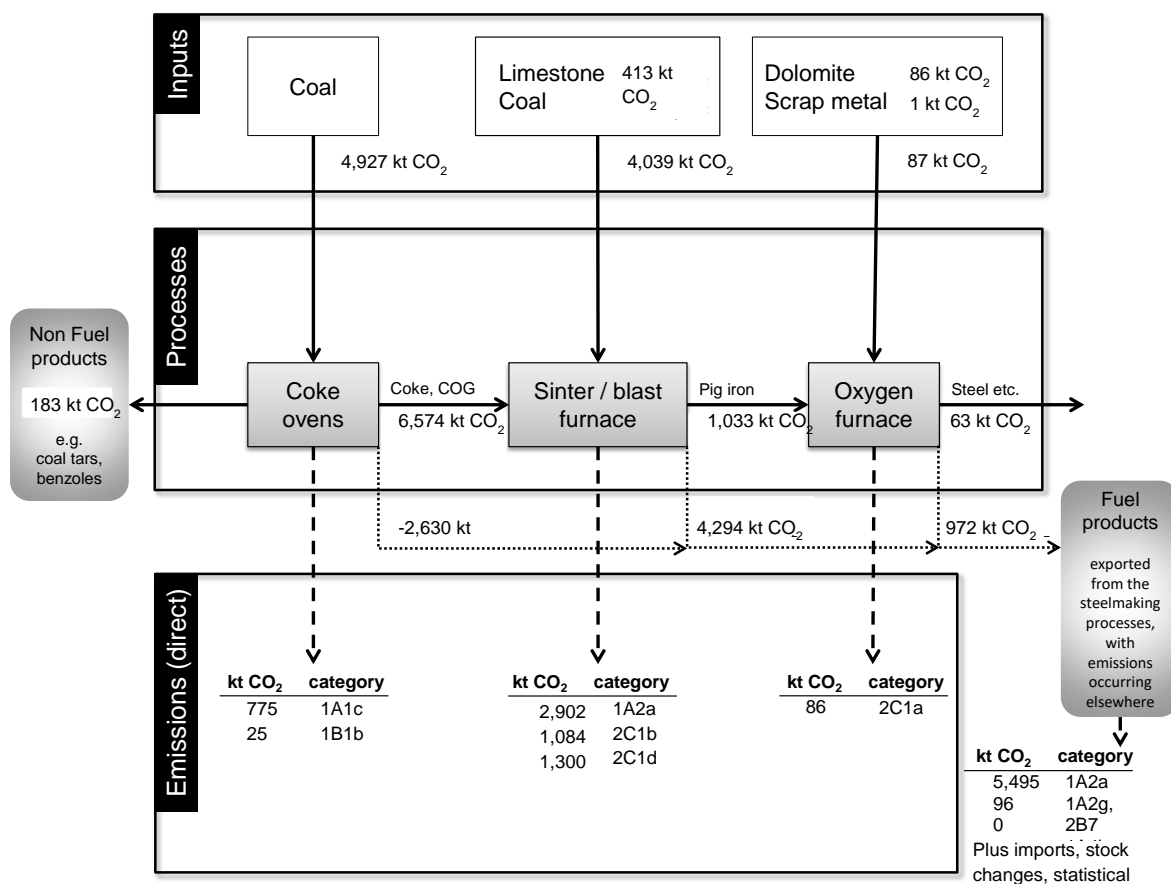
coke + limestone + iron ore → sinter + carbon emission

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 CO₂) given for the year 2017 as an example. Note that there is one negative value in the diagram because the figures take into account imports, exports, and stock changes. For some years, DUKES does not have sufficient coke oven coke to account for all known uses and so the GHGI has to deviate from DUKES by assuming a higher demand for this fuel.

Figure 3.1 Carbon balance model for 2017^a

^a Other adjustments includes statistical differences (+21 kt CO₂), imports (-2898 kt CO₂), exports (0 kt CO₂), stock changes (+18 kt CO₂), fugitive emissions from coke ovens reported as methane (16 kt CO₂), adjustments for natural gas added to coke oven gas (-27 kt CO₂), carbon stored in dusts (+11 kt CO₂), and deviations from DUKES (-96 kt CO₂)

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, 2018) and carbon contents from the operators (Tata Steel, SSI Steel, both 2015), and based on their EU ETS reporting (EA, NRW, both 2018).

Emissions of CH₄ and N₂O are estimated using IPCC 2006 default emission factors.

Assumptions & observations

A detailed description of the carbon balance methodology has been given in Ricardo-AEA, GHG Inventory Research: Use of EU ETS Data - Iron & Steel Sector, Chemical Industry Feedstock Use, April 2014 (available for download on the NAEI website³⁹) and so only a brief summary of assumptions is given here.

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 CO₂ is therefore

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https://uk-air.defra.gov.uk/assets/documents/reports/cat19/1405081135_GHG_Inventory_Research_Report_EU_ETSEU_ETS_final.pdf

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 2003-2017 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 *Code of Practice for Statistics*³⁸. 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 fully available for 2015-2017, partly due to the Teesside works closing in September 2015, and the sale of the Scunthorpe works to a new operator in early 2016, so 2014 values for some parameters have been assumed to be correct for 2015-2017 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 CO₂ 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

CO₂, CH₄, N₂O

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, 2018)

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

*An accompanying spreadsheet "Energy_background_data_uk_2019.xlsx" lists all emission factors used in the energy sector, including a full list of references³⁷. **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-CO₂ 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).

There is no biomass combustion reported in 1A4a Commercial/Institutional combustion in the UK energy statistics. This source is therefore Not Occurring in the UK inventory. Due to an anomaly in the CRF reporting software, it is not practicable to enter "NO" in the CRF for emissions from 1A4a biomass combustion, and hence this apparent gap in the CRF is explained here, in response to the ERT findings from the 2017 submission.

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;
- We have re-allocated some plant-based biomass from 1A4c to 1A2g across the time-series. This is partly to reflect revisions to DUKES, but these revisions extend only over recent years and so we have extended them to the entire time-series to avoid a large step-change in the time-series.

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 0**. 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*³⁸.

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. Petroleum 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 CO₂ emissions accurately. Non-CO₂ 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

CO₂, CH₄, N₂O

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_2019.xlsx” lists all emission factors used in the energy sector, including a full list of references³⁷. 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 Guidebook (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.

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, 2017 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.", http://www.ons.gov.uk/businessindustryandtrade/constructionindustry/datasets/outputintheconstructionindustry Table 2b – Value of construction output in Great Britain: non-seasonally adjusted. The value of all new work (i.e. excluding repair and maintenance work) at constant (2010) prices. The seasonally non-adjusted figures were used and scaled to ensure time-series consistency.	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
Quarrying	Data on UK production of minerals, taken from UK Minerals Yearbook data, BGS (2017).	rough terrain forklifts
		bore/drill rigs
		off highway trucks
Construction and Quarrying	Growth driver based on the combination of the quarrying and construction drivers detailed above.	crushing/processing equipment
		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 (2009) 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.

The main re-calculation is due to changes in fuel consumption for industrial and construction mobile machinery affecting 1A2gvii arising from the re-allocation of changed gas oil activity data in DUKES. The changes to this sector are made to retain fuel mass balance with DUKES and are affected by changes made to other sectors using gas oil.

Other re-calculations arise from:

- Revision to DUKES gas oil consumed in agriculture used as a driver for the agricultural machinery sector.
- Change in N₂O EF for all diesel and gas oil off-road machinery types to be more in line with other transport sources. N₂O emissions are around 90% lower across the time-series in the 2019 submission.

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 1.6**.

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 and 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

CO₂, CH₄, N₂O

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 (including climb and descent) 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 15**.

Key Data sources

Activity data: CAA (2018a); CAA (2018b); BEIS (2018a); DfT (2018)

Emission Factors: Baggott et al. (2004); EMEP/EEA (2016); IPCC (1997); IPCC (2006)

An accompanying spreadsheet “Energy_background_data_uk_2019.xlsx” lists all emission factors used in the energy sector, including a full list of references³⁷. 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 method, and use the number of aircraft movements broken down by aircraft type at each UK airport together with UK energy statistics.

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, 2018a). 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 Ministry of Defence (MoD). Military aviation estimates are included in MS 15. 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, 1990-2017

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
2010	734.0	393.9	1395.	146.4
2015	821.7	356.0	1565.8	135.0
2016	874.6	349.5	1675.5	133.7
2017	903.2	349.3	1751.7	135.2

Gm Giga metres, or 10⁹ 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_2019.xlsx” 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 for Take-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 of 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 for 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, 2016) provides fuel consumption and emission data for non-GHGs (NO_x, HC and CO) for a number of aircraft cruise modes (climb cruise and descent). 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**.

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

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

Where:

$FC_{Cruise_{d,g,p}}$	is the fuel consumption in cruise of pollutant p for generic aircraft type g and flight distance d (kg)
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 CO₂ 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 N₂O 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 2019). 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 2019 inventory submission incorporates the adoption of taxing times as reported in the spreadsheet annex to the EMEP/EEA (2016) Guidebook.

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 1.6**.

Time series consistency

Consistent data sets and methods are used across the full time series to ensure time series consistency. It should be noted that since emissions of methane from engines consuming aviation spirit vary significantly, and that total use of this fuel in aviation is low, the time-series of implied emission factors of methane is subject to large year-on-year variations, including a notable change in methane IEF between 2009-2010.

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 CO₂ emissions accurately. Non-CO₂ 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

CO₂, CH₄, N₂O

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). 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).

Emission factors: COPERT 5, EMEP/EEA 2016 Emission Inventory Guidebook.

*An accompanying spreadsheet "Energy_background_data_uk_2019.xlsx" lists all emission factors used in the energy sector, including a full list of references³⁷. **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), heavy goods vehicles, buses and coaches (1A3biii) and motorcycles (1A3biv).

Petrol and diesel vehicle fuel consumption (and emissions) are estimated for individual vehicle types from a bottom-up approach 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 2016 Guidelines and includes 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 CO₂ 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 and fleet information before a final fuel reconciliation is done. Details of the methodology are given in a separate report “*Methodology for the UK’s Road Transport Emissions Inventory*” (Brown et al, 2018) which will be updated periodically covering any new methodological changes for both greenhouse gases and air pollutants. This describes the very detailed information available on road transport activities in the UK and how these are used in estimating the road transport inventory. Only a brief overview of the approach used and the activity data and emission factors specific to the greenhouse gases in the current inventory are provided in this report.

Fuel consumption and emissions of CH₄ and N₂O, as well as the indirect GHGs and air pollutants, NMVOCs, NO_x, CO and SO₂, from individual vehicle types are calculated from measured emission factors expressed in g/km and road traffic and fleet composition statistics from the Department for Transport. The emission factors are from the COPERT 5 (Emisia, 2018) and EMEP/EEA (2016) Emissions Inventory Guidebook source, expressed as equations relating emission factor to average vehicle speed or road type for different vehicle types compliant with different legislative emission standards (Euro standards).

The type of emissions include:

- **Hot exhaust emissions:** emissions from the vehicle exhaust when the engine has warmed up to its normal operating temperature.
- **Cold start emissions:** the excess emissions that occur when a vehicle is started with its engine below its normal operating temperature.

For NMVOCs, evaporative emissions of fuel vapour from petrol-fuelled vehicles are also included.

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 CH₄ and N₂O by vehicle category before the normalisation to fuel sales is carried out.

Activity data for traffic-based emission calculations:

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, 2018a). DfT provides a consistent time series of vehicle km data by vehicle and road types going back to 1993 for the 2017 inventory, 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 are 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, Northern Ireland, Road Services (DRDNI, 2016). 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 (2016) and DRDNI (2013) for the given vehicle type and road type considered. Data for 2015, 2016 and 2017 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 2017 in Great Britain. Motorcycle vehicle km data were not available from the DAERA 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. Information about the petrol/diesel split for cars and LGVs in the traffic flow are based on licensing data for Northern Ireland as provided by DfT (2018b).

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 2017. Table 3.11 shows the time-series of total UK vehicle kilometres by vehicle and road type for select years from 1990 to 2017.

Table 3.11 UK Vehicle km by Type of Road Vehicle, 1990-2017

Billion vkm		1990	2000	2005	2010	2015	2016	2017
Petrol cars	urban	142.2	135.1	119.9	99.4	89.3	87.1	85.0
	rural	140.9	134.1	127.2	109.0	93.5	95.0	95.0
	m-way	49.3	53.0	48.9	41.7	34.3	34.3	34.0
Diesel cars	urban	5.8	26.1	40.8	54.0	65.2	67.1	69.3
	rural	6.1	28.3	47.5	65.8	88.3	92.7	96.8
	m-way	2.8	14.7	25.2	33.6	46.0	47.1	48.0
Petrol LGVs	urban	11.1	4.2	1.9	1.3	1.0	0.9	0.9
	rural	11.4	5.0	2.3	1.6	1.3	1.3	1.3
	m-way	3.9	2.0	0.9	0.6	0.6	0.5	0.6
Diesel LGVs	urban	5.8	15.6	21.2	22.7	25.3	26.2	26.5
	rural	6.0	18.8	25.9	29.5	33.9	36.0	37.2
	m-way	2.0	7.4	10.4	11.4	14.7	15.4	16.1
Rigid HGVs	urban	4.5	3.9	4.0	3.2	2.9	2.8	2.6
	rural	7.1	7.2	7.5	6.6	6.3	6.4	6.3
	m-way	3.7	4.2	4.2	4.1	3.9	4.0	4.0
Artic HGVs	urban	1.1	1.1	1.1	0.8	0.9	0.9	0.9
	rural	4.4	5.2	5.4	5.1	5.3	5.4	5.7
	m-way	4.7	7.4	7.9	7.5	8.4	8.5	8.8
Buses	urban	2.4	3.0	3.2	3.1	2.6	2.5	2.3
	rural	1.7	1.7	1.5	1.6	1.4	1.3	1.3
	m-way	0.6	0.5	0.5	0.5	0.4	0.4	0.4
M/cycle	urban	3.3	2.3	2.9	2.5	2.2	2.3	2.3
	rural	2.0	2.0	2.2	1.8	2.0	1.9	1.9
	m-way	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Total		423.3	482.9	512.9	507.9	529.9	540.4	547.4

The vehicle speeds assigned to the different vehicle and road types are given in Brown et al (2018). These are used to derive the emission factors for each vehicle and road type from the emission factor-speed relationships available for different pollutants.

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 to define the UK's vehicle fleet composition on the road. The ANPR data has been collected at over 256 sites in the UK on different road types (urban and rural major/minor roads, and motorways) and regions. They cover various vehicle and road characteristics such as fuel type, age of vehicle (which can be associated with its Euro standard), engine size, 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), leading to the vehicle km data for petrol and diesel cars on different road types in the UK shown in Table 3.11; and
- Variations in age and Euro standard mix on different road types.

The year-of-first registration of a vehicle determines the type of emission regulation that the vehicle complies with. These have entailed the successive introduction of tighter emission control technologies. Although emission standards do not apply to CH₄ and N₂O, technologies designed to control the regulated pollutants such as hydrocarbons and NO_x affect these GHG emissions.

ANPR data were not available for all years, including 2016, so a method based on trends in DfT vehicle licensing statistics on the fuel and age mix of the fleet was applied to the fleet derived from ANPR data for an adjacent year (Brown et al, 2018).

Further vehicle licensing statistics and mileage data were used to define trends in:

- The breakdown in vkm of cars, mopeds and motorcycles by engine size category
- The breakdown in vkm by rigid HGVs, artic HGVs, buses and coaches by vehicle weight category

Detailed information on the fleet in London was provided each year by Transport for London (TfL). The inventory pays particular attention to the unique features of the bus, taxi, HGV and LGV fleets in London. This is primarily so as to be able to account for measures taken to reduce emissions and improve air quality in London through the introduction of the London Low Emission Zone introduced in stages since 2008.

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:

Fuel consumption is calculated for each vehicle type using the fuel consumption-speed relationships given in COPERT 5 and the EMEP/EEA Emissions Inventory Guidebook (2016). This includes a method for passenger cars which applies a year-dependent 'real-world' correction to the average type-approval CO₂ factor weighted by new car sales in the UK from 2005-2017. The new car average type-approval CO₂ factors for cars in different engine size bands were provided by the Society of Motor Manufacturers and Traders (SMMT, 2018). 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, fleet average fuel consumption factors for each main vehicle category are shown in Table 3.12 for a selection of years between 1990 and 2017.

Table 3.12 UK Fleet-averaged fuel consumption factors for road vehicles (in g fuel/km)

	1990	2000	2005	2010	2015	2016	2017
Petrol cars	56.3	54.8	54.9	54.0	50.6	49.3	48.5
Diesel cars	54.8	53.4	53.5	54.1	50.3	49.5	49.0
LGVs	77.9	77.6	74.9	74.7	72.1	71.5	70.9
HGVs	210	194	207	211	216	217	218
Buses and coaches	292	268	267	262	255	254	253
Mopeds and motorcycles	36.2	38.0	36.9	35.9	34.9	34.9	34.8

Carbon Factors

CO₂ 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_2019.xlsx".

CH₄ and N₂O Emission Factors for Vehicle Types

The emission factors for N₂O and CH₄ for all vehicle types in g/km are based on the recommendation of the Emissions Inventory Guidebook (EMEP, 2016) derived from the COPERT 5 model “*Computer Programme to Calculate Emissions from Road Transport*”. Tables showing the emission factors for different vehicle types, Euro standards and road types are provided in Annex A in the road transport inventory report by Brown et al (2018). This also shows the cold start emission factors for N₂O emissions from petrol cars and LGVs included in the calculations.

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 which also reduces N₂O emissions. 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. Factors for HGVs and buses have been increasing with more recent Euro standards (Euro IV-VI). This is most likely due to the fitting of selective catalytic reduction (SCR) systems on the exhaust system for controlling NO_x emissions.

Road transport is a relatively unimportant emitter of CH₄, only being produced as a consequence of incomplete combustion, but largely controlled by catalysts on petrol vehicles. Tighter regulations on hydrocarbon emissions from petrol and diesel vehicles have led to reductions in CH₄ emissions with the introduction of successive Euro standards.

Table 3.13 summarises the N₂O and CH₄ implied emission factors for each vehicle type in mg/km. 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 3.13 N₂O and CH₄ Implied Emission Factors for Road Transport (in mg/km)^a

Pollutant	Source	1990	2000	2005	2010	2015	2016	2017
CH ₄	Petrol cars	108.4	53.2	31.9	17.8	13.0	12.3	11.9
	DERV cars	16.4	7.5	2.7	0.9	0.3	0.2	0.2
	LGVs	76.8	24.8	7.4	2.5	0.8	0.7	0.5
	HGVs	73.4	64.2	63.1	36.6	12.1	9.5	7.7
	Buses and coaches	127.2	108.4	90.3	50.4	21.4	15.5	12.1
	Mopeds and motorcycles	201.3	187.2	152.5	109.8	82.1	76.5	71.0
N ₂ O	Petrol cars	8.0	11.0	7.2	2.8	1.5	1.4	1.3
	DERV cars	-	3.7	5.7	6.3	6.2	6.1	6.1
	LGVs	5.2	4.9	5.9	6.2	6.2	6.1	6.0
	HGVs	30.0	13.4	8.1	17.2	37.6	40.1	42.4
	Buses and coaches	30.0	15.4	8.8	13.7	25.5	28.5	30.7
	Mopeds and motorcycles	1.9	1.9	1.9	1.9	2.0	2.0	2.0

^a Includes cold start emissions.

Using the CH₄ and N₂O emissions and fuel consumption calculated from the traffic data, it is possible to derive implied fuel-based emission factors of CH₄ and N₂O (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.

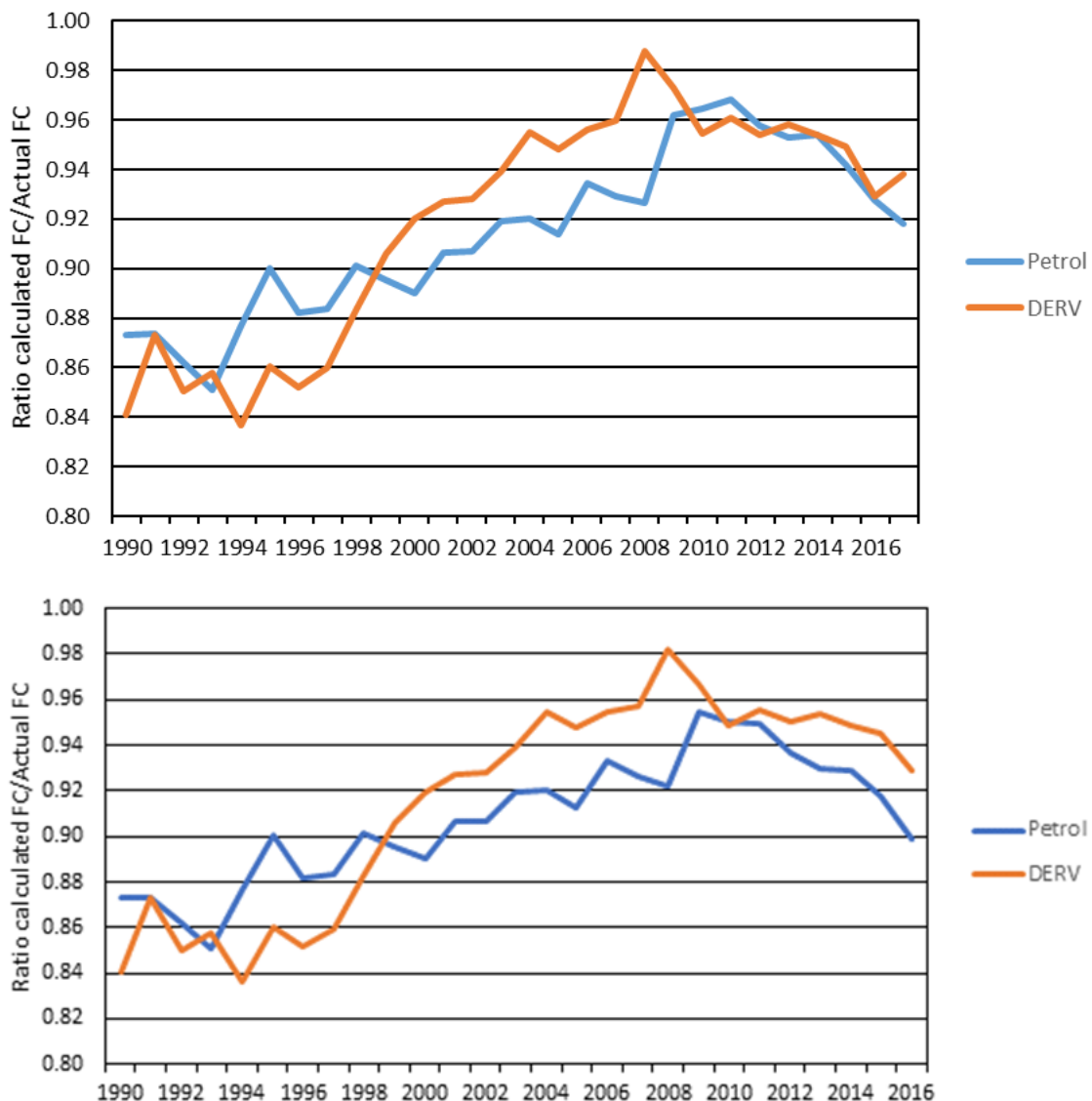
Figure 3.2 shows the ratio of model calculated fuel consumption (corrected for biofuel consumption) to the figures in DUKES based on total fuel sales of petrol and diesel in the UK, allowing for off-road consumption. In all years, the bottom-up method tends to underestimate fuel consumption. The maximum 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 2017, the bottom-up method underestimates petrol and diesel consumption by 8% and 6%, 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 CO₂ emissions for each vehicle type. For CH₄ and N₂O, the year-dependent 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-CO₂ 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.

Emission factors for CH₄ and N₂O 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_2019.xlsx*”.

Consumption of LPG is relatively small in the UK (0.2% of all road fuels in 2017) 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 2017.

Assuming all the LPG consumed in the UK is by Light Goods Vehicles, the amount of LPG consumed was used to estimate the number of vehicle km travelled by LGVs using LPG. Emissions of CH₄ and N₂O from consumption of LPG were then calculated from the vehicle km data and emission factors (expressed as g of pollutant per km) available from the EMEP/EEA Emissions Inventory Guidebook (2016) covering all types of light duty vehicles. Further details are given in Brown et al (2018).

Emission from lubricants

Lubricant consumption by the unintended combustion in vehicle engines is estimated using the method from the EMEP/EEA Emissions Inventory Guidebook (2016). These consumption estimates were used to calculate CO₂ emissions from lubricant combustion in road vehicle engines and are reported in IPCC sector 2D1 (**Section 4.22**) except for lubricants use by 2-stroke mopeds, which is deemed to be intentional fuel use and hence reported in IPCC sector 1A3biv.

Emissions of CH₄ and N₂O 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 CH₄ and N₂O (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 and used to disaggregate the fuel consumption data. More detailed fleet composition data for the UK were used to further 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 detailed road transport inventory methodology report by Brown et al (2018).

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 CO₂, 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 CH₄ and N₂O 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 CH₄ and N₂O 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. From 2009, a change in the repair rate is taken into account for Euro 3 and above petrol LDVs assuming all failed vehicles are rectified properly due to the introduction of EU Regulations Controlling Sale and Installation of Replacement Catalytic Converters. Further details are given in Brown et al (2018).

Other key assumptions that affect CH₄ and N₂O 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. However, several smaller re-calculations have occurred for the following reasons:

- After consultation with Working Group 1, estimates of the fossil-carbon content of biofuels, such as FAME and bio-MTBE, are now included in the emissions inventory.
- Revised vehicle km data provided by DfT for 2016.
- Updated ANPR data and assumption for the introduction year of Euro 4 petrol cars.
- Revised CH₄ EFs for LPG vehicles, and Euro 5 & 6 diesel cars/LGVs from the latest EMEP/EEA Emissions Inventory Guidebook (2016), as published in July 2018.

Improvements (completed and planned)

No specific improvements are currently 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 1.6**.

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. 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 CH₄ and N₂O. 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 CO₂ emissions between vehicle types.

There are greater uncertainties in the emission factors for CH₄ and N₂O 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 CH₄ and N₂O inventories are in the division of diesel fuel consumption between vehicle types and the uncertainty in the fuel consumption factors that determine how much CH₄ and N₂O emissions are scaled to be consistent with national fuel consumption. There are

also uncertainties affecting the emission estimates for CH₄ and N₂O 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

CO₂, CH₄, N₂O

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_2019.xlsx" lists all emission factors used in the energy sector, including a full list of references³⁷. **Table 1.6** 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 for 2005-2017 and are believed to be due to consumption by heritage trains. No coal use is allocated to railways in DUKES for earlier years, it is assumed that this is included within other reporting categories. 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, which provides data on the tonne kilometres travelled. An assumption is then made that the ratio between the tonne kilometres and freight train kilometres is the same as it was in 2004 for all years.

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 2011-2016. No data is available for the years 1970-2004 and 2010 and data for 2017 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 fleet for other years is estimated based on the year of introduction of new engines.
- For freight trains:
The breakdown by locomotive class was obtained from the Department for Transport's Rail Emissions Model of 2009. The fleet for other years is estimated based on the year of introduction of new engines.

The emission factor for SO₂ 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

In recent years passenger train kilometres have steadily increased until a small decline in 2016 and 2017. This trend is generally reflected in the passenger train fuel consumption data. The amount of freight moved has declined steadily since 2013 as a result of a substantial decline in the amount of coal hauled. The amount of freight moved in 2017 is around 76% of the amount estimated for 2013. However, fuel consumption has not reduced accordingly due to an increase in container traffic. Freight fuel consumption in 2017 is 90% of the 2013 fuel consumption.

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

Recalculations

Fuel consumption for 2016 was updated to reflect finalised ORR data. The fuel consumption for freight trains in 2016 was lower than estimated in the previous submission leading to higher aggregated implied emission factors for freight trains for this year in the case of CH₄ and other pollutants where emissions are derived from train km data. For passenger trains the reverse is true in that the fuel consumption is higher than estimated in the previous submission leading to lower aggregated implied emission factors.

Improvements (completed and planned)

A watching brief is kept on developments in emission factors and activity data for all modes of transport, especially those that may arise from stakeholder initiatives and which can be reasonably incorporated in the inventory.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**.

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 2017. 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 National navigation and fishing**Relevant Categories, source names**

1A3d: Shipping – coastal

1A4ciii: Fishing vessels

Relevant Gases

CO₂, CH₄, N₂O

Relevant fuels, activities

Gas oil, fuel oil

Background

This MS includes emissions from UK domestic and crown dependency coastal shipping and fishing, including fishing outside UK territorial waters. Emissions from inland waterways are

covered in MS 12, and shipping between the UK and OTs (classified as domestic) are described in MS 11.

Key Data sources

Activity: UK Maritime and Coastguard Agency, DfT Maritime Statistics (2018c), MMO Fishing statistics (MMO, 2017), DUKES (BEIS 2018a), Scarbrough et al. (2017).

Emission factors: IMO (2015).

*An accompanying spreadsheet “Energy_background_data_uk_2019.xlsx” lists all emission factors used in the energy sector, including a full list of references³⁷. **Table 1.6** gives additional information for common activity data sources.*

Method approach

The shipping emissions model applied uses 2014 high resolution terrestrial Automatic Identification System (AIS) vessel movement data supplied by the UK Maritime and Coastguard Agency. This methodology meets and exceeds the requirements of a Tier 3 methodology set out in the EMEP EEA Emissions Inventory Guidebook 2016 and the requirements for reporting national greenhouse gas emissions to the UNFCCC under the 2006 IPCC Guidelines. The new methodology carries out an emission calculation specific to each vessel and for each point of the vessel's voyage around the UK coast that is tracked with AIS receivers on the UK shore.

The receivers capture a number of smaller vessels and voyages such as movements to and from off-shore oil and gas rigs, and journeys to/from crown dependencies. The approach also uses a detailed set of port statistics for different vessel categories as proxies for estimating activities in years back to 1990 and forward to 2017 from the 2014 base year.

A significant step in the process is identifying whether a vessel movement is a UK domestic movement, and reported under 1A3dii, or part of an international voyage calling in the UK reported as a Memo item under 1A3di.

Details of the methodology are given in the report by Scarbrough et al (2017) and only a summary is given here.

a) Activity data for 2014

The model methodology estimates the Heavy Fuel Oil (HFO) and Marine Diesel Oil (MDO) fuel consumption for each AIS position message down-sampled to 5-minute temporal resolution. The calculation takes into account where available the individual vessel characteristics of main engine power, engine speed and load, and makes bottom-up assumptions for auxiliary engines. The fuel and emissions are estimated for each AIS message to cover the time period until the next AIS message, which is often 5 minutes, but in cases where the vessel travels at or outside the range of the terrestrial AIS receivers, may be longer or much longer. Many assumptions for the modelling have been drawn from the International Maritime Organization's (IMO) Third Greenhouse Gas Study (IMO, 2015).

The emissions are calculated separately for each vessel and for each AIS data point assuming that the vessel continues to combust fuel and emit pollution at the same rate until the subsequent AIS message. The fuel consumption and emission factors are tailored to the specific vessel that is identified in the AIS dataset. The factors account for:

- The fuel type assumed to be used by the vessel, the known engine type and engine speed (rpm).

- The rated power of the engines, which are either known from a third party vessel characteristics database, or estimated based on other known or reported vessel characteristics (e.g. vessel length).
- The actual power demands on the main engines for each AIS message, expressed as a function of reported and designed vessel speed, and reported and designed vessel draught.
- The location and type of the vessel, i.e. whether the vessel is in a Sulphur Emission Control Area (SECA), whether the vessel is at berth, and whether the vessel is a passenger vessel.

In those cases where part of a voyage is not captured within the range of the terrestrial AIS dataset (defined as a gap in AIS coverage of 24 hours), allocation assumptions have been based on vessel type. Specifically, if cargo or passenger vessel journeys had a gap between AIS messages of greater than 24 hours, these vessels were assumed to have been on UK international voyages if they had started or finished at a UK port. For the remaining vessel types, which includes offshore industry vessels, fishing fleets and service vessels, voyages were assumed to be UK domestic if the AIS dataset showed the vessel had started and finished at a UK port, regardless of the length of time of any gaps in AIS coverage.

The detailed Tier 3 approach used in Scarbrough et al. (2017) is able to distinguish fuel consumption and emissions between domestic movements from one UK port to another and UK international movements between a UK port and a port overseas. This enables the correct activities and emissions to be allocated to the NFR14 category 1A3dii Domestic Water-borne Navigation.

The Scarbrough et al. (2017) inventory excluded emissions and fuel consumption from military vessel movements which are not captured in the AIS movements database. Naval shipping emissions are reported separately using fuel consumption data supplied by the Ministry of Defence (MoD). Emissions from these vessels are covered in **MS 14**.

The Scarbrough et al. (2017) study did not cover small tugs and service craft used in estuaries, private leisure craft and vessels used in UK rivers, lakes and canals as these were not captured in the AIS data. These were captured in the estimates for inland waterways described in **MS 12**.

Commercial fishing vessels were captured by AIS data, including those that eventually leave the UK to fish in overseas waters, before returning later so emissions could be calculated in the same way as for other domestic navigation and reported separately under 1A4ciii. Although these fishing vessels go out of range of UK shore-based terrestrial AIS data capture, the time period between successive AIS messages from these vessels is known corresponding to the times when the vessels first go out of range on route to their fishing destination to the point when they return.

b) Time-series trends in activity data

The approach to estimate emissions for historical years before 2014 and years after 2014 uses DfT port statistics as proxies for activity levels.. This is detailed further in section 3 of Scarbrough et al. (2017).

Overall, there are 15 vessel categories that are each mapped to a DfT port statistic. This includes separating cargo or freight commodity types. The statistical time-series cover all years back from 2014 to 1990 and forward to the most recent year of statistics (currently 2017). In many cases, multiple statistical series need to be used if no complete series is available to cover the entire period to 1990. The specific statistical series used for each vessel category is indicated in Table 3.14. The main DfT statistics used are (DfT, 2018c):

- PORT0102 UK major and minor port freight traffic, international and domestic by direction, annually: 1965 - 2017
- PORT0201 Domestic UK major port freight traffic by cargo type and direction, annually: 2000 – 2017
- PORT0202 UK major and minor ports main freight units, by route, annually: 1970 - 2017

Table 3.14 Summary of activity indices

Vessel category	Activity index used	Separate domestic index?
Bulk carrier	2000-2017: Table PORT0201 – 'All dry bulk traffic' [Note 1]	✓
Chemical tanker	2000-2017: Table PORT0201 – 'Other liquid bulk products' [Note 1]	✓
Container	2000-2017: Table PORT0201 – 'All container traffic' [Note 1]	✓
General cargo	2000-2017: Table PORT0201 – 'All other general cargo traffic' [Note 1]	✓
Liquefied gas tanker	2000-2017: Table PORT0201 – 'liquefied gas' [Note 1]	✓
Oil tanker	2000-2017: Table PORT0201 – 'total of Crude Oil and Oil Products' [Note 1]	✓
Ferry-pax only	2003-2017: UK domestic sea passenger movements by type of route – Table SPAS0201. <i>Pre-2003 trend uses the approach described in Entec (2010).</i>	✓
Cruise	<i>Same approach as used for the Ferry-pax only vessel category</i>	✓
Refrigerated bulk	2000-2017: Table PORT0201 – 'Other dry bulk' [Note 1]	✓
Ro-Ro	2000-2017: Table PORT0201 – 'Roll-on/roll-off traffic' [Note 1]	✓
Service - tug	2000-2017: Table PORT0201 – 'total domestic traffic' [Note 1]	✓
Miscellaneous - fishing	2010-2017: MMO UK Sea Fisheries Annual Statistics – Chapter 3 Landings. <i>Pre-2010 trend uses the approach described in Entec (2010).</i>	No
Offshore	Gross UK Oil and NGL Production in kt (DUKES table 3.1.1 Crude oil and petroleum products: production, imports and exports; Indigenous production of crude oil)	No
Service – other	2000-2017: Table PORT0201 – 'total domestic traffic' [Note 1]	✓
Miscellaneous - other	2000-2017: Table PORT0201 – 'total domestic traffic' [Note 1]	✓

Note 1 – pre-2000 trend uses the approach described in Entec (2010). Table PORT0201 was previously called PORT0107.

The model assumes that there is a fuel switch from HFO to MDO as a result of the tightening in 2015 of the SECA fuel sulphur limit from 0.5% to 0.1%. This assumption is made on the basis of evidence that low sulphur heavy fuel oil was available to comply with the SECA fuel sulphur limits of 1.5% to 2010 and 1% from 2010 (IMO, 2010).

The requirement that vessels at berth from 2010 use fuel which complies with a sulphur limit of 0.1% implies the need for MDO. Therefore, in the backcasted inventory prior to 2010, any

vessels that would have used HFO, save for the at berth requirement of 0.1% S fuel, are assumed prior to 2010 to use HFO.

c) Emission factors

The source of the raw emission factors used for CO₂, CH₄ and N₂O is given in section 2.2.8 of Scarbrough et al. (2017). Fuel-based emission factors in kg/tonne fuel are used and may differ by engine type and/or fuel type.

The fuel-based CO₂ emissions factors for main and auxiliary engines are the same as assumed in IMO (2015) and are based on MEPC 63/23, Annex 8:

- HFO: 3,114 kg CO₂/tonne fuel
- MDO: 3,206 kg CO₂/ tonne fuel

Methane emission factors for diesel-fuelled engines, steam boilers and gas turbines are the same as used in IMO (2015). These are derived from IVL (2004) which states that CH₄ emissions are approximately 2% the magnitude of NMVOCs. Therefore, the CH₄ factors are derived by multiplying the NMVOC factors by 2%. Values of methane emission factors are 0.04-0.06 kg/tonne fuel depending on engine type.

The N₂O emission factors are taken from IMO (2015). N₂O emission factors are unaffected by fuel sulphur content but do differ slightly between HFO and MDO. Values for HFO are 0.16 kg/tonne fuel and are 6% less for MDO.

Emission factors for other pollutants are given in section 2.2.8 of Scarbrough et al. (2017). These emission factors also derive from IMO (2015).

Emission factors remain constant over the time-series. However, vessels using HFO in a SECA are assumed to switch to using MDO from 2015 onwards, with an SO₂ emission factor reduction of 90% (from 1% S HFO to 0.1% MDO) accordingly.

Fuel consumption is calculated for each vessel based on the characteristics of the vessel, engine type, movement and draught for the 2014 activity dataset received.

It is expected that shipping transport efficiency increases over time in response to financial and regulatory drivers. For all vessels it is assumed that the efficiency of sea transport improves by 1% per year from 2014 onwards to account for lower fuel consumption per unit (tonne or container or passenger) transported and more fuel efficient new vessels compared to old vessels

$$\text{i.e. Efficiency index}_y = 0.99^{(y-2014)}$$

Further details on how this value was derived are given in section 3.2.3. of Scarbrough et al. (2017). The current inventory therefore implies a small improvement in the fuel efficiency of the fleet from the 2014 base to 2017.

Assumptions & observations

The coverage of vessels captured by the AIS receivers is considered complete for this sector. Small vessels which do not have AIS transmitters, such as small recreational craft and service vessels, are captured in the inventory for inland waterways. The main assumption concerns the allocation of a vessel movement to UK domestic or international for a cargo or passenger vessel starting or finishing at a UK port when it goes out of AIS signal range, based on the gap between AIS messages being greater or less than 24 hours.

Recalculations

The only significant recalculation in this sector affects fishing vessels, as a result of using updated UK Sea Fisheries Annual Statistics data. This leads to small changes in most years, however an 8% uplift in the activity for 2016. Minor changes in the DfT port statistics used as

timeseries proxies also result in minor revisions in the average emission factors for this sector. These changes in emission factors are all less than 0.3% different to those used in the previous submission.

Improvements (completed and planned)

A major methodology change was undertaken for the 2018 submission based on detailed AIS vessel movement data, updated DfT port statistics and updated emission factors. This major change in methodology took two years to develop and introduce to the UK inventory. As a result, no further major method changes are anticipated in the near future. A watching brief is being kept on the assumptions made around fuel consumption for vessels at berth.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. The new approach that has been adopted is described in detail in Scarbrough et al (2017) and has been peer-reviewed by BEIS, Defra, DfT as well as presented to experts in the maritime industry. Scarbrough et al (2017) also reports on validation with other estimates of shipping emissions given in the literature covering the same geographical area of the North Sea and English Channel.

Time-series consistency

The time-series for national navigation and fishing 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 for different vessel types..

The approach assumes that a switch from HFO to MDO occurs as a result of the tightening in 2015 of the North Sea and English Channel SECA fuel sulphur limit from 0.5% to 0.1%.

This break in the time-series is not considered to be a time-series consistency issue.

Uncertainties

The uncertainty analysis is set out in **Annex 2**. The uncertainty in the bottom up calculated estimates of fuel consumption in 2014 is considered to be less than the allocation of fuel to national navigation provided in DUKES and more representative of UK domestic shipping activities as defined in the IPCC 2006 Guidelines.

Further consideration of uncertainties in the approach is given in Scarbrough et al (2017), particularly with respect to the allocation of a vessel movement to domestic or international when the vessel goes out of AIS range. However, overall, the emission calculations are estimated to have relatively low uncertainty for most large vessels which are responsible for 85% of total emissions. Scarbrough et al (2017) also report that the model estimates compare well with those from other European shipping inventories when comparisons are made on a like-for-like basis.

Additional uncertainty is introduced through the use of proxy statistics to develop the time-series. The uncertainty in the carbon emission factor is considered low, whereas the uncertainties for non-CO₂ 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

CO₂, CH₄, N₂O

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 new methodology for domestic shipping developed by Scarbrough et al (2017) (described in **MS 10**) 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 2016

Emission factors: Scarbrough et al. (2017) and based on IMO (2015)

*An accompanying spreadsheet “Energy_background_data_uk_2019.xlsx” lists all emission factors used in the energy sector, including a full list of references³⁷. **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, 2018d) 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 the EMEP Emissions Inventory Guidebook 2016 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 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 2013-2017 (DfT, 2018a). Detailed movement data were held by the port authority of Gibraltar listing all voyages departing to or arriving from the UK from 2003 to 2012⁴⁰. 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.

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

All fuel used for voyages between the UK and OTs is assumed to be fuel oil. The emission factors used are average factors implied by Scarbrough et al. (2017) for all vessels involved in international voyages from or to a UK port from/to a non-UK destination.

Assumptions & observations

All fuel used for voyages between the UK and OTs is assumed to be fuel oil as it is cheaper to run and so will be the preferred choice where vessels don't need to use gas oil to meet emission limits within Sulphur Emission Control Areas. Also, only the larger ships will tend to do these long-distance journeys, and these larger ships use fuel oil as it is a heavier fuel and a larger engine is required to use it efficiently. Emission factors are assumed to be the average of all vessels involved in UK international voyages.

Data provided by various data sources are assumed to be complete.

Recalculations

There have been minor recalculations to the emission factors. This is due to revised vessel type splits as a result of updated DfT port activity data. Fuel consumption is up 12% from OTs to UK due to updated DfT activity data.

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.

⁴⁰ <http://www.gibraltarport.com/cruise/schedules>

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. 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.

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

CO₂, CH₄, N₂O

Relevant fuels, activities

DERV, Gas oil, Petrol

Background

The category 1A3dii Waterborne Navigation includes emissions from fuel used for small 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, Visit England, OECD Stat, DfT Maritime Statistics (elaborated under Method approach, below).

Emission factors: EMEP/EEA 2016, IMO 2015

*An accompanying spreadsheet "Energy_background_data_uk_2019.xlsx" lists all emission factors used in the energy sector, including a full list of references³⁷. **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 an approach consistent with the 2016 EMEP/EEA Emissions Inventory Guidebooks (EMEP, 2016).

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 2017, Full Report: <https://www.visitbritain.org/annual-survey-visits-visitor-attractions-latest-results> : "Total England Attractions"
- 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 three 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 CH₄ were taken from the EMEP/EEA 2009. Emission factors for carbon are from Baggott et al, 2004. For N₂O, the emission factor for fuel oil is taken from EMEP/EEA 2009. For N₂O from diesel and gas oil, the emission factor used is 0.15 g /kg fuel, consistent with the emission factor used in MS 10 (from IMO, 2015).

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.

Walker et al. (2011) and Murrells et al. (2011) had previously drawn 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. This potential overlap was reconsidered in light of the methodology for domestic shipping (Scarborough et al (2017).) since certain types of vessels operating at sea close to shore that were previously included in the inland waterways sector of the inventory were now captured in the AIS data. Hence their emissions are included under coastal shipping described above and by Scarborough et al (2017). These vessels were considered to be passenger vessels with >12 passengers and 3 or more engines operating in estuaries, tugs, cranes, and chartered and commercial fishing vessels. To avoid a double count, the activities for these vessels were therefore removed from the inland waterways database.

Recalculations

The main recalculation is to the N₂O emission factor used for diesel and gas oil. This has been revised up from 0.08 g/kg fuel to 0.15 g/kg fuel (88% increase) to be consistent with the emission factor used in MS 10.

New data on the freight sub-category from DWF0101 leads to a 5% reduction in the activity for this class of vessels in 2016. There are also minor (<1%) revisions to the activity for private leisure craft going back to 2010, due to updated OECD data.

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 1.6**.

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 inland waterways activities 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 small coastal shipping and inland waterways.

MS 13 International shipping

Relevant Categories, source names

Marine bunkers: Shipping - international IPCC definition

Relevant Gases

CO₂, CH₄, N₂O

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, 2018);

Emission factors: Scarbrough et al. (2017) and based on IMO (2015)

*An accompanying spreadsheet "Energy_background_data_uk_2019.xlsx" lists all emission factors used in the energy sector, including a full list of references³⁷. **Table 1.6** gives additional information for common activity data sources.*

Method approach**Activity data**

Fuel consumption for international shipping is taken directly from DUKES figures for international marine fuel bunkers, as discussions with BEIS indicate that there is higher confidence in the DUKES estimates of the international 'marine bunkers' fuel sales data than the portion allocated to national navigation. As such, the marine bunkers fuel statistics in DUKES are used without further adjustment as the activity data for emissions from the international navigation Memo item under 1A3di.

The consequence of having emissions for national navigation and inland waterways (1A3dii), fishing (1A4ciii) and naval (1A5b) based on a bottom-up method derived from vessel activity and of having emissions for international navigation (1A3di) based on DUKES data for international bunkers is that the total marine fuel consumption exceeds that given in DUKES for national navigation plus marine bunkers. In some years, the fuel consumption for national navigation and inland waterways (1A3dii), fishing (1A4ciii) and naval (1A5b) alone exceeds the total given in DUKES for national navigation plus marine bunkers.

Notwithstanding uncertainties in the modelling approach which were discussed by Scarbrough et al (2017), one possible reason for this difference is that a significant proportion of domestic voyages in the UK are taken by vessels that fuelled overseas. This amount of "fuel tankering" is not known. However, given the high uncertainty in the DUKES figure on fuel used for national navigation and for consistency with the IPCC 2016 Guidelines definition of domestic shipping, the UK prefers to use the higher bottom-up estimates for the domestic sources to be included in the national totals, particularly as they are based directly on vessel activities.

Emission factors

Emissions for international shipping (1A3di) were calculated by multiplying the fuel consumption calculated above with an implied emission factor for international vessel movements. The emission factors used are average factors implied by Scarbrough et al. (2017) for all vessels involved in international voyages from or to a UK port to/from a non-UK destination. The source of these factors is as described in MS 10 for national navigation and is derived from IMO (2015).

Assumptions & observations

The activity data for the International navigation Memo item 1A3di in this inventory is based solely on figures in DUKES for international fuel bunkers. It reflects emissions from UK international marine fuel sales whereas the emissions for national navigation and inland waterways (1A3dii) and fishing (1A4ciii) reflect the amount of fuel used for domestic navigation purposes.

The main observation is that with international shipping fuel consumption and emissions being based on DUKES, and with fuel consumption and emissions for domestic marine activities being derived from vessel activities, the total marine fuel consumption implied by the inventory exceeds the amount available according to DUKES.

This aspect has been discussed with the UK national energy statistics team at BEIS.

The shipping methodology described above and in MS 10 leads to a different fuel use allocation for national navigation marine fuels compared with the allocations in the national energy statistics (DUKES) and submissions to IEA/EUROSTAT.

Recalculations

There are no recalculations in the activity data for this MS. There are only minor (<0.2%) recalculations to emission factors due to updated DfT port statistics used to derive the time-series.

Table 3.15 summarises the time-series in gas oil and fuel oil consumption for domestic coastal and military shipping, fishing, inland waterways, international shipping and voyages from the UK to the OTs since 1990 based on the new approach for all these marine activities. Fuel consumed in the OTs and for voyages from the OTs to the UK are not included in this table.

Table 3.15 Fuel consumption (Mtonnes) for UK marine derived from inventory method

Mtonnes fuel	Gas oil				Fuel oil			
	Domestic coastal and military	Fishing	Inland waterways	International bunkers	Domestic coastal and military	Fishing	Voyages from UK to OTs	International bunkers
1990	1.89	0.23	0.03	1.14	0.82	0.82	0.008	1.39
1991	1.89	0.23	0.03	1.19	0.80	0.80	0.008	1.28
1992	1.86	0.24	0.03	1.24	0.78	0.78	0.008	1.30
1993	1.84	0.25	0.03	1.16	0.77	0.77	0.008	1.31
1994	2.06	0.25	0.04	1.20	0.84	0.84	0.009	1.11
1995	2.13	0.26	0.04	1.11	0.89	0.89	0.009	1.35
1996	2.14	0.24	0.04	1.20	0.90	0.90	0.009	1.45
1997	2.12	0.21	0.03	1.16	0.86	0.86	0.010	1.80
1998	2.06	0.20	0.03	1.40	0.88	0.88	0.010	1.67
1999	2.12	0.19	0.03	1.15	0.89	0.89	0.011	1.17
2000	1.96	0.18	0.03	1.14	0.80	0.80	0.011	0.93
2001	1.84	0.18	0.03	1.43	0.76	0.76	0.011	0.83
2002	1.83	0.18	0.03	1.14	0.79	0.79	0.008	0.76
2003	1.76	0.19	0.04	0.90	0.75	0.75	0.009	0.86
2004	1.73	0.19	0.03	1.07	0.75	0.75	0.010	1.00
2005	1.64	0.19	0.04	0.89	0.78	0.78	0.009	1.16
2006	1.53	0.18	0.04	1.04	0.72	0.72	0.013	1.30
2007	1.54	0.18	0.04	0.90	0.74	0.74	0.019	1.45
2008	1.47	0.18	0.04	1.03	0.70	0.70	0.011	2.44

	Gas oil				Fuel oil			
Mtonnes fuel	Domestic coastal and military	Fishing	Inland waterways	International bunkers	Domestic coastal and military	Fishing	Voyages from UK to OTs	International bunkers
2009	1.43	0.16	0.04	1.05	0.66	0.66	0.009	2.25
2010	1.41	0.17	0.04	0.96	0.57	0.57	0.011	1.83
2011	1.29	0.16	0.04	0.99	0.56	0.56	0.011	2.13
2012	1.15	0.16	0.04	1.12	0.52	0.52	0.009	1.53
2013	1.06	0.15	0.05	1.34	0.47	0.47	0.008	1.37
2014	1.04	0.17	0.05	1.68	0.49	0.49	0.010	1.14
2015	1.41	0.16	0.05	1.67	0.18	0.18	0.009	0.83
2016	1.38	0.17	0.05	1.77	0.17	0.17	0.010	0.88
2017	1.34	0.17	0.05	1.65	0.17	0.17	0.011	0.77

Improvements (completed and planned)

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 1.6**.

Time-series consistency

Time-series consistency is ensured by using fuel consumption data for international fuel bunkers taken directly from the latest version of DUKES in all years. Fluctuations reflect any fluctuations in the bunker fuel figures in DUKES.

Uncertainties

The uncertainty analysis is set out in **Annex 2**. Uncertainty for international bunkers is not estimated.

MS 14 Naval shipping**Relevant Categories, source names**

1A5b: Shipping - naval

Relevant Gases

CO₂, CH₄, N₂O

Relevant fuels, activities

Gas oil

Background

Emissions from military shipping are reported separately under IPCC code 1A5b.

Key Data sources

Activity: MoD, 2018

Emission factors: Scarbrough et al. (2017) and based on IMO (2015)

*An accompanying spreadsheet “Energy_background_data_uk_2019.xlsx” lists all emission factors used in the energy sector, including a full list of references³⁷. **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 team of the MoD (MoD, 2018). Data are provided on a financial year basis and are amended to derive figures on a calendar year basis.

Implied emission factors derived for international shipping vessels running on marine distillate oil (MDO) from Scarbrough et al. (2017) were assumed to apply for military shipping vessels.

Assumptions & observations

It is assumed that emission factors for international shipping vessels apply to military vessels.

Recalculations

There are no changes to the activity data. There are only minor (<0.2%) recalculations to emission factors due to updated DfT port statistics used to derive the time-series.

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 1.6**.

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 directly from the MoD. The carbon factors of fuel used by naval vessels would be known with low uncertainty, but default factors for CH₄ and N₂O taken from international shipping vessels and their relevance to naval vessel engines are much more uncertain.

MS 15 Military aircraft

Relevant Categories, source names

1A5b: Aircraft - military

Relevant Gases

CO₂, CH₄, N₂O

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, 2015, 2017

Emission factors: Baggott et al., 2004, EMEP/EEA 1999, IPCC, 1997.

An accompanying spreadsheet “Energy_background_data_uk_2019.xlsx” lists all emission factors used in the energy sector, including a full list of references²⁴. 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, 2017) 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. An earlier data set (MoD, 2015) also includes fuel shipped to overseas garrisons and casual uplift at civilian airports; these data have been extrapolated assuming constant consumption at the level the latest data indicates to generate a complete time-series.

Assumptions & observations

Most 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, 2017) 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 1.6.

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-CO₂ gases are reliant on defaults, which can lead to higher uncertainties.

MS 16 Coal mining and handling**Relevant Categories, source names**

1B1a1i: Deep-mined coal

1B1a1ii: Coal storage and transport

1B1a2i: Open-cast coal

Relevant GasesCH₄**Relevant fuels, activities**

Coal produced

Background

In 2017 there were only 3 small deep-mining collieries operational in the UK. The UK coal industry has been in decline for many years and during 2015 the last large deep coal mines closed, and this is reflected in the 99% reduction in UK coal production from 2015 to 2017, according to UK energy statistics (BEIS, 2018). None of the remaining 3 mines are large enough to warrant investment in methane drainage and recovery systems used to collect and burn mine gas to raise power; until 2015 there were still operational deep mines in the UK that did capture and utilise methane. A further 17 open cast coal mines were also operating in the UK in 2017. This is compared with 188 deep mining collieries and 126 open cast mines operating in 1990⁴¹.

Key Data sources

Activity Data: All activity data on coal production at open cast and deep mines is from DUKES (BEIS, 2018), 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 available for many years of the inventory time series (1998-2014), and are used to derive CS EFs (UK Coal, 2015; Coal Authority, 2015), in conjunction with UK energy statistics from DUKES (BEIS, 2018). However, due to the closure of all UK large deep mines there are no operator-reported emissions data for 2015, 2016 and 2017. Up to and including 2014, many UK deep mines were operating and, for a high proportion of those deep mines, data are available at the mine-specific level on coal production, methane drainage, methane used in gas engines and methane emitted to atmosphere. From these data, mine-specific methane emission factors are derived for (i) total methane released from the mining activity (i.e. including the methane that is available for use in gas engines), and (ii) the total methane emitted to atmosphere (i.e. after having subtracted the amount of methane used in gas engines). In deriving inventory estimates for 2015, the mine-specific emission factors from 2014 (UK Coal, 2015) were applied to 2015 data

⁴¹

http://webarchive.nationalarchives.gov.uk/20140721140515/http://coal.decc.gov.uk/assets/coal/DyGgJafg_pdf_part.pdf

on mine-specific production (Coal Authority, 2016), taking account of where those deep mines were still utilising methane in engines. For 2016 onwards, with UK deep-mined coal production only at a handful of small mines with no methane capture and utilisation, the inventory estimates are derived based on the UK weighted-average emission factor from 2014 (UK Coal, 2014) *excluding any mitigation of methane in gas engines*, applied to the 2016 and 2017 UK activity data on coal production in deep mines (BEIS, 2018). Methane EFs from mining operations from UK research are used to estimate emissions from open cast mines and licensed mines (both from Williams, 1993), and emissions from coal storage and transport (Bennett et al, 1995).

An accompanying spreadsheet “Energy_background_data_uk_2019.xlsx” lists all emission factors used in the energy sector, including a full list of references³⁷. 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, 2018). 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, 2018).

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 CH₄ per tonne coal extracted.

1990-1995 The methane emission factor of 1.36 kg CH₄/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, but following closures fell back to 78% in 2014 and no mine-specific data from operators are available for 2015, 2016 nor 2017.

In **2015**, only data on the production of coal at the UK's large deep mines was available (Coal Authority, 2016). In order to maintain time series consistency of the method, the inventory agency used the mine-specific production data from 2015 and applied the emission factors derived from the 2014 dataset for each of the large deep mines.

In **2016 and 2017**, all of the UK's deep mines were already closed leaving just a small number of small deep mines, and total UK coal production declined to its lowest level across the time series. Again to maintain time series consistency, the inventory agency applied the 2014 emission factor derived for all UK coal deep-mined extraction but *discounting any methane mitigation* as none of the remaining small mines have any systems to capture and use the eluted methane in gas engines. This is reflected in the increase in the IEF for 2016 and 2017 compared to recent years.

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:

$$\text{UK Emissions} = D + (E \cdot F)$$

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 CH₄ 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 CH₄ 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 CH₄ 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.
- Decline in emissions from deep-mined coal.** The 99% reduction in emissions reported in 1B1a1i, for 2015 to 2016 with very low activity also in 2017, is fully consistent with the almost complete closure of UK deep-mined coal production. The UK energy statistics publication, DUKES 2018, states on p39 that:

- *"Deep mined production fell to just 0.02 million tonnes in 2017. Following closure of the last three deep mines in 2015 (Hatfield, Thoresby and Kellingley), production remains a fraction of the values seen two years ago."*

Recalculations

Recalculations to the coal produced by open-cast mines in the DUKES publication (BEIS, 2018) are minor and affect 2016 estimates only.

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. As described in the methodology section above, for the last three years of reporting (2015 to 2017) the inventory agency has extrapolated the latest EFs from 2014 in order to maintain time series consistency of the method, in light of the decline in the industry and the cessation of any operator-reported data on methane elution, utilisation (in gas engines) and emissions to atmosphere.

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 now 100% in 2016 and 2017. Therefore the overall uncertainty of deep-mined coal methane emissions is higher for these years, but it is set against the context that deep mined coal emissions only account for less than 0.01% of total methane emissions in the UK in 2017, whilst open-cast coal mining only accounts for 0.06% of total UK methane emissions.

MS 17 Closed coal mines

Relevant Categories, source names

1B1a1iii: Closed Coal Mines

Relevant Gases

CH₄

Relevant fuels, activities

Modelled emissions

Background

Methane emissions from **closed coal mines** are accounted for within category 1B1a1iii 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. Note that all UK deep coal mines (other than 5 very small mines) were closed by the end of 2015 and the model was updated to reflect this for the 2017 submission, and therefore there has been no further update to the model in the 2019 submission. 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_2019.xlsx" lists all emission factors used in the energy sector, including a full list of references³⁷. **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.

Assumptions & observations

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 and industry information on the quantity of underlying methane gas and expected rates of flooding of each mine following closure. The 2017 emission estimates in this 2019 UK GHGI submission are therefore taken from the projections of emissions within the 2011 WSP report, with the emission profiles through time for all major UK deep mines recently closed (i.e. since the study in 2011) brought forward to the actual date of closure, as all such mines were closed by the end of 2015. Each large deep mine within the model had a profile of projected flooding and emissions of methane upon closure; the closure dates in the model have now been fixed to the actual dates rather than projected dates, and the emissions of methane following closure are therefore now occurring for every deep mine, and will diminish over time. Following the rapid decline of the UK deep-mined coal industry, this source is now the most significant emission source in 1B1, and accounts for 0.9% of total UK methane emissions in 2017.

The emissions from all abandoned mines are included within the 1B1a1iii source category. The emissions from the recently closed mines offset the declining trend from deep mines closed earlier in the time series, and this leads to an almost flat trajectory 2015-2017, and there will now be a continuing declining trend into the future.

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. All remaining large deep coal mines closed by the end of 2015, and the model was modified to reflect the closures in deriving estimates for the 2017 submission. No further modifications to the model were required for the 2019 submission.

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. However, as all large deep mines in the UK that contribute significantly to this emission source are now closed, the emissions trend is diminishing through time and in 2017 only accounts for 0.9% of the UK methane inventory total, this source is considered a low priority for future improvement work.

QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. 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 $\pm 17\%$ to $\pm 41\%$ 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 18 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

1B2b2: Upstream Gas Production – Natural gas production (*reported as IE*)

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

CO₂, CH₄, N₂O

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. The reported emissions from offshore well testing (1B2a1, 1B2b1) also include some emissions from fuel gas combustion, as well as fugitive 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, other than at the well testing phase in offshore production. 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**. However, the operator-reported emissions from offshore well testing comprise emissions from both combustion of fuel gas and fugitive releases; due to the limited data resolution in reported emissions, all of these well testing emissions are reported under 1B2a1 and 1B2b1. Emissions from leakage during gas transmission and distribution, and the point of use are included in **MS 19**.

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 CH₄ 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 CH₄ and VOC also occur from storage tanks at oil terminals.

Key Data sources

Activity data: EEMS (BEIS, 2018), DUKES (BEIS, 2018), IED/PRTR-reported data (EA, NRW and SEPA, 2018) EU ETS data (BEIS, 2018), UKOOA (2005), UKPIA (2018)

Emission factors: EEMS (BEIS, 2018), EU ETS (BEIS, 2018), UKOOA (2005)

*An accompanying spreadsheet "Energy_background_data_uk_2019.xlsx" lists all emission factors used in the energy sector, including a full list of references³⁷. **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. Note that in the UK there are different regulatory mechanisms that govern the activities of: (i) offshore oil & gas exploration and production, (ii) onshore conventional oil & gas exploration and production, and (iii) onshore unconventional shale gas exploration (there is no current production). These different regulatory systems define the data that is available for upstream oil and gas activities, which impacts on the best available method for each sector of the inventory; for example, the data available for offshore rigs is more detailed (source-specific) than for onshore terminals (where only some resolution of emissions by source is feasible).

It is important to note however that despite these different methods and data availability, the UK inventory agency does report in a **time series consistent** manner for each source, and that the UK inventory is **complete** for all emission sources, with two exceptions: (i) there are no data available currently to estimate emissions from oil & gas well blowouts, and (ii) there are no data available to enable the inventory agency to derive estimates for the ten onshore shale gas sites that have been spudded⁴² since 2010, with eight well completions. These issues are detailed 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 BEIS OPRD 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 **IED/PRTR 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 CO₂, CH₄ and N₂O;
- For 1995 to 2009, all terminals reported source-specific emission estimates to the **EEMS system**. For combustion and flaring sources, the EEMS dataset for this period includes mass-based activity data, and emission estimates for a suite of GHG and air quality pollutants including CO₂, CH₄ and N₂O. However, in 2010 it was agreed with the offshore regulator (then called DECC, now BEIS) that onshore terminals no longer had to report to EEMS, as it was a duplication of regulatory reporting, as onshore terminals are also regulated under the IED/PRTR regulatory system by the EA and SEPA. Since 2010 onshore terminals may report voluntarily to EEMS, but the reporting is incomplete across UK terminals. Therefore from 2010 onwards the EEMS dataset does not provide a comprehensive dataset from which to derive emission estimates for onshore terminals for the UK GHGI, and the IED/PRTR data are used in conjunction with EU ETS data in preference; **together these data provide a complete dataset**

⁴² Spudding is the initial process of beginning to drill a new well. A large drill bit is used to create a surface hole, which is subsequently lined (cement casing) to protect groundwater, prior to the next phase of drilling and well completion.

for emission sources on terminals and they provide source-specific detail for combustion and flaring sources;

- From 2005 onwards, **combustion CO₂** emissions from upstream oil and gas facilities (both offshore installations and onshore terminals) have been reported under **EU ETS**, and from 2008 onwards **combustion and flaring CO₂** emissions from upstream oil and gas facilities has been reported under EU ETS. The scope of source emissions under EU ETS for each installation is not as comprehensive as EEMS or IED/PRTR (e.g. EU ETS does not include emissions from fugitives or venting), but the data are useful to check carbon emission factors and to inform a de-minimis emission value for each site. The EU ETS data submissions by operators are also subject to third party verification as part of the requirements for the trading scheme, and therefore the EU ETS data are regarded as high quality data. 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 IED/PRTR. The EU ETS data provides emission estimates that can be broken down by fuel and between combustion and flaring sources, to augment the IED/PRTR 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 estimate emissions. The inventory agency continues to explore the possibility of accessing data from UK researchers, regulators and operators, and will continue to review published research and engage with oil & gas sector experts.
- All UK onshore oil and gas production to date is from conventional oil and gas wells. These installations are all regulated under the IED/PRTR by UK environmental regulators (EA, SEPA) and the operators report on annual methane emissions and these estimates are aggregated and included within the UK GHGI under 1B2a2. However, the inventory agency continues to investigate ways in which methane emissions from onshore shale gas exploration activities can be estimated; there are currently no estimates of emissions from this activity in the UK GHGI. To date there has been no production of natural gas from unconventional shale gas resources in the UK, however the inventory agency notes that since 2010 there have been ten shale

gas wells spudded in the UK, eight of which have been completed. None of these sites are actively producing gas as UK planning applications have yet to be passed on a site-by-site bases. Therefore none of the shale gas sites are yet under IED/PRTR regulation by the EA or SEPA, and there are no annual reported emission estimates by operators from their initial well spudding and completion activities. Also as there has been no production of natural gas at any of these sites, there is no activity data that the inventory agency can use to apply a Tier 1 factor as provided in Table 4.2.4 in section 4.2.2.3 of the Fugitives chapter of the IPCC 2006 Guidelines. Any fugitive emissions from these initial well spudding and completion activities are expected to be well below the threshold of significance for UK reporting for sources that are Not Estimated. We note that using the fugitive EF 0.0023 Gg CH₄ per million m³ gas produced, from Table 4.2.4 of the IPCC 2006 Guidelines (the upper value in the table, for onshore gas production) that for the source to exceed the 0.05% value of annual reported UK GHGI emissions from 2010 to 2016 would require an annual production each year of over 4,000 million m³ gas. Annual production each year at these well sites to date is zero.

A summary of how the data sources above are applied to the detailed categories and subcategories under 1B2 are presented in Table 3.16 below.

Table 3.16 Summary of Data Sources and Estimation methods for 1B2 source categories in the UK GHG Inventory

Categories and subcategories		Methodology
Onshore terminals, Offshore oil and gas platforms & Offshore floating production and storage vessels, well testing rigs	1B2a ⁱⁱ , 1B2b ⁱⁱ Oil, Gas Production: Upstream facility process and fugitive releases	1990-1997 (UKOOA 2005): 1998-Latest year from EEMS (BEIS, 2018): For onshore terminals and wells, missing sites from EEMS are estimated based on IED/PRTR-reported data (EA, NRW and SEPA, 2018).
	1B2a ⁱⁱⁱ Transport: Offshore loading of oil, 1B2a ^{vi} Other: Onshore loading of oil	1990-1997 (UKOOA 2005): 1998-Latest year from EEMS (BEIS, 2018): 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 IED/PRTR-reported data (EA, NRW and SEPA, 2018).
	1B2c ^{i,ii} Venting at upstream oil, gas facilities	1990-1997 (UKOOA 2005): 1998-Latest year from EEMS (BEIS, 2018): For onshore terminals and wells, missing sites from EEMS are estimated based on IED/PRTR-reported data (EA, NRW and SEPA, 2018).
	1B2c ^{i,ii} Flaring at upstream oil, gas facilities	1990-1996 (UKOOA 2005): 1997-Latest year from EEMS (BEIS, 2018): Assuming the same oil:gas split as in EEMS 1997, and aggregate oil and gas flaring volumes 1990-Latest year (BEIS, 2018). 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 IED/PRTR data are allocated to flaring.
	1B2a ⁱ , 1B2b ⁱ Oil, Gas Exploration: well testing	1990-1996 (UKOOA 2005): 1997-Latest year from EEMS (BEIS, 2018): AD estimated

Categories and subcategories		Methodology
		assuming CO ₂ IEF from 1998 is valid for earlier years.
Refineries	1B2aiv Refining / Storage: Petroleum processes, Oil Terminal storage	All years - Fugitive emissions from oil storage and refinery processes are derived from aggregate industry estimates provided by the refinery trade association (UKPIA, 2018). All flaring emissions from refineries are reported aggregated with combustion emissions, in 1A1b.

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 provided as emissions data without any underlying activity and emission factor information, and the UK inventory method is to aggregate those operator-reported data and conduct QC against other reported data to ensure completeness, the estimates for the early part of the time series are simply based on the oil:gas ratio (for each pollutant) from 1998.

The resolution of data by source type within the EEMS dataset is such that fugitive emission sources are typically reported aggregated for each installation, without any further information on the specific source/unit. Further, the emissions reported from gas terminals are aggregated across all sources under the IED/PRTR reporting system. These national circumstances of data availability mean that the UK inventory data cannot be disaggregated to separate fugitive emissions from gas processing units, from other fugitives, such as tie-ins to transmission systems, acid gas removal units, other connectors, flanges and pipeline infrastructure. Hence the emissions from all of these sources are reported together under 1B2biii, with the reporting of emissions from 1B2bii as “IE”. Through EU ETS reporting, emissions at terminals from combustion and flaring sources can be estimated separately.

In the 2017 EEMS dataset, following a change in the reporting system by the regulator, the reported emissions from well testing were noted to be a low outlier. Clarification was sought from the regulator, and the reported emissions were considered to be potentially incomplete. Therefore, the UK estimated emissions from well testing in 2017 are based on the 2016 well testing emission estimates scaled for the 2016-2017 trends in UK production of crude oil, condensate and natural gas, as reported in the UK energy statistics (BEIS, 2018). In the EEMS dataset there is no separate reporting of emissions from well drilling, completions and testing; it is assumed that any releases of gases at the sea bed during drilling or completions will dissolve in the water column, whereas any fugitive releases on the rigs are reported within EEMS. The inventory agency has consulted with the Co-ordinating Lead Author of the 2019 IPCC Refinement, Energy Fugitives, and national expert in oil and gas emissions inventory reporting, and confirmed that there are no default data to estimate well drilling and completion emissions in offshore production; therefore the UK inventory estimates are considered to be accurate as they are based on the best available operator-reported data, complete and consistent with the IPCC Guidelines.

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. New data have become available for emissions in 2016 from the newly-commissioned Shetland Gas Plant, and these data have been added to the UK inventory, leading to minor increases in emissions from process sources (1B2b3) and flaring (1B2c2ii); and updated 2016 data have been provided for the Frigg terminal, also leading to small increases in reported flaring emissions (1B2c2ii). Quantitative data are presented in **Section 10**.

Improvements (completed and planned)

Emission factors and activity data are kept under review. The inventory agency will maintain dialogue with regulators and industry experts in order to seek any new data on emissions from oil and gas well blowouts, and to follow-up on the reporting of well testing within the new EEMS system. The inventory agency will also maintain a watching brief on the development of the shale gas industry, in order to ensure that if the industry does start to produce gas in the UK, that the inventory agency will have access to information to allow emission estimates to be derived for future inventory submissions.

QA/QC

The EEMS dataset quality system is managed by the regulatory agency (BEIS OPRED) 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 IED/PRTR system is similar to EEMS, but regulated by the onshore environment agencies (EA, NRW, SEPA); it also has operator guidance on emission estimation and reporting, and a system of annual checks on data submitted by operators, by a Site Inspector / Process Engineer assigned by the regulator to manage the performance and compliance assessments for each installation. The data reported under IED/PRTR however are installation-wide, rather than source-specific.

The EU ETS dataset quality system is managed by the regulatory agency (BEIS OPRED). The monitoring and reporting system is consistent across the EU, with estimation methods that operators may use, defined within their permit. The data are third party verified and submitted to the regulator.

The Inventory Agency combines UK energy statistics, the EEMS data, EU ETS and IED/PRTR 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 IED/PRTR data are inconsistent with the EEMS data, the Inventory Agency works with BEIS OPRED and facility operators to determine the best available data for each source to ensure that the reported data are **complete for each installation**. 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 BEIS OPRED. An example is noted above regarding the 2017 EEMS dataset for emissions from well testing, where the outlier data were considered to be potentially incomplete and therefore a more conservative emission estimate for that source was derived through extrapolation of the 2016 data, scaled using the 2016 and 2017 UK production of crude oil, condensate and natural gas.

Time series consistency

The emission estimates for the offshore industry are based on the EEMS dataset for 1998-2017, 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, 2018) provides a consistent time-series of emission estimates for many facilities and sources, but since 2010 the reporting by onshore terminals is voluntary. 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 CO₂ 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, CO₂ emissions from this source are highly variable. This is because CO₂ 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 19 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

CO₂, CH₄

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, Cadent Gas, SGN, Northern Gas Networks, Wales & West, and Airtricity .

AD for gas use in domestic and commercial sectors from DUKES (BEIS, 2018) 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_2019.xlsx” lists all emission factors used in the energy sector, including a full list of references³⁷.

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 (Cadent Gas, SGN, 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; Cadent Gas operates 5 of the LDZs; Northern Gas Networks operates 2 LDZs; SGN 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 (NG) based on (i) periodic fugitive emission surveys for the National Transmission System (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, and for 2011-2017, with data for other years estimated using interpolation (2005-2010) and extrapolation (early time series).

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; CO₂ 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 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 CO₂ 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, 2018), and the data for 1999 to 2004 have been extrapolated back from the 2005 figure.

Gas Leakage at the Point of Use

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, 2018).

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 (BEIS, 2018) which provides a time-series of gas use for heating, water heating and cooking in the domestic sector, 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. 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 (BEIS, 2018) which provides a time series of gas use for catering and other uses in the commercial sector to 2017. 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 across the time series 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

The only significant recalculation in the 2019 submission is to the fugitive emission estimates from transmission leakage. In previous submissions, no data were available from the NTS for leakage from 2012 onwards; and extrapolation methods were applied to derive inventory estimates. For this submission, consultation with National Grid has led to the provision of new emission estimates for leakage and venting from the NTS, including from LNG terminals, for every year since 2012. Therefore the recent time-series has been recalculated, leading to an increase in emission estimates, with methane emissions 1.6kt higher in 2016 than previously estimated.

Other recalculations to leakage at the point of use are minor and due to revisions in the natural gas activity data for the commercial and public sectors in DUKES 2017.

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 CH₄

Using IPCC 1996 GLs Tier 1 method, the range for emissions is derived as 155 to 215 kt CH₄

Using IPCC 2006 GLs Tier 1 method, the range for emissions is derived as 67 to 105 kt CH₄

Therefore, compared to both Tier 1 methods, the 1990 UK GHGI estimate is higher than the range of values.

2013 UK GHGI total (transmission plus distribution) = 168.5 kt CH₄

Using IPCC 1996 GLs Tier 1 method, the range for emissions is derived as 155 to 215 kt CH₄

Using IPCC 2006 GLs Tier 1 method, the range for emissions is derived as 95 to 148 kt CH₄

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 is 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 throughput 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 and Product Use (IPPU; CRF Sector 2)

4.1 OVERVIEW OF SECTOR

The table below gives an overview of the industrial processes and product use (IPPU) sector. The Key Categories indicated are based on both the Approach 1 and Approach 2 analyses. The uncertainty estimate has been taken from Monte Carlo analysis.

Emission trends are presented for 1990-2017 and 2016-2017. A description of the trends and the main drivers behind these can be found in **Chapter 2**.

Table 4.1 Industrial Processes and Produce Use Overview

Industrial Processes and Product Use	Key Categories	Latest year total (Mt CO ₂ e)	Base Year (BY)- Latest year trend	2016-2017 trend	Recalculation:- 2016	Recalculation:- BY	Gases included	Methodology reference (NIR Section)	Methods	Emission factors
Greenhouse Gas Source and Sink Categories										
Total industrial processes		30.33	-57%	-2%	0%	0%				
A. Mineral industry		6.26	-36%	-1%	0%	0%				
1. Cement production	CO ₂ (L1)	4.41	-40%	-3%	0%	0%	CO ₂	4.2	T2	CS
2. Lime production		1.05	-28%	3%	0%	0%	CO ₂	4.3	T1	D
3. Glass production		0.37	-9%	2%	0%	0%	CO ₂	4.4	T2	CS
4. Other process uses of carbonates		0.43	-37%	7%	0%	0%	CO ₂ , CH ₄	4.5	CS	CS (bricks), D (FGD)
B. Chemical industry	CO ₂ (L2), HFCs (L2, T2)	5.21	-89%	8%	0%	0%				
1. Ammonia production		1.81	-12%	21%	0%	-1%	CO ₂ , CH ₄ , N ₂ O	4.6	T3 (CO ₂), T1 (CH ₄ , N ₂ O)	CS (CO ₂), D (CH ₄ , N ₂ O)
2. Nitric acid production	N ₂ O (T1)	0.04	-99%	51%	0%	0%	N ₂ O	4.7	T2	CS
3. Adipic acid production	N ₂ O (L1, T1, L2, T2)	0.00	-100%	N/A	N/A	0%	N ₂ O	4.8	T2	CS
4. Caprolactam, glyoxal and glyoxylic acid production		0.00	N/A	N/A	N/A	N/A	N/A	4.9	N/A	N/A
5. Carbide production		0.00	N/A	N/A	N/A	N/A	N/A	4.10	N/A	N/A
6. Titanium dioxide production		0.18	73%	7%	0%	0%	CO ₂	4.11	CS	CS
7. Soda ash production		0.14	-39%	-2%	0%	0%	CO ₂	4.12	CS	CS
8. Petrochemical and carbon black production	CO ₂ (L1)	2.86	-37%	2%	1%	0%	CO ₂ , CH ₄ , N ₂ O	4.13	CS, T1	CS, D
9. Fluorochemical production	HFCs, PFCs, SF ₆ and NF ₃ (L1, T1)	0.18	-99%	1%	-3%	0%	HFCs, PFCs	4.14	T2	PS
10. Other (as specified in table 2(I).A-H)		0.05	-72%	-20%	-2%	-6%	CH ₄	4.15	CS	CS
C. Metal industry		2.72	-67%	5%	0%	0%				

Industrial Processes and Product Use	Key Categories	Latest year total (Mt CO ₂ e)	Base Year (BY)- Latest year trend	2016-2017 trend	Recalculation:- 2016	Recalculation:- BY	Gases included	Methodology reference (NIR Section)	Methods	Emission factors
Greenhouse Gas Source and Sink Categories										
1. Iron and steel production	CO ₂ (L1)	2.52	-55%	4%	0%	0%	CO ₂ , CH ₄ , N ₂ O	4.16	T2 (CO ₂), T1, T3 (CH ₄)	CS (CO ₂), CR, CD, D (CH ₄)
2. Ferroalloys production		0.00	N/A	N/A	N/A	N/A	N/A	4.17	N/A	N/A
3. Aluminium production		0.09	-89%	-1%	0%	0%	CO ₂ , PFCs	4.18	T1 (CO ₂), T2 (PFCs)	CS (CO ₂), PS (PFCs)
4. Magnesium production		0.11	-71%	45%	0%	0%	HFCs, SF ₆	4.19	T2	PS
5. Lead production		0.00	N/A	N/A	N/A	N/A	N/A	4.20	N/A	N/A
6. Zinc production		0.00	-100%	N/A	N/A	0%	CO ₂	4.21	CS	CS
7. Other (as specified in table 2(I).A-H)		0.00	N/A	N/A	N/A	N/A	N/A		T1	CR
D. Non-energy products from fuels and solvent use		0.52	-6%	-1%	48%	0%				
1. Lubricant use		0.27	-49%	3%	-5%	0%	CO ₂	4.22	T1	CS
2. Paraffin wax use		0.02	-27%	2%	18%	0%	CO ₂	4.23	T1	D
3. Other		0.23	N/A	-5%	294%	N/A	CO ₂	4.24	T2 (non energy use of petroleum coke), T3 (urea use)	D (non energy use of petroleum coke), CR (urea use)
E. Electronics industry		0.02	127%	10%	0%	0%				
1. Integrated circuit or semiconductor		0.02	127%	10%	0%	0%	HFCs, NF ₃	4.25	T2	D
2. TFT flat panel display		0.00	N/A	N/A	N/A	N/A	N/A	4.26	N/A	N/A
3. Photovoltaics		0.00	N/A	N/A	N/A	N/A	N/A	4.27	N/A	N/A
4. Heat transfer fluid		0.00	N/A	N/A	N/A	N/A	N/A	4.28	N/A	N/A
5. Other (as specified in table 2(II))		0.00	N/A	N/A	N/A	N/A	N/A		N/A	N/A
F. Product uses as substitutes for ODS⁽²⁾	HFCs (L2, T2)	14.17	900%	-7%	0%	1%				
1. Refrigeration and air conditioning	HFCs, PFCs, SF ₆ and NF ₃ (L1, T1)	11.65	2093%	-8%	0%	0%	HFCs	4.29	T2	CS
2. Foam blowing agents		0.45	144%	6%	0%	0%	HFCs	4.30, 4.31	T2	CS
3. Fire protection		0.32	22852%	0%	-2%	0%	HFCs, PFCs	4.32	T2	CS
4. Aerosols	HFCs, PFCs, SF ₆ and NF ₃ (T1)	1.66	150%	-4%	0%	0%	HFCs	4.33	T2	CS
5. Solvents		0.02	N/A	-7%	-74%	N/A	HFCs	4.34	T1a	OTH
6. Other applications		0.06	67%	5%	9%	34%	HFCs	4.35	CS	CS
G. Other product manufacture and use	N ₂ O (L2, T2)	1.44	-13%	2%	-1%	2%				
1. Electrical equipment		0.28	-64%	0%	-6%	5%	SF ₆	4.36	T3	CS

Industrial Processes and Product Use	Key Categories	Latest year total (Mt CO ₂ e)	Base Year (BY)- Latest year trend	2016-2017 trend	Recalculation:- 2016	Recalculation:- BY	Gases included	Methodology reference (NIR Section)	Methods	Emission factors
Greenhouse Gas Source and Sink Categories										
2. SF ₆ and PFCs from other product use		0.32	14%	5%	0%	0%	PFCs, SF ₆	4.37, 4.38, 4.39	T2 (Accelerat ors), T2, T3 (Electroni cs and shoes), OTH (Tracer gas), T1 (military)	D (Accelerat ors), CS, D, (Electroni cs and shoes), CS (Tracer gas), D (military)
3. N ₂ O from product uses		0.65	N/A	N/A	0%	0%	N ₂ O	4.40, 4.41	OTH (Medical), CS (propellan ts)	CS (Medical), OTH (Propellan ts)
4. Other		0.20	N/A	N/A	0%	0%	N ₂ O	4.42	CS	CS
H. Other (as specified in tables 2(I).A-H and 2(II))⁽³⁾		0.00	N/A	N/A	N/A	N/A			CS	CS

* CH₄ emissions from fletton brick production are reported under 2H in the CRF tables, as not possible to report in 2A4 alongside CO₂ emissions from this source.

** N₂O emissions from 2B8 are reported under 2B10 in the CRF tables

***N₂O emissions from 2C1 are reported under 2C7 in the CRF tables

The industrial processes and other product use sector (IPCC Sector 2) contributes 6.5% 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 54% decline in emissions, mostly due to changes in the emissions from the chemical production and halocarbon and SF₆ 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).

The figures in **Figure 2.15 - Figure 2.17** 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

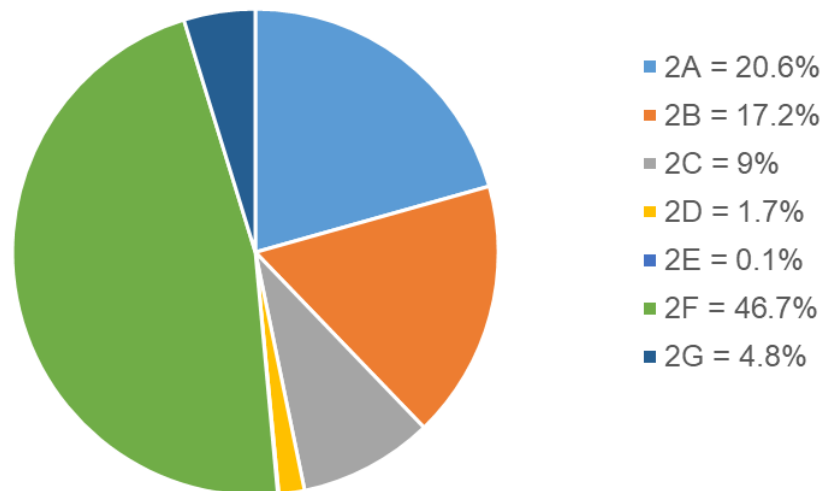
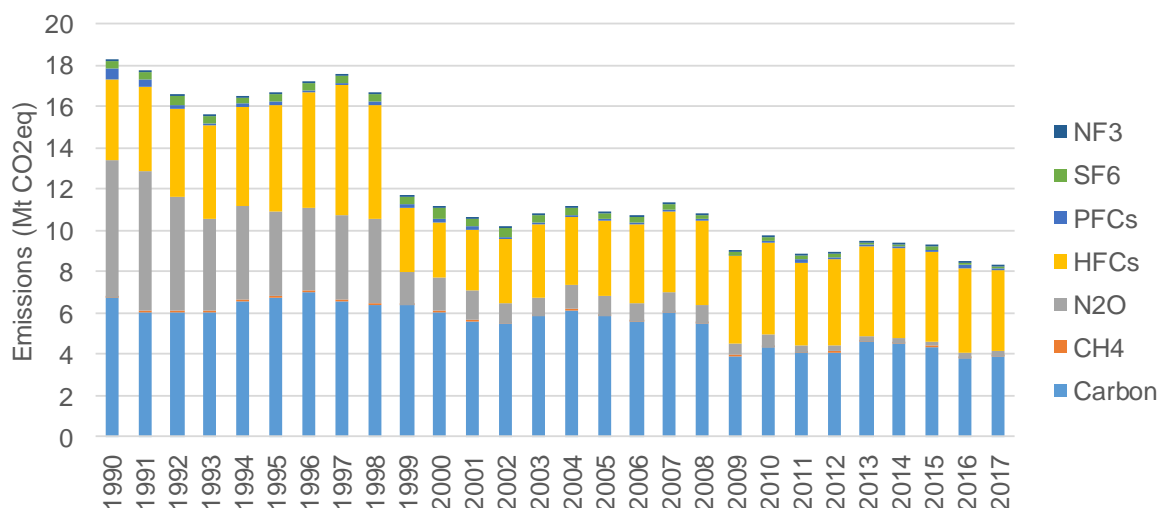


Figure 4.2 Trend in total GHG emissions in Industrial Processes sector



4.2 SOURCE CATEGORY 2A1 – CEMENT PRODUCTION

4.2.1 Source Category Description

Emissions of CO₂ from fuels burnt in cement kilns are reported under CRF category 1A2f, whilst emissions from calcination of non-fuel feedstocks are reported under category 2A1.

Fuel combustion also gives rise to emissions of nitrous oxide, reported under 1A2f. Emissions of methane also occur, both due to fuel combustion but also due to the evaporation of organic components present in the raw materials. The current GHGI methodology for estimating emissions of methane does not allow emissions from fuels and from raw materials to be quantified separately so all emissions are reported under 1A2f.

4.2.2 Methodological Issues

Emission estimates for 2005-2017 are available from the annual UK production of clinker and emission factors provided by the Mineral Products Association (MPA, 2018), formerly the British Cement Association (BCA). These AD and EFs are based on data generated by UK

cement clinker producers for the purposes of reporting to the EU Emission Trading Scheme. Data from the MPA are cross-checked against the EU ETS data set supplied directly by regulators for use in the inventory. The EU ETS data are incomplete for 2005-2006 as several kilns were reporting within a different trading system, and therefore EU ETS-MPA data comparisons for those two years are not useful. From 2007 onwards, the scope of the two datasets are the same, and they are closely consistent, particularly from 2008 onwards where there is an average difference of 0.2%. In each year, the inventory estimates are based on the higher of the two figures, i.e. MPA data for 2005-2007, 2010 & 2015-2017, and EU ETS for 2008-2009 and 2011-2014. The EU ETS and MPA/BCA data all include emissions associated with cement kiln dust.

EU ETS and MPA data are available for 2005 to 2017 only, and are regarded as the best available data to represent the emissions performance of UK cement kilns. Therefore, the emission factor value for 2005 has been extrapolated to all earlier years, as it is the most representative figure of the full range of UK kilns operating back to 1990, noting that there have been several closures during the economic down-turn of the late 2000s.

The methodology used for estimating CO₂ from calcination is summarised in **Table 4.2**.

Table 4.2 Methods used to estimate cement production emissions of CO₂

Period	Activity data	Emission factor, kt C / kt carbonate	Method
1990-2000	British Geological Survey – UK Minerals Yearbook, clinker production data for the UK	Use of the 2005 emission factor derived from emissions from all UK cement plant, from the British Cement Association	Emission = AD x EF
2001-2004	British Cement Association, clinker production data for UK		
2005-2007, 2010, 2015-2017	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)	Emission = AD x EF
2008-2009, 2011-2014		Factor derived from site-specific EU ETS returns for all UK sites (since higher than MPA-based CEF for that year).	

4.2.3 Uncertainties and Time Series Consistency

The time-series consistency of the activity data used in the UK GHGI emission calculations is very good across all years, as the inventory agency has a complete, consistent dataset from the UK trade association (BCA then MPA) from 2001 onwards, and routine statistical datasets for the earlier years from BGS. Furthermore, since 2005 there is a comprehensive sector-wide dataset for emissions and the EFs applied for carbonisation emissions. Cross-checks with EU ETS data received directly from UK regulators indicate only very small differences. The

extrapolation of the EF from 2005 back to 1990 is the best available data to use for the UK cement sector, but does lead to higher uncertainties for the emissions total in the base year.

It is important to note that there is a distinction to be made between: (i) the data used to estimate emissions in the UK methodology; and (ii) the data that can be released into the public domain for the purposes of reporting the national inventory.

The data used to estimate emissions are a complete dataset (of emissions and production) from all UK cement kilns. *These data can be provided to a UNFCCC Expert Review team on request.*

The data reported in the CRF and NIR, however, are limited by commercial confidentiality. Statistical publications of cement production since 2001 are routinely made for Great Britain only, i.e. excluding production in Northern Ireland. Throughout the recent time series either one or two cement kilns have operated in Northern Ireland. Their emissions and production data are provided to the inventory agency and used in the inventory calculations. However, to release the complete UK clinker production statistics would be disclosive for the sites in Northern Ireland. Therefore, in the table below and the CRF dataset, only GB production data are presented from 2001 onwards. This is the reason for the step-change upwards in IEF over the time series between 2000 and 2001. The underlying calculations do not exhibit any such step-change.

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**. The CO₂ emissions data in the table are for the whole of the UK. The CO₂ 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 shown to give an indication of the trend in the factor over time.

Table 4.3 Activity data and CEF for cement production, 1990 - 2017.

Year	Cement Clinker production (kt) ^a	CO ₂ emitted (kt)	CO ₂ emission factor, (t / t clinker)
1990	13,199	7,295	0.553
1995	11,371	6,285	0.553
2000	11,456	6,332	0.553
2005	<i>10,074</i>	5,941	0.590
2006	<i>10,069</i>	5,893	0.585
2007	<i>10,227</i>	6,117	0.598
2008	<i>8,700</i>	5,205	0.598
2009	<i>6,421</i>	3,721	0.580
2010	<i>6,598</i>	3,792	0.575
2011	<i>7,096</i>	4,097	0.577
2012	<i>6,555</i>	3,724	0.568
2013	<i>6,712</i>	4,029	0.600
2014	<i>7,197</i>	4,215	0.586
2015	<i>7,804</i>	4,451	0.570
2016	<i>8,056</i>	4,553	0.565
2017	<i>7,824</i>	4,410	0.564

^a Figures in italics exclude production in Northern Ireland

A large drop in clinker production after 1990 can be explained by a sharp drop in construction activity. This initial 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, production of which is likely to have risen sharply over the same period; the inventory agency estimates that capacity for slag cement production increased from 0.75 Mtonnes in 1990 to 2 Mtonnes by 2007. 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 kilns were closed or mothballed during those years, and none have subsequently been re-opened. However, there has been a slow increase in clinker production since 2009, and production in 2016 was at the highest level since 2008.

The UK-specific emission factor for cement clinker production is constant for 1990-2000 because no year-specific data are available, and a UK factor from the EU ETS reporting period is extrapolated back to UK production data. Factors presented above for the period 2005-2015 are all higher than the factor for 1990-2000, because of the change in the activity data from UK to GB in 2001, as explained above. Since the later activity data exclude a small number of sites in Northern Ireland, the activity data are lower, and the implied emission factors for CO₂ are therefore higher. The emission factors in the period 2001-2017 do vary from year to year, from a minimum value of 0.564 t CO₂ / t in 2017 and a maximum value of 0.600 t CO₂ / 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 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 significant recalculations have been made in this category. Some very minor changes to the EU ETS based figures used in the UK inventory have led to very small recalculations for 2008, 2009 and 2015, the latter being the most significant with a change of 0.2%.

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

Lime (CaO) is manufactured by the calcination of limestone (CaCO₃) and dolomite (CaCO₃MgCO₃) in kilns fired by coal, coke or gas. The calcination results in the evolution of carbon dioxide. However 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. Emissions from lime kilns used in the manufacture of sodium carbonate are, in line with IPCC Guidelines, reported in 2B7.

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 CO₂ 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, a 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, CO₂ 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 CO₂ i.e. include emissions from both decarbonisation and fuel combustion on a site, but estimates of the CO₂ 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 CO₂ in the PI and so site-specific CO₂ 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. There are 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, it is assumed that BGS data for 1990-1993 would also underestimate emissions and the inventory agency has 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 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
2007-2017	(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 for UK sugar producers do not include any emissions from calcination, and consultation with the industry in the past confirmed that the industry considers there to be no CO₂ emissions from this source - all of the lime used in the carbonatation process (whereby lime and carbon dioxide are used to remove impurities in sugar solutions) is considered to be converted to calcium carbonate, meaning no net emission in CO₂. However, the UNFCCC centralised review of the 2013 submission of the UK GHG Inventory recommended that CO₂ emission estimates were needed and that it should be assumed that some unreacted lime was

present in waste sludges at the end of the carbonation process. Emission estimates are therefore included 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 indicate zero emissions. Due to the confidentiality of the lime production data at the sugar production sites, further details of the methodology are not presented here, but can be provided to a UNFCCC Expert Review Team.

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**.

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 provides a full dataset for UK facilities from 2008 onwards, and the uncertainties associated with these verified data are low. EU ETS data for 2005-2007 provide partial coverage of the sector and are used in conjunction with other data sources to derive inventory estimates, and hence these estimates are also regarded as subject to 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 CO₂ 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 used in sugar production are highly uncertain since EU ETS data for those sites suggest no CO₂ is emitted. 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 CO₂ 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 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. In response to the ERT recommendation (2017 ARR, item I.14) to collect lime production data to enable the UK to derive and report a production-based IEF, the UK inventory agency has consulted with the Office of National Statistics (ONS) to seek any data that are available from the industry on production of lime, via the Prodcom surveys and database. The inventory agency research has found that there is no complete, consistent time series of annual production data from UK producers from ONS. This is due to the nature of the periodic surveys conducted by ONS, the combination of production data from several mineral sectors (e.g. cement with lime

aggregated) and the commercial sensitivity of reported production data. The inventory agency notes that the EU ETS emissions reporting is known to cover all existing UK lime works and therefore is complete and accurate for recent years, and that to gather any further activity data from the industry is not practicable given the competing priorities for inventory improvement resources.

4.4 SOURCE CATEGORY 2A3 – GLASS PRODUCTION

4.4.1 Source Category Description

Emissions from glass manufacture include emissions of carbon dioxide resulting from the use of limestone, dolomite and soda ash as sources of CaO, MgO and Na₂O 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 2017, producing 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 is also a small site producing ceramic fibres. Ballotini are produced at three sites, but production is small - output was less than 1% of UK glass production in 2017. Special and non-lead domestic glasses are no longer manufactured in the UK, and production of lead glass is only on a very small scale. The last producer of frits closed in 2014. 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 stone wool sector separately would be problematic. The UK therefore combines the data with emissions for other glass industry sites.

Process emissions of N₂O are not estimated for glass production 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 N₂O from these sites (including N₂O from combustion of fuels) must be below the reporting threshold of 10 tonnes and therefore any process 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, and assumes all of the carbon is released to atmosphere i.e.

120 t carbon/kt limestone;

130 t carbon/kt dolomite;
113 t carbon/kt soda ash.

The EU ETS data are for CO₂ emissions, disaggregated by the source of the emission e.g. use of natural gas, use of limestone etc. The data have to be analysed so that emissions can be separated into those that occur due to use of fuels, and those that are due to use of the three carbonates. Data are available for the period 2008-2017 for all sites manufacturing flat glass, container glass, continuous filament glass fibre, glass wool and stone wool. Carbonate use is back-calculated using the stoichiometric relationships 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 also includes extremely small CO₂ emissions (<1 tonne) occurring due to use of barium or potassium carbonate by the 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 / CO₂ emissions for each sub-sector of the glass industry as follows:

2008-2017: flat, container, glass fibre, glass wool, stone wool;
2006: flat, container, glass fibre/glass wool (combined in the survey).

These data 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 and 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, data are only available from the EU ETS for 2008-2017, 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 contains information on special or domestic glasses because the only UK sites producing either type of glass closed before the end of 2006. Therefore, carbonate usage for both types of glass has 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, 2018), 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 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 CO₂ emissions from carbonate use

Glass Sector	1990 production, kt	2017 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	0.3	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
Ceramic fibres	14	14	No	No	No
Frits	13	0	No	No	No
Ballotini	20	35	No	No	No

a - confidential

4.4.3 Uncertainties and Time Series Consistency

For the years 2008-2017, 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 2008-2017 since the source gives carbonate usage figures only, and emissions have to be calculated assuming that these figures refer to pure carbonates and that all carbon in the minerals is released to atmosphere. While the emissions data are therefore conservative, the uncertainty is still considered to be 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 these years.

4.4.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the inventory in **Section 1.6**.

4.4.5 Source Specific Recalculations

There have been no significant changes to this category.

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

The UK has a large number of sites involved in the production of heavy clay goods such as 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. 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 CO₂ from the carbonaceous material in the clay. Limestone, dolomite and barium carbonate can also be used in brickmaking, leading to further releases of CO₂ during firing. 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 it is 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, the UK inventory estimates include 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 CO₂ 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 SO₂ 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. The Ferrybridge C and Rugeley B stations were both closed during 2016. Various small, predominantly waste and/or biomass-fired stations also report CO₂ emissions from limestone scrubbing in the EU ETS. In all of these processes, limestone reacts with the SO₂ present in flue gases, being converted to gypsum, with CO₂ being evolved. Uskmouth B has a dry lime-injection system, so there is no potential for CO₂ emissions at this site. Seawater scrubbing systems are used at Aberthaw, Kilroot, and Longannet power stations but CO₂ 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 SO₂ emissions: as with Uskmouth B, there will be no CO₂ 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 CO₂ occurred at this site. The use of soda ash outside of the glass industry is not reported in the UK, and hence no emission estimates for non-glass sector uses are included in the inventory.

4.5.2 Methodological Issues

CO₂ emissions from production of bricks and tiles are based on data reported in the EU ETS. EU ETS provides site by site emissions, broken down by source (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 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 on the source of the CO₂ is ambiguous. So although it is possible to make a crude split, the process emissions are reported as a group. Note that this does mean that emissions from the colourant (coke oven or petroleum coke) are included here, but 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 Ceramic 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 2008-2012 covered 93% of sector production. A single further site joined EU ETS in 2013, bringing coverage to 95%. The EU ETS emissions data for 2008-2017 are therefore increased using these figures 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 in 2013, the non-reporting sites over the period 2008-2017 are much smaller producers and it is not known how representative the industry factors will be for these atypical sites. In the absence of better data, it is assumed that emission rates are the same.

ETS data are incomplete before 2008, and therefore are not used to derive a national total. Instead, annual brick production data are used, available in Government Statistics (Monthly Statistics of Building Materials and Components, September 2018, 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 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. The inventory method therefore assumes a 25% share in 1990, falling to 20% in 1995, then falling to 10% by 2010. EU ETS data for the fletton works suggest production has fallen further since 2010 and so is used to estimate the trend for fletton bricks since 2010. Using these data and assumptions, it is possible to then generate estimates of the numbers of fletton bricks and non-fletton bricks

produced each year. For 2017, it is estimated that 6% of UK bricks produced were of the fletton type.

A figure of 152 grams CO₂ per non-fletton 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 CO₂ emissions are reported for the Stewartby and Saxon/Kings Dyke sites 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	8 fletton works operating 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- and process-related emissions. Estimates for non-fletton bricks have to be generated using emission factors from later EU ETS data Annual production (numbers) of all bricks available: fletton and non-fletton brick production estimated.
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.

Years	Number of sites and fuels	Availability of data
2009-2017	<p>Saxon works closed in 2011, leaving only the Kings Dyke fletton brickworks in operation.</p> <p>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.</p>	<p>Annual emission of CO₂ and methane available in the Pollution Inventory for the Saxon/Kings Dyke works.</p> <p>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.</p>

Other types of ceramics are manufactured in the UK, including wall and floor tiles, refractories, sanitary ware, household ceramics etc. There are no national 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 can be considered insignificant in the UK inventory context.

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 brick makers. It will also likely be used for refractories and sanitary ware and, in the absence of any data, a 50/50 split of fireclay usage between bricks and other ceramics is assumed. The Kaolin and Ball Clay Association (KABCA) give estimates of the markets for both ball clay and china clay on their website⁴³. 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 not available for 2010), approximate figures for clays used in bricks and in other ceramics can be derived, as follows:

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	
	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	

⁴³ 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
	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 in order to generate a full time-series of activity data. For the purposes of determining the significance of the source, a time-series can be derived based on 11% of the clay usage in bricks, and to assume the same average carbon content in clay for ceramics as in the common clays used in brickmaking (noting that this is a worst case due to the very low carbon content of ball clay), to yield emission estimates that are 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 are available from the UK Minerals Yearbook (British Geological Survey, 2016 and earlier versions), 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 2005-2017. 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). No data are available from BGS for 2015-2017 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 2008-2017 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 inventory in **Section 1.6**.

4.5.5 Source Specific Recalculations

In the case of fletton brick production, some revisions have been made to the assumptions used to separate total site emissions data for the years 2001-2005 into energy and IPPU components. These changes result in slightly more of the site emissions being assumed to be

fuel related and therefore slightly less being process-related. The new assumptions are more consistent with the good quality data available for later years via EU ETS.

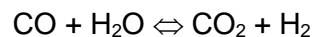
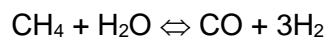
4.5.6 Source Specific Planned Improvements

Emission factors and activity data for bricks, ceramics and FGD will be kept under review. Research is currently being carried out with the aim of quantifying the quantities of soda ash used for applications other than glass production and the potential for CO₂ emissions resulting from these applications. It is anticipated that emission estimates will be added to the next version of the UK inventory, should evidence be obtained for any emissive sources.

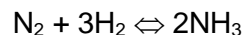
4.6 SOURCE CATEGORY 2B1 – AMMONIA PRODUCTION

4.6.1 Source Category Description

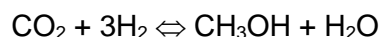
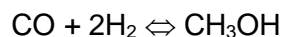
Ammonia is typically produced using the Haber process, which starts with the steam reforming of natural gas to make hydrogen. The simplified reactions are:



The hydrogen is then reacted with nitrogen to form ammonia.



If the by-products CO and CO₂ 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:



Over the time period covered by the UK greenhouse gas inventory, ammonia has been manufactured at four locations in the UK. CO₂ 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 CO₂ 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 CO₂ to the food industry and nuclear industry. Because this CO₂ 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 CO₂ will also be emitted from other processes within those sectors, for example from fermentation.

Methane emissions from the steam reforming processes and the associated ammonia production facilities are reported under 2B10, together with methane emissions from other 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. 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 the inventory agency is confident that there has been no production of urea in the UK since 1990, and the UK ammonia production estimates throughout the time series need not take any 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 CO₂ from both fuel and feedstock use of natural gas are calculated by combining reported data on CO₂ 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 CO₂.

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	1895	1.43
1995	1388	1944	1.40
2000	1213	1886	1.56
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	1386	1.45
2014	987	1482	1.50
2015	1022	1602	1.57
2016	959	1442	1.50
2017	1129	1764	1.56

*As reported within the CRF table 2(l).A-Gs1

CRF table 2(l).A-Gs1 presents the ammonia production data for all UK sites (including Hull where there are no CO₂ 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 CO₂ 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 CO₂ / tonne NH₃ for a 'modern' European plant, but a higher Tier 1 default of 2.104 tonnes CO₂ / tonne NH₃ 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 CO₂ emissions; Aggregate UK factors for the three sites with CO₂ emissions show an average of 1.84 tonnes CO₂ / tonne NH₃ for production across the whole 1990-2017 time-series, and averages for individual years 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 CO₂ / tonne NH₃, and 2002 when the emission factor was slightly higher than 2.1 tonnes CO₂ / tonne NH₃. *[Note that fully detailed 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 ammonia production facilities.

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 inventory in **Section 1.6** 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, although we have revised the split of CO₂ emissions between fuel combustion and feedstock use for 2014-2016. This is

merely a re-allocation between UK inventory categories within 2B1 and has no impact on the emissions data reported at 2B1 level.

4.6.6 Source Specific Planned Improvements

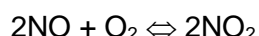
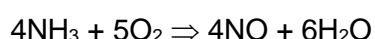
Emission factors and activity data will be kept under review.

4.7 SOURCE CATEGORY 2B2 – NITRIC ACID PRODUCTION

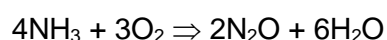
4.7.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2B2: Nitric Acid Production	T3, T2	CS
Gases Reported	N ₂ O, NO _x		
Key Categories	2B2: Nitric acid production - N ₂ O (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 to the data and methods. Further information on the abatement technology applied at UK installations has been added below.		

Nitric acid is produced by the catalytic oxidation of ammonia:



Nitrous oxide is also formed by oxidation of ammonia:



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 2017, 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/N₂O 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 4.11** below).

4.7.2 Methodological Issues

Across the 1990-2017 time-series the availability of emissions and production data for UK nitric acid plant is inconsistent, and so a range of methodologies have had to be used to provide estimates and derive emission factors. 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 N₂O 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 N₂O /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 N₂O emissions for the UK inventory and 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 continuous monitors at both sites are certified to MCERTS, installed and maintained to EN14181, and subject to EU ETS Permit. MCERTS (Monitoring Certification Scheme) was set up by the Environment Agency to ensure good quality environmental measurements. The scheme is based on international standards and provides for the product certification of instruments, the competency certification of personnel and the accreditation of laboratories. The European Standard EN14181 covers quality assurance for automated measuring systems. 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; the N₂O monitoring systems at these sites comply with the requirements of EU ETS reporting, and are subject to low uncertainty (5-10%). Therefore, the emissions data reported by operators are associated with low uncertainty, and are representative of the technology and abatement in the UK installations.

Some nitric acid capacity was co-located with a process that manufactured adipic acid. For the years 1990-1993, its emissions are reported combined with those from the adipic acid plant (see **Section 4.7**) 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 (figures are numbers of sites)

Period	Site specific production data		Site Specific emissions data, kt N ₂ O			
			Reported by operator		Estimated by Inventory Agency	
	Estimated	Operator data	Based on emission factors	Based on monitoring	Site-specific EF	IPCC EF
1990-1993	7	1			5	3
1994	5	1			6	
1995-1997	4	2			6	
1998-1999		6	4	1	1	
2000	1	5	4	1	1	

Period	Site specific production data		Site Specific emissions data, kt N ₂ O			
			Reported by operator		Estimated by Inventory Agency	
	Estimated	Operator data	Based on emission factors	Based on monitoring	Site-specific EF	IPCC EF
2001		5	3	1	1	
2002-2004		4	3	1		
2005		4	2	2		
2006-2007		4	1	3		
2008		4	2 ^a	2		
2009-2017		2	-	2		

^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 4.11 Summary of Nitric Acid Production in the UK, 1990-2017

Year	Number of sites	Production (Mt 100% Nitric Acid)	Aggregate EF (kt N ₂ O / Mt Acid)
1990	8	2.41	5.38
1995	6	2.40	3.82
2000	6	2.03	6.94
2005	4	1.71	3.80
2006	4	1.47	3.87
2007	4	1.61	3.54
2008	4	1.29	3.89
2009	2	0.93	3.89
2010	2	1.21	3.51
2011	2	1.08	0.616
2012	2	1.13	0.115
2013	2	1.01	0.142
2014	2	1.10	0.124
2015	2	1.13	0.087
2016	2	1.17	0.071
2017	2	1.22	0.103

The larger of the two remaining UK plants fitted control equipment to reduce N₂O emissions in early 2011, and this has 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. A large increase in N₂O 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 N₂O as well as NO_x, whereas SCR only abates NO_x and can actually increase N₂O emissions.

Since 2011 all of the UK nitric acid production facilities are fitted with EnviNO_x SCR abatement (Alexander, 2019) which includes heating of the tail gases from the production vessels, followed by NO_x and N₂O destruction in a catalyst bed using ammonia gas and hydrocarbon inputs to mitigate the NO_x and N₂O. The technology is described in a reference document

(Groves and Sasonow, 2010)⁴⁴. The UK installations apply the technology in process variant 2 design, which achieves N₂O mitigation performance of around 99.5%, and this is the reason for the very low IEF of the UK nitric acid production sector since 2011. The N₂O emissions from all UK plant are monitored (since 2009 for all plant) using Continuous Emission Monitoring systems, and the annual operator submissions to the Environment Agency (the environmental regulatory agency for both UK nitric acid facilities) are subject to quality checks by the Site Inspectors to validate that the annual data reported to the PI and used in the UK GHGI are accurate.

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 N₂O for this sector does vary through the time-series depending upon the availability of data. The calculated N₂O 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 N₂O EF, as plants with generally above-average emission rates cease production. Abatement of N₂O using catalytic decomposition technology at the remaining UK production 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. Emission estimates for recent years have been based partially (1998-2008) or wholly (2009-2017) on continuous monitoring, and therefore will be subject to low uncertainty. The monitoring systems used at the 2 sites currently in operation are subject to an uncertainty of 5-10%.

The nitric acid plant emissions data reported by operators since 1998 are considered to be complete and accurate, since they are subject to internal QA/QC checks by the plant operators and the Environment Agency before being reported in the Pollution Inventory.

4.7.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the inventory in **Section 1.6**.

4.7.5 Source Specific Recalculations

Emissions data were added for 2002 for one site. This site actually ceased operation in the second half of that year but had previously been assumed to have not operated at all in 2002. Emissions data were discovered however in data provided to the site's regulator. Emission estimates for other years are unchanged.

4.7.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

⁴⁴ <https://doi.org/10.1080/19438151003621334> See Figure 3 for the process variant 2 design, as applied in UK installations, and Figure 5 for information on the N₂O abatement performance of the technology.

4.8 SOURCE CATEGORY 2B3 – ADIPIC ACID PRODUCTION

4.8.1 Source Category Description

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.

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 N₂O 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 N₂O 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 N₂O. 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 N₂O 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 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 regulator. A higher uncertainty is assumed for 1990 than for later years. Emissions no longer occur from this source since the plant has closed.

Fluctuations in the N₂O 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 inventory in **Section 1.6**. 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

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, however the scope of reporting has varied over the years:

- From the PI, a single figure covering CO_2 from reducing agents and fuel use in plant utilities. However, for three years (2006-2008), the process operators were required

to report thermal CO₂ and chemical CO₂ separately, so the latter could be assumed to cover emissions from coke use only;

- From the EU ETS, detailed data covering fuel use for energy production in site boilers during phase II (2008-2012), extended to cover fuels burnt in furnaces, driers etc. as well as use of reducing agents (coke) for phase III (2013 onwards).

From these data it is possible to obtain the emissions from the chemical process for some years: 2006-2008 (using the PI data for chemical CO₂ emissions), and 2013-2017 (from the detailed EU ETS data). The fuel/process split in emissions for these years can be calculated, and the PI provides total CO₂ 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 TiO₂ 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 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, 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 inventory in **Section 1.6**.

4.11.5 Source Specific Recalculations

There have been no significant recalculations in this category.

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

Soda ash has been produced in the UK using the Solvay process at two sites 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 CO₂ gas, both of which are used in the process. Coke oven coke is used to fire the lime kilns and CO₂ 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 CO₂ emitted should be equal just to those emissions occurring from the coke. In practice, the process is not 100%

efficient so emissions of CO₂ are actually 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 & CO₂, which we assume is sourced from the neighbouring Lostock plant. EU ETS data suggest this sodium bicarbonate process does emit some CO₂ – presumably unreacted CO₂ that passes through the process and, since this CO₂ probably originates with the soda ash process at Lostock, it is included in the emission estimates for 2B7.

Emissions from soda ash (sodium carbonate, Na₂CO₃) 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 CO₂ around the whole chemical process". In the UK, soda ash has been produced at two sites and both began to report under the EU ETS in 2013, although one is now closed. 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 2013-2017 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 CO₂ emissions have been reported in the PI from 1998 onwards. Comparison of the PI and EU ETS data for 2013-2017 shows that EU ETS data were 38% higher than emissions in the PI in 2013, 68% higher in 2014, 80% higher in 2015, 69% higher in 2016, and 76% higher in 2017. 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 across the entire time-series (possibly they represent CO₂ releases from just part of the process, rather than the whole-process balance used in the EU ETS). We have assumed that the level of underestimation in 1998-2012 is at the same level as in 2013 and 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 2014-2017 was higher and so a more conservative approach would be to use a factor based on data for all five years between 2013 and 2017 (1.66). However, the Winnington plant was closed in early 2014 and so the years from 2014 onwards 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 2013-2017 should ensure that the emission estimates for those years are quite certain. The poor agreement between the PI and EU ETS data in 2013-2017 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 2014-2017 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 inventory in **Section 1.6**.

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

This category includes emissions from the following sources: 2B8a Methanol, 2B8b Ethylene, 2B8c Ethylene Dichloride, 2B8d Ethylene Oxide, 2B8e Acrylonitrile, 2B8f Carbon Black and 2B8g Chemicals: OPG. 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 1990-2017, although a series of site closures in recent years has reduced the number of products manufactured.

Methanol was manufactured in the UK until 2001 in a process which was integrated with ammonia production. Ethylene was produced at five sites in 1990, although the closure of the two works in 1993 and 2010 reduced this to three at the end of 2017. 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 CO₂. 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 CO₂ due to the use of off-gases as fuels. Emissions of CO₂ at these sites are very small relative to the emissions from ethylene production. All emissions of CO₂ 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 4.12**.

Table 4.12 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 ^a .
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 2008-2017 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.
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 PI emissions are assumed to be 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.

Chemical product	Reporting for		Methodology
	CO ₂	CH ₄	
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 – 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.

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 CO₂, and additional CO₂ produced in the methanol plant's own reforming process is assumed stored. The plant closed in 2001 and there is 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 CO₂ / t methanol) to give the emission reported in 2B8b. The production estimates are also used to calculate the CO₂ stored, and finally, both emitted CO₂ and stored CO₂ 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 4.13** summarises the data for methanol production.

Table 4.13 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 CO₂ emissions from 2B8g was 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 level of completeness of the data over the whole time-series is 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 CO₂), 2B8d and 2B8f (both CH₄, 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 CO₂ 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 inventory in **Section 1.8**.

4.13.5 Source Specific Recalculations

Some minor revisions to the estimates for CO₂ from 2B8g following review of the available EU ETS data. New figures for 2B8g are about 1% higher than previously for the years from 2013 onwards.

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 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 HCFC plants closed in 2008/9; one reopened in 2013 and was shut down again in 2016. HFC production ended in 2016.

There is no UK production of SF₆.

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.

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 and was shut down in 2016.

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 inventory in **Section 1.6**, 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

Emissions estimates from this sector have been revised to reallocate emissions associated with f-gas handling to 2F6. These emissions were previously aggregated with the fugitive emissions estimates.

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

The UK has a large chemical manufacturing sector and emissions of methane 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 are included in 2B10, rather than being reported separately in 2B1.

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, 2018) and Welsh Emission Inventory (NRW, 2018) 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, 2018).

All of the data available are in the form of emission estimates 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 (2018).

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 the period prior to 1994 are also more uncertain due to the need for extrapolation of emissions data for 1994 or some other year backwards, using general indicators of chemical industry output.

4.15.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the inventory in **Section 1.6**. 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

We have made some changes to the way in which we generate emission estimates from the available data from regulators. The regulators' emissions data will not necessarily cover all sites in operation – for example, some sites may not need to report emissions if those are considered below reporting thresholds. So UK estimates require a degree of extrapolation in order to address gaps in the data. We have introduced procedures to try to make the gap-filling process more complete and more consistent. The new procedures also make it easier to ensure that the UK estimates include all relevant regulator data – previously, it is likely that a very small proportion of data were omitted in error. These revisions to procedures do not result in any large revisions to UK totals for methane: estimates are mostly slightly lower: 6% lower in 1990 (11 ktonnes CO₂ eq) and 2% lower in 2016 (1 ktonne CO₂ eq). As well as the more consistent use of the regulator data, the revisions also result from the removal of a double-count since one chemical process had previously been included in both the estimates for 2B8d and 2B10, and is now only included in 2B8d.

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	T1, T2	CS
	Iron & steel flaring (BFG)	T1, T2	D, CS
	Electric arc furnaces	T1, T2	CR, CS
	Ladle arc furnaces	T2	CS
	Sinter plant – limestone	T2	CS
	Sinter plant - dolomite	T2	CS
	Basic oxygen furnaces - dolomite	T2	CS
	Following for indirect gases only:		
	Blast furnaces	T2	CS
	Basic oxygen furnaces	T2	CS
	Iron and Steel (other)	T2	CS
	Rolling Mills (Hot & Cold Rolling)	T2	CS

Iron and steel production may be divided into integrated steelworks, electric arc steelworks, downstream processes such as continuous casting, 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 agglomerates the 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 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 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. These generally use blast furnace gas (BFG), together with coke oven gas and/or natural gas as fuels. Emissions are reported in CRF category 1A2a. Gases emitted from the top of the blast furnace are collected and emissions occur when this BFG is subsequently used as fuel. Emissions from BFG combustion are reported according to the process using them, rather than being reported in 2C1. However some BFG is lost and the carbon content of this gas is reported in 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 in 2C1.

Limestone and dolomite are used in steelmaking, typically being added to sinter where they are calcined, releasing CO₂ which is emitted. Some of the limestone or dolomite used may be added directly to blast furnaces without being sintered first, which would mean that the CO₂

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 CO₂ evolved from the dolomite is reported as a separate category under 2C1.

Electric arc furnaces produce steel from ferrous scrap using electricity to generate the high temperatures necessary to melt the scrap. Carbon dioxide emissions occur due to the breakdown of the graphite electrodes used in the furnace.

The UK had 2 integrated steelworks (at Port Talbot & Scunthorpe) in operation at the end of 2016, 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 3 large steelworks, in Rotherham, Sheffield and Tremorfa, and a few smaller works. Other large steelworks once operated in Sheerness, and Newport.

4.16.2 Methodological Issues

The methodology for estimating CO₂ 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 from 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.

Usage of limestone and dolomite for steel production is available from the Iron & Steel Statistics Bureau (2018). The carbon content of limestone and dolomite used at steelworks is available from operators via the EU ETS data. Separate values are available for the years 2007-2017. These data show close consistency across the time series and therefore the 2007 value has been extrapolated back to 1990.

Carbon emissions from electrodes in electric arc 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 2005-2017, 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 other process emissions from foundries of direct GHGs are likely to be very small and are not estimated. **Table 4.14** summarises the methods used for emissions reported under 2C1.

Table 4.14 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	<p><u>Carbon</u>: UK-specific factor from carbon balance</p> <p><u>CH₄</u>: UK-specific based on reported emissions</p> <p><u>N₂O</u>: Fynes & Sage (1994)</p>

Source Category	Method	Activity Data	Emission Factors
Sintering – carbonates	AD x EF	ISSB	<u>Carbon</u> : UK-specific from EU ETS
Iron & steel - flaring	AD x EF	BEIS energy statistics	<u>Carbon</u> : UK-specific factor from carbon balance <u>CH₄, N₂O</u> : IPCC (2006)
Electric arc furnaces	AD x EF	ISSB	<u>Carbon</u> : UK-specific factor <u>CH₄, N₂O</u> : EMEP/EEA
Ladle arc furnaces	AD x EF	ISSB	<u>Carbon</u> : UK-specific factors

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 and from DUKES. Time-series consistency of these activity data is very good due to the continuity in data in these publications.

4.16.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the inventory in **Section 1.6**.

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, due to revisions to UK energy statistics affecting the carbon balance calculations.

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 come to light. Emission factors and activity data will be kept under review. Where appropriate, fuel characterisation data from verified EU ETS 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 CO₂ 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 previous version of the BREF note (Best Available Techniques Reference document) for the non-ferrous metals industry, produced by the European IPPC Bureau⁴⁵ estimated UK production in 1993 as 55 ktonnes out of a European total production of 2,620 ktonnes while the updated version of that document, published in 2017, 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 CO₂ 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 of direct GHGs. 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 as all UK consumption of these fuels is assumed to lead to emissions of CO₂. Any emissions associated with ferroalloy production would therefore already be included in 1A2a or 1A2b for coal, or 1A2g or 2C6 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 or 2C6 to 2C2.

There is no evidence of any current 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.

4.18 SOURCE CATEGORY 2C3 – ALUMINIUM PRODUCTION

4.18.1 Source Category Description

Aluminium was produced by the electrolytic reduction of alumina at two UK sites 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 closed

⁴⁵ downloadable from <http://eippcb.jrc.ec.europa.eu/reference/>

in mid-2000. The operational site and the recently-closed processes all use or used the pre-baked anode process, whereas the plant 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 CO₂. The PFC species tetrafluoromethane (CF₄) and hexafluoroethane (C₂F₆) 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.

The smelter design has a large effect on the rate of PFC emissions, and point feeder prebake technology is regarded as the best option for feeding aluminium oxide into the electrolytic cells, allowing addition at controlled intervals, resulting in fewer anode effects. Over the time series, the UK operators of aluminium smelters have invested to improve plant performance, and all sites were converted to point feeder technology, leading to large reductions in PFC emissions per unit production as a result.

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.

All emissions of PFCs (CF₄ and C₂F₆) occur during the aluminium smelting process during anode effects. The UK inventory data are directly reported by plant operators, and are emission estimates calculated from the number and duration of anode effects at each facility.

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. 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.

The UK total primary aluminium production activity data are taken from the UK Minerals Yearbook (BGS, 2018) in years where complete data on production from operators are not available, 1990-2004 and 2006. In all other years of the time series, we have both the BGS data and also a complete set of operator production estimates. The two datasets are very closely consistent (perhaps as there are only up to three operators in any one year); for example, over the last 5 years (2013-2017) both sets of data present UK production of 228 ktonnes aluminium, with very small % differences at the year-specific level. The BGS data are presented rounded to 2 significant figures, and due to this lack of precision but close consistency, the UK inventory method uses the sum of all operator-reported data from 2005 and 2007 onwards, as these are regarded as the most accurate data to use in each year.

Methodologies used for direct gases from 2C3 are summarised in **Table 4.15**.

Table 4.15 Emission Estimation Methods for Primary Aluminium Production, CRF Category 2C3

Source Category, Gas	Method	Activity Data	Emission Factors
Primary aluminium, CO ₂	AD x EF	UK Minerals Yearbook (BGS, 2018); Σ operator production data (Anglesey Aluminium, to 2010; RioTintoAlcan, 2018)	Technology-specific default EFs for Soderberg and pre-bake processes
Primary aluminium, PFCs	Σ operator emissions data		Derived from operator reported emissions data, based on IPCC T2 method

The time series of emission factors and activity data used are reported in **Table 4.16** below. Note that the PFC EFs presented here are essentially back-calculated IEFs for the UK industry as a whole, derived from the reported production data and sum of operator-reported emissions.

Table 4.16 Activity Data and Emission Factors: UK Aluminium Production 1990-2017

Year	Activity data	Emission factors - kt/Mt		
	Mt Al Produced	Carbon	CF ₄	C ₂ F ₆
1990	0.290	423.8	0.601	0.075
1995	0.238	423.2	0.158	0.019
2000	0.305	420.0	0.110	0.014
2005	0.370	420.0	0.035	0.004
2008	0.327	420.0	0.046	0.006
2009	0.254	420.0	0.032	0.004
2010	0.186	420.0	0.079	0.010
2011	0.214	420.0	0.099	0.013
2012	0.060	420.0	0.031	0.004
2013	0.044	420.0	0.018	0.002
2014	0.042	420.0	0.115	0.014
2015	0.048	420.0	0.027	0.003
2016	0.048	420.0	0.034	0.004
2017	0.047	420.0	0.037	0.004

4.18.2.1 Aluminium alloy production

No emissions of SF₆ are reported by any of the aluminium foundries in the Pollution Inventory or SPRI. Emissions from the use of SF₆ in the UK aluminium sector are therefore reported as Not Occurring.

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.

Activity data on UK aluminium production since 2006 is available from both the British Geological Survey UK Minerals Yearbook, as well as directly from operators, with the latter data set presented at a greater level of precision. The two datasets show very close consistency over time, with small % differences year to year, which is at least partly due to the rounding in the BGS data. The BGS data are from a long running publication and the compilers of the activity data strive to use consistent methods to produce the activity data; there are also only a small number of UK producers, and complete reporting of their production, direct to the inventory agency, for over a decade.

Similarly the methods used by operators to estimate emissions are specific to the technology of their plant, and for PFCs are consistent with the IPCC Tier 2 method across the time series.

The consistent access to good quality data from the UK industry therefore helps to ensure good time series consistency of the emission estimates across all years, despite the switch to use (more precise) operator activity data from 2007 onwards.

There was a large decline in emissions in 2012 as aluminium smelting activities came to an end in March 2012 at one of the largest UK production plants at Lynemouth. In 2010, 2011 and 2014 there was a significant increase in the implied emission factor for PFCs because of process issues during those years, for example an 'anode crisis' in 2014.

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 1.6**. Emissions data taken from the Pollution Inventory are subject to additional QA/QC from the Inventory Agency.

4.18.5 Source Specific Recalculations

There have been no significant recalculations for this sector.

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

In the UK, SF₆ and an HFC act as cover gases to prevent molten magnesium from burning during the production of magnesium.

4.19.2 Methodological Issues

Sulphur hexafluoride is used as a cover gas to prevent magnesium oxidising when exposed to air, because it is non-flammable and heavier than air. It is estimated that 95% of SF₆ (Gluckman, 2013) used in this way is released to the atmosphere unless capture/recycle technologies are employed. SF₆ is non-flammable and non-toxic, and is therefore a safe gas to use. In the UK, SF₆ has been used as an alternative cover gas to SO₂ in magnesium alloy production and sand and die-casting since the early 1990s. Since 2006, EU magnesium producers have looked for alternatives to SF₆ in response to bans in the EU F-Gas regulation. Some die casters have gone back to using SO₂. 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, SF₆ is used for casting specific magnesium alloys where other cover gases, such as HFC-134a, are currently considered not suitable.

The 2014 EU F-Gas Regulation prohibits the use of SF₆ in magnesium die casting, from 1 Jan 2018, the ban is extended to installations using a quantity below 850kg per year. Note that, as mentioned below, most UK magnesium production uses processes other than die casting, so this ban only has a limited impact on this sector.

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 SF₆ 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 SF₆ 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).

For magnesium alloy production, SF₆ 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 SF₆ 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 SF₆ (and thus reducing emissions on a CO₂ 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 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 SF₆ and HFC-134a (that represent 99% of UK emissions from magnesium) are now contacted annually for their activity data (consumption of SF₆ and HFC-134a).

Emissions of FK 5-1-12 cannot currently be reported via the CRF as there is no space to report this product, it would also be a low priority to include as it is a sparingly used product with a GWP comparable to CO₂. It is estimated that the decomposition of 1 tonne of FK 5-1-12 during use as a cover gas generates ~400 tonnes CO₂e of PFCs, but as this product is used only at 1 small magnesium site and trialled at one larger site, total emissions in the UK due to the decomposition of FK 5-1-12 have been estimated to be less than 0.001% of the UK national total since 2012 and 0 beforehand. According to the UNFCCC Guidance for reporting, emissions could be "... considered insignificant if the likely level of emissions is below 0.05 per cent of the national total GHG emissions, and does not exceed 500 kt CO₂ eq.". Therefore, the UK considers this a low priority to formally estimate and report emissions for.

As far as we know, HFC-134a does not decompose into other potent GHGs; any other products potentially emitted would be offset by our conservative estimate of the proportion of HFC-134a emitted.

4.19.3 Uncertainties and Time Series Consistency

The main area of uncertainty is regarding emissions of SF₆ 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 1998-2017, 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.

SF₆ emissions from UK magnesium producers peaked in 2000 at approximately 1,000 kt CO₂ equivalent. The use has fallen steadily, particularly from 2006 onwards, being 110 kt CO₂ equivalent in 2017. HFC-134a emissions were zero until 2008 and are 2 kt CO₂ equivalent in 2017.

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 1.6**. 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 which closed in 2003. Emissions are reported under 2C6 and so this process is described in the following section. Emissions of CO₂ 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 is included in UK fuel statistics as an energy use, and thus emissions of CO₂ are included in the UK inventory, reported under 1A2.

4.21 SOURCE CATEGORY 2C6 – ZINC PRODUCTION

4.21.1 Source Category Description

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 CO₂ 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 lead to process emissions of CO₂, and emission estimates from these two sites are also reported under 2C6.

4.21.2 Methodological Issues

Britannia Zinc reported CO₂ emissions in the Pollution Inventory (Environment Agency, 2018) from 1998 until 2002, at which point the site ceased operation. Emissions of CO₂ 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. No data are available on the quantities of coke and other fuels used, or the quantities of limestone that might have been used. The operator-reported CO₂ emissions in the Pollution Inventory are totals only, and do not provide any insight regarding the split of emissions source 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. 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 (BEIS, 2018), '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. Based on all available information, the inventory agency considers 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 possibly in the blast furnaces at Capper Pass as well) but there is no information 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 no emission estimates for these source categories are 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.

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 Britannia 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 inventory in **Section 1.6**.

4.21.5 Source Specific Recalculations

There have been no significant recalculations in this category.

4.21.6 Source Specific Planned Improvements

It is noted that this sector has been identified as a key category in this inventory submission, due to the site closures and resultant sector contribution to the UK inventory trend, and that a tier 1 method is used. The UK has recently reviewed this sector and included some additional sources using the best currently available data. Unfortunately as the only sites in this sector have been closed for a number of years it is highly unlikely that new data will be found to derive a better estimate.

4.22 SOURCE CATEGORY 2D1 – LUBRICANT USE

4.22.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2D1:Industrial engines – lubricants	T1	D, CS
	Agricultural engines – lubricants	T1	D, CS
	Marine engines – lubricants	T1	D, CS
	Road vehicle engines – lubricants	T1	D, CS

Emissions of CO₂, CH₄ and N₂O arise from lubricant combustion in engines and other machinery. Note that waste lubricants can be recovered and subsequently used as fuels but emissions from this source are included in CRF 1.A.

4.22.2 Methodological Issues

Detailed activity data on lubricant use by source category are not available in the UK; there is insufficient data to implement an IPCC Tier 2 method, and therefore the 2006 IPCC GLs Tier 1 method is applied. DUKES (BEIS, 2018) includes some limited data breakdown on sector-specific lubricant use (e.g. use by industry, agricultural sector, shipping) in addition to the total lubricant demand time-series. Lubricant consumption in road vehicle engines is estimated using the COPERT method from the EMEP/EEA Emissions Inventory Guidebook (2016). 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.

The consumption estimates are used to calculate CO₂ emissions which 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. Whereas the COPERT method directly calculates the quantity of lubricant consumed or burnt in road vehicles, for other sectors we assume that 20% of lubricant use is oxidized during use. In all cases we apply a UK-specific carbon emission factor for lubricants which is based on analysis of UK waste oil samples.

Emissions of CH₄ and N₂O also arise from lubricant combustion in road vehicle 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 CH₄ and N₂O (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.

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 a 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 inventory in **Section 1.6**.

4.22.5 Source Specific Recalculations

There have been some very minor revisions to UK energy statistics, and a small re-allocation of lubricant from 2D1 to 1A3biv.

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

This category includes CO₂ emissions from paraffin wax use.

4.23.2 Methodological Issues

DUKES gives total consumption of petroleum waxes for the years 1990-2008 only. For 2009 onwards, petroleum wax consumption is only available as part of the much larger consumption of 'miscellaneous petroleum products'. Activity data for UK consumption of petroleum wax from 2009 onwards are available from the UK energy statistics team (Personal communication: Cartwright, 2018) on the same basis as the earlier data, as they comprise part of other long-term energy data reporting outputs, e.g. to EUROSTAT.

Therefore, in this submission the UK inventory is based on the full time series of data for petroleum wax use; in previous submissions, the 2009 onwards data had been extrapolated from the 2008 data.

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

Estimates for this sector are uncertain because of the use of a Tier 1 methodology. The time series consistency of the activity data are good, as they are part of a long-running routine energy data compilation and reporting system, by the UK energy statistics team in BEIS, and also for the EFs as a Tier 1 default is used in all years.

4.23.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the inventory in **Section 1.6**.

4.23.5 Source Specific Recalculations

The activity data from 2009 onwards have been recalculated, as indicated in the method section, due to the inventory agency accessing activity data specific to petroleum waxes in each year, instead of extrapolating data from the last dataset that was included in the DUKES publication (for 2008). These are very small recalculations in the UK inventory context, of around 3-13kt CO₂ per year, and the data in some years are increases, others are decreases. The 2016 data are now around 4ktCO₂ higher than the last submission, which is an 18% increase of a very small emission source.

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 of CO₂ 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 (NH₂)₂CO and is injected into the exhaust stream of certain types of diesel vehicles (currently Euro IV, V and VI 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 CO₂ 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 (20 out of 28) between 1990 and 2017, it is assumed that there are additional, unknown uses of the fuel 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 DUKES as 'non-energy use', it has been assumed that it is used for an unknown process. Such uses could be non-emissive with the carbon stored, but in the UK inventory it is assumed that all carbon in this petroleum coke is emitted, and reported in 2D3.

4.24.2 Methodological Issues

The 2006 IPCC Guidelines specify two approaches for estimating CO₂ 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 IVV and VI standards. These came into effect from 2006. The EMEP/EEA Emissions Inventory Guidebook (2016) provides the means for estimating urea consumption as a proportion of fuel consumed by these specific types of vehicles. Fuel consumption by Euro IV, V and VI HGVs and buses was estimated using a bottom-up method described in **Chapter 3**. 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 and it is assumed that 100% of Euro VI vehicles are equipped with SCR. 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 or bus, 6% for Euro V and 3.5% for Euro VI. 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 kgCO₂/kg urea solution was used, from the EMEP/EEA Guidebook. 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 in this fuel being emitted. The 2006 IPCC default factor for petroleum coke has been used in conjunction 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.

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 CO₂ 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 nine 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.

4.24.4 Source Specific QA/QC and Verification

This category is covered by the general QA/QC of the inventory in **Section 1.6**.

4.24.5 Source Specific Recalculations

The estimate of urea emissions is dependent on the fraction of specific HDVs' fuel use; therefore, the revision to the fuel consumption factors and fuel normalisation methodologies in 1A3b means that there are small recalculations to 2D3 emissions from urea use in this submission, of around 0.8 ktCO₂ in 2016

In addition, there have been revisions to the estimates of petroleum coke used in other sectors (such as 2C), and these recalculations have an impact on the estimates of petroleum coke used in 2D3, as the 2D3 activity data is the residual once known uses of petroleum coke in other source categories are subtracted from the total UK petroleum coke demand. The change is small for all years, with the exception of 2016, where emission estimates for 2D3 are now 179 kt CO₂ compared with a previous figure of zero (i.e. in the previous inventory, the petroleum coke used in other sectors exceeded the UK demand total).

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 SF₆ 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 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 given⁴⁶ 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.

4.26.2 Source Specific Planned Improvements

Any emergence of volume manufacturing capacity of TFT flat panel display is kept under review.

⁴⁶ Table 6.7 of Volume 3 of the IPCC 2006 Guidelines

4.27 SOURCE CATEGORY 2E3 – PHOTOVOLTAICS

4.27.1 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 given⁴⁷ 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.

4.27.2 Source Specific Planned Improvements

Any emergence of volume manufacturing capacity of photovoltaics is kept under review.

4.28 SOURCE CATEGORY 2E4 – ELECTRONICS INDUSTRY – HEAT TRANSFER FLUID

4.28.1 Source Category Description

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 (C₆H₁₄), 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.

⁴⁷ Table 6.8 of Volume 3 of the IPCC 2006 Guidelines

4.29 SOURCE CATEGORY 2F1 – REFRIGERATION AND AIR CONDITIONING EQUIPMENT

4.29.1 Source Category Description

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 4.17 Model End-Uses and Definitions

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.
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.

End-Use		Description
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

A refrigeration/air conditioning inventory model developed by ICF International in 2011, based on revised industry input and a Tier 2 modelling approach. Specifically, the model comprises 13 end-use sub-sectors (as described in **Table 4.17**), for which detailed assumptions were developed to utilise a fully bottom-up approach. The model makes use of a bottom up approach with assumptions made about emission factors and stock levels. The model is 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), including bans of some higher HFCs for some applications and a general phased down of HFC consumption. The model is reviewed on a regular basis.

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. 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 region 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).

Table 4.18 Summary of 2017 Input Assumptions by End-Use^b

Application		2016 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	43,046,902	3,116,386	15	0.10	HCS	0.6%	0.3%	28% ^b
Commercial Refrigeration	Small Hermetic Stand-Alone Refrigeration Units	2,951,697	351,225	10	0.5	HFC-134a, R-404A, R-407C, HCs, HFO-1234yf, R-744	1%	1.2%	28% ^b
	Condensing Units	665,907	47,666	14	6	HFC-134a, R-404A, R-407A, R-407F, R-410A, R-744	2%	6%	12% ^b
	Centralised Supermarket Refrigeration Systems	12,465,659 (m ²)	990,374 (m ²)	18 ^b	0.55 (kg/m ²)	HFC-134a, R-407A, R-407C, HCs, R-744	2%	9%	5% ^b
Transport Refrigeration	Land Transport Refrigeration	97,252	11,322	7	3.3	HFC-134a, R-404A, R-407F, HFO-1234yf, R-744	0.2%	9% ^b	12% ^b
	Marine Transport Refrigeration	527	16	25 ^b	1,500 ^b	HFC-134a, R-407F, R-717	1%	13%	12% ^b
Industrial Refrigeration	Industrial Systems	45,947	1,915	25	99	HFC-134a, R-407F, HCs, R-717, R-744	1%	9%	8%
Stationary Air-Conditioning	Small Stationary Air Conditioning	6,643,972	516,757	13	1.8	R-410A, HFC-32, HCs	0.5%	4%	23%
	Medium Stationary Air Conditioning	346,245	22,296	15	15	HFC-134a, HFC-32, R-410A	1%	5%	17% ^b
	Large Stationary Air Conditioning (Chillers)	45,051	2,809	18	180	HFC-134a, HFC-32, R-410A, R-717, HCs, HFO-1234yf	0.5%	3%	7%
	Heat Pumps	188,246	43,441	15	3.5	R-410A, R-717, HCs, HFO-1234yf, HFC-32	1%	6% ^b	25% ^b
Mobile Air-Conditioning	Light Duty Mobile Air Conditioning	29,020,205	2,271,374	15	0.7	HFC-134a, HFO-1234yf	0.5%	8% ^b	25% ^b
	Other Mobile Air Conditioning	543,171	50,706	10	4 ^b	HFC-134a, HFC-32, R-410A, R-717, HFO-1234yf	0.5%	9% ^b	18% ^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. The indicators for each activity were chosen based on expert judgement and are as follows:

- GDP for refrigerated transport and commercial and industrial refrigeration
- Population for domestic refrigeration and stationary air conditioning
- Number of vehicles for mobile air conditioning

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 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 cycle⁴⁸.

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:

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.

⁴⁸ 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.

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 4.19 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 4.20 summarises 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 4.21.

Table 4.20 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%	
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%	

Application	EF Source	Product Lifetime (years)	Manufacturing Factor	Product Lifetime Factor	Notes
	UK GHGI Model		12-25%	2.5%	Annual cell losses greater but decreases with greater thickness

^a Decommissioning and waste factors are not compared here as they are not comparable to the maximum potential end of life emission factors given in the 2006 IPCC guidelines.

Table 4.21 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%
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 1.6**. Details of verification of emissions are given in **Annex 6**.

4.30.5 Source Specific Recalculations

There have not been any major recalculations to this sector this year.

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

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 of GWP 150 or greater 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. This was maintained in the 2014 F-gas regulations (EC 517/2014).

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 CO₂ equivalent per annum (3100 tonnes of HFC-134a); and
- 2000: 1,700 kt CO₂ equivalent per annum (1200 tonnes of HFC-134a; 1000 tonnes of HFC-152a)

Emissions in tonnes of CO₂ 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 were 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. 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 1.6**. 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

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 emission estimation equation (Equation 7.17) considers 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.

ICF reviewed available literature to confirm/update key assumptions—notably, EEA (2014, 2016)—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).

4.32.2.1 Stock

Annual stock estimates for 1997-2002 were based on data reported by the Fire Industry Confederation and input from industry experts (AEA 2005) and 1995-6 based on estimates presented by March (1999). HFCs and PFCs are not believed to be used in the UK for this application before 1995.

The equipment stock in years beyond 2007 is estimated based on EEA (2017) 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, and 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 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.

The gap for 2003-2006 are filled by using a combination of growth assumptions, assumptions around the phase out of ODS and interpolation.

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, it is assumed that HFC-227ea accounts for 100% of HFC consumption in this sector (over the full product lifetime).

The UK has also reported emissions of C₄F₁₀ from 1995 to 2007.

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 create 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 are only reported from 2015—i.e., 20 years following the initial installation of F-gases in 1995.

Table 4.22 Key assumptions used to estimate HFC emissions from fire extinguishers

Parameter	1990-2000	2001-2004	2005 onwards
Equipment lifetime (yrs)	20		

Parameter	1990-2000	2001-2004	2005 onwards
% released through fire (lifetime)	1.5		
% released through servicing	3.4	1.5-2.9 ⁴⁹	1.0
% released during recovery (disposal)	0.1		

Speciated emissions for the OTs and CDs are reported under 2F3. Emission estimates from the UK GHGI were scaled by the relative 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 1.6**. 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

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. Note that HFC use in MDIs are excepted from the 2014 EU F-gas regulation phase down of HFC consumption.

⁴⁹ Interpolated between 2000 and 2005

4.33.2 Methodological Issues

4.33.2.1 Aerosols

The methodology used to estimate 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) up to 2012. BAMA discontinued collecting data for 2013 onwards, so for these years we have projected estimates of HFC consumption using knowledge of the regulatory landscape and industry insight of the market from a contact at 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%. The lifetime and end of life emissions are calculated after import and exports have been taken into account.

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 2015. Estimates for 1990-1997 are based on extrapolated data from 1998.

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 in recent years (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 CO₂ emissions for this level of MDI consumption (assuming 96% HFC-134a and 4% HFC-227ea).

Table 4.23 Key assumptions used to estimate HFC emissions from MDIs

Year	MDI Number (thousands)	Average Propellant (g per MDI)	Emissions (kt CO ₂ e)
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

Year	MDI Number (thousands)	Average Propellant (g per MDI)	Emissions (kt CO ₂ e)
2014	53,317	12	961
2015	53,612	12	966
2016	54,174	12	976
2017	53,452	12	963

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 1.6**. 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

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:

$$Emissions_t = S_t \times EF + S_{t-1} \times (1-EF) - D_{t-1}$$

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

ICF reviewed available literature to confirm/update key assumptions - notably, Harnish & Schwarz (2003), and EEA (2013).

4.34.2.1 Stock

Annual sales data of HFCs in the UK solvent sector have not been identified. 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 addition to historical F-gas supply data in the EU. Because the consumption estimates in Harnish & Schwarz (2003) in years beyond 2002 were projections, EEA (2017) data on HFC-43-10mee supply data in the EU was used to estimate HFC consumption from 2007 onwards.

To estimate the amount of HFCs placed on the market in the UK, the EU estimates from EEA (2017) were scaled down using a time-dependent UK to EU GDP ratio from Eurostat (2017). 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%⁵⁰ 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.

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.

⁵⁰ Note the ICF report (ICF, 2013) states 45%, but the spreadsheet indicates 50% was used.

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 1.6**. 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

Activity data and emission factors will be kept under review. 2F6b: Refrigerant Containers

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 Refrigerant handling	CS CS	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	No major improvements		

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 includes 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 Consulting Limited (2008), Defra (2008), and 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.

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, and 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 consistent with the UK RACHP model. 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.

Table 4.24 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%
Other HFC blends	10%	10%	80%

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 or 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:

- 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
- 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

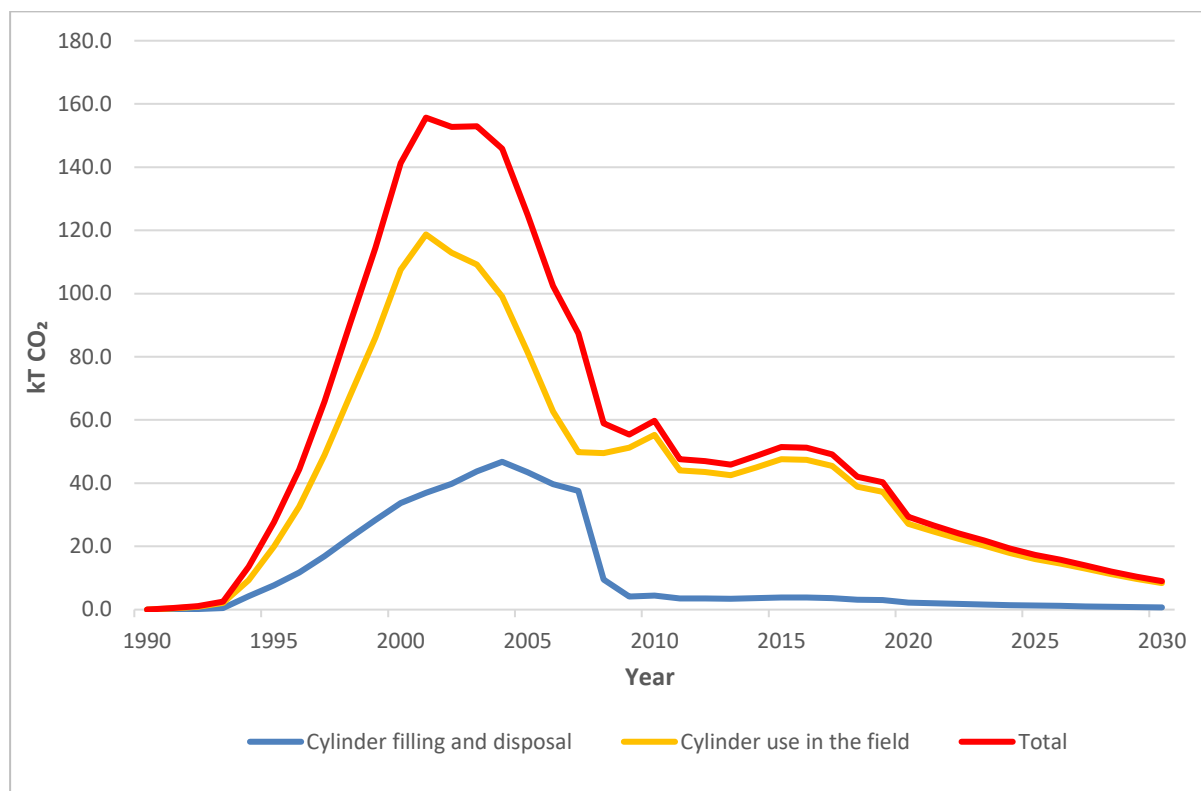
Any heel left in a non-returnable cylinder will be emitted e.g. from a landfill site or a waste metal reprocessing site. There is no data on the average heel size for non-returnable cylinders or small cans. Only a small proportion of UK refrigerant was sold in non-returnable packages in the period 1990 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 4.3 Trends in refrigerant container emissions

4.35.2.5 Refrigerant handling by other organisations

In addition to the Fillers & Packers, Mexichem, an organisation involved in HFC manufacture, processing and bulk transportation in the UK provides estimates of the HFCs and PFCs emitted as a result of refrigerant handling separately from emissions associated with halocarbon manufacturing.

It's likely that there is some overlap in scope with the modelled approach to total UK emissions due to the transportation of refrigerants. However, we know that some of the activities being conducted – like the refinement of HFC-134a to medical grade – are not considered in the transport of refrigerants model, so we include both to ensure completeness.

4.35.3 Uncertainties and Time Series Consistency

As discussed above, emissions in the field dominate the total. From 2009 the emissions from filling and disposal of cylinders are well under 10% of the total. There is a high confidence in the estimates for filling and disposal post-2009. Prior to 2008 the filling and disposal estimates have a lower confidence because of uncertainties regarding the quantity of refrigerant left in non-returnable cylinders/cans on disposal. 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 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

No recalculations have been made to this category.

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

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 mature alternative technologies to using SF₆.

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 is reported by the key UK users of Gas Insulated Switchgear (GIS), including National Grid and the UK electricity distribution companies via the electricity industry Regulator, Ofgem. Data was also obtained from ENA (Electrical Networks Association) and data for power stations that use relatively small amounts of SF₆ for switchgear from the environmental regulators' inventories (EA, NRW, SEPA and NIEA; all 2018). 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 SF₆.

The operator-reported annual data are used to estimate the size of the SF₆ bank in GIS and emissions for 2013 onwards. Estimates for 2008-12 are based on reporting from the National Grid and each of the distribution companies. 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.

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 1.6**. 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

Military applications include Airborne Warning and Control System (AWACS), which are military reconnaissance planes. In AWACS, the SF₆ 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 SF₆ per plane per year is used to estimate emissions.

The method uses 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 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 MOD have shared data for one year, which suggested that the current estimate is conservative. We are continuing to engage with the MOD to obtain a time-series of data and consent to use these data for reporting.

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 1.6**. 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**

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 SF₆ are used. The emissions of SF₆ are planned releases. Radiotherapy accelerators are typically opened two times a year when being serviced and the SF₆ contained is not captured but completely released. (Schwartz, 2005).

SF₆ 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):

$$\text{Total emissions} = \text{University and research particle accelerator Emission Factor} \times \sum \text{Individual Accelerator Charges}$$

Where:

SF₆ university and research particle accelerator Emission Factor = 0.07 kg SF₆ per kg SF₆ charge, the average annual university and research particle accelerator emission rate as a fraction of the total charge.

Individual Accelerator Charges = SF₆ contained within each university and research accelerator.

The SF₆ 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):

$$\text{Emissions} = (\text{number of particle accelerators that use SF}_6 \text{ by process description in the country}) \times (\text{SF}_6 \text{ charge factor, kg}) \times (\text{SF}_6 \text{ applicable particle emission factor})$$

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)

SF₆ charge factor = the average SF₆ charge in a particle accelerator by process description.

SF₆ particle accelerator Emission Factor = the average annual SF₆ particle accelerator emission rate as a fraction of the total charge by process description. These factors are presented in **Table 4.25** below.

Table 4.25 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 SF₆ 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 SF₆, ICF conservatively assumed that 100% of UK medical particle accelerators use and emit SF₆. To estimate SF₆ emissions for years 1990-2011 and 2013 onwards, 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 SF₆ 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 SF₆ 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 SF₆ 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 1.6**. 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 – SF₆ AND PFCS FROM OTHER PRODUCT USE

4.39.1 Source Category Description

Emissions of PFCs and SF₆ from the production of semiconductors, the use of SF₆ as a tracer gas, and PFCs and SF₆ from sporting goods (training shoes) have been combined in order to preserve the confidentiality of estimates of emissions of SF₆ and PFCs used in training shoes.

The electronics industry is one of the largest sources of PFC emissions in the UK. The main uses of PFCs are:

- 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, SF₆ is used in etching processes for polysilicon and nitride surfaces, and there is some usage of CHF₃ and NF₃.

The UK uses of SF₆ as a tracer in scientific research.

A sports goods manufacturer selling shoes in the UK used SF₆ 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. SF₆ 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 SF₆ from its training shoes by 30 June 2003 – a goal which was achieved. It had originally planned to replace all SF₆ 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 SF₆.

Cushioning units typically outlast the lifetime of the training shoe because the rate of diffusion of SF₆ is so slow. In the UK, training shoes are generally sent to landfill at the end of their useful lives, where any SF₆ or PFC will eventually leak to the atmosphere.

4.39.2 Methodological Issues

4.39.2.1 Semiconductor manufacture:

For the semiconductor manufacture sector, the 2006 GLs Tier 1 method estimates emissions based on the amount of substrate processed, in units of m².

The 2006 GL Tier 2a method is represented by the following equation:

$$\text{Emissions for } E_i = (1-h) \cdot FC_i \cdot (1-U_i) \cdot (1-a_i \cdot d_i)$$

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 estimates by-product emissions of CF₄, C₂F₆, C₃F₈ and CHF₃. The Tier 2a equation used for by-product emissions is:

$$\text{By-Product Emissions of gas } j \text{ (BPE}_{j,i}) = (1-h) \cdot B_{j,i} \cdot FC_i \cdot (1-a_i \cdot d_i)$$

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 = CF₄, C₂F₆, CHF₃ and C₃F₈

4.39.2.1.1 Activity Data

Estimates of PFC used for the UK semiconductor industry in 2001 were provided by UK Microelectronics Environmental Advisory Committee, based on 2001 purchases of PFCs as reported by individual companies in the UK semiconductors industry. No suitable further activity data have been identified during consultations with relevant UK and EU trade bodies, although, UK industry have contributed to determining suitable estimates of the trends, both in terms of total semiconductor industry trends and the relative use of different PFCs.

The NF₃ consumption has been divided into NF₃ remote clean and all other NF₃ consumption (i.e., for in-situ chamber clean and etch processes). NF₃ remote clean refers to a cleaning method for chemical vapour deposition chambers in which the film cleaning-agents formed from NF₃ (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 NF₃ or other F-gases to generate F-atoms in the chambers whose walls are being cleaned. NF₃ may also be used to etch patterns (i.e., circuits) on semiconductors. The use of NF₃ remote clean is assumed to start in 2003 and growing increasingly over time. As no data on the UK's use of NF₃ remote clean processes was made available from NMI, the US semiconductor market was used as a proxy to estimate the use of NF₃ in remote clean processes relative to all other processes.

Specifically, the share of NF₃ remote clean versus other uses was estimated based on industry-reported NF₃ 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 NF₃ 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 NF₃ use in remote clean and NF₃ 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 4.26 Summary of 2006 GL Tier 2a emission factors for the semiconductor manufacture sector

Process Gas (i) ^a	CF ₄	C ₂ F ₆	CHF ₃	CH ₂ F ₂	C ₃ F ₈	c-C ₄ F ₈	NF ₃ Remote	NF ₃	SF ₆
Emission Factor (1-U _i) ^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 ₂ F ₆	NA	NA	NA	NA	NA	0.1	NA	NA	NA
BC ₃ F 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 U_i = 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. The assumptions regarding destruction efficiencies for emission control technologies are based on the 2006 GLs.

Table 4.27 Key assumptions used to estimate emissions from semiconductor manufacture

Gas	Destruction efficiency ⁵¹	Fraction fed to abatement					
		1990	1995	2000	2005	2010	2012 onwards
CF ₄	0.9	0%	0%	0%	15%	40%	45%
C ₂ F ₆	0.9	0%	0%	0%	15%	40%	45%
C ₃ F ₈	0.9	0%	0%	0%	15%	40%	45%
C ₄ F 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 SF₆ as a tracer gas in scientific research:

SF₆ 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 SF₆ 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"

⁵¹ Destruction Efficiency: Source: IPCC 2006 Guidelines, Chapter 6, Table 6.6

(ASHRAE, 1995). SF₆ 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 SF₆ 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 SF₆ (IPCC 2006). SF₆ is also used for tracer testing of nuclear power plant control room emergency ventilation systems (CARB, 2009).

Due to data limitations, SF₆ emissions were estimated using a slightly modified Equation 8.23 of Volume 3 of the 2006 GLs. The SF₆ 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 SF₆ emissions from this sector. This method is represented in the following equation:

$$\text{Total emissions} = \text{emissions per test} \times \text{number of tests}$$

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.

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 SF₆ 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 SF₆ 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 SF₆ 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.

SF₆ 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.*).

A small charge of SF₆ 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 CH₄ emissions are inferred from the differential concentrations of SF₆ and CH₄ between the flask and atmosphere.

The total amounts of SF₆ used are given in the table below:

Table 4.28 Quantities of SF₆ 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

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 1.6**. 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

This category includes emissions from N₂O used as an anaesthetic.

4.40.2 Methodological Issues

Emissions have been calculated using the outcomes of a study by NHS England (2013). This report calculates the total N₂O 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 N₂O/bed/year⁵². This provides an estimated total N₂O 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 N₂O for anaesthetic use) this was considered the best approach to a country specific estimate for this source. Suppliers of N₂O for anaesthesia were contacted, but they declined to provide data.

In order to expand this figure to incorporate all emissions within the United Kingdom a per-capita N₂O emission of 0.031 kg per annum has been derived from the total N₂O 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 complete time-series of emissions.

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 N₂O should be considered to have a high degree of uncertainty. The methodology doesn't take into account N₂O 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 N₂O as an anaesthetic, as some methods can reduce the consumption of N₂O. 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 1.6**.

In the case of Gibraltar, we have actual data on N₂O imports for anaesthetic use for one year. When compared to the population of Gibraltar this yields an IEF of 0.015 kg per capita. In addition to providing robust data upon which to base Gibraltar emission estimates (using population data to generate a time-series), this improves our confidence that the UK estimate is of the correct order of magnitude.

4.40.5 Source Specific Recalculations

There are no major recalculations to this source for this submission. For information on the magnitude of recalculations, see **Section 10**.

⁵² <http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2013>

4.40.6 Source Specific Planned Improvements

The inventory team will continue to search for data relating to the sales of N₂O for anaesthetic use, and will make improvements to the methodology when this information is available.

4.41 SOURCE CATEGORY 2G3B – OTHER PRODUCT USES OF N₂O

4.41.1 Source Category Description

Very little UK data are available on the use of N₂O in cream products, therefore the approach adopted has been based on the method used in the Danish GHG Inventory (Hjelgaard, 2015). The method therefore assumes:

- 1% of cream consumption is in the form of whipped cream sprays;
- N₂O consumption in those sprays is equal to 5% of the mass of the cream; and
- All N₂O is emitted.

UK cream consumption data are available from Government (DEFRA) statistics (Defra, 2018).

Activity data on the number of adults using new psychoactive substances in the UK is available from 2012 in the Home Office Drug Misuse tables (Home Office, 2018), whilst frequency of use is available only for 2017. It is therefore assumed that;

- The average frequency of use implied by the 2018 statistics is appropriate for all years of the time-series;
- Each recorded use of new psychoactive substances is only a single canister;
- An N₂O cartridge has a volume of 10ml and is compressed to 60 bar; and,
- All N₂O is emitted.

4.41.2 Uncertainties and Time Series Consistency

The UK method for cream consumption 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 N₂O 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.

The UK method for recreational use of N₂O relies on the assumptions that the canister volume and pressure are similar to those used in the whipped cream industry in the absence of more robust data.

Activity data on the number of adults who use new psychoactive substances is available on an annual basis since 2012 with the exception of 2013. In this case, the number of adults is gapfilled by interpolation of the surrounding years. Prior to 2012, no data is available. In these years, the Inventory Agency believes that the level of emissions will not exceed the value of 2012 and therefore are insufficient to demand estimates are made, and say are recorded as “Not Estimated”. The frequency of use per adult is determined using the most recent Home Office Drug Misuse dataset (Home Office, 2018). Since no data is available for other years of the time-series, the 2017 frequency of use is extrapolated to all estimated previous years.

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 1.6**.

4.41.4 Source Specific Recalculations

Revisions to milk utilisation data from DEFRA statistics (Defra, 2018) since 2012 causes a 37-59% increase in activity data from this source.

Estimates for recreational use of N₂O were introduced in the 2019 submission.

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

This category reports N₂O emissions from the chemical industry that are not captured elsewhere. All chemical sites reporting significant N₂O emissions are included where that emission is believed to be from a chemical process, rather than combustion. Other sites do report N₂O emissions, but these emissions are small, and there is no evidence that they are from chemical processes. As such, these estimates are thought to be complete. Emissions from nitric and adipic acid are not included here, as these are reported in 2B2 and 2B3.

4.42.2 Methodological Issues

The UK has a large chemicals sector and all manufacturing sites are regulated and required to report emissions of N₂O (as well as other pollutants). From 1998, when reporting was first required, until 2001 there was no threshold for reporting N₂O, but since 2002, reporting is required only when emissions exceed 10 tonnes. Across the 18 years of reported data, N₂O emissions have been reported in at least one year for 19 sites which can be described as chemical sites. For most of those sites, N₂O is reported for only one or two years out of the time-series and we think it is likely that the reported N₂O is an error (operators do occasionally confuse N₂O and NO_x on their reporting submissions) and in a few other cases it is likely that the N₂O occurs from the substantial combustion processes that constitute part of the reporting installation. In three cases however N₂O 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 N₂O). 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 (PI). 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 N₂O back to 2002, but reports NO_x in 2002 as well, and also in 1997-2001. Emissions of N₂O 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 N₂O 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

Gaps in the PI data for the three sites is the most significant source of uncertainty in the estimates. It is possible but unlikely that other sites that report N₂O emit the gas from chemical manufacturing processes but if this were the case, these emissions would be much smaller than those from the three sites currently included.

4.42.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the inventory in **Section 1.6** and the source emissions data from plant operators is subject to the QA/QC procedures of the PI.

4.42.5 Source Specific Recalculations

No significant recalculations have been made for this category.

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

The UK paper industry is mainly confined to the production of pulp from recycled material and the production of papers using 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 and these are reported under CRF category 1A2d. Other emissions of GHGs from UK paper and pulp processes will be minor and are not estimated.

4.44 SOURCE CATEGORY 2H2 – FOOD AND BEVERAGES INDUSTRY

4.44.1 Source Category Description

Food and drink processes will use fuels and emissions from this fuel use are reported in 1A2e. No process emissions of GHGs have been identified, however.

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 3J: Overseas Territory and Crown Dependency emissions
Gases Reported	CO ₂ , CH ₄ , N ₂ O, 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) 3B1: Manure management from cattle – CH ₄ (L1, T1) 3B2: Manure management from sheet – N ₂ O (L1) 3D: Agricultural soils – N ₂ O (L1, T1, L2)
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	No major method changes in the 2019 submission. Data is now presented on a more disaggregated level, but this does not represent methodological improvements.

In source sector 3, the United Kingdom reports emissions from the following categories: enteric fermentation (CH₄) (Table 3A), manure management (CH₄, N₂O) (Table 3B), agricultural soils direct and indirect (N₂O, including synthetic fertiliser, manures applied to soils, urine and dung deposition, sewage sludge, mineralisation, crop residues, histosols) (Table 3D); urea application (CO₂) (Table 3H); liming (CO₂) (Table 3G).

Emissions from rice cultivation (Table 3C) and land burning (Table 3E) do not occur in the UK, and field burning of crop residues (Table 3F) only occurred and are reported until 1993.

Emissions of other pollutants included NO_x, NMVOCs, PM

The agriculture sector has the second largest contribution to total GHG emissions in the UK, after the energy sector. It contributed approximately 8.9% to total emissions in 2017. 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 2017⁵³

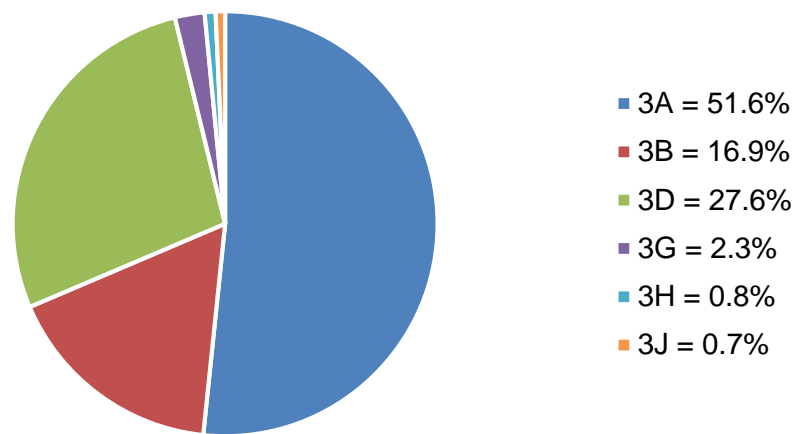


Figure 5.2 Trend in total GHG emissions in the Agriculture sector



⁵³ The Agriculture sectors are explained in the IPCC categories section.

5.1.1 The UK greenhouse gas Inventory model for the Agriculture sector

The UK Government funded a major programme between 2011 and 2017 to substantially improve the calculation methodology, emission factors and sector representation in the estimate of GHG emissions for the Agriculture sector. This culminated in the development of a sector-specific model with a fully revised structure to enable representation of the key underlying driving variables of the GHG emissions, including soils, climate, livestock and cropping characteristics and farm management practices including the uptake of specific mitigation methods. The model also includes detailed representation of uncertainties, allowing full uncertainty analyses to highlight areas for future improvement.

5.1.1.1 Model description

The Agriculture sector model is written in C#, calling on a SQL Server database, using stored Queries. The coded model covers the major components of the Agriculture sector: Dairy, Beef, Sheep, Swine, Poultry, Grassland and Arable, with a separate module for each component with component-specific input tables and component-specific output. Other more minor components (Goats, Horses, Deer, sewage sludge, etc.) are estimated using simpler Excel spreadsheet models.

Data are collated and calculations performed by year (from 1990) and by country (England, Wales, Scotland and Northern Ireland) at a 10 x 10 km grid cell resolution, the results being cumulated across the four countries to derive UK totals. The choice of grid size reflects uncertainty in agricultural holdings that are variously geo-referenced by parish, holding office or field centroids, but is principally justified by the confidentiality restrictions placed on the mapping of inventory input and output datasets.

5.1.2 General sector characteristics

Activity data that apply to more than one source category are: (i) farm types (section 5.2.1); (ii) livestock types and numbers (section 5.2.2); (iii) crop types and crop areas (section 5.2.3); (iv) fertiliser types and application rates (section 5.2.4). These are described in this section and are referred to in the relevant sections throughout this chapter. Year-specific activity data are provided in supplementary tables as Excel files.

5.1.2.1 Soil and climate

Soil properties, notably field capacity, plant available water and percent clay and organic carbon content are used as input to inventory calculations of grass growth and nitrogen leaching following application of fertilisers, managed manures and excreta returns. The improved inventory uses the RB209 (MAFF, 2000) soils classification, based on soil texture and depth to rock, with seven soil types (light sandy, shallow, medium, deep clay, deep fertile silty, organic, peaty). For each country, soil scientists from the James Hutton Institute (Scotland), National Soils Resources Institute University (England and Wales) and the Agri-Food and Biosciences Institute (Northern Ireland) applied the RB209 soil typology to national digital soils datasets. The resulting United Kingdom map of RB209 soil types was spatially intersected with the reference 10 by 10 km grid to provide a statistical summary of the percent of the agricultural land area located on each of the RB209 soil types. The same national digital soils datasets were also used to calculate the percent of the soil area within each grid cell

(excluding peaty soils) that is alkaline, based on top soil measurements of pH (≥ 7), which is used in calculations of ammonia emissions from manufactured fertilisers.

Long-term annual and monthly average rainfall and air temperatures were obtained under project license from the Met Office. Met Office UKCP09 baseline average datasets are for the period 1981 to 2010 (Jenkins et al., 2008). The data were made available at a 5 by 5 km resolution and summarised to the reference 10 by 10 km grid cell. Daily time-series of measured rainfall derived from the UK synoptic network for the MORECS model (Hough and Jones, 1997) were obtained under project licence from the Met Office. Time series for the period 1981 to 2010 were made available at a 40 by 40 km resolution. The probabilities of more than 5 mm of rainfall falling in 24 hours within 1 to 6 days (or more) of a nitrogen application to land (used in calculations of ammonia emissions from manufactured fertilisers), occurring with equal probability on each day of the year, were calculated for each of the MORECS grid squares. The resulting probabilities were correlated with annual rainfall and downscaled to the reference 10 by 10 km grid cell.

5.1.2.2 Farm types

Farm types may be associated with specific structures and practices (from survey data stratified by Farm Type) which can be used to provide better representation in the emission calculations. The classification of agricultural holdings by Farm Type as used in the UK inventory is based on the method described in the EC typology book⁵⁴. It is based on the type of farming and economic size, determined on the basis of Standard Output (SO) coefficients and structural information (area of crops and number of heads of livestock) of the various types of agricultural production. Ten robust farm types (RFT) are applied at Devolved Administration level (England, Wales, Scotland and Northern Ireland): (1) cereals; (2) general cropping; (3) horticulture; (4) specialist pig; (5) specialist poultry; (6) dairy; (7) Grazing livestock (LFA); (8) Grazing livestock (Lowland); (9) mixed; (10) other.

5.1.2.3 Livestock types and numbers

There are eight livestock categories in the UK inventory: dairy cattle, beef cattle, sheep, swine, poultry, goats, deer and horses. The June Agricultural Survey (JAS) data (and since 2005 for England, Wales and Scotland, Cattle Tracing Scheme data) provide a number of sub-categories within the major livestock categories, which are used as the basis for subsequent emission calculations. Actual subcategories included in the JAS vary across years and countries, so standard methods for category aggregation (or occasionally disaggregation) have been developed to provide a consistent set of livestock categories across all countries and years (Defra AC0114, report in press). All livestock are associated with a holding, which is located within a 10 by 10 km grid cell, and with a Farm Type. For animals which are present for less than 1 year (e.g. broilers, finishing swine, lambs) the survey data are assumed to represent the number of animal places and all subsequent calculations are performed on an animal place basis (e.g. N excretion calculations will account for the number of crop cycles within a year for broilers). More details of individual sector structure are given below.

5.1.2.3.1 Dairy cattle

Dairy cattle are disaggregated into three production/breed types (large, medium, small), associated with different average milk yields for each year (high, medium, low) and into four sub-categories by age and physiological status (dairy calf < 1 year, dairy replacement > 1 year

⁵⁴ European Commission Directorate-General for Agriculture and Rural Development, 2016: http://fadn.pl/wp-content/uploads/2016/07/RICC-1500-rev-4-Typology-Handbook_EN.pdf

not in calf, dairy replacement in calf, dairy cow). Data are derived from the Cattle Tracing Scheme (CTS) at a monthly resolution for England, Wales and Scotland since 2005. Each animal is categorised by breed, gender, age and parity (if relevant) and associated with a holding. Breed is associated with a role (dairy, beef, dual purpose). All dairy females are included in the dairy sector; bulls used in the dairy sector and replacements for adult bulls are not included because of the difficulties of differentiating them from the beef sector. This does not affect reporting of total emissions from UK agriculture, as all bulls are accounted for in the beef sector. Dual purpose animals are assigned as dairy or beef according to the majority cattle type on the specific holding. Each breed type is associated to the inventory categories of large, medium or small annual average milk yields. For years prior to the introduction of the CTS in England, Scotland and Wales (1990-2004) and for Northern Ireland for 1990-2015 annual data are derived from the JAS at holding level. Monthly cattle numbers for these years are assumed to be equal to the annual JAS total. Dairy industry data were used to characterise the proportion of dairy cattle associated with each production system for pre-CTS years.

5.1.2.3.2 Beef cattle

Beef cattle are disaggregated into 15 age bands, four breed types (Continental, lowland native, upland and dairy males) and six sub-categories by role, associated with different live weights, growth rates and management practices. The roles include heifers for breeding, beef females for slaughter, bulls for breeding, cereal fed bulls for slaughter, steers for slaughter and beef cows. Data from the CTS are used to populate the inventory categories at a monthly resolution for England, Scotland and Wales from 2005 onwards. Prior to this date, JAS data are used with monthly population scalars applied as derived from the period 2005 to 2009 when both CTS and JAS data were available. For Northern Ireland, JAS data are used for the entire time series.

5.1.2.3.3 Sheep

Sheep are disaggregated into three production systems (hill, upland and lowland) associated with different livestock parameters and management practices, and three types (ewe, lamb and ram) using data from the JAS, the December Agricultural Survey and a specific survey on the structure of the UK sheep flock by Wheeler et al. (2012). The ewe category includes replacement breeding sheep and cull ewes, as well as the ewes and ewe lambs that were successfully lambed in the survey year. The lamb category includes slaughtered lambs and those retained for breeding. The survey count of lambs is raised by between 1% (Scotland) and 5% (England) to account for the fraction of early spring lambs that are born, reared and marketed before the June Agricultural Survey takes place (Pollott, 2003; Wheeler et al., 2012). Animal numbers are split between hill, upland and lowland systems (associated with breed and management practices), based on holding location with respect to the Less Favoured Areas weighted by survey data from Wheeler et al. (2012). For each system, the fraction of ewes first tupped as ewe lambs, and the fractions of lambs finished at grass, finished as stores, or used for breeding replacements, are taken from the December Agricultural Survey (Defra, 1990 to 2000) and Wheeler et al. (2012).

5.1.2.3.4 Swine

Six categories of swine are included: (1) sows (including sows in pig, sows being suckled and dry sows being kept for further breeding); (2) gilts (including gilts in pig and gilts not yet in pig); (3) boars for service; (4) fattening swine >80 kg (incl. barren sows for fattening); (5) fattening swine 20-80 kg; (6) fattening swine <20 kg. Data are obtained from the JAS for England, Wales, Scotland and Northern Ireland, and where JAS categories do not match the inventory categories, consistent data translation rules are applied (Defra AC0114, in press).

5.1.2.3.5 Poultry

Eight categories of poultry are included: (1) growing pullets; (2) laying hens; (3) breeding flock; (4) broilers; (5) turkeys; (6) ducks; (7) geese; (8) all other poultry (exc. turkeys, ducks and geese). Data are obtained from the JAS for England, Wales, Scotland and Northern Ireland, and where JAS categories do not match the inventory categories, consistent data translation rules are applied (Defra AC0114, in press). Data for England & Wales in 1996 were missing from the agricultural census (holding level) data and have been recreated by scaling these at a holding-level with the 1995 census to national totals.

5.1.2.3.6 Goats, deer and horses

Number of goats, deer and horses are derived from holding level data (JAS). Missing data for some years were gap-filled using data from other years as described in Defra AC0114 (in press).

5.1.2.4 Crop types and crop areas

Data are required by crop type, end purpose, location, rates, time and type of fertiliser or manures applied, residue management practises, crop yield, residue N concentrations and mitigation methods.

A total of 48 arable/sowing time crops combinations are categorised in the UK inventory. Cereals comprise oats, wheat, barley and other minor cereals (with disaggregation for spring and winter types where possible); pulses include field beans and peas; potatoes, sugar beet, oilseed rape, maize, rootcrops, , leafy forage and other fodder crops; vegetables and other horticultural crops, soft and top fruit, miscanthus, willow, vine grapes, and linseed. Full details of crops are in the supplementary material.

Grassland is classed as improved temporary (sown within the last 5 years), improved permanent (not sown with the last 5 years), and unimproved (Unimproved Sole Right Rough Grazing and Unimproved Common Grazing). Areas are estimated using a new categorisation of holding level records from the June Agricultural Survey. Improved grass area is disaggregated between representative farm types, defined by enterprise share of standard output. Values for the proportion of both temporary and permanent improved grassland area that is renewed annually are between 3.7 (Wales) and 14.7% (England) for temporary grass, and between 2.0 (England) and 4.0% (Scotland) for permanent grass (BSFP 2004 to 2016).

5.1.2.5 Crop residues

Calculations of N inputs from the biomass in crop residues now include much UK-specific data on above and below ground biomass and the N concentrations in such biomass (Williams and Goglio, 2017). Nitrogen inputs from cereal crop and oilseed rape residues are estimated in the UK inventory using an approach based on the Harvest index parameterised using mostly UK (and some European) data. The IPCC Tier 1 method considerably overestimates cereal crop residues when primary yields are as high as those in the UK. Activity data on residue management available since 2004 from the British Survey of Fertiliser Practice (BSFP) enables limited disaggregation by country, crop and type.

Areas of crop residues that were harvested or burned came initially from national level surveys from 1990 to 1993 and then from the BSFP field level data from 2004. Primary crop yields are taken from national statistics. Regional yields of major cereals in England became available from 1999 and these are used in preference to the national values for England. Farm practice data in Northern Ireland (NI) is supplied by the lead NI government agricultural statistician.

Details of values used are in the supplementary material.

5.1.2.6 Fertiliser types and application rates

Six N fertiliser types are considered in the UK greenhouse gas inventory: ammonium nitrate, urea, urea ammonium nitrate, ammonium sulphate/diammonium sulphate (considered together), calcium ammonium nitrate, and all other N fertilisers. The inventory uses data from the British Survey of Fertiliser Practice for England, Wales and Scotland and the Farm Business Survey for Northern Ireland on application rates to crop type and the relative use of different fertiliser types. From 2004, field level data are available from BSFP enabling N applications for most crops to be disaggregated to the levels of country, region, Farm Type and crop. Minor crops where less data exist are disaggregated at the country level only.

For grassland, emissions are calculated for improved temporary and permanent grassland, it is assumed that no N is applied and no renewal takes place in sole rights or commons rough grazing land. Field average fertiliser N application rate for improved temporary and permanent grassland are calculated separately, by Farm Type, using additional information sourced from these surveys on the proportion of the grass area receiving fertiliser N.

5.1.2.7 Calculation of Emission Factors for N₂O emissions from soils

Sources leading to N₂O emissions include slurry, farm yard manure (FYM), fertiliser, and dung and urine applied to the land, where the latter is simulating conditions leading to the emissions from grazed lands. Water filled pore space (wfps) was identified as a key driver of N₂O emissions (Conen et al., 2000), and is affected by both soil clay content and rainfall. The clay content of the soils (NRSI Cranfield, JHI and Ireland) is available at a 1km grid square while the weather data (MORECS) is available at a 40 km grid square. Detailed information on some of the individual experiments that provided the data for the analysis can be found in reports (AC0114, AC0116) and journal articles (e.g. Bell et al., 2016a; Bell et al., 2016b; Bell et al., 2015; Smith et al. 2012; Sylvester-Bradley et al., 2015). Following the guidelines of the IPCC (2006) for the derivation of N₂O EFs, all the data from the experiments were collected over a 12-month period. The static chamber methodology was used to collect all the data, which is consistent with the Global Research Alliance guidelines (de Klein and Harvey, 2012). Data were collected by N-source: surface-spread and broadcast slurry, farm yard manure, dung and urine, and ammonium-based and urea-based fertilisers. In all experiments a control treatment, which received no organic or inorganic fertiliser was included. In all cases, as well as the emissions and the nitrogen application rates, data on the soil characteristics, and the total rainfall (RainYr, mm) and the average daily temperature for the 365 days associated with the experimental period were collated. The analysis was carried out by using REML regression using Genstat 17th Edition Release 17.1 VSN International Ltd., Oxford. With the exception of the Other N to grassland, the EFs for fertiliser application, FYM, broadcast slurry and grazing were lower than the IPCC default value of 1%.

The resulting model for urea application to estimate yearly emission values was:

$$\ln(\text{CumN}_2\text{O} + 1) = 0.494(\pm 0.10008) + 0.002035(\pm 0.0001542) * \text{NRate}$$

Where *CumN₂O* is the cumulative annual N₂O-N emission (g ha⁻¹), *NRate* is the rate (kg ha⁻¹) at which fertiliser N is applied.

For ammonium nitrate, the model was:

$$\begin{aligned} \ln(\text{CumN}_2\text{O} + 1) = & 0.1616(\pm 0.13526) + \\ & 0.00006093(\pm 0.000240365) * \text{NRate} + \\ & 0.0005187(\pm 0.00016259) * \text{RainYr} + \\ & 0.00000354(\pm 0.0000002785) * \text{NRate} * \text{RainYr} \end{aligned}$$

where $CumN_2O$ is the cumulative annual N_2O -N emission ($g\ ha^{-1}$), $NRate$ is the rate ($kg\ ha^{-1}$) at which fertiliser N is applied and $RainYr$ (mm) is the total rainfall for the 365 of the experimental period.

In the case of FYM and slurry the results from the field experiments carried out with applications in the spring and autumn under the Defra AC0116, AC0213 and other projects were used. For excreta deposition under grazing, the new emission factors were estimated from application of urine and dung to soil either the spring, summer or autumn. The resulting emission factors were calculated as the mean of all the experiments for each source (see Annex, further details of the resulting values can be provided on request or from Defra report AC0116).

5.2 SOURCE CATEGORY 3A – ENTERIC FERMENTATION

5.2.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3A1: Dairy Cows Enteric	T3	CS
	Beef Cows enteric	T3	CS
	Other Cattle Enteric	T3	CS
	3A2: Sheep Enteric	T3	CS
	3A3: Swine Enteric	T1	D
	3A4: Goats Enteric	T1	D
	3A4: Horses Enteric	T1	D
	3A4: Deer Enteric	T1	D
Gases Reported	CH ₄		
Key Categories	3A: Enteric Fermentation - CH ₄ (L2, T2) 3A1: Enteric fermentation from Cattle - CH ₄ (L1, T3) 3A2: Enteric fermentation from Sheep - CH ₄ (L1, T3)		
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). UK implied EFs are applied to animal numbers in the CDs, and 2006 IPCC default EFs are applied to animal numbers in the OTs. Tables of animal numbers used in calculations can be found in Annex 3.3.1 .		
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 have been made since the last submission		

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 CH₄, although ruminants are the largest source per unit of feed intake.

5.2.2 Methodological issues

5.2.2.1 Dairy cows

Enteric methane emissions for dairy cows are estimated using a UK-specific relationship between daily enteric emission and feed dry matter intake, as developed under Defra-funded projects AC0115 (Defra AC0115) and AC0114 (Defra AC0114):

$$CH_{4_enteric_dc} = (15.8185 \times DMI) + 88.6002$$

Where:

CH_{4_enteric_dc} is the enteric methane emission per dairy cow, g d⁻¹;

DMI is feed dry matter intake, kg d⁻¹; and standard error values for the slope and intercept are 0.8338 and 14.5782, respectively.

Calculations are performed at a monthly resolution, with characterisation of production, management and feed by dairy cow category for each month. Further details are given in **Annex 3.3**.

5.2.2.1.1 Feed intake

Dry matter intake by dairy cows is determined using UK-specific energy balance equations as published in Feed into Milk (Thomas, 2004), based on metabolisable energy (ME). The daily ME intake by the animal is assumed to correspond with the requirement for live weight gain, activity, milk and gestation. Average milk yield per cow is derived from national statistics provided by each country and this is disaggregated to breed type (large, medium, small) based on industry data regarding yields for specific breeds⁵⁵.

5.2.2.1.2 Live weight (LW)

A standard growth curve is defined for dairy cattle, based on that given by Coffey et al, (2006) is used to define live weights for each age category, with annual data for mature cow weight by proxy breed type being obtained from UK slaughter statistics as analysed by SRUC (Tracey Pritchard). Calf birth weight is related to mature cow weight (AFRC, 1993). Average age of conception for first calving is defined as 19, 20 and 18 months for large, medium and small breed proxies, respectively, giving respective age at first calving of 28, 29 and 27 months, for which relevant live weights can be derived. There is no evidence from industry data of any consistent trend over time in age of first calving.

5.2.2.1.3 Diet

Standard dietary components have been defined and associated with the outdoor grazing and indoor housing periods for each production system. Cattle are assumed to be fed concentrates at an average level as reported annually in Nix Farm Management Pocket book and the remainder of the diet derived from forage (at grazing or fed as conserved silage). Forage diet components include grazed grass (with and without clover), grass silage, maize silage and whole crop silage. Increased use of forage maize, with associated higher energy and lower crude protein content, is reflected in the time series.

5.2.2.1.4 Housing and grazing period

Dairy cattle are managed according to four regimes: year-round housing, winter housed and summer part-housed (overnight), winter housed and summer grazing, extended grazing. The proportion of the national herd associated with each management regime is based on a survey reported by March et al. (2014) and industry expert judgement on trends between 1990 (assuming no year-round housing) and that time.

5.2.2.2 Other cattle

Enteric methane emissions from other cattle, including dairy sector replacements and calves, and all beef sector cattle, are estimated using the same approach as for dairy cows but with different relationships between enteric emission and dry matter intake for lactating and non-lactating cattle. For lactating cattle (i.e. beef suckler cows) the same equation as for dairy cows

⁵⁵ www.nbdc.uk

(presented above in 5.2.2.1) is used. For all non-lactating cattle, the relationship as developed under Defra-funded projects AC0115 (Defra AC0115) and AC0114 (Defra AC0114) is:

$$CH_{4_enteric_oc} = (17.5653 \times DMI) + 45.8688$$

Where:

$CH_{4_enteric_oc}$ is the enteric methane emission per other cattle, g d⁻¹;

DMI is feed dry matter intake, kg d⁻¹; and standard error values for the slope and intercept are 2.4112 and 16.1505, respectively. As for dairy cows, dry matter intake for other cattle categories is determined using UK-specific energy balance equations, derived for non-lactating cattle from AFRC (1993) combined with cattle category- and system-specific production and diet characteristics at a monthly resolution as described for dairy cows (and further detail given in **Annex 3.3**).

5.2.2.2.1 Feed intake

The AFRC (1993) recommendations on the energy allowances for cattle are used to estimate the metabolisable energy (ME) needs of cattle (based on liveweight, growth rate, gestation and lactation). The ME coupled with activity data from a Defra Farm Business Survey module (Parsons and Williams 2015) is used to derive diets, composition of ME (MJ/d), gross energy (GE) and crude protein (CP) in each diet. DMI (kg/d), GE and CP intakes are derived from the ME needs (MJ/d) and the ME density in feed (MJ/[kg DMI]).

5.2.2.2.2 Cattle live weights (LW)

Cattle live weights are based on a Michaelis-Menten type growth model (López et al., 2000). The model requires mature LW, calf LW and two fitted parameters. Mature LW data are obtained from the established time series of slaughter weights that are collected at national level⁵⁶ and supplemented with a very large sample of data from which separate populations are derived of the breed types and age bands used in the model (Wall and Pritchard, 2017). Calf weights are calculated from an established equation in AFRC (1993). Parameters were fitted from a variety of industry and literature sources (Williams and Sandars, 2017).

The fractions of cattle lactating and/or gestating are derived from industry performance data and an analysis of the CTS dataset. The fractions of cattle lactating and/or gestating are applied uniformly over the population throughout the year. The ME needs for maintenance, growth, lactation and gestation are calculated for every age band and cattle type to estimate the DM intake and intakes of CP and GE, which are used to calculate enteric methane emissions, volatile solids (VS) excretion and N excretion.

5.2.2.2.3 Diets

There are 11 standard diets assumed for cattle, three corresponding to different types of grass and two corresponding to suckled calves at grazing with mixed nutrition from milk and grass. Data for feeds used (by material) are from the FBS (Parsons and Williams, 2015) and nutritional properties of each material in the diets are derived mainly from the Feed Composition Tables (MAFF, 1992), with some from Ewing (1998).

5.2.2.2.4 Housing and grazing period

Data came from a Farm Business Survey module (Parsons, Williams, 2015) and other farm practices surveys⁵⁷ were used to derive the grazing season lengths across the UK at DA level

⁵⁶ <https://www.gov.uk/government/statistics/cattle-sheep-and-pig-slaughter>

⁵⁷ e.g. <https://www.gov.uk/government/collections/farm-practices-survey>

and with England split into three parts. These applied to cattle roles and ages, although ages bands were more aggregated than the CTS-based age bands. Farm practices survey data is used to quantify the housing systems and manure management regimes used as follows: (1) housed all year; (2) Housed in the winter, out in the summer; (3) Outside all year; (4) Housed all year + yards; (5) Housed winter, out summer + yards. The housing management regimes were used to define cattle locations by month, i.e. grazing, in resting areas and in feeding yards. Each of these has its own emission factors for ammonia and N₂O.

5.2.2.3 Sheep

The same approach to estimating enteric emissions for cattle is taken with sheep, but using a UK-measurement derived relationship between enteric emission and dry matter intake specific to sheep:

$$CH_{4_enteric_sheep} = (12.3894 \times DMI) + 5.1595$$

Where:

$CH_{4_enteric_sheep}$ is the enteric methane emission per sheep, g d⁻¹;

DMI is feed dry matter intake, kg d⁻¹; and standard error values for the slope and intercept are 1.483 and 0.8301, respectively.

5.2.2.3.1 Feed intake

Feed intake is calculated using the energy balance model according to requirements to meet the metabolisable energy needs of the animal. It is applied to a description of the live-weight gain of the animal from birth to slaughter. Each type of ewe and lamb has separate growth-curves, access to housing and handling yards, and different access to forage, concentrate and conserved feeds that determine its feed intake.

5.2.2.3.2 Sheep live weights (LW)

The inventory uses country- and system-specific values for the LW of the adult ewe and lamb, and for the rate of weight gain. The annual average weight of ewes and slaughter weight of lambs are calculated separately for each country based on average carcase weights and a fixed killing-out percentage of 46 and 44% respectively, derived from national slaughter house statistics (Defra, DARD-NI, Welsh Government, Scottish Government, 1990 to 2016). The relative ewe weights for the hill, upland and lowland systems within each country are estimated based on an analysis of breed lists and expected mature weights, and are centred on the country average.

5.2.2.3.3 Diets

Fresh grass is the most important feed, with an metabolisable energy content of 11.1 MJ kg⁻¹ DMI and a crude protein content that varies spatially in response to the clover content and level of manufactured fertiliser nitrogen applied to pasture. Ewe and rams are fed a supplement of conserved silage and hay for 120 days over-winter, and store lambs are fed silage, hay and roots for 100 days. The metabolisable energy contents are 10.6 MJ kg⁻¹ dm for silage, 9.4 MJ kg⁻¹ DMI for hay, and 9.2 MJ kg⁻¹ DMI for roots. The crude protein contents are 130 g kg⁻¹ DMI for silage, 111 g kg⁻¹ DMI for hay, and 192 g kg⁻¹ DMI for roots. Lambs are provided with an average creep feed ration of c. 0.150 kg day⁻¹ DMI for 42 days prior to weaning, and ewes are provided with a concentrate ration of c. 0.130 kg day⁻¹ DMI in the 56 days before and after lambing. The metabolisable energy and crude protein content of concentrate are 160 g kg⁻¹ DMI and 12.5 MJ kg⁻¹ DMI for the ewe and 180 g kg⁻¹ DMI and 12.6 MJ kg⁻¹ DMI for the lamb.

5.2.2.3.3 Housing and grazing periods

The pregnant ewe and ewe lamb is housed for 42 days prior to lambing. The fraction of ewes housed varies with system from 40 (hill) to 75% (lowland) (Roderick, 2001). Straw is added to excreta in housing at a rate of 0.60 kg FW day⁻¹. All ewes occupy handling yards for an overall average of 5 days, for essential welfare tasks. Feed and manure management is assumed to be the same as during housing. Lambs finished at grass are slaughtered at between 133 and 172 days, and store lambs at between 276 and 331 days, varying with country and system (Wheeler et al., 2012). Lambs intended for breeding replacement, and all ewes and rams are present all year.

5.2.2.4 Other livestock

Enteric emissions for pigs, goats, horses and deer are estimated using IPCC (2006) Tier 1 methodology by combining the Tier 1 default EF with the UK-specific activity data on animal numbers.

5.2.2.5 Overseas Territories and Crown Dependencies

Emission estimates were compiled by Aether-UK 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.

Note that, due to time constraints, the uncertainty analysis has not been updated to fully reflect the differences to uncertainty due to the adoption of new methods and data for estimating emissions from agriculture this year. These parameters will be reviewed for the next inventory cycle. It is likely uncertainties will be lower than the current assessment, as the new methodology makes use of data and methodologies which we have higher confidence in than previously, but would be of a similar order of magnitude

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 live weight with time for the years immediately prior to and following this period.

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 5.8.6**.

5.2.5 Source-specific recalculations

Details of and justifications for recalculations to activity data and to emission factors are given in the tables below.

Table 5.1 3A Source specific recalculations to activity data since previous submission

IPCC Category	Source Name	2018 submission		2019 submission		Units	Comment/Justification
		1990	2016	1990	2016		
3.A.1	Enteric fermentation	280.28	230.67	280.32	229.76	kt	Correction of error in 2016 breed breakdown. Inventory code updated to correct an error in the sector recipe relating to the calculation of maintenance energy in some non-dairy cattle categories.
	- Dairy cattle						
	- Non-dairy cattle	538.98	463.55	514.93	442.48		

Table 5.2 3A Recalculations to Emission Factors since the previous submission

IPCC Category	Source Name	2018 submission		2019 submission		Units	Comment/Justification
		1990	2016	1990	2016		
3.A.1	Enteric fermentation	98.40	120.80	98.42	120.32	kg CH ₄ head ⁻¹ yr ⁻¹	As IPCC category 3.A.1 above.
	- Dairy cattle						
	- Non-dairy cattle	58.10	58.11	55.51	55.47		

5.2.6 Source-specific planned improvements

Revise the parameters for the energy balance equations for sheep and non-lactating cattle based on recent and ongoing research (AFBI).

5.3 SOURCE CATEGORY 3B – MANURE MANAGEMENT

5.3.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3B11: Dairy Cattle Wastes	T3	CS, D
	Other Cattle Wastes	T3	CS, D
	3B12: Sheep Wastes	T3	CS, D
	3B13: Swine Wastes	T2	CS, D
	3B14: Goats Wastes	T2	CS, D
	3B14: Horses Wastes	T2	CS, D
	3B14: Broilers Wastes	T2	CS, D
	Laying Hens Wastes	T2	CS, D
	Other Poultry Wastes	T2	CS, D
	3B14: Deer Wastes	T1	D
	3B21: Dairy Cattle Wastes	T2	CS, D
	Other Cattle Wastes	T2	CS, D
	3B22: Sheep Wastes	T2	CS, D
	3B23: Swine Wastes	T2	CS, D
	3B24: Goats Wastes	T2	CS, D
	3B24: Horses Wastes	T2	D
	3B24: Poultry Wastes	T2	CS, D
Gases Reported	CH ₄ , N ₂ O		
Key Categories	3B1: Manure management from Cattle - CH ₄ (L1, T1, T3) 3B2: Manure Management - N ₂ O (L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	All estimated emissions for Overseas Territories and Crown Dependencies are included in category 3J. In the OTs, Estimates for both CH ₄ and N ₂ O emissions are calculated using 2006 IPCC default EFs. In the CDs, estimates are calculated using UK GHGI EFs. This distinction is based on the knowledge of local agricultural practices and climatic conditions. A time series of UK EFs are applied to animal numbers. 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		

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.

The emission factors for manure management are calculated following IPCC Tier 2 methodology for cattle, sheep, pigs and poultry, according to IPCC (2006) Equation 10.23. For cattle and sheep, country-specific values for volatile solids (VS) excretion are derived by animal sub-category and production system using the UK-specific ME balance equations (as described in Section 5.2.2) and an estimate of GE intake (based on estimated dry matter intake and feed energy content) according to a variation of IPCC (2006) Equation 10.24:

$$VS_{ex} = \left(GE_i \times \left(1 - (Me_{req}/GE_i) \right) \right) \times ((1 - ASH)/(GE_i/DMI))$$

Where:

VS_{ex} is the volatile solids excretion, kg d⁻¹

GE_i is the gross energy intake, MJ d⁻¹

ASH is the ash content of the manure as a fraction of the dry matter feed intake

DMI is the dry matter intake, kg d⁻¹

UK-specific data on the methane producing potential (B_0) of cattle excreta were not significantly different from IPCC (2006) default values (Defra AC0115), so the default values are retained. For pigs and poultry, IPCC (2006) default values for VS and B_0 are used.

Default IPCC (2006) MCF values (IPCC Table 10.17) are applied, with the exception of liquid/slurry systems with a natural crust cover, where no reduction in the MCF value is assumed in accordance with literature evidence (e.g. Petersen et al., 2013). These data are combined with country-specific data for the proportion of manure from each livestock type managed according to the different animal waste management systems (AWMS). The emission factors are listed in **Table A 3.3.2** in **Annex 3**. **Table A 3.3.3** in **Annex 3** shows the methane conversion factors assumed for the different systems.

For goats, deer and horses, IPCC (2006) Tier 1 default emission factors were used (IPCC Tables 10.15).

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 different animal waste management systems (AWMS) defined by IPCC. Emissions from the following AWMS are reported under the Manure Management IPCC category (it is assumed that uncovered anaerobic lagoons are not present in the UK):

- Liquid/slurry;
- Solid storage/deep litter/poultry manure

According to IPCC (2006), the following AWMS are reported in the Agricultural Soils category:

- All animal manures and slurries applied to soils; and
- Pasture range and paddock

Nitrous oxide emissions from manure management are estimated following IPCC (2006) (equation 10.25) for each livestock category and subcategory, using country-specific data for N excretion by the different livestock types and for the proportion of manure managed according to the different AWMS, and a combination of default and country-specific emission factors for the different AWMS. The UK has implemented a detailed N-flow model describing the flow of N from livestock excretion through the manure management chain (based on Webb and Misselbrook, 2004), accounting for all N losses (via NH_3 , N_2O , NO , N_2 and N leaching) and transformations (immobilisation, mineralisation) at each manure management stage.

For cattle and sheep, N excretion is estimated based as the balance of N intake and N retained in live weight gain, milk, wool and developing foetus, specific to livestock sub-category, production system and diet. N intake is estimated from the calculation of dry matter intake, based on energy requirement and feed characteristics (Section 5.2.2), and the crude protein content of the feed. For cattle, N excreta are partitioned to urine N and dung N, based on literature equations relating N excreta to N intake (Reed et al., 2015). The urine N is assumed to rapidly convert to ammoniacal N whereas the dung N remains as organic N; these different N forms have important implications for subsequent N losses and transformations through the manure management chain (Webb and Misselbrook, 2004). For sheep, 60% of excreta N is assumed to be excreted as urine and 40% as dung. For other livestock types, country-specific values for N excretion were derived from the report of Defra project WT0715NVZ (Cottrill and Smith, 2007) with interpretation by Cottrill and Smith (ADAS) **Table A 3.3.4 in Annex 3**. For pigs and poultry, 70% of excreta is assumed to rapidly become ammoniacal N with 30% remaining as organic N. For goats, horses and deer, the respective excretal proportions are assumed to be 60 and 40%.

The conversion of excreted N into N_2O emissions is determined by the type of manure management system used. The distribution of AWMS is given in **Table A 3.3.5 in Annex 3**. For manure types with bedding addition, the N content of the added bedding is included in the manure N content. Default emission factors (IPCC, 2006; Table 10.21) are assumed except for cattle, pig, sheep, goat, deer and horse deep litter systems where a UK-specific EF of 2.0 is used and for poultry manure where a UK-specific EF of 0.5 is used (**Table A 3.3.6 in Annex 3**).

For estimation of indirect N_2O emissions from manure management, country-specific values for $\text{Frac}_{\text{GASM}}$ and $\text{Frac}_{\text{LEACH}}$ are used. $\text{Frac}_{\text{GASM}}$ is derived directly as output from the UK N-flow model for each livestock x AWMS combination, as the sum of the $\text{NH}_3\text{-N}$ and NO-N emissions (further details can be found in the UK Informative Inventory Report). A country-specific value of 3% of manure N for $\text{Frac}_{\text{LEACH}}$ is used, based on Nicholson et al. (2011) and applied only to solid manure heaps stored in fields. For manure heaps stored on concrete pads, the leachate is assumed to be collected and is subsequently included in the N content of liquid/slurry managed manure. Indirect emissions from manure management due to volatilisation and leaching are then calculated according to IPCC (2006) equations 10.27 and 10.29, respectively, applying IPCC (2006) default values for EF_4 and EF_5 .

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 on animal numbers and manure management practices. Where available, data on manure management specific to each OT was used, otherwise default IPCC practices for the appropriate geographic region were assumed. For CDs, UK implied emission factors were applied to the animal numbers data (i.e. manure management practices assumed to be the same as for the rest of the UK), both for CH_4 and N_2O . These different approaches are used for OTs and CDs to ensure

accurate representation of local agricultural practices, and the differing climatic conditions in these locations around the world.

5.3.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category.

The estimates of uncertainties in emissions were calculated using Approach 2 (Monte Carlo simulation) described by the IPCC using the new Tier 3 models derived for the UK greenhouse gas inventory. We note that uncertainties related to emissions from goats, deer and horses are not currently included. The uncertainties in the estimates of livestock data were provided by the devolved administrations.

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.

5.3.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.8.6**.

5.3.5 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 3A, see **Section 10**.

Table 5.3 3B Source specific recalculations to activity data since previous submission

IPCC Category	Source Name	2018 submission		2019 submission		Units	Comment/Justification
		1990	2016	1990	2016		
3.B.1.1	Methane Emissions from Manure Management - Dairy cattle - Non-dairy cattle					kt	Correction of error in 2016 breed breakdown. Inventory code updated to correct an error in the sector recipe relating to the calculation of maintenance energy in some non-dairy cattle categories.
		59.931	69.715	59.947	69.373		
		81.384	68.568	75.923	63.956		
3.B.1.4	Methane Emissions from Manure Management – Goats	0.030	0.031	0.013	0.013	kt	Corrected manure management EF
3.B.1.4	Methane Emissions from Manure Management – Poultry	3.498	3.563	3.701	3.639	kt	Correction of missing emission factor values for laying hens on deep litter.
3.B.2.1	Nitrous oxide Emissions from Manure Management - Dairy cattle - Non-dairy cattle					kt	Correction of error in 2016 breed breakdown. Inventory code updated to correct an error in the sector recipe relating to the calculation of maintenance energy in some non-dairy cattle categories.
		1.172	0.951	1.172	0.947		
		6.090	4.934	5.833	4.731		
3.B.2.4	Nitrous oxide Emissions from Manure Management – Poultry	0.857	0.835	0.905	0.849	kt	Correction of missing emission factor values for laying hens on deep litter.
3.B.2.5	Nitrous oxide Emissions from Manure Management – Indirect emissions - Atmospheric deposition - Leaching and runoff					kt	Correction of error in 2016 breed breakdown. Inventory code updated to correct an error in the sector recipe relating to the calculation of maintenance energy in some non-dairy cattle categories. Correction of missing emission factor values for laying hens on deep litter.
		1.712	1.390	1.708	1.368		
		0.039	0.036	0.036	0.030		

Table 5.4 3B Recalculations to Emission Factors since the previous submission

IPCC Category	Source Name	2018 submission		2019 submission		Units	Comment/Justification
		1990	2016	1990	2016		
3.B.1.1	Methane Emissions from Manure Management - Dairy cattle - Non-dairy cattle	21.041 8.773	36.508 8.596	21.047 8.184	36.329 8.018	kg CH ₄ /hd/yr	As IPCC category 3.B.1.1 above.
3.B.1.4	Methane Emissions from Manure Management - Goats	0.306	0.306	0.130	0.130	kg CH ₄ /hd/yr	As IPCC category 3.B.1.4 above.
3.B.1.4	Methane Emissions from Manure Management - Poultry	0.025	0.021	0.027	0.021	kg CH ₄ /hd/yr	As IPCC category 3.B.1.4 above
3.B.2.1	Nitrous oxide Emissions from Manure Management - Dairy cattle - Non-dairy cattle	0.412 0.657	0.498 0.618	0.412 0.629	0.496 0.593	kg N ₂ O/hd/yr	As IPCC category 3.B.2.1 above.
3.B.2.4	Nitrous oxide Emissions from Manure Management – Poultry	0.006	0.005	0.007	0.005	kg N ₂ O/hd/yr	As IPCC category 3.B.2.4 above

5.3.6 Source-specific planned improvements

Emission factors and activity data will continue to 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 3D – AGRICULTURAL SOILS

5.4.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3D1: Direct N ₂ O Emissions From Managed Soils	T2, T1	D, CS
	3D2: Indirect N ₂ O Emissions From Managed Soil	T2,T1,CS	D, CS
Gases Reported	N ₂ O		
Key Categories	3D: Agricultural soils - N ₂ O (L1, T1, L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Emissions included under 3J in the CRF. These estimates use tier 1 methodology and 2006 IPCC default EFs.		
Completeness	A general assessment of completeness for the inventory is included in Section 1.8 .		
Major improvements since last submission	<p>Spatial disaggregation of the country-specific value of EF₁ for inorganic N fertiliser applications, with EF calculated on a 10 km grid basis according to fertiliser type, application rate and annual rainfall amount.</p> <p>Full implementation of the N-flow model (Webb and Misselbrook, 2004) in the combined ammonia and GHG inventory model for UK agriculture, accounting for all N losses and transformations through the manure management chain and thus influencing the N remaining for land application.</p>		

Direct emissions of nitrous oxide from agricultural soils are estimated using IPCC (2006) Tier 2 methodology (IPCC Equation 11.2), implementing UK-specific EF and parameters where available.

The IPCC (2006) method involves estimating direct emissions from:

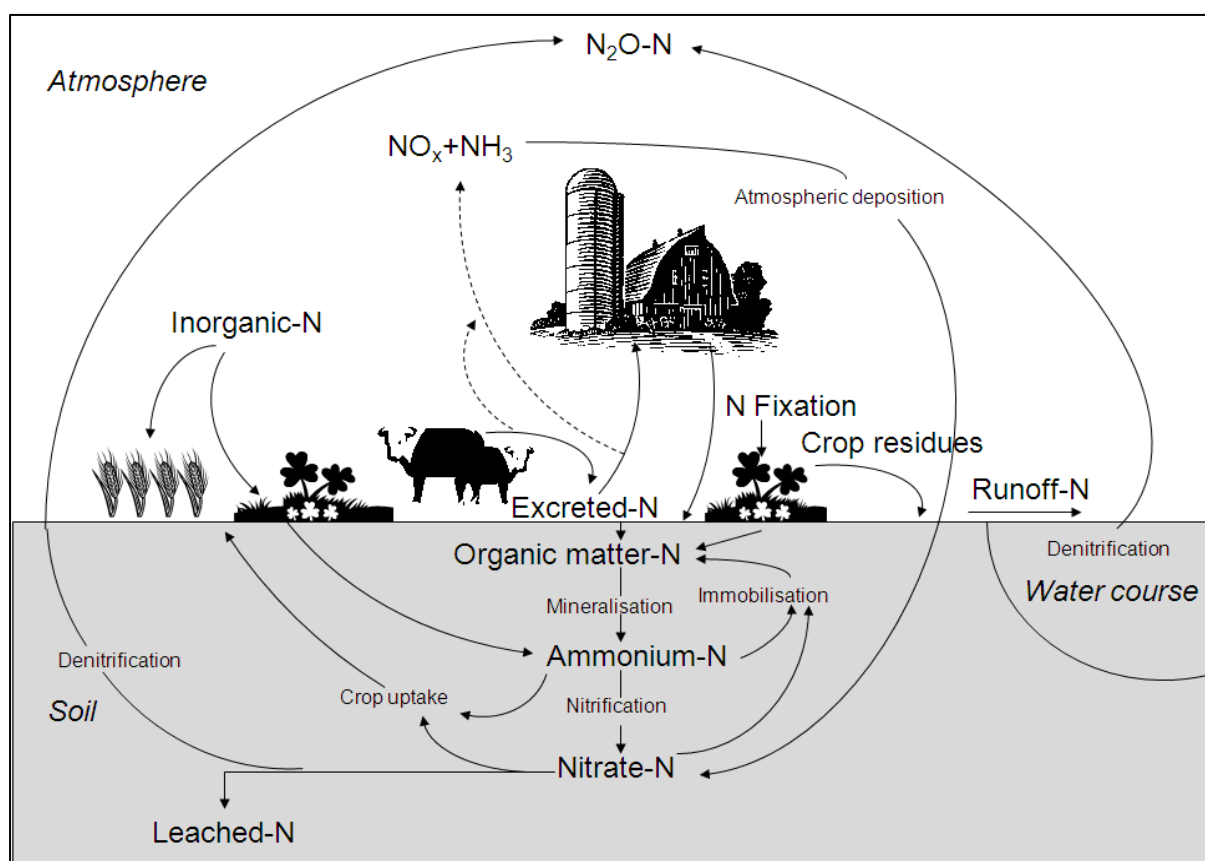
- (i) The use of inorganic fertiliser
- (ii) Application of livestock manures to land
- (iii) Application of sewage sludge and compost to land
- (iv) Urine and dung deposited by grazing animals in the field
- (v) Crop residues returned to soils
- (vi) Mineralisation
- (vii) Cultivation of histosols (organic soils)

Indirect N₂O emissions are estimated from 2 sources:

- (viii) Atmospheric deposition of agricultural NO_x and NH₃ (from (i), (ii), (iii) and (iv))
- (ix) Leaching and run-off of agricultural nitrate (from (i), (ii), (iii), (iv), (v) and (vi)).

Further details on activity data and EF are given in **Annex 3.3**.

Figure 5.3 Simplified nitrogen cycle highlighting the steps involved in the production of N₂O from agriculture.



5.4.2 Methodological issues

5.4.2.1 Inorganic Fertiliser

Direct N₂O emissions from fertiliser N applications are calculated using values of EF1 derived from UK-specific measurements (Topp et al., 2016). Direct N₂O emission is related to fertiliser type, application rate and average annual rainfall, with the relationship for urea-based fertilisers as in equation 1. For all other fertiliser types, the calculation involves fertiliser rate applied and average annual rainfall (equation 2).

$$\ln(\text{CumN}_2\text{O} + 1) = 0.494(\pm 0.10008) + 0.002035(\pm 0.0001542) * \text{NRate} \quad (\text{eq.1})$$

$$\ln(\text{CumN}_2\text{O} + 1) = 0.1616(\pm 0.13526) + 0.00006093(\pm 0.000240365) * \text{NRate} + 0.0005187(\pm 0.00016259) * \text{RainYr} + 0.00000354(\pm 0.0000002785) * \text{NRate} * \text{RainYr} \quad (\text{eq.2})$$

CumN₂O = cumulative annual N₂O-N emission (g ha⁻¹)

NRate = rate at which fertiliser N is applied (kg ha⁻¹)

RainYr = annual average rainfall (mm).

EF are derived as shown in equation 3.

$$((CumN_2O \text{ at specified } NRate - CumN_2O \text{ at zero } NRate) / NRate) \quad (eq.3)$$

5.4.2.2 Application of livestock manures to land

Emissions are calculated following IPCC methodology (2006, equation 11.1). Proportions of managed manure N applied to GB cropland are derived from Smith et al. (2015) until 2004. The nature of manure management differs between farms types such that more is retained on the farms with grazing livestock than for pig and poultry farms and also more is spread on grassland than arable crops. In general, slurries are less likely to be transported long distances than solid manures. The fate of manure is calculated by considering spatial disaggregation as in the BSFP; for livestock is calculated according to Smith et al. (2015). On broiler and turkey farms a proportion is deducted to allow for that amount going to biomass power stations and the remainder is assumed to be applied to land in the neighbourhood. Proportions of land types are used for each manure type and in suggested “radius” and it is then assumed that manure is uniformly applied to the soils in those cells.

5.4.2.3 Application of sewage sludge to land

Emissions from sewage sludge application to land are calculated following IPCC methodology (2006, equation 11.1). The calculation involves estimating the amount of N contained per dry matter unit of sludge that is applied to land. Activity data are provided by Ricardo Energy & Environment from a combination of Environment Agencies and water companies. The data are disaggregated at the most at DA level, with the proportions on arable and grassland being derived from the BSFP from 2005. Uniform application rates across land from the DAs are assumed. Non-agricultural materials applied to agricultural land in GB was addressed according to Hulin et al. (2015). These included: Digested liquid sewage sludge, composted green manure, digested sludge cake, thermally dried sludge cake, lime-stabilised sludge and biosolids.

5.4.2.4 Urine and dung deposited by grazing animals in the field

Emissions are calculated following 2006 IPCC methodology, equation 11.1). Estimates of the proportions of dry matter (DM) that were given to stock were made by Parsons and Williams (2015) in a module of the FBS in England. We assumed that all excretion from grazing livestock is deposited on grassland. N excretion for cattle is partitioned to urine and dung N as described in Section 5.3.2.2, and the separate UK-specific values for EF₃ for urine and dung are applied accordingly (Annex 3.3, Table A3.3.7). The default IPCC (2006) EF₃ for sheep is lower than that for cattle. The UK do not have any experimental data specifically for sheep grazing, but as the weighted average (across dung and urine) UK-specific EF₃ for cattle is lower than the IPCC (2006) default EF₃ for sheep, the UK assumes the same value for sheep as for cattle (and for goats, horses and deer), rather than create an anomaly by having a higher EF₃ value for sheep than for cattle. For swine and poultry, where behaviour of outdoor animals is quite different to that of cattle and sheep, the default IPCC (2006) EF₃ is used.

5.4.2.5 Crop Residues returned to soils

Direct N₂O emissions from crop residues are estimated following IPCC (2006, equation 11.2) using the default value for EF₁. However, a country-specific approach is taken to deriving the quantity of N returned in crop residues, based on UK-specific data for the harvest index and, where available, UK-specific data for N content of crop residues (**Annex 3.3, Tables A 3.3.10 and A 3.3.11**). More specifically, the IPCC calculation involves the ratio of crop yield (DM) to total above-ground dry weight (DM harvest index, HI DM. The harvest index can also be defined with respect to nitrogen (N) as nitrogen harvest index (NHI).

The DM harvest index is the ratio of the primary crop DM yield of crop T over the sum of the primary crop DM yield ($Crop_T$) and the above ground biomass DM (eq. 4). The N harvest (HIN) index is shown in eq. 5 and with data for the DM harvest index, AG DM(T) can be calculated by rearranging eq.5 to obtain the above ground residue per unit area ($AG_{DM(T)}$) (eq.6 and 7).

$$H_{DM} = Crop_T / (Crop_T + AG_{DM(T)}) \quad (eq.4)$$

$$H_{IN} = (Crop_T * Crop_N(T)) / (Crop_T * Crop_N(T) + AG_{DM(T)} * N_{AG(T)}) \quad (eq.5)$$

$Crop_{N(T)}$ = fraction of N in the DM of crop_T.

$$AG_{DM(T)} = Crop_T - (Crop_T * H_{DM}) / H_{DM} \quad (eq.6)$$

$$AG_{DM(T)} = (1 - H_{DM}) * Crop_T / H_{DM} \quad (eq.7)$$

Estimates of the N in cover crops were made from the NDICEA crop simulation model (van der Burgt et al., 2006), which was calibrated and tested in UK conditions by Smith et al. (2015).

5.4.2.6 Mineralisation

N₂O 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).

N₂O 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 A3.4.7**.

5.4.2.7 Cultivation of histosols (organic soils)

Direct N₂O emissions from the cultivation of histosols are estimated following IPCC (2006, equation 11.2) using the default value for EF₂ and UK-specific data for the area of cultivated histosols.

5.4.2.8 Atmospheric deposition of NO_x and NH₃

Indirect emissions of N₂O from the atmospheric deposition of ammonia and NO_x are estimated according to IPCC (2006, equation 11.9) using the default value for EF₄ and country-specific values for the fraction of N that is volatilised as NH₃ and NO from inorganic fertiliser and organic (livestock manure, sewage sludge, digestate, grazing returns) N applications to land (FracGASF and FracGASM, respectively) derived directly from the combined ammonia and greenhouse gas inventory model for UK agriculture, using an N-flow approach (Webb and Misselbrook, 2004). UK-specific NH₃ EF are used for inorganic fertiliser and organic manure applications to land, as detailed in the UK Informative Inventory Report. Emissions of NO from fertiliser, organic manure applications and grazing returns are assumed to be a factor of 0.1 of the N₂O emissions estimated for each source. The method used corrects for the N content of manures used as fuel (poultry litter incineration) and therefore not applied to land.

5.4.2.9 Leaching and runoff

Indirect emissions of N₂O from leaching and runoff are estimated according to IPCC (2006, equation 11.10) using the default value for 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 mineralisation. A country-specific value for the proportion of N applied that is leached (FracLEACH) is used for both inorganic fertiliser and manure application to grassland and excretal returns from grazing livestock, based on a modelling study using the NITCAT model at a UK county level disaggregation (Cardenas et al., 2013). For fertiliser and manure application to arable land, crop residues and sewage sludge the default IPCC (2006) FracLEACH value is used as this was supported by Cardenas et al. (2013) for UK conditions. For mineralisation, the default IPCC (2006) value is also used. The method used corrects for the N content of manures used as fuel (poultry litter incineration) which are not applied to land.

5.4.2.10 Overseas Territories and Crown Dependencies

For the CDs, estimates of emissions from agricultural soils were made by applying UK GHGI implied EFs to animal numbers (for livestock manure-related activities) and land areas of cropland and grassland (for non-manure fertilisers and emission related to loss of soil carbon). For OTs, the Tier 1 methodology from the IPCC Guidelines was applied to calculate emissions from agricultural soils. Livestock numbers, mineral fertiliser application and crop production data were provided from each of the OTs, or sourced from FAO; these data can be found in **Annex 3.9**. Emission factors taken from the 2006 IPCC guidelines were applied to all activity data from OTs. These different approaches are used for OTs and CDs to ensure accurate representation of local agricultural practices, and the differing climatic conditions in these locations around the world.

In the Falklands, despite there being a very large area of grassland histosols, N₂O emissions from managed histosols are only reported for cropland areas. The reason for this is that information from local experts indicates that grasslands are unmanaged (i.e. no fertilisation, liming, drainage or cultivation) and livestock density is low, so these soils are not likely to be a source of N₂O emissions.

5.4.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category.

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 were omitted but will be included in further developments of the model. The uncertainties in the new UK specific emission factors and model parameters were calculated from the data used to derive the emission factors.

Emissions are calculated from a range of activity data and appropriate emission factors (see **Annex 3**). Emissions of N₂O from the use of fertilisers are important in this source category. The annual consumption of synthetic fertiliser is estimated based on crop areas (crop area data reported annually by the Devolved Administrations) and fertiliser 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.

5.4.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.8.6**.

5.4.5 Source-specific recalculations

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	2018 submission		2019 submission		Units	Comment/Justification
		1990	2016	1990	2016		
3.D.1.1	Direct Nitrous Oxide Emissions from Managed Soils – Inorganic N fertilisers	20.457	12.353	20.456	12.344	kt	Update to activity data and shift in some of the timing of fertiliser application.
3.D.1.2	Direct Nitrous Oxide Emissions from Managed Soils – Organic N fertilisers (Animal manure)	3.630	3.130	3.596	3.078	kt	Correction of error in 2016 breed breakdown. Inventory code updated to correct an error in the sector recipe relating to the calculation of maintenance energy in some non-dairy cattle categories. Correction of missing emission factor values for laying hens on deep litter. Update to beef tables to replace incorrect values (from dairy sector) with values specific to the beef sector.
3.D.1.3	Direct Nitrous Oxide Emissions from Managed Soils –Urine and dung deposited by Grazing Animals	3.920	3.271	3.796	3.156	kt	Correction of error in 2016 breed breakdown. Inventory code updated to correct an error in the sector recipe relating to the calculation of maintenance energy in some non-dairy cattle categories.
3.D.1.4	Direct Nitrous Oxide Emissions from Managed Soils –Crop residues	5.172	5.830	5.194	5.828	kt	Minor changes to activity data
3.D.2.1	Indirect Nitrous Oxide Emissions from Managed Soils – Atmospheric Deposition	2.169	1.853	2.112	1.724	kt	Correction of error in 2016 breed breakdown. Inventory code updated to correct an error in the sector recipe relating to the calculation of maintenance energy in some non-dairy cattle categories. Correction of missing emission factor values for laying hens on deep litter. Update to beef tables to replace incorrect values (from dairy sector) with values specific to the beef sector. The inventory code was modified to correct an error in the application of the emission factor modification for ammonia due to non-alkaline soils (AS-DAP). Update to

IPCC Category	Source Name	2018 submission		2019 submission		Units	Comment/Justification
		1990	2016	1990	2016		
							activity data and shift in some of the timing of fertiliser application.
3.D.2.2	Indirect Emissions – Nitrogen Leaching and Runoff	5.917	5.568	6.022	5.631	kt	Correction of error in 2016 breed breakdown. Inventory code updated to correct an error in the sector recipe relating to the calculation of maintenance energy in some non-dairy cattle categories. Correction of missing emission factor values for laying hens on deep litter. Update to beef tables to replace incorrect values (from dairy sector) with values specific to the beef sector. Update to activity data and shift in some of the timing of fertiliser application. The inventory code was modified to correct an error that meant that the nitrate leached was not being correctly accumulated.

5.4.6 Source-specific planned improvements

Emission factors and activity data will continue to 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

5.5 SOURCE CATEGORY 3E – PRESCRIBED BURNING OF SAVANNAS

This source is not relevant in the UK.

5.6 SOURCE CATEGORY 3F – FIELD BURNING OF AGRICULTURAL RESIDUES

5.6.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3F11: Wheat	T1	D
	3F12: Barley	T1	D
Gases Reported	CH ₄ , N ₂ O, NO _x , CO, NMVOC, SO ₂		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Emissions reported for Isle of Man, Guernsey and Jersey (1990-1993) based on UK implied emission factors. No data is available in the case of Overseas Territories, so no emissions are reported		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in Section 1.8 .		
Major improvements since last submission	Implementation of the harvest index approach and use of country-specific data where available in estimating quantities of crop residues burned.		

5.6.2 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), a UK-specific harvest index approach to derive residue amounts (Williams and Goglio, 2017) 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.

5.6.2.1 Overseas Territories and Crown Dependencies

For CDs, estimates of emissions from field burning are made by applying UK GHGI implied EFs to cropland and grassland land areas. As such, estimates are zero from 1994 onwards.

No quantitative data is available from any OT, so emissions from field burning are not currently estimated. Efforts to improve data collection for this category are planned; however, it is thought that these would be insignificant relative to total UK emissions. This improvement will be considered for future submissions as part of the prioritised inventory improvements, taking into account available resources.

5.6.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category.

Field burning ceased in 1994 and emissions are reported as NO after this date.

5.6.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.8.6**.

5.6.5 Source-specific recalculations

There have been no recalculations since the previous inventory submission.

5.6.6 Source-specific planned improvements

No improvements are planned.

5.7 SOURCE CATEGORY 3G - LIMING

5.7.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3G1: Limestone CaCO_3	T1	D
	3G2: Dolomite $\text{CaMg}(\text{CO}_3)_2$	T1	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 do not occur or have not been estimated.		

Completeness	A general assessment of completeness for the inventory is included in Section 1.8 .
Major improvements since last submission	Revision of the historical time series for activity data based on a new data provider.

5.7.2 Methodological issues

CO₂ emissions due to the application of lime and related compounds are estimated using the Tier 1 IPCC (2006) methodology. 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 CO₂ loss from the carbonates and assume pure limestone/chalk and dolomite.

Liming activity data (% area limed and application rate to three land use types: 'all tillage', 'grass under 5 years old' and 'grass 5 years and over') were obtained from the British Survey of Fertiliser Practice (BSFP; Table EW1.4 for England & Wales and Table SC1.4 for Scotland) from 1992 onwards; activity for 1990 and 1991 were assumed to be the same as for 1992. The % area limed and application rate of lime in Northern Ireland was assumed to be the same as that for Scotland by land use type. For each of the liming types in BSFP (i) Ground limestone, ii) Ground chalk, iii) Magnesian limestone, iv) Sugar beet lime, iv) Other), the application rate and % area limed were multiplied by the area of 'all tillage', 'grass under 5 years old' and 'grass 5 years and over' to derive the total limestone and dolomite applied for each Devolved Administration.

The 'Other' category in BSFP is made up of Ag slag, Calcified pelleted limestone, Calicfert, Granules, Humistar, Lime slag, Screed lime (personal communication Alison Wray, Defra); the majority of these are CaCO₃ based limes and thus were included in the activity data for limestone.

Sugar beet lime (Limex) is assumed to have 46% CaCO₃ content (British Sugar, Chemical Safety Data; Median of LimeX45 (45%) and LimeX70 (52%) CaCO₃ content).

5.7.2.1 Overseas Territories and Crown Dependencies

Emission estimates are provided for Isle of Man, Jersey and Guernsey, and are calculated by the Centre for Ecology and Hydrology (CEH). These emissions are thought to include both Limestone and Dolomite, but data characteristics mean that emissions from either rocky type cannot be resolved. As the IPCC 2006 default emission factor in this case refers to Limestone, these emissions have been allocated accordingly.

No quantitative data on liming is available for OTs, but local expert input suggests that liming does not occur in the Falklands or Cayman Islands. In Bermuda, this category has not been estimated as no expert judgement is available. Efforts to improve data collection for this category are planned; however, it is thought that these would be insignificant relative to total UK emissions. This improvement will be considered for future submissions as part of the prioritised inventory improvements, taking into account available resources.

5.7.3 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.

5.7.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.8.6**.

5.7.5 Source-specific recalculations

There have been no recalculations since the previous inventory submission.

5.7.6 Source-specific planned improvements

Emission factors and activity data will continue to be reviewed when new data are available.

5.8 SOURCE CATEGORY 3H - UREA APPLICATION

5.8.1 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 and Bermuda.		
Completeness	A general assessment of completeness for the inventory is included in Section 1.8 .		
Major improvements since last submission	Revision to the historical time series of urea use		

CO₂ emissions due to the application of urea and related compounds are estimated using the Tier 1 methodology from the IPCC 2006 Guidelines.

5.8.2 Methodological issues

The annual amount of fertiliser as urea (alone or as part of urea ammonium nitrate, UAN) used in ktN was estimated from the British Survey of Fertiliser Practice (for England, Wales and Scotland) and the Northern Ireland Fertiliser Supply statistics. 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 (2006) default value of 0.2 tonne of C tonnes of urea⁻¹, and emission estimates were made using IPCC Tier 1 (2006, equation 11.13).

5.8.2.1 Overseas Territories and Crown Dependencies

For all Crown Dependencies, emissions have been estimated by applying UK GHGI implied EFs for urea application per hectare, to cropland and grassland land area data. This reflects the fact that local agricultural practices and climatic conditions are similar to the UK.

For the Cayman Islands, the amount of urea applied was available from official statistics, and the IPCC default value applied. Emissions for the Falklands Islands and Bermuda were not estimated, due to lack of data availability. However, local expert judgement suggests that urea application in the Falkland islands is minimal, if not zero. Efforts to improve data collection for

this category are planned; however, it is thought that these would be insignificant relative to total UK emissions. This improvement will be considered for future submissions as part of the prioritised inventory improvements, taking into account available resources.

5.8.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category. The same data source is used for the entire time series to ensure consistency.

5.8.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.8.6**

5.8.5 Source-specific recalculations

Recalculations since the previous inventory submission are shown in **Table 5.6**.

Table 5.6 Source Category 3F – Source specific recalculations to activity data since previous submission

IPCC Category	Source Name	2018 submission		2019 submission		Units	Comment/Justification
		1990	2016	1990	2016		
3.H	Urea application	327.53	365.57	327.60	365.10	kt	Minor updates to activity data

5.8.6 Source-specific planned improvements

Emission factors and activity data will continue to be reviewed when new data are available.

5.9 GENERAL COMMENTS ON QA/QC

The UK Agriculture Inventory has a documented QA/QC plan covering the annual compilation of the inventory by the contracted consortium (led by Rothamsted Research) addressing governance, data management, quality control (procedures and checks) and quality assurance activities. The organisational roles and responsibilities of the delivery team and government stakeholders are described. The inventory compilation, reporting, review and improvement cycle for an annual submission to UNFCCC and UNECE is outlined with an overview of the key QC and QA activities at different stages in the cycle, including the timings for the annual compilation cycle and details of source-specific quality checks to be performed on the incoming data, the calculation models and the data validation checks on model outputs. The Agriculture inventory data quality objectives are based on the inventory quality objectives of Transparency, Accuracy, Consistency, Comparability and Completeness (TACCC) as set out in the IPCC national inventory reporting guidelines and clear statements are provided as to how these are to be met. Security, scope and timeliness of data supply are addressed, with Data Supply Agreements being developed with suppliers of key input data. Procedures are in place for the management of confidential data (e.g. farm holding level data) and for data storage, back-up and archiving. During the finalisation of the agriculture “master” dataset and the integration of these data into the wider UK inventory data for onwards submission to the UNFCCC and

UNECE, there are iterative quality checks performed by the Inventory Agency (under contract to BEIS) to highlight any data anomalies, recalculations and inventory trends compared against previous inventory submissions. There is then a period of dialogue and clarification of the agriculture data and supporting information is provided to the Inventory Agency where applicable. Peer and bilateral reviews of the Agriculture inventory have been conducted, and the revised methodological approaches introduced in the 2018 submission through the Defra GHG improvement programme were reviewed by an international Research Expert Group (including several IPCC Inventory Review Experts) as part of the programme. The QA/QC plan is subject to annual review.

6 Land-Use, Land Use Change and Forestry (CRF Sector 4)

Table 6.1 gives an overview of the LULUCF sector, which includes carbon stock changes and emissions of greenhouse gases and precursors (CO₂, CH₄, N₂O, NO_x and CO) from Land Use, Land Use Change and Forestry (LULUCF) activities. Removals of carbon dioxide are conventionally presented as negative quantities.

The numbers presented in Table 6.1 are for the UK only. Emissions and removals from LULUCF activities in the UK's Overseas Territories and Crown Dependencies are reported in section 6.9, but have little impact on overall emissions and removals from the sector.

Table 6.1 LULUCF Sector Overview

LULUCF Greenhouse Gas Source and Sink Categories	KCA Rank ¹ (gas)	Uncertainty ²	1990 emissions total (Mt CO ₂ e)	2016 emissions total (Mt CO ₂ e)	2017 emissions total (Mt CO ₂ e)	Recalculations 1990 ³ (Mt CO ₂ e)	Recalculations 2016 ³ (Mt CO ₂ e)
Total LULUCF	-	-	0.3	-9.8	-9.9	2.4	4.8
A.Forest Land	2 (CO ₂)	35%	-14.8	-18.2	-18.0	2.4	5.7
B.Cropland	3 (CO ₂)	45%	15.3	11.5	11.4	-0.8	-0.4
C.Grassland	4 (CO ₂)	50%	-7.1	-8.6	-8.8	0.6	0.7
D.Wetlands	-	100%	0.5	0.3	0.3	0.0	0.0
E.Settlements	5 (CO ₂)	50%	7.6	7.0	7.0	0.1	0.1
G. Harvested Wood Products	19 (CO ₂)	45%	-1.6	-2.2	-2.0	0.0	-1.3
Indirect N ₂ O emissions	-	165%	0.4	0.2	0.2	0.0	0.0

¹These values are the rank for each category using the Approach 2 Level assessment for the latest year, showing that many LULUCF categories are among the primary contributors to the overall uncertainty of the inventory.

²All values for uncertainty refer to those associated with the latest year CO₂ emissions with the exception of Indirect N₂O where the value is for latest year N₂O.

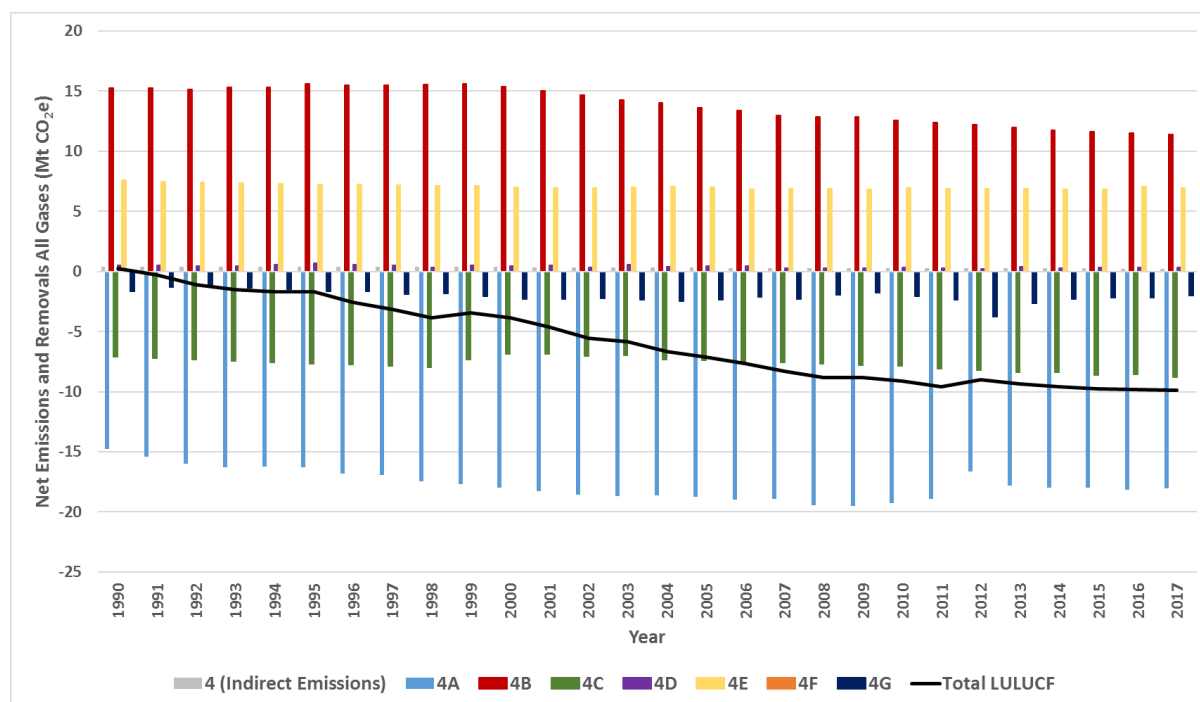
³The values given are the difference in 1990 or 2016 emissions/removals from the data reported in the previous UK GHGI submission.

The summary analysis of the trends in greenhouse gas emissions from the LULUCF sector is provided in **Section 2**. The methodological differences since the previous UK GHGI submission are explained in this chapter (*Major improvements since last submission*).

The LULUCF sector covers emissions and removals of direct greenhouse gases under eight categories, of which Forest Land (4A), Grassland (4C) and Harvested Wood Products (4G) are net sinks, and Cropland (4B), Wetlands (4D), and Settlements (4E) are net sources (**Figure 6.1**) as well as indirect N₂O emissions. The UK does not report any emissions or removals from the Other Land (4F) and Other (4H) categories.

The LULUCF sector is the only sector within the national greenhouse gas inventory to report net removals. The net sink 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 LULUCF sector is a source of methane and nitrous oxide, but these are small in relation to carbon fluxes.

Figure 6.1 LULUCF emissions and removals from the UK 1990-2017 by category



6.1.1 The land use transition matrix

The Standard Area Measurement to mean high water is used for the total area of the UK (24,438.5 kha) (Office for National Statistics) and all of this area is assigned to one of the LULUCF land use categories. All land use in the UK is considered to be managed.

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 land use transition matrices have been updated in this submission to take account of the most recently published data and maintain consistency in both the annual matrices (Table 4.1 for each year in the CRF Reporter) and the CRF carbon stock reporting tables. It is assumed that:

- The total areas of land use categories from recent reports (baseline date of 2015, see Table 6.2) are the most reliable;
- The areas of LUC used for carbon stock changes are the most consistent sources of land use change available.

Table 6.2: Data sources and areas for the 2015 baseline land use matrix

LULUCF Category	Source dataset	Relevant components of dataset	Area in 2015, kha
Forest Land	National Forest Inventory (NFI) (GB) ¹ and Northern Ireland Woodland Base Map	NFI main dataset (woods >0.5 ha)	3573 ²

LULUCF Category	Source dataset	Relevant components of dataset	Area in 2015, kha
		Tree cover outside woodland (0.1-0.5 ha)	
Cropland	UK Agricultural Census (Defra, DAERA, Scottish Government, Welsh Government)	Arable land Orchards and perennial crops Fallow and set-aside land	5171
Grassland	ONS Standard Area Measurement land area – area of other categories ³	NA	13321
Wetlands	ONS Standard Area Measurement (water bodies >1km ²) UK Directory of Mines and Quarries and Google Earth imagery (peat extraction sites)	Natural water bodies > 1km ² Reservoirs >1 km ² Peat extraction sites	170
Settlements	Land Cover Map 2015	Urban land cover class Suburban land cover class	1765
Other Land	Land Cover Map 2015	Inland rock, supra-littoral rock, supra-littoral sediment and freshwater classes, adjusted for area of inland water included in Wetlands category	420

¹ Forestry Commission (2017) “Tree cover outside woodland in Great Britain report”

² Adjusted from 2016 value for afforestation gains and deforestation losses

³ The ONS Standard Area measurement in 2015 was 24419 kha but this has since been revised (due to changes in mapping methodology). The difference in total area is absorbed by the Grassland category, which acts as the buffer category for the UK.

Note there is a very slight difference in the total area and sum of the individual areas due to rounding

The baseline areas in Table 6.2 are used as the initial land use areas in the 2015 land use matrix. The initial land use areas in 2015 are also the final land use areas in 2014. These are used with the transitions to and from each land use category in 2014 (see the individual land use category sections 6.2 to 6.7 for details) to calculate the initial land use areas in 2014 and area of each category that does not undergo any change. This approach is used to calculate the initial and final land use areas back in time to 1990, and forward in time from 2015. Annual land use change matrices for the UK are shown in Table 6.3.

Methodological development has been undertaken to improve the estimation of land use change using Bayesian assimilation of multiple land use datasets (Levy *et al.* 2017). This is being reviewed before the National Inventory Steering Committee decide on its implementation in the LULUCF sector inventory. A BEIS-funded project was also undertaken in 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 results of this study are still being processed.

Land-Use, Land Use Change and Forestry (CRF Sector 4) 6

Table 6.3: Annual land use change matrices for the UK, kha (Total land area is 24 438.5 kha)

Year	4A Forest Land					4B Cropland				4C Grassland					4D Wetland		4E Settlement					4F Other Land
	Forest remaining Forest	Forest Land converted to Cropland	Forest land converted to Grassland	Forest Land converted to Settlement	Cropland remaining Cropland	Cropland converted to Cropland	Cropland converted to Grassland	Cropland converted to Settlement	Grassland remaining Grassland	Grassland converted to Forest Land	Grassland converted to Cropland	Grassland converted to Wetland	Grassland converted to Settlement	Wetland remaining Wetland	Wetland converted to Grassland	Settlement remaining Settlement	Settlement converted to Forest Land	Settlement converted to Cropland	Settlement converted to Grassland	Other land remaining other land		
1990	3102.3	0.0	0.3	0.7	5870.5	5.0	83.4	2.5	13052.3	35.0	95.9	0.0	13.5	174.4	0.5	1572.7	2.8	0.9	4.7	420.9		
1991	3144.2	0.0	0.3	0.6	5878.8	2.7	83.4	2.5	13010.8	20.2	95.9	0.8	13.5	173.9	0.5	1582.2	1.5	0.9	4.7	420.9		
1992	3167.6	0.0	0.3	0.6	5887.0	2.8	83.4	2.5	12970.2	20.1	95.9	0.0	13.5	174.2	0.5	1591.7	1.6	0.9	4.7	420.9		
1993	3191.2	0.0	0.3	0.6	5894.8	3.2	83.4	2.5	12929.4	20.3	95.9	0.0	13.5	173.7	0.5	1600.8	1.8	0.9	4.7	420.9		
1994	3215.6	0.0	0.3	0.6	5902.7	3.1	83.4	2.5	12886.8	22.1	95.9	0.0	13.5	173.1	0.5	1610.0	1.7	0.9	4.7	420.9		
1995	3241.6	0.0	0.3	0.5	5911.0	2.7	83.4	2.5	12846.9	19.2	95.9	0.3	13.5	172.6	0.5	1619.4	1.5	0.9	4.7	420.9		
1996	3264.1	0.0	0.3	0.6	5919.4	2.6	83.4	2.5	12807.8	18.7	95.9	0.0	13.5	172.4	0.5	1628.9	1.4	0.9	4.7	420.9		
1997	3285.7	0.0	0.4	0.6	5927.8	2.6	83.4	2.5	12767.9	19.5	95.9	0.0	13.5	171.8	0.5	1638.3	1.5	0.9	4.7	420.9		
1998	3308.3	0.0	0.3	0.6	5936.2	2.6	83.4	2.5	12728.8	18.7	95.9	0.0	13.5	171.3	0.5	1647.8	1.5	0.9	4.7	420.9		
1999	3330.0	0.0	0.3	0.8	5944.3	2.8	83.4	2.5	12689.9	18.4	95.9	0.0	13.5	170.8	0.5	1657.1	1.6	0.9	4.7	420.9		
2000	3349.5	0.0	3.1	0.2	5934.1	2.9	99.0	5.3	12698.8	17.7	52.1	0.0	10.2	170.2	0.5	1663.4	2.7	0.1	7.7	420.9		
2001	3369.2	0.0	3.5	0.2	5879.9	2.1	99.0	5.3	12730.9	16.0	52.1	0.0	10.2	169.7	0.5	1668.8	2.3	0.1	7.7	420.9		
2002	3386.2	0.0	3.1	0.3	5825.7	2.2	99.0	5.3	12764.3	15.1	52.1	0.0	10.2	169.2	0.5	1674.4	2.2	0.1	7.7	420.9		
2003	3401.6	0.0	3.5	0.6	5771.9	1.8	99.0	5.3	12798.4	13.7	52.1	0.2	10.2	169.2	0.0	1680.3	2.0	0.1	7.7	420.9		
2004	3415.6	0.0	2.6	1.0	5717.9	1.9	99.0	5.3	12830.4	15.7	52.1	0.2	10.2	169.3	0.0	1686.2	2.3	0.1	7.7	420.9		
2005	3431.8	0.0	2.9	0.8	5664.2	1.7	99.0	5.3	12863.5	13.7	52.1	0.2	10.2	169.5	0.0	1692.8	2.0	0.1	7.7	420.9		
2006	3446.6	0.0	2.4	0.2	5610.5	1.7	99.0	5.3	12895.8	15.0	52.1	0.0	10.2	169.5	0.3	1699.1	2.1	0.1	7.7	420.9		
2007	3462.3	0.0	2.9	0.4	5557.0	1.4	99.0	5.3	12930.2	12.6	52.1	0.0	10.2	169.2	0.3	1705.0	1.8	0.1	7.7	420.9		
2008	3475.0	0.0	2.7	0.4	5503.8	1.2	99.0	5.3	12967.0	10.7	52.1	0.2	10.2	169.0	0.3	1711.4	1.5	0.1	7.7	420.9		
2009	3485.3	0.0	2.8	0.4	5450.7	1.1	99.0	5.3	13004.4	10.0	52.1	0.0	10.2	168.9	0.3	1718.0	1.4	0.1	7.7	420.9		
2010	3494.2	0.0	2.8	0.8	5397.3	1.3	99.0	5.3	13039.0	12.8	52.1	0.0	10.2	168.6	0.3	1724.1	1.8	0.1	7.7	420.9		
2011	3507.4	0.0	2.1	0.7	5343.7	1.6	99.0	5.3	13069.0	17.5	52.1	0.0	10.2	168.6	0.1	1730.0	2.5	0.1	7.7	420.9		
2012	3526.2	0.0	2.1	0.7	5290.2	1.4	99.0	5.3	13099.7	15.3	52.1	0.7	10.2	168.6	0.1	1736.2	2.1	0.1	7.7	420.9		
2013	3542.5	0.0	1.9	0.6	5236.6	1.5	99.0	5.3	13132.0	14.3	52.1	0.0	10.2	169.2	0.1	1742.4	2.0	0.1	7.7	420.9		
2014	3557.4	0.0	2.3	0.5	5183.3	1.3	99.0	5.3	13166.4	12.1	52.1	0.0	10.2	169.2	0.1	1748.9	1.8	0.1	7.7	420.9		
2015	3570.1	0.0	1.9	0.6	5130.7	0.6	99.0	5.3	13207.7	5.5	52.1	0.0	10.2	169.2	0.0	1756.1	0.8	0.1	7.7	420.9		
2016	3573.3	0.0	2.3	1.4	5078.1	0.5	99.0	5.3	13248.9	5.1	52.1	0.0	10.2	168.9	0.2	1763.6	0.7	0.1	7.7	420.9		
2017	3576.7	0.0	1.9	1.1	5025.4	0.7	99.0	5.3	13288.9	6.8	52.1	0.1	10.2	168.9	0.0	1771.6	1.0	0.1	7.7	420.9		

Note: Total areas in each year summed across all LULUCF categories may not equal the UK total land area in some years because of small rounding errors.

6.2 CATEGORY 4A – FOREST LAND**6.2.1 Description**

Emissions sources	4A Forest Land: carbon stock change 4(I) Direct nitrous oxide (N ₂ O) 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 ₂ O) 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 ₂ O
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, L2)
Key Categories (Qualitative)	None identified
Completeness	Methane emissions from drained forest soils are not estimated due to insufficient information. GHG emissions from rewetted forest soils are not estimated due to insufficient information.
Major improvements since last submission	Activity data on historic forest planting rates have been adjusted after reconciliation of harvest levels from the published wood production statistics and forest age data. Improvements to the CARBINE model include: the correction of double-counting of deadwood inputs in the year of harvest; disaggregated reporting of biomass, litter and deadwood carbon stock changes; adjustment of turnover calculations to avoid double-counting; and adjusting volume calculations for managed non-clearfell areas.

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 72% 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 to date there has been 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, productivity (yield class) data and assumptions over approaches to forest management. Forest carbon stock changes and fluxes are modelled by CARBINE, the Forest Research forest carbon stock model (described in **Annex 3.4.1**). CARBINE takes account of the effects of forest management on carbon stocks, and also calculates the carbon stocks in the Harvested Wood Products pool.

Carbon stock changes resulting from afforestation on Cropland, Grassland and Settlement areas are calculated. Conversion of Wetlands and Other Land to Forest Land does not occur in the UK. The reported forest area and carbon stock changes take account of losses of forest land converted to other land use categories (deforestation) and the associated carbon stock

changes and emissions and removals are then estimated and reported under the category concerned.

In the UK inorganic nitrogen fertilisers are only applied to forest when absolutely necessary. This occurs during the first rotation on 'poor' soils, such as reclaimed slag heaps, impoverished brown field sites and upland organic soils, hence N fertilisation is assumed for all areas of Settlements converted to Forest Land and Grassland converted to Forest Land on organic soils. N₂O 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 N₂O 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 drained prior to planting. 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. CO₂ emissions from drainage are included with carbon stock changes in Table 4.A and N₂O 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 reporting 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 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 Statistics⁵⁸ and a detailed breakdown (by forest type and management) is used as input to the CARBINE model, supplemented by information from the National Forest Inventory (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 (see **Section 6.3** and **Annex 3.4**).

6.2.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

The UK uses the following definition of forest for reporting UK forestry statistics as it relates to the UK's greenhouse gas inventory submitted under the UNFCCC:

- 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 hectares.

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

⁵⁸ <http://www.forestry.gov.uk/statistics>

are actively managed for landscape, soil protection, habitat conservation, amenity and recreation, which may or may not include active management for wood production.

6.2.4 Methodological Issues

In this inventory submission the carbon uptake by UK forests is calculated using a Tier 3 carbon accounting model, CARBINE. Overall carbon uptake is calculated as the net change in the pools of carbon in standing trees, dead organic matter, 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 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.

The CARBINE model produces separate gains and losses for carbon stock change in above- and below-ground living biomass, rather than net change. Carbon stock changes in dead wood and litter are now reported separately. Further detail on the CARBINE model is given in **Annex 3.4.1** and Matthews *et al.* (2014). There have been methodological improvements to the CARBINE model for this submission: these improvements and their impact are described in the recalculations (section 6.2.7).

Other greenhouse gas emissions, including those arising from forest fertilisation and wildfires together with estimates of N₂O 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

The uncertainties associated with net emissions or emissions from 4A Forest Land, as 95 percentile confidence intervals are: 35-40% for CO₂, 55% for CH₄, and 95-105% for N₂O.

This is largely based on an uncertainty analysis which 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 based on that analysis, for which the uncertainty arising from model choice was also 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 based on the C-Flow model which was used before being replaced by CARBINE, 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).

There will be a new uncertainty analysis, following the methodology of the previous uncertainty analysis, which will include the latest version of the CARBINE model and the uncertainty inherent in the NFI due to the sampling intensity. The results of this analysis are likely to be included in the next National Inventory Report.

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). Complete geographical coverage of the UK in these statistics and accurate division of the UK into the four constituent countries is assumed and the associated statistical uncertainties are assumed to be negligible.

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 NFI woodland map, together with small woods of between 0.1 and 0.5 ha. 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.

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 for England, Scotland and Wales 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 the area affected by wildfires is consistent with that reported to the FAO (2005, 2010, 2015).

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 (after 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; Laganieri, 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.

The full specification and information on the validation of the soil and litter model that has been implemented in CARBINE will be published in a separate technical report.

In 2018, a new automatic algorithm was introduced to adjust the assumptions about forest management to ensure a good match between modelled forest harvest (and thus HWP) and

the wood production statistics. This has also improved the repeatability and QC of this part of the inventory. As part of this project, the timber volume production module of CARBINE was re-implemented to enable that automation. This semi-independent implementation of this part of the model was cross-validated against the version in the CARBINE model. This exercise also identified an issue with the modelling of areas of forest thinned but not clearfelled, which was corrected for this inventory.

6.2.7 Category-Specific Recalculations

The reported overall net GHG sink in category 4A has decreased by between 2.2 and 6.0 Mt CO₂e (13-25%) across the time series compared to the 2016 inventory.

The changes were mainly seen in the carbon stock changes in the living biomass (above- and below-ground), and litter and deadwood pools under Forest Remaining Forest. The main causes of this change were the correction of the previous double-counting of input to the deadwood and litter pools at harvest in the CARBINE model.

The changes and their justification are:

- **Reconciliation of harvest volume and forest age data:** The process of generating activity data for the Forest Land category takes information from the forest inventories for the private and public forest estates and assigns the forest areas to either afforestation or restocking (i.e. this land has been restocked at least once, so the age of the forest in the inventory does not represent the year the land was afforested) with a range of forest management regimes. In order to better ensure consistency between the modelled timber production and the timber production statistics, an automated algorithm was introduced to adjust the assumed forest management to reconcile the modelled and reported levels of timber production. This automation was in response to a recommendation from a previous QA review by Hartley McMaster in 2015 to improve transparency and accuracy. The change has made small adjustments to the area of forest in 4A.1 and 4A.2 over time and the proportion of forest on mineral and organic soils. This also affected the volume of fertiliser and the area of drainage.
- **Improvements to CARBINE**
 - **Correction of a double-counting of inputs to the deadwood and litter pools** : deadwood and litter had previously been counted in both felled and restocked stands in the year of harvesting. This error was identified and corrected during the compilation of the 2019 inventory, improving consistency and accuracy. This affected carbon stock changes in the litter and dead wood pools and carbon transfers to the soil pool. It also affected **average forest biomass densities** over the time series, which are used to calculate the fuel available for burning during wildfire and controlled burning following deforestation.
 - **Disaggregated reporting of carbon stock changes:** gains and loss of living biomass are now reported separately under above-ground and below-ground biomass, and deadwood carbon stock changes are now reported separately from litter. These changes were in response to a UNFCCC reviewer recommendation to improve transparency.
 - **Adjustment of turnover calculations:** the calculations for turnover of foliage, branch and root were adjusted to occur after harvest to improve accuracy. A possible double-counting of carbon in litter due to turnover and harvest was identified prior to inventory compilation, as carbon for deciduous foliage could enter the litter pool as both turnover at senescence and as residue from harvest.

The magnitude of the changes and the abbreviated justification are given in **Table 6.4**.

Table 6.4 4A Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2018 Submission		2019 Submission		Units	Comment / Justification
		1990	2016	1990	2016		
4A1	Carbon stock change in living biomass - gains	-10969.6	-16000.6	-10848.3	-15588.2	Gg C	Reconciliation of harvest volume and forest age data
4A1	Carbon stock change in living biomass - losses	8176.0	12236.8	8057.4	12975.1	Gg C	
4A1	Net carbon stock change in litter	-1325.1	-1441.0	-111.6	-84.0	Gg C	Correction of double-counting of dead wood and litter
4A1	Net carbon stock change in dead wood	IE	IE	-625.2	-1004.0	Gg C	Disaggregated reporting of carbon stock changes Adjustment of turnover calculations
4A1	Net carbon stock change in soils - mineral soils	-459.4	-1084.4	-428.0	-1064.7	Gg C	Reconciliation of harvest volume and forest age data
4A1	Net carbon stock change in soils - organic soils	10.9	-184.7	11.0	-176.5	Gg C	Correction of double-counting of dead wood and litter Adjustment of turnover calculations
4A1/4(V)	Biomass burning - wildfires	10.3	1.4	10.2	1.4	Gg C	Adjustment of average biomass densities due to error correction
4A2.1	Carbon stock change in living biomass - gains	-54.9	-46.2	-54.8	-44.7	Gg C	Reconciliation of harvest volume and forest age data
4A2.1	Carbon stock change in living biomass - losses	9.5	7.6	10.0	7.8	Gg C	
4A2.1	Net carbon stock change in litter	-3.4	-2.5	-1.1	-0.8	Gg C	Disaggregated reporting of carbon stock changes
4A2.1	Net carbon stock change in dead wood	IE	IE	-1.5	-1.0	Gg C	Adjustment of turnover calculations Reconciliation of harvest volume and forest age data
4A2.1	Net carbon stock change in soils - mineral soils	39.2	29.7	40.0	29.3	Gg C	Reconciliation of harvest volume and forest age data

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IPCC Category	Source Name	2018 Submission		2019 Submission		Units	Comment / Justification
		1990	2016	1990	2016		
4A2.1	Net carbon stock change in soils - organic soils	3.4	1.4	3.4	1.2	Gg C	Adjustment of turnover calculations
4A2.2	Carbon stock change in living biomass - gains	-884.1	-355.0	-867.8	-324.7	Gg C	Reconciliation of harvest volume and forest age data
4A2.2	Carbon stock change in living biomass - losses	144.0	57.0	147.1	55.6	Gg C	
4A2.2	Net carbon stock change in litter	-54.4	-20.0	-16.6	-5.9	Gg C	Disaggregated reporting of carbon stock changes
4A2.2	Net carbon stock change in dead wood	IE	IE	-23.4	-8.0	Gg C	Adjustment of turnover calculations Reconciliation of harvest volume and forest age data
4A2.2	Net carbon stock change in soils - mineral soils	496.5	236.7	496.7	224.7	Gg C	Reconciliation of harvest volume and forest age data
4A2.2	Net carbon stock change in soils - organic soils	116.8	23.1	117.4	19.0	Gg C	Adjustment of turnover calculations
4A2.4	Carbon stock change in living biomass - gains	-19.4	-46.3	-19.0	-42.4	Gg C	Reconciliation of harvest volume and forest age data
4A2.4	Carbon stock change in living biomass - losses	3.1	7.5	3.2	7.3	Gg C	
4A2.4	Net carbon stock change in litter	-1.2	-2.6	-0.4	-0.8	Gg C	Disaggregated reporting of carbon stock changes
4A2.4	Net carbon stock change in dead wood	IE	IE	-0.5	-1.0	Gg C	Adjustment of turnover calculations Reconciliation of harvest volume and forest age data
4A2.4	Net carbon stock change in soils - mineral soils	11.2	30.9	11.2	29.2	Gg C	Reconciliation of harvest volume and forest age data
4A2.4	Net carbon stock change in soils - organic soils	2.6	2.6	2.6	2.1	Gg C	Adjustment of turnover calculations

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IPCC Category	Source Name	2018 Submission		2019 Submission		Units	Comment / Justification
		1990	2016	1990	2016		
4A1/4(V)	Biomass burning - wildfires	0.117	0.016	0.115	0.016	Gg CH ₄	Adjustment of average biomass densities due to error correction
4A1/4(V)	Biomass burning - wildfires	0.006	0.001	0.006	0.001	Gg N ₂ O	
4A2.1/4(III)	Direct N ₂ O from N mineralisation	0.041	0.031	0.042	0.031	Gg N ₂ O	Reconciliation of harvest volume and forest age data
4A2.2/4(III)	Direct N ₂ O from N mineralisation	0.520	0.248	0.520	0.235	Gg N ₂ O	
4A2.4/4(III)	Direct N ₂ O from N mineralisation	0.012	0.032	0.012	0.031	Gg N ₂ O	
4A2/4(I)	Direct N ₂ O emissions from inorganic fertilisers	0.029	0.008	0.029	0.008	Gg N ₂ O	Reconciliation of harvest volume and forest age data
4A/4(II)	Emissions and removals from drainage of organic and mineral soils	0.166	0.191	0.167	0.190	Gg N ₂ O	Reconciliation of harvest volume and forest age data

6.2.8 Category-Specific Planned Improvements

A piece of work is in progress to better quantify the uncertainties associated with outputs from the CARBINE model. This will be a revision of the uncertainty analysis published in the 1990-2010 National Inventory Report.

6.3 CATEGORY 4B – CROPLAND

6.3.1 Description

Emissions sources	4B Cropland: carbon stock change 4B Cropland:4(III) N ₂ O emissions from disturbance associated with LUC to Cropland 4B Cropland:4(V) Biomass burning
Gases Reported	CO ₂ , CH ₄ , N ₂ O
Methods	T3 for carbon stock changes, T1 for other emissions
Emission Factors	Country-specific for T3 methods, T1/2 for other emissions
Key Categories	4B: Cropland - CO ₂ (L1, T1, L2, T2)
Key Categories (Qualitative)	None identified
Completeness	No known omissions.
Major improvements since last submission	Average biomass densities for cropland and grassland used in the LUC model were changed to be consistent with those used in the cropland and grassland management calculations.

Net emissions from the Cropland category include carbon stock gains and losses due to land use change (LUC) and GHG emissions from cropland management and overall is the largest net source in the LULUCF sector.

Ongoing carbon stock changes in soils arising from LUC to Cropland are reported under both 4.B.2. (for LUC in the past 20 years) and 4.B.1 (for historic LUC >20 years before the inventory reporting year). These soil net carbon stock changes are the largest component of the category total emissions, and are calculated using a Tier 3 dynamic soil carbon model.

Other contributors to the Cropland net total emissions are:

- carbon emissions resulting from drainage of organic soils;
- carbon stock changes in biomass and soils resulting from changes in cropland management;
- biomass carbon stock changes due to LUC;
- N₂O emissions from soil disturbance associated with LUC;
- biomass burning emissions of GHGs from controlled burning following forest land conversion to cropland; and
- biomass burning emissions of GHGs due to wildfires.

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.

Ongoing N₂O emissions from soil as a result of land use change > 20 years ago are reported in the Agricultural sector inventory as N₂O emissions from managed agricultural soils. CEH provide the appropriate areas and carbon stock changes to Rothamsted Research. Nitrous oxide emissions from loss of soil organic matter as a result of Cropland Management are also reported in the Agricultural sector inventory as N₂O emissions from managed agricultural soils.

Emissions of CO₂, CH₄ and N₂O from controlled 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. 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 (see section 6.1.1 for details).

Data sources that contain area information for reporting carbon stock changes and/or emissions from Cropland are:

- Habitat/landscape surveys
 - The Countryside Survey (1984, 1990, 2000, 2007) is used to compile land use transition matrices.
- An assessment of Cropland drainage on organic soils
 - 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 also exist.
- Agricultural survey data
 - Areas of the main crop types are obtained from the June Agricultural Censuses for each UK administration.
 - The areas of Cropland receiving inputs of manure, fertiliser and crop residues are obtained from the British Survey of Fertiliser Practice.
- Data on wildfires on agricultural land from Fire and Rescue service and satellite data.
 - Areas of wildfire on Cropland for 2010 to the present come 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 2010-present.
 - 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, Orchards and Market Garden land cover types in the Monitoring Landscape Change project (MLC 1986). Post-1980, Cropland is the area of cropland reported in the June Agricultural censuses. Crop type definitions are those used in the June Agricultural censuses.

6.3.4 Methodological Issues

6.3.4.1 Land Use change

Activity data for land use change are estimated using a land use change (LUC) matrix approach. Detailed descriptions of the methods, emission factors and data flows used for Cropland activities are given in **Annex 3.4.2**.

A dynamic model of carbon stock change is used with the LUC matrices to estimate soil carbon stock changes due to all LUC. Soil carbon stock changes are modelled as changing exponentially between initial and final land uses with the most rapid change in the early years following the transition. It is assumed that LUC does not occur on cropland on organic soils because of the high productivity (and high monetary value) 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. 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. The mean soil carbon flux for each region is summed to give the UK total for the Inventory.

Biomass carbon stock change is calculated using the LUC matrix and literature-derived Tier 2 stock change factors, with all stock gains or losses assumed to occur in a single year.

N₂O emissions associated with soil disturbance from LUC are reported using the areas of Forest land and Grassland converted to Cropland from the LUC matrices and the IPCC Tier 1 emission factors.

6.3.4.2 Cropland management

Carbon stock change (CSC) in mineral soils as a result of cropland management is estimated using agricultural survey activity data and Tier 1 CSC factors for most activities except for tillage reduction (Tier 2).

Carbon stock changes in biomass due to cropland management activities are estimated using literature-derived Tier 2 stock change factors and activity data from agricultural surveys. Carbon stock changes in biomass can arise from changes in annual crops, orchards and shrubby perennial crops (see **Annex 3.4** for details).

6.3.4.3 Drained organic soils

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).

6.3.4.4 Biomass burning emissions

Emissions from controlled burning on cropland are only reported for Forest Land conversion to Cropland and are estimated using Tier 1 emission factors and country-specific fuel densities.

Emissions from wildfires on Cropland are reporting using Tier 1 emission factors and activity from a range of sources (see 6.3.2).

6.3.5 Uncertainties and Time-Series Consistency

4B Cropland is estimated to have a combined uncertainty of 45% for CO₂, 55% for CH₄ and 35% for N₂O.

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. 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.

With regard to time series consistency:

- Drainage of organic soils: 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.
- Changes in biomass and soil carbon due to LUC: the data sources for Great Britain have maintained consistent methodology across the time series. Consistency between these and Northern Ireland data sources has improved with better methodological integration between land use surveys.
- Controlled biomass burning after conversion of Forest Land to Cropland: the time series consistency is high as country-specific data sets are used.
- Wildfires: a consistent dataset is used from 2010 onwards. Burnt areas are 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.
- Cropland management: 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 and the size of the loss was related to initial carbon concentration, 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 (Kirk *et al.* 2011), although there are methodological differences between the two surveys. Subsequent modelling studies (e.g. Smith *et al.* 2007, Barraclough *et al.* 2015) have shown that climate changes could only account for a small part of the decrease in soil carbon reported in Bellamy *et al.* (2005). The importance of prior land use history in priming soil carbon dynamic models has also been highlighted.

6.3.7 Category-Specific Recalculations

The reported overall net GHG source in category 4B has reduced by between 0.4 and 0.8 Mt CO₂e (-2.7 to -4.8 %) across the time series compared to the 2016 inventory. The changes were mainly seen in biomass carbon stock change in Land converted to Cropland.

The changes and their justification are:

- **Adjustment to uncropped land area:** a misalignment in the time series for uncropped land (fallow and set-aside) in England for 2009-2017 was corrected. This affected the calculated biomass and soil carbon stock changes due to cropland management activities.
- **Adjustment of average biomass densities due to error correction:** see section 6.2.7 for further explanation. These changes affected the average biomass density used to calculate biomass burning emissions and biomass losses.
- **Changes to the average deforestation rate for soil CSC calculation:** Continuous improvement of the deforestation data set as more information becomes available has affected the average deforestation rate from 2010, altering the estimated soil carbon stock change from the LUC model.
- **Changes to the living biomass densities for cropland and grassland:** The average living biomass densities for cropland and grassland used in the non-forest biomass LUC model have been updated to those used in the cropland and grassland management calculations (these were based on a more recent UK-relevant literature review in Moxley et al. 2014). This change was in response to a UNFCCC review recommendation and improves consistency within the LULUCF inventory. It has resulted in change from a net emission to a net removal (and vice versa) in the LUC sub-categories for 4B2, 4C2 and 4E2.

Changes in emissions are described in **Table 6.5**.

Table 6.5 4B Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2018 Submission		2019 Submission		Units	Comment / Justification
		1990	2016	1990	2016		
4B1	Carbon stock change in living biomass - losses	6.5	3.4	6.5	3.5	Gg C	Adjustment to uncropped land area
4B1	Net carbon stock change in soils - mineral soils – Cropland Management	-239.9	-175.9	-239.8	-180.1	Gg C	
4B2.1/4(V)	Biomass burning - controlled burning	0.2	0.0	0.2	0.0	Gg C	Adjustment of average biomass densities due to error correction
4B2.1	Carbon stock change in living biomass - losses	0.3	0.0	0.3	0.0	Gg C	Adjustment of average biomass densities due to error correction
4B2.1	Carbon stock change in dead organic matter	0.0	0.0	0.0	0.0	Gg C	
4B2.1	Carbon stock change in soils - mineral soils	0.0	0.2	0.0	0.2	Gg C	Changes to the average deforestation rate for soil CSC calculation
4B2.2	Carbon stock change in living biomass - gains	IE	IE	-140.7	-78.4	Gg C	Changes to the living biomass densities for cropland and grassland
4B2.2	Carbon stock change in living biomass - losses	65.4	35.8	IE	IE	Gg C	
4B2.4	Carbon stock change in living biomass - gains	IE	IE	-2.1	-0.3	Gg C	
4B2.4	Carbon stock change in living biomass - losses	1.2	0.2	IE	IE	Gg C	
4B2.1/4(III)	Direct N ₂ O from N mineralisation	0.000	0.000	0.000	0.000	Gg N ₂ O	Changes to the average deforestation rate for soil CSC calculation
4B2.1/4(V)	Biomass burning - controlled burning	0.000	0.000	0.000	0.000	Gg N ₂ O	Adjustment of average biomass densities due to error correction

6.3.8 Category-Specific Planned Improvements

A vector based approach to tracking land use change has been piloted that assimilates data to provide a more accurate assessment of land use change history in the UK (Levy et al. 2017). Further implementation of this approach is under discussion, awaiting the outcome of related projects on the potential of earth observation to track LUC in the UK and clarity on the long-term availability of relevant datasets.

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 ₂ O emissions from N mineralisation. 4C Grassland: 4(V) Biomass burning
Gases Reported	CO ₂ , CH ₄ , N ₂ O
Methods	T3 for carbon stock changes, T1 for other emissions
Emission Factors	Country-specific for T3 methods, T1/2 for other emissions
Key Categories	4C: Grassland - CO ₂ (L1, T1, L2, T2)
Key Categories (Qualitative)	None identified
Completeness	No known omissions- areas are reported for land uses with no associated emissions.
Major improvements since last submission	Average biomass densities for cropland and grassland used in the LUC model were changed to be consistent with those used in the cropland and grassland management calculations.

Net emissions from the Grassland category include carbon stock gains and losses due to land use change (LUC) and GHG emissions from grassland management. It is the second largest net sink in the LULUCF sector.

Ongoing carbon stock changes in soils arising from LUC to Grassland are reported under both 4.C.2 Land Converted to Grassland (for LUC in the past 20 years) and 4.C.1 Grassland Remaining Grassland (for historic LUC >20 years before the inventory reporting year). These soil net carbon stock changes are the largest component of the category total emissions and removals, and are calculated using a Tier 3 dynamic soil carbon model.

The area of undisturbed grassland which has not been converted from other land uses in the past is reported in 4.C.1. “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. The undisturbed grassland area is calculated as the difference between the total land area (from the official national statistic of UK land area, Office for National Statistics) 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.

Other contributors to the Grassland net total emissions are:

- carbon emissions resulting from drainage of organic soils (reported in 4(II));
- carbon stock changes in biomass resulting from changes in grassland management;
- biomass carbon stock changes due to LUC;

- N₂O emissions from soil disturbance associated with LUC;
- biomass burning emissions of GHGs from controlled burning following forest land conversion to grassland; and
- biomass burning emissions of GHGs due to wildfires.

Carbon stock changes from drainage of improved Grassland on organic soils arise from areas which were drained many decades ago for agriculture. Soil carbon in these areas continues to oxidise and be released as CO₂, resulting in an ongoing change in soil carbon stock. These emissions are reported in Table 4(II). There are large areas of organic and organo-mineral soils under unimproved Grassland throughout the UK and it is known that there has been some drainage of these areas although the full extent is unclear. Consequently, reporting just the area of, and emissions from, drained and improved grassland under Table 4C would be misleading. Work has been undertaken to address this in the BEIS-funded project on the implementation of the Wetlands Supplement guidance, but is awaiting the completion of further work before sign-off for implementation in the inventory.

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 (see section 6.1.1 for details).

Data sources that contain area information for reporting carbon stock changes and/or emissions from Grassland:

- Habitat/landscape surveys;
 - Countryside Survey (1984, 1990, 2000, 2007) is used to compile land use transition matrices. Changes in grassland types and in hedge length/condition are used to calculate biomass carbon stock changes under grassland management.
- Data on deforestation areas from various sources;
 - Post-2000 deforestation areas are assessed from the NFI and administrative records of the conversion of areas in the public forest estate as part of habitat restoration and windfarm development.
 - Pre-2000 deforestation areas are estimated from unconditional felling licence data (felling licences granted without a requirement to restock), national forest estate administrative information and land conversion ratios from Countryside Survey. Details are given in **Annex 3.4.4**.
- An assessment of the area of improved Grassland on drained organic soils (see 6.2 for further details).
- Data on wildfires on agricultural land and moorland from Fire and Rescue service and satellite data.

6.4.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

Grassland that has undergone land use change and direct management is defined in accordance with the Agriculture, Forestry and Other Land Uses guidance (IPCC 2006). There are also large areas of extensively grazed semi-natural grassland, which are assigned to the 4.C.1 “undisturbed grassland” sub-category and calculated as the area remaining after all other land use areas are subtracted from the total UK land area. This is the buffer land use category for the UK, so may contain small areas of other land uses that are not directly managed.

Grazing is the main land use on peatland habitats that would otherwise fall within the Wetland category, so areas of peatland habitat not used for peat extraction, such as bogs, are also included in the Grassland category.

For pre-1980 LUC the grassland area 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. For post-1980 LUC, 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

6.4.4.1 Land Use Change

Activity data for land use change are estimated using a land use matrix approach. Detailed descriptions of the methods, emission factors and data flows used for the Grassland are given in **Annex 3.4.2**.

The dynamic model of soil carbon stock change is described in **Section 6.3.4**. Biomass carbon stock change is calculated using the LUC matrix and literature-derived Tier 2 stock change factors with all stock gains or losses assumed to occur in a single year.

N₂O emissions associated with the soil disturbance from LUC are reported using the areas of Forest land converted to Grassland from the LUC matrices and the IPCC Tier 1 emission factors.

6.4.4.2 Grassland management

Carbon stock changes in biomass due to grassland management activities are estimated using literature-derived Tier 2 stock change factors and activity data from agricultural surveys. These include changes in the length and condition of hedgerows.

6.4.4.3 Drained organic soils

Emissions from Grassland 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).

6.4.4.4 Biomass burning emissions

Emissions from controlled burning on grassland are only reported for Forest Land conversion to Grassland and are estimated using Tier 1 emission factors and country-specific fuel densities.

Emissions from wildfires on Grassland (agricultural grassland and semi-natural grassland) are reported using Tier 1 emission factors and activity from a range of sources (see Section 6.3.2).

6.4.5 Uncertainties and Time-Series Consistency

4C Grassland is estimated to have a combined uncertainty of 45-50% for CO₂, 55% for CH₄ and 55-115% for N₂O.

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. 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.

With regard to time series consistency:

- Drainage of organic soils: 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.
- Changes in biomass and soil carbon due to LUC: the data sources for Great Britain have maintained consistent methodology across the time series. Consistency between these and Northern Ireland data sources has improved with better methodological integration between land use surveys.
- Controlled biomass burning after conversion of Forest Land to Grassland: the time series consistency is as country-specific data sets are used.
- Grassland management: activity data come from Countryside Survey, which is also used to estimate change in carbon stocks due to land use change and has good internal consistency.
- Wildfires: a consistent dataset is used for 2010 onwards. Burnt areas are 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 Grassland, and the time series is filled by extrapolating the 2001 - 2011 average wildfire area.

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 unclear, as discussed in **Section 6.3.6**.

6.4.7 Category-Specific Recalculations

The reported overall net GHG sink in category 4C has reduced slightly between 0.6 - 0.7 Mt CO₂e (8.4 - 7.7 %) across the time series compared to the 2016 inventory. The changes were mainly seen in biomass carbon stock change in Land converted to Grassland.

The changes and their justification are:

- **Adjustment of average biomass densities due to error correction:** see section 6.2.7 for further explanation. These changes affected the average biomass density used to calculate biomass burning emissions and biomass losses.
- **Changes to the average deforestation rate for soil CSC calculation:** Continuous improvement of the deforestation data set as more information becomes available has affected the average deforestation rate from 2010, altering the estimated soil carbon stock change from the LUC model.
- **Changes to the living biomass densities for cropland and grassland:** The average living biomass densities for cropland and grassland used in the non-forest biomass

LUC model have been updated to those used in the cropland and grassland management calculations (these were based on a more recent UK-relevant literature review in Moxley *et al.* 2014). This change was in response to a UNFCCC review recommendation and improves consistency within the LULUCF inventory. It has resulted in change from a net emission to a net removal (and vice versa) in the LUC sub-categories for 4B2, 4C2 and 4E2.

Changes in emissions are described in Table 6.6.

Table 6.6 4C Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2018 Submission		2019 Submission		Units	Comment / Justification
		1990	2016	1990	2016		
4C2.1/4(V)	Biomass burning - controlled burning	4.8	65.3	4.7	62.3	Gg C	Adjustment of average biomass densities due to error correction
4C2.1	Carbon stock change in living biomass - losses	8.1	110.4	7.9	105.4	Gg C	Adjustment of average biomass densities due to error correction
4C2.1	Net carbon stock change in dead organic matter	0.3	4.1	0.3	3.8	Gg C	
4C2.1	Net carbon stock change in soils - mineral soils	0.1	62.7	0.1	61.7	Gg C	Changes to the average deforestation rate for soil CSC calculation
4C2.2	Carbon stock change in living biomass - gains	-58.4	-68.6	IE	IE	Gg C	Changes to the living biomass densities for cropland and grassland
4C2.2	Carbon stock change in living biomass - losses	IE	IE	125.4	147.6	Gg C	
4C2.4	Carbon stock change in living biomass - gains	IE	IE	-3.4	-6.0	Gg C	
4C2.4	Carbon stock change in living biomass - losses	3.7	6.2	IE	IE	Gg C	
4C1/4(V)	Biomass burning - wildfires	0.348	0.228	0.347	0.228	Gg CH ₄	Adjustment of average biomass densities due to error correction
4C2.1/4(V)	Biomass burning - controlled burning	0.052	0.717	0.051	0.684	Gg CH ₄	
4C1/4(V)	Biomass burning - wildfires	0.032	0.021	0.032	0.021	Gg N ₂ O	Adjustment of average biomass densities due to error correction
4C2.1/4(III)	Direct N ₂ O from N mineralisation	0.000	0.066	0.000	0.065	Gg N ₂ O	Changes to the average deforestation rate for soil CSC calculation
4C2.1/4(V)	Biomass burning - controlled burning	0.003	0.040	0.003	0.038	Gg N ₂ O	Adjustment of average biomass densities due to error correction

6.4.8 Category-Specific Planned Improvements

A BEIS-funded research project has been completed to improve understanding of the effect of grassland management practices on carbon stock changes in organic and organo-mineral soils. It is currently awaiting review and sign-off by the NISC. This work will fill a knowledge gap and could enable more carbon stock changes resulting from Grassland management to be included in the inventory.

A vector based approach to tracking land use change has been piloted that assimilates data to provide a more accurate assessment of land use change history in the UK (Levy et al. 2017). Further implementation of this approach is under discussion, awaiting the outcome of related projects on the potential of earth observation to track LUC in the UK and clarity on the long-term availability of relevant datasets.

Hedgerows (which fall within the Boundary and Linear Feature Broad Habitat which falls under the Settlement category) will be allocated consistently to the Grassland category in the next submission.

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 ₂ O
Methods	Tier 1
Emission Factors	Country specific and default EFs
Key Categories	None identified
Key Categories (Qualitative)	None identified
Completeness	No known omissions- areas are reported for land uses with no associated emissions.
Major improvements since last submission	None.

Net emissions from the Wetlands category 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 most UK wetland habitats (e.g. marsh, bog, swamp and fen) are grazed their emissions and removals are estimated within the Grassland category. A research project has been completed to identify UK-specific activity data and emission factors to use with the 2013 Wetlands Supplement methodology; additional work to implement it in the GHGI methodology is underway (see 6.5.8 for further discussion).

Emissions from on-site peat production and off-site emissions from horticultural peat are reported 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 reported under 4.D.2. The associated soil emissions and living biomass carbon stock changes estimated using the appropriate Tier 1 methodologies. N₂O emissions from wetland drainage (as part of peat production) are reported under 4.D and 4(II).

The area of UK natural inland water is reported in the category Other Wetlands remaining Other Wetlands and the area of reservoirs created before 1990 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 4.D.2.2.3 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

The approach used for representing Wetlands differs from that used for other land use categories because peat extraction sites and reservoirs are not explicitly identified in the habitat and landscape surveys used for the land use matrix.

Data from the Directory of Mines and Quarries, Google Earth, the Minerals Extraction in Great Britain report (and its predecessor the Minerals Raised Inquiry, Office for National Statistics), 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 post-1990 constructed 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).

The remaining area of inland water (natural water bodies and reservoirs established before 1990) is known from the area of inland water reported as part of the Standard Area Measurement. There are no emissions or removals associated with this area.

6.5.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

Areas of peat extraction are defined as areas that are currently undergoing, or have recently undergone, peat extraction activities (locations are known from administrative records: see Section 6.5.2). It is assumed that extraction areas continue to produce emissions while there is visible evidence of exposed peat soil from Google Earth satellite imagery. An extraction site is considered to have ceased emissions when there is visible evidence of the re-establishment of vegetation cover on the satellite imagery.

The area of inland water is taken from the “UK Standard Area Measurements” (Office for National Statistics). It defines inland water as ‘bounded’ permanent water bodies, e.g. lakes, lochs and reservoirs, exceeding 1 km² (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. Areas of water below the size threshold are included in the 4F Other Land category.

6.5.4 Methodological Issues

6.5.4.1 Peat extraction

Emissions from peat extraction are estimated using a 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.1.1. All carbon in horticultural peat is assumed to be emitted during the extraction year. Methane emissions are assumed to be insignificant. N₂O emissions from drainage are reported, although emissions are considered insignificant on nutrient-poor peatlands. The administrative records categorise sites as producing horticultural or energy source (fuel) peat. This information is used to extract the area of nutrient-rich peats that will produce N₂O 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 imagery is checked annually and extraction site areas are updated as

new imagery becomes available. A new extraction site in Northern Ireland was identified in this compilation cycle using this method.

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. Sites that have no active record of extraction, and show no change in area on the Google Earth imagery, 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.

6.5.4.2 Land converted to Flooded Land

A Tier 1 methodology was applied for emissions from Flooded Lands. 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

4D Wetland is estimated to have a combined uncertainty of 100% for CO₂ and 100% for N₂O.

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 is very low as there have only been five reservoirs established since 1990 and their extents are well quantified.

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 has been 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

The reported overall net GHG source in category 4D has decreased slightly by 0.01 Mt CO₂e (2.2 %) in 2016 in the latest submission compared to the 2016 inventory.

The change was due to updating the calculation of total area of horticultural peat: rather than using a roll-over of the 2015 value, the 2016 value is now from activity data and reflects a reduction in the area of peat extraction due to restoration.

The changes in emissions are shown in **Table 6.7**.

Table 6.7 4D Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2018 Submission		2019 Submission		Units	Comment / Justification
		1990	2016	1990	2016		
4D1.1	Net carbon stock change in soils - organic soils	132.8	87.2	132.8	85.3	Gg C	Adjustment of total horticultural peat extraction area due to error correction

6.5.8 Category-specific planned improvements

A BEIS-funded project to implement the Wetlands Supplement (IPCC, 2013a) guidance is expected to be published within the next few months (see box). Preliminary results show large uncertainty in the areas assigned to different management actions around drainage and rewetting and on emission factors for certain type of peatlands under forestland, cropland and grassland. Further work is underway to incorporate the results into the inventory, with the aim of implementation in the 2020 inventory submission. The inclusion of some peatland condition categories may be delayed pending further work on reducing their associated uncertainties.

Implementing the IPCC 2013 Wetlands Supplement in the UK

BEIS funded a research project (Evans *et al.* forthcoming) to develop and implement a new method for reporting GHG emissions from peatlands (highly organic soils) in the UK's emissions inventory.

The project:

- Collated and analysed UK-relevant measurement data to develop Tier 2 EFs for the broad range of peat condition categories present in the UK;
- Developed methods to quantify current status and change in peat condition since 1990, based on a new 'unified' map of peat extent for all four UK countries, collated spatial land cover and peat condition datasets, and records of peat restoration and management activities; and
- Implemented an emissions inventory for UK peatlands and assessed the associated uncertainties.

Peatland condition categories comprised near-natural peatlands, semi-natural peatlands affected by human activity (such as drainage, controlled burning and livestock grazing), cropland, extensive and intensive grassland, woodland, peat extraction areas and active peatland restoration areas. Peatland soils occur in all LULUCF categories apart from 4E Settlement, 4F Other Land and 4G Harvested Wood Products. The KP-LULUCF categories of Deforestation, Forest Management, Cropland Management, Grazing Land Management and Wetland Drainage and Rewetting will also be affected.

Tier 2 EFs and 95% confidence intervals were derived for CO₂, CH₄ and N₂O for each peatland condition category. It was not possible to quantify uncertainties for the activity data, and consequently more than 50% of the total emissions calculated by the project could only be estimated with a low level of confidence.

Next steps:

- Implementation of the research results in an operational LULUCF reporting format, requiring the integration of the peatland spatial data into the UK land area matrix and the establishment of calculation and QA/QC processes (March 2019).
- Consideration by the LULUCF Scientific Steering Committee and incorporation of any recommendations (Anticipated September 2019).
- Sign-off by the NISC (Dependent on progress in previous steps).

6.6 CATEGORY 4E – SETTLEMENTS**6.6.1 Description**

Emissions sources	4E Settlements: Carbon stock change 4E Settlements: 4(III) Direct N ₂ O emissions from N mineralization 4E Settlements: 4(V) Biomass burning
Gases Reported	CO ₂ , CH ₄ , N ₂ O
Methods	T3 for carbon stock changes, T1 for other emissions
Emission Factors	Country-specific for T3 methods, T1/2 for other emissions
Key Categories	4E: Settlements – CO ₂ (L1, T1, L2, T2)
Key Categories (Qualitative)	None identified
Completeness	No known omissions- areas are reported for land uses with no associated emissions.
Major improvements since last submission	Average biomass densities for cropland and grassland used in the LUC model were changed to be consistent with those used in the cropland and grassland management calculations.

Net emissions from the Settlements category include carbon stock gains and losses due to land use change (LUC) and associated GHG emissions.

Ongoing carbon stock changes in soils and direct N₂O emissions from N mineralization arising from LUC to Settlements are reported under both 4.E.1 Settlements remaining Settlements (for historic LUC >20 years before the inventory reporting year) and 4.E.2 Land converted to Settlements (for LUC in the past 20 years). These soil net carbon stock changes are the largest component of the category total emissions, and are calculated using a Tier 3 dynamic soil carbon model.

Other contributors to the Settlements net total emissions are:

- biomass carbon stock changes due to LUC;
- N₂O emissions from soil disturbance associated with LUC; and
- biomass burning emissions of GHGs from controlled burning following forest land conversion to Settlements.

Full details of the methods and activity data are given in **Annex 3.4.4** and **Annex 3.4.5**.

6.6.2 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 (see section 6.1.1 for details).

Data sources that contain area information for reporting carbon stock changes and/or emissions from Settlements are:

- Habitat/landscape surveys
 - Countryside Survey (1984, 1990, 2000, 2007) is used to compile land use transition matrices.
- Data on deforestation areas from various sources;

- Post-2000 deforestation areas are assessed from the NFI and administrative records of the conversion of areas in the public forest estate as art of habitat restoration and windfarm development.
- Pre-2000 deforestation areas are estimated from unconditional felling licence data (felling licences granted without a requirement to restock), national forest estate administrative information and land conversion ratios from Countryside Survey. Details are given in **Annex 3.4.4**.

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 LUC 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). For post-1980 LUC, 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.”

Although hedgerows are included in the definition of the “Boundary and linear features” Broad Habitat type, any carbon stock changes associated with hedgerow change are calculated separately under grassland management. The “Boundary and linear features” Broad Habitat type is a very small component of the UK land area (<2% in the 2007 Countryside Survey) so the overlap in definitions will not materially affect net LULUCF emissions.

6.6.4 Methodological Issues

6.6.4.1 Land Use Change

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 LUC is given in **Section 6.3.4**. Detailed descriptions of the methods, emission factors and data flows used for the Settlement category are given in **Annex 3.4.7**.

N₂O emissions associated with the soil disturbance from LUC are reported using the areas from the LUC matrices and the IPCC Tier 1 emission factors.

6.6.4.2 Biomass burning emissions

Emissions from controlled burning on settlement land are only reported for Forest Land conversion to Settlements and are estimated using Tier 1 emission factors and country-specific fuel densities.

6.6.5 Uncertainties and Time-Series Consistency

4E Settlement is estimated to have a combined uncertainty of 50% for CO₂, 55% for CH₄ and 15-135% for N₂O.

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.

With regard to time series consistency:

- Changes in biomass and soil carbon due to LUC: the data sources for Great Britain have maintained consistent methodology across the time series. Consistency between these and Northern Ireland data sources has improved with better methodological integration between land use surveys.
- Controlled 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 reported overall net GHG source in category 4E has increased slightly by up to 0.1 Mt CO₂e (1.4-1.9 %) across the time series compared to the 2016 inventory.

The changes were in biomass carbon stock change in Land converted to Settlement. The changes and their justification are:

- **Adjustment of average biomass densities due to error correction:** see section 6.2.7 for further explanation. These changes affected the average biomass density used to calculate biomass burning emissions and biomass losses.
- Changes to the average deforestation rate for soil CSC calculation: Continuous improvement of the deforestation data set as more information becomes available has affected the average deforestation rate from 2010, altering the estimated soil carbon stock change from the LUC model.
- **Changes to the living biomass densities for cropland and grassland:** The average living biomass densities for cropland and grassland used in the non-forest biomass LUC model have been updated to those used in the cropland and grassland management calculations (these were based on a more recent UK-relevant literature review in Moxley *et al.* 2014). This change was in response to a UNFCCC review recommendation and improves consistency within the LULUCF inventory. It has resulted in a change in sign for the biomass carbon stock changes in the LUC sub-categories for 4B2, 4C2 and 4E2 (i.e. biomass CSC previously calculated as net emissions are now net removals and biomass CSC previously calculated as net removals are now net emissions).

Changes in emissions are described in Table 6.8.

Table 6.8 4E Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2018 Submission		2019 Submission		Units	Comment / Justification
		1990	2016	1990	2016		
4E2.1/4(V)	Biomass burning - controlled burning	11.1	38.8	10.9	37.0	Gg C	Adjustment of average biomass densities due to error correction
4E2.1	Carbon stock change in living biomass - losses	18.8	65.6	18.6	62.6	Gg C	Adjustment of average biomass densities due to error correction
4E2.1	Net carbon stock change in dead organic matter	0.6	2.4	0.6	2.3	Gg C	
4E2.1	Net carbon stock change in soils - mineral soils	10.4	72.5	10.4	75.4	Gg C	Changes to the average deforestation rate for soil CSC calculation
4E2.1/4(V)	Biomass burning - controlled burning	0.122	0.426	0.120	0.406	Gg CH ₄	Adjustment of average biomass densities due to error correction
4E2.1/4(III)	Direct N ₂ O from N mineralisation	0.011	0.076	0.011	0.079	Gg N ₂ O	Changes to the average deforestation rate for soil CSC calculation
4E2.1/4(V)	Biomass burning - controlled burning	0.007	0.024	0.007	0.022	Gg N ₂ O	Adjustment of average biomass densities due to error correction
4E2.2	Carbon stock change in living biomass - gains	-3.3	-6.7			Gg C	Changes to the living biomass densities for cropland and grassland
4E2.2	Carbon stock change in living biomass - losses			5.7	11.7	Gg C	
4E2.3	Carbon stock change in living biomass - gains	-10.8	-7.8			Gg C	
4E2.3	Carbon stock change in living biomass - losses			9.7	6.8	Gg C	

6.6.8 Category-Specific Planned Improvements

A vector based approach to tracking land use change has been piloted that assimilates data to provide a more accurate assessment of land use change history in the UK (Levy et al. 2017). Further implementation of this approach is under discussion, awaiting the outcome of related projects on the potential of earth observation to track LUC in the UK and clarity on the long-term availability of relevant datasets.

Hedgerows (which fall within the Boundary and Linear Feature Broad Habitat) will be allocated consistently to the Grassland category in the next submission.

6.7 CATEGORY 4F – OTHER LAND

6.7.1 Description

Emissions sources	None
Gases Reported	None
Methods	NA
Emission Factors	NA
Key Categories	None identified
Key Categories (Qualitative)	None identified
Completeness	No known omissions- areas are reported for land uses with no associated emissions.
Major improvements since last submission	None

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).

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 1km² are included in 4D Wetlands, but water bodies below this threshold would still be included under Other Land.

6.7.4 Category-specific recalculations

There are no emissions associated with Other Land and no recalculations.

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 (T1, T2)
Key Categories (Qualitative)	None identified
Completeness	No known omissions
Major improvements since last submission	Activity data on historic forest planting rates have been adjusted after reconciliation of harvest volume and forest age data. This affects the modelled timing and quantity of harvested wood products.

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).

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. 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 Forest Land. Changes in carbon stocks from HWP arising from deforestation (conversion of Forest Land to Grassland, Cropland or Settlement) are also estimated using CARBINE. The estimated carbon in harvested wood is split in to harvested wood product classes based on information on wood use from Forestry Commission statistics and the FAO. A description of the method is outlined in **Annex 3.4.10**. Data from the Forestry Statistics on consumption of wood products in the UK are then used to disaggregate the HWP into either consumed domestically or exported. This dataset exists from 2002 onwards and the 2002-2011 average values are used for 1990-2001.

6.8.3 Uncertainties and Time-Series Consistency

4G Harvested Wood Products is estimated to have a combined uncertainty of 45% for CO₂.

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 total quantity of softwood and hardwood production are available from 1976. Data on the relative proportions of wood from UK sources used for different harvested wood products is available from 1994 onwards, the proportions prior to 1994 are estimated from FAO data. Data on the export 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.

There has been an improvement in this inventory involving the introduction of an automated algorithm to adjust the assumptions about forest management to ensure the best fit between wood production estimated by the CARBINE model and that reported in the wood production statistics. This improves the HWP estimates and ensures repeatability. This project also included re-implementing the timber volume production module of CARBINE in the automated algorithm. This semi-independent implementation was cross-validated against the CARBINE timber production module.

6.8.5 Category-Specific Recalculations

The reported overall net GHG sink in category 4G increased by 0.02 to 0.27 Mt CO₂e between 1990 and 2011 (2 to 21 %) and by 1.05 and 1.90 Mt CO₂e between 2012 and 2016 (93 to 157%) compared to the 2016 inventory.

The changes resulted from the automated reconciliation of harvest volume and change data, as described in 6.2.7.

The changes are described in **Table 6.9**.

Table 6.9 4G Category specific recalculations to activity data since previous submission

IPCC Category	Source Name	2018 Submission		2019 Submission		Units	Comment / Justification
		1990	2016	1990	2016		
4G	Total HWP from domestic harvest	-440.3	-230.4	-447.0	-590.9	Gg C	Reconciliation of harvest volume and forest age data.

6.8.6 Category-Specific Planned Improvements

There will be an updated uncertainty analysis to better quantify the uncertainties from varying the parameters of the CARBINE model. This will be a revision of the uncertainty analysis published in the 1990-2010 National Inventory Report.

6.9 LULUCF EMISSIONS AND REMOVALS IN THE OVERSEAS TERRITORIES AND CROWN DEPENDENCIES

6.9.1 Description

Emissions sources	Carbon stock change: 4A Forest Land, 4B Cropland, 4C Grassland, 4E Settlements, 4G Harvested Wood Products 4(III) Direct N ₂ O emissions from N mineralization (4B Cropland, 4E Settlements)
Gases Reported	CO ₂ , N ₂ O
Methods	Tier 1 (Tier 3 for Forest Land)
Emission Factors	Default EFs
Key Categories	None identified
Key Categories (Qualitative)	None identified
Completeness	Not estimated: 4D Wetlands, Grassland drained organic soils, GHG emissions from wildfires
Major improvements since last submission	None.

GHG emissions and removals from the UK Crown Dependencies (CD) and Overseas Territories (OT) are reported under the relevant categories for the LULUCF sector in the CRF GBR and GBK (omitting Bermuda) submissions (Table 6.10). Currently emissions estimates are 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. Discussions have started with the Cayman Islands government with a view to reporting LULUCF emissions from this OT in the future. Gibraltar wished to produce its own inventory and has assessed its LULUCF net emissions/removals as Not Occurring (**Annex 3.6**).

The estimated emissions are uncertain and may not capture all relevant activities, but given the size of the territories any missing sources are likely to be extremely small. **Annex 3.4.11** provides detailed descriptions of the methods and emission factors used.

Table 6.10 LULUCF Sector in the Overseas Territories and Crown Dependencies (Mt CO₂e)

LULUCF Greenhouse Source and Categories	Gas Sink	1990 emissions total	2016 emissions total	2017 emissions total	Recalculations 1990 ¹	Recalculations 2016 ¹
Total LULUCF		-0.015	0.004	0.000	-13.5%	-74.6%
A.Forest Land		-0.037	-0.038	-0.038	0.0%	0.0%

LULUCF Greenhouse Gas Source and Sink Categories	1990 emissions total	2016 emissions total	2017 emissions total	Recalculations 1990 ¹	Recalculations 2016 ¹
B.Cropland	0.011	0.036	0.036	-1.2%	-23.4%
C.Grassland	-0.008	-0.024	-0.028	22.7%	-11.9%
D.Wetlands	0.000	0.000	0.000	NO	NO
E.Settlements	0.020	0.030	0.029	24.3%	-8.8%
G. Harvested Wood Products	0.000	0.000	0.000	0.0%	0.0%
Indirect emissions N ₂ O	0.000	0.000	0.000	0.000	78.4%

¹ The values given are the % difference in 1990 or 2016 emissions/removals from the data reported in the previous UK GHGI submission.

The Forest Land, Grassland categories are net sinks in the OTs and CDs (and HWP until 2015), and the Cropland and Settlement categories are net sources. The overall trend in the LULUCF sector has moved from being a very small net sink in 1990, to being a very small net source from 2007 onwards. The individual territory trends are:

- Falkland Islands: slowly increasing net source, due to disturbance of organic soils and expansion of settlement
- Isle of Man: net sink, with net sources in cropland and settlement counterbalanced by net sinks in forest and grassland
- Guernsey: small net source, with net sources in cropland and settlement counterbalanced by net sinks in forest and grassland
- Jersey: moves from being a small net source to a small net sink from 2001 onwards.

6.9.2 Land use areas

Land cover surveys and agricultural land statistics have been used to compile annual land use change matrices for the OTs and CDs (Table 6.11), which are converted into the UNFCCC land use change matrices using the 20 year transitions (reported in CRF tables 4A-4E in the GBR submission). The total land area of the OTs and CDs increases slightly from 2009 onwards, due to land reclamation in Jersey.

The definition of each land category is in accordance with the Agriculture, Forestry and Other Land Use Guidance (IPCC 2006). The Grassland category is used as the “buffer” category to ensure consistency in total land area.

Table 6.11 Areas of land by category in the Crown Dependencies and Overseas Territories 1990-2017, kha

Year	4A Forest Land		4B Cropland			4C Grassland					4D Wetland	4E Settlement			4F Other Land	Total land area
	Forest remaining Forest	Forest land converted to Grassland	Cropland remaining Cropland	Cropland converted to Grassland	Cropland converted to Settlement	Grassland remaining Grassland	Grassland converted to Forest Land	Grassland converted to Cropland	Grassland converted to Wetland	Grassland converted to Settlement	Wetland remaining Wetland	Settlement remaining Settlement	Settlement converted to Forest Land	Settlement converted to Grassland	Other land remaining other land	
1990	4.440	0.000	12.916	0.145	0.000	1264.551	0.080	0.000	0.000	0.036	0.095	10.354	0.000	0.000	0.136	1292.75
1991	4.520	0.000	12.844	0.072	0.000	1264.617	0.000	0.050	0.000	0.029	0.095	10.390	0.000	0.000	0.136	1292.75
1992	4.520	0.000	12.820	0.074	0.000	1264.676	0.000	0.000	0.000	0.013	0.095	10.420	0.000	0.000	0.136	1292.75
1993	4.520	0.000	12.747	0.073	0.000	1264.589	0.000	0.000	0.000	0.162	0.095	10.432	0.000	0.000	0.136	1292.75
1994	4.520	0.000	12.674	0.074	0.000	1264.649	0.000	0.000	0.000	0.013	0.095	10.594	0.000	0.000	0.136	1292.75
1995	4.520	0.000	12.602	0.072	0.000	1264.534	0.000	0.126	0.000	0.063	0.095	10.606	0.000	0.000	0.136	1292.75
1996	4.520	0.000	12.727	0.000	0.000	1264.488	0.000	0.056	0.000	0.063	0.095	10.669	0.000	0.000	0.136	1292.75
1997	4.520	0.000	12.783	0.000	0.000	1264.387	0.000	0.019	0.000	0.082	0.095	10.732	0.000	0.000	0.136	1292.75
1998	4.520	0.000	12.729	0.000	0.074	1264.283	0.000	0.020	0.002	0.083	0.095	10.813	0.000	0.000	0.136	1292.75
1999	4.520	0.000	12.517	0.158	0.074	1264.197	0.000	0.001	0.002	0.083	0.097	10.970	0.000	0.000	0.136	1292.75
2000	4.518	0.002	12.194	0.250	0.075	1264.195	0.009	0.055	0.002	0.094	0.098	11.123	0.004	0.000	0.136	1292.75
2001	4.528	0.002	11.897	0.277	0.075	1264.289	0.009	0.054	0.002	0.094	0.100	11.288	0.004	0.000	0.136	1292.75
2002	4.538	0.002	11.739	0.136	0.075	1264.428	0.009	0.054	0.002	0.077	0.101	11.454	0.004	0.000	0.136	1292.75
2003	4.548	0.002	11.523	0.195	0.075	1264.423	0.009	0.054	0.002	0.079	0.103	11.602	0.004	0.000	0.136	1292.75
2004	4.558	0.002	11.424	0.078	0.075	1264.308	0.009	0.225	0.002	0.077	0.105	11.753	0.004	0.000	0.136	1292.75
2005	4.568	0.002	11.400	0.175	0.075	1264.156	0.009	0.142	0.002	0.079	0.106	11.901	0.004	0.000	0.136	1292.75
2006	4.578	0.002	11.458	0.010	0.075	1263.776	0.009	0.386	0.002	0.160	0.108	12.052	0.004	0.000	0.136	1292.75
2007	4.587	0.002	11.731	0.038	0.075	1263.356	0.009	0.319	0.002	0.103	0.109	12.283	0.004	0.000	0.136	1292.75
2008	4.597	0.002	11.957	0.018	0.075	1263.048	0.009	0.276	0.002	0.102	0.111	12.457	0.004	0.000	0.136	1292.75

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Year	4A Forest Land		4B Cropland			4C Grassland					4D Wetland	4E Settlement			4F Other Land	Total land area
2009	4.607	0.002	11.606	0.625	0.001	1262.712	0.009	0.243	0.003	0.102	0.112	12.624	0.004	0.007	0.136	1292.79
2010	4.617	0.002	11.837	0.011	0.001	1262.945	0.009	0.306	0.003	0.102	0.115	12.716	0.004	0.007	0.136	1292.79
2011	4.627	0.002	11.965	0.177	0.001	1262.848	0.009	0.054	0.003	0.052	0.118	12.809	0.004	0.007	0.136	1292.81
2012	4.637	0.002	10.976	1.042	0.001	1262.908	0.009	0.054	0.003	0.060	0.121	12.851	0.004	0.007	0.136	1292.81
2013	4.647	0.002	10.882	0.146	0.001	1263.508	0.009	0.380	0.003	0.060	0.124	12.904	0.004	0.005	0.136	1292.81
2014	4.657	0.002	10.056	1.205	0.001	1263.597	0.009	0.054	0.003	0.060	0.128	12.956	0.004	0.005	0.136	1292.81
2015	4.667	0.002	9.884	0.225	0.001	1263.703	0.009	1.035	0.003	0.060	0.131	13.009	0.004	0.005	0.136	1292.87
2016	4.677	0.002	10.445	0.473	0.001	1263.796	0.009	0.054	0.000	0.077	0.134	13.066	0.004	0.000	0.136	1292.87
2017	4.687	0.002	10.426	0.071	0.001	1264.148	0.009	0.054	0.000	0.060	0.134	13.141	0.004	0.000	0.136	1292.87

6.9.3 Methodological Issues

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 Agriculture, Forestry, and Land Use (AFOLU) Guidelines have been used to estimate all other emissions and removals.

6.9.4 Recalculations

The net LULUCF emissions from the OTs and CDs changed compared to the previous inventory, with a 2.26 Gg CO₂e reduction in the net sink in 1990 and a 10.66 Gg CO₂e decrease in the net source in 2016.

These changes are due to:

- Emission calculations (4B.1, 4B.2 and 4C.2) from organic soils in the Falkland Islands have changed so that once land has been converted to cropland it stays as cropland: otherwise, from 2014 onwards the area of land converted to cropland was greater than the total area of cropland reported in the agricultural statistics. The Falkland islands have organic soils which keep losing carbon once disturbed but do not use intensive agricultural practices: the emissions are now calculated so that the area reported as annual forage (i.e. tilled) uses the Cropland EF, and the remaining area (counted as cropland but not tilled) uses the Pasture grassland EF.
- The biomass carbon stock densities in the OTs and CDS have been changed to use the updated UK values: this maintains consistency within the UK inventory. This affects 4B.2, 4C.2 and 4E.2.
- A 5 year rolling average has been applied to the reported cropland area in Jersey to remove the impact of crop-grass rotation and the resulting insufficient grassland area. This has reduced soil CSC from land use change between grassland and cropland in Jersey (4B.2 and 4C.2).
- An error in the Forest to Grassland calculations in Guernsey was corrected during compilation, lowering biomass carbon stock losses in 4C.2.
- Emissions from land converted to permanently flooded land (4D.2) are now reported separately, resulting in a small increase in emissions between 1997 and 2016. An error in the inventory calculations was identified during the UNFCCC 2016 review: these emissions had been calculated but had not been incorporated into the final dataset.
- Small inconsistencies in the reporting of conversion to Settlement in Jersey have been resolved (4E.2).

6.9.5 Planned improvements

Discussions with the Cayman Islands government regarding the reporting of LULUCF net emissions from the Cayman Islands have not progressed since the last inventory submission. The initial contact focussed on gathering appropriate land use and activity data and ascertaining its compatibility with IPCC land use definitions.

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 are dedicated to delivering world-class scientific research which fully meets our customers' requirements for quality, timeliness and cost. The quality of science is supported by a Quality Management System (QMS) which ensures that appropriately-trained and qualified personnel use correctly maintained and calibrated equipment and appropriate techniques to produce reliable outputs. Our system of records management enables us to fully demonstrate the quality of our science. Forest Research applies the standards required by the Defra Joint Code of Practice for Research as described above for CEH. The Expert Committee on Forest Science provides guidance for the Forestry Commission on the quality and direction of their research.

In 2015 a review of the QA framework and procedures for the full UK inventory was carried out (Hartley McMaster Ltd, 2015). In 2016 all the LULUCF models based in Excel spread sheets were reviewed by Hartley McMaster using a bespoke quality auditing tool developed in Excel. The outputs from this auditing tool resulted in improvements to model documentation and the correction of a few minor errors.

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 Environment Agency.

A programme of upgrade to the LULUCF models began in 2016. This includes verification of model calculations, improvement of documentation, addition of built in QA checks and storage in a version control repository. So far nine LULUCF models have been upgraded. A Microsoft Access 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 recording requests for data from stakeholders and external parties.

In collaboration with Ricardo Energy & Environment, CEH has developed a QA/QC plan to standardise and structure the way checks are carried out within the LULUCF inventory. The plan is implemented and revised as required in each inventory cycle. 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.

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 ₂ O, 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 waste – CH ₄ (T1, L2, T2) 5B: Biological treatment of waste – N ₂ O (L2, T2) 5C: Waste incineration – CO ₂ (L2, T2) 5D: Wastewater handling – CH ₄ (L1, L2) 5D: Wastewater handling – N ₂ O (L2, T2)
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	5C1: Previously, carbon emission factors for the incineration of municipal solid waste (MSW) were based on uncertain UK-specific data. The Inventory Agency considers this approach is no longer justified, and so have reverted to the use of IPCC Tier 1 default emission factors. Additionally, biodegradable waste emissions from incineration are calculated for the first time, using IPCC Tier 1 default emission factors.

Emissions from the waste sector contributed 4.6% to greenhouse gas emissions in 2017. Emissions consist of CO₂, N₂O and CH₄ from waste incineration, CH₄ from solid waste disposal on land, and both CH₄ and N₂O from wastewater handling and biological treatment of solid waste. Overall emissions from the waste sector have decreased by 69% 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 2016⁵⁹

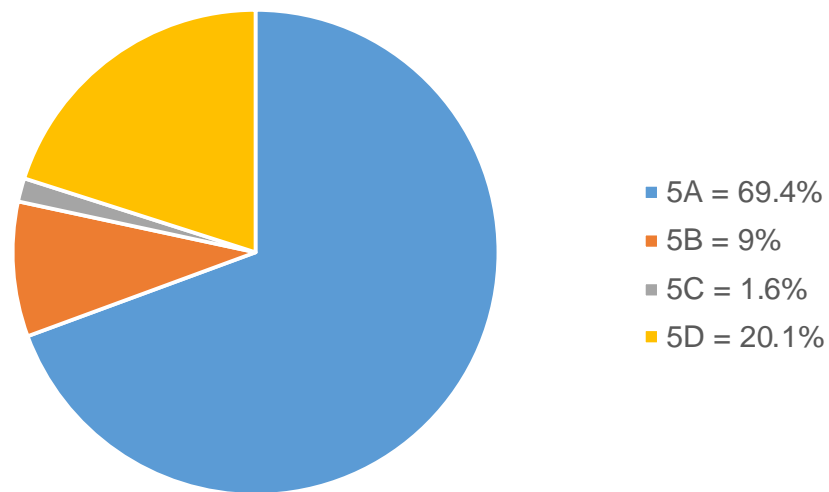
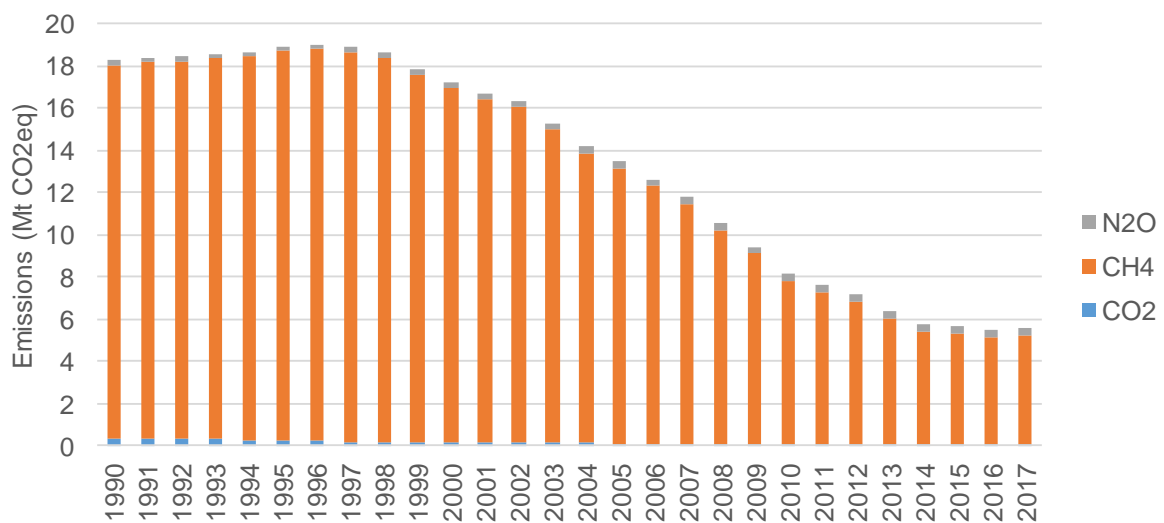


Figure 7.2 Trend in total GHG emissions in the Waste sector



⁵⁹ The categories in the Waste sector are explained in the IPCC categories section.

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 input data and parameters for the MELMod model were updated based on new data on the quantity of waste landfilled. Data on 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. Emissions from the use of landfill gas to generate power are reported in IPCC sector 1A1a (see MS1).

Estimated emissions from this sector in 2017 were 14.1 Mt CO₂e. Emissions have been on a downward trend since 1996, although emissions in 2017 were marginally higher than in 2016.

In addition to CH₄, anaerobic decomposition also produces an approximately equivalent amount of carbon dioxide and further CO₂ 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 CO₂ from solid waste disposal sites (SWDS) are not considered further. Emissions of CO₂ 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 the 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 CH₄ 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 landfills continue to produce CH₄ 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 most recently as part of the Environmental Permitting (England and Wales) Regulations 2016. 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) 2003. 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 EU Waste Framework Directive 2008/98/EC and Landfill Directive 1999/31/EC provides the legislative framework for collection, transport, recovery and disposal of waste. The Waste Framework 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. Defra’s Resources and Waste Strategy published in December 2018 set out how the Government intends to minimise waste, promote resource efficiency and move towards a circular economy in England. Similar approaches are being adopted in the Devolved Administrations.

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; those that can be converted to methane and carbon dioxide)⁶⁰ 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.

⁶⁰ DDOC is the amount of degradable organic carbon (DOC) that is converted (i.e. dissimilated) to methane and carbon dioxide under landfill conditions. $DDOC = DOC \times DOC_F$ where DOC_F is the fraction of DOC that dissimilates.

In the UK model, the various waste types are allocated to three pools (p) of 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. 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 equations set out below are copied directly from the IPCC 2006 Guideline.

- Equation 3.1 represents the overall approach of calculating methane formation for each year, subtracting the quantity of methane collected, and allowing for the quantity of methane oxidised in the Solid Waste Disposal Site (SWDS) cover layer. This equation is used explicitly in the UK inventory as set out in IPCC (2006).

$$\begin{aligned} &\text{EQUATION 3.1} \\ &\text{CH}_4 \text{ EMISSION FROM SWDS} \\ &CH_4 \text{ Emissions} = \left[\sum_x CH_4 \text{ generated}_{x,T} - R_T \right] \cdot (1 - OX_T) \end{aligned}$$

- Equation 3.2 enables the mass of DDOC deposited to be calculated from the mass of waste deposited, the fraction of Degradable Organic Carbon (DOC) in the waste, and the methane correction factor. This equation is applied to individual waste streams in the UK inventory based on their lignin and non-lignin carbon contents (rather than using an overall figure for the fraction of DOC in the waste) (Eunomia Consulting and Research, 2011). Separate Methane Correction Factors are applied to waste deposited in unmanaged sites prior to 1980, and waste deposited in managed sites from 1980 onwards (see below).

$$\begin{aligned} &\text{EQUATION 3.2} \\ &\text{DECOMPOSABLE DOC FROM WASTE DISPOSAL DATA} \\ &DDOC_m = W \cdot DOC \cdot DOC_f \cdot MCF \end{aligned}$$

- Equation 3.3 is a calculation of methane generation potential from the mass of DDOC deposited, and the fraction of methane in landfill gas. This equation is used in the UK inventory as set out in IPCC (2006). Following a review of data on the composition of landfill gas, the fraction of methane in landfill gas as formed in UK landfill sites is assumed to be 50%, the default value given in the 2006 IPCC Guidelines.

$$\begin{aligned} &\text{EQUATION 3.3} \\ &\text{TRANSFORMATION FROM DDOC}_m \text{ TO } L_o \\ &L_o = DDOC_m \cdot F \cdot 16/12 \end{aligned}$$

- Equation 3.4 describes the accumulation of DDOC in the landfill site, accounting for new material deposited, and material which decomposes in each year. This equation is used in the UK inventory as described in IPCC (2006) Section 3A1.4, by carrying out a calculation of the mass of rapidly, medium and slowly-decaying carbon present in the landfill in each year, calculated as:
 - The mass of DDOC remaining from the preceding year

- Plus the mass of DDOC landfilled in that year
- Minus the mass of DDOC removed due to decomposition in that year

The calculation has been amended to account for the commencement of decomposition during the year of deposition, as described in IPCC (2006) Equation 3A1.12.

EQUATION 3.4
DDOC_m ACCUMULATED IN THE SWDS AT THE END OF YEAR T

$$DDOCma_T = DDOCmd_T + (DDOCma_{T-1} \cdot e^{-k})$$

- Equation 3.5 describes the rate at which DDOC is removed from landfill sites in each year by decomposition and formation of methane and carbon dioxide in landfill gas. The calculation has been amended to account for the commencement of decomposition during the year of deposition, as described in IPCC (2006) Equation 3A1.13.

EQUATION 3.5
DDOC_m DECOMPOSED AT THE END OF YEAR T

$$DDOCm_{decomp_T} = DDOCma_{T-1} \cdot (1 - e^{-k})$$

- Equation 3.6 is a calculation of methane generated from the mass of DDOC which decomposes during any given year, and the fraction of methane in landfill gas. This equation is used in the UK inventory as set out in IPCC (2006). As described for Equation 3.3, the fraction of methane in landfill gas as formed in UK landfill sites is assumed to be 50%.

EQUATION 3.6
CH₄ GENERATED FROM DECAYED DDOC_m

$$CH_4_{generated_T} = DDOCm_{decomp_T} \cdot F \cdot 16/12$$

The values used for DOC and DOCf for different material types, and the composition of different material types, are set out in **Table A3.5.2**.

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 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 the 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).

A spreadsheet model system known as MELMod was used to carry out these calculations from 2008 (Brown et al., 2008). Separate calculations are carried out for England, Scotland, Wales and Northern Ireland. 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. In the 2017 submission, the UK implemented for the first time a revised set of input data and parameters for the inventory model calculations, whilst not altering the methodology itself. This followed research to access and use more data from within individual Devolved Administrations (Scotland, Wales and Northern Ireland) and England, in order to better-reflect differences in waste management around the UK, as it is an area of devolved policy.

7.2.3 Activity data

Records of individual waste consignments treated and disposed, together with European Waste Category (EWC) codes are compiled by the regulatory authorities in the Devolved Administrations:

- Data on waste consignments landfilled in England for the period 2006 to 2017 are published by the Environment Agency.
- Data on waste consignments landfilled in Scotland for the period 2005 to 2017 are published by the Scottish Environmental Protection Agency.
- Data on waste consignments landfilled in Wales for the period 2006 to 2017 are published by Natural Resources Wales.
- Data on waste consignments landfilled in Northern Ireland for the period 2008 to 2017 were provided by the Northern Ireland Environment Agency.

This information is considered to be of good quality. The composition of waste landfilled was evaluated by allocating EWC codes to the categories used in the UK model, as set out in **Section A 3.5.1.1**.

For years prior to 2005-2008, the quantities of waste landfilled and its composition were taken from a report compiled and peer-reviewed on behalf of the UK Government (Eunomia, 2011). The quantities of waste landfilled are set out in **Table A 3.5.3**.

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. Small quantities of other GHGs (methane and nitrous oxide) are emitted from landfill gas use for power generation, and are included in Section 1.A.1.a.

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 3.5.4**.

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, 2017), is given in **Table A 3.5.4**. In 2017, 4284 GWh renewable electricity was generated from combustion of landfill gas. Carbon dioxide emitted from the combustion of landfill gas is biogenic in origin and is therefore not reported.

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 from 2013 onwards.

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 250 individual sites in 2017. 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 3.5.4** 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 have been 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 as described in **Section 7.2.3**. The new sources of data on waste receipts from 2005 – 2008 onwards are considered to be more robust and consistent than the previous combination of data sources. The approach to calculating DDOC, the main driver behind methane formation, was reviewed and updated in 2011, and was endorsed by peer reviewers.

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 (BEIS 2018). 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.

Landfill permit conditions are designed to deliver a high standard of gas collection and combustion efficiency. Requirements to design and operate landfills in order to minimise gas escape have strengthened considerably since the 1990s. In this context, the calculated collection efficiencies of 59% to 63% for the period 2013 to 2017 derived in this analysis appear reasonable. Lower collection efficiencies in the years between 1990 and 2012 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 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 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

This chapter provides the information described in IPCC (2006) Section 3.8 “QA/QC, Reporting and Documentation.”

Methodological data are described in **Section 7.2.2** above, with quantitative data in **Annex 3.5.1**. Activity data are described in **Section 7.2.3** above, with quantitative data on annual waste amounts and the quantities of landfill gas collected in **Annex 3.5.1**. A breakdown of waste composition for each year is available but as noted in IPCC (2006) Section 3.8, it is not practical to provide all documentation in the National Inventory Report.

In relation to specific recommendations of IPCC (2006) Section 3.8:

- “Countries using other methods or models should provide similar data (description of the method, key assumptions and parameters)” – this is provided in Section 7.2.2.
- “If country-specific data are used for any part of the time series, it should be documented.” – country-specific data on DOC, DOCf and MCF are used, as documented in **Section 7.2.2** and **Table A 3.5.2**.
- “The distribution of waste to managed and unmanaged sites for the purpose of MCF estimation should also be documented with supporting information.” This is documented in **Section 7.2.2**.
- “If CH₄ recovery is reported, an inventory of known recovery facilities is desirable. Flaring and energy recovery should be documented separately from each other.” Data on methane recovery for electricity generation is based on national statistics on electricity generation from landfill methane combustion, rather than reports of recovery at individual facilities. Data on methane recovery and flaring in 2017 is based on records from a total of 280 individual facilities in England, 41 in Scotland, 17 in Wales, and 5 in Northern Ireland: however, it is not practical to provide documentation for all

these facilities in the National Inventory Report. Methane recovery for flaring and energy recovery are separately documented in **Section 7.2.3** and **Annex 3.5.1**.

- “Changes in parameters from year to year should be clearly explained and referenced.”
The change in source of waste data from 2015 to 2016 is described in **Section 7.2.3**.

The landfill methane model has been subject to peer review in 2011 and 2014 (see Eunomia Consulting and Research, 2011; Golder Associates 2014). The landfill methane model is subject to normal quality assurance procedures, as described in **Section 1.6**.

IPCC (2006) guidelines, section 3.8 suggests that calculated emissions can be compared with those of similar countries. Relatively few countries have a similar history of landfill use to the UK, but emissions were compared to data taken from NIRs recently produced by Ireland and Italy where landfill use has been extensive in the past, and continues to be a significant component of waste disposal to the present, as shown in **Table 7.1**.

Table 7.1 UK calculated emissions compared to Ireland and Italy

Year	Waste landfilled (MT)			Methane generated (kT)			Methane collected (%)		
	UK	EI (approx.)	IT	UK	EI	IT	UK	EI	IT
1990	93.3	1.9	25.2	2709	53	726	1%	0%	15%
1995	104.5	2.0	28.5	2939	64	677	5%	0%	21%
2000	84.9	2.1	27.4	3028	74	776	17%	32%	28%
2005	72.6	2.3	21.2	2870	90	787	32%	55%	40%
2010	51.4	1.6	19.1	2278	98	701	53%	89%	60%
2011	52.5	1.4	16.7	2159	96	678	55%	84%	65%
2012	49.6	1.2	14.4	2041	93	680	55%	87%	61%
2013	48.4	1.0	13.8	1929	89	612	60%	79%	76%
2014	48.2	0.8	12.6	1820	84	600	63%	69%	74%
2015	51.0	0.6	11.4	1716	80	565	62%	63%	81%
2016	52.3			1627			62%		
2017	52.3			1544			59%		

There is no more than a very approximate connection between the amount of waste landfilled in any year, and the amount of methane generated. The connection is stronger in cases where the quantities and composition is constant over a longer period of time. Nevertheless, for the majority of years, the reported quantity of methane generated in all three countries was in the range 24 to 50 kT methane per MT waste landfilled. The UK was in the range 28 to 44 kT methane per MT waste landfilled throughout the time series, with both higher and lower values exhibited by Italy and Ireland. This indicates that there are no causes for concern regarding any obvious inconsistency in the overall results for methane generation with the values reported by these other countries. Since 2013, the UK has reported an estimated methane collection efficiency of between 59% and 63%. This is comparable with, and if anything lower than, the collection efficiencies reported by Ireland and Italy. This indicates that there are no causes for concern regarding any obvious inconsistency in the estimated methane collection efficiency with the values reported by these other countries.

The verification of MELMod has been described in the 2008 NIR. The update undertaken by Eunomia (Eunomia, 2011) in 2010 resulted in the 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.

The MELMod outputs have been compared to the outputs that would result from applying the IPCC Tier 1 methodology to the available data on UK waste receipts. This process indicated that the UK model does not have significant errors in how it is set up, and the use of UK-specific inputs to the UK Tier 2 model or the IPCC Tier 1 model gives more reliable results than the use of the IPCC Tier 1 model with IPCC default inputs. This provides confidence in the greenhouse gas inventory for Sector 5.A.

As described in **Section 1.6.3**, the UK GHGI is verified against data measured from the InTEM network of measurement masts. These measurements indicate good agreement with the UK inventory for the period 2010 onwards, during which time there has been no strong trend in the landfill methane inventory, the total UK methane inventory, or the estimated inventory derived from the InTEM measurements. However, over the period 1990 – 2010, the InTEM measurements indicate a reduction of about 30% to 40% in methane emissions, whereas the GHGI indicates a more significant reduction of up to 60%. The trend in the UK GHGI is driven mainly by reductions in landfill methane emissions. The reasons for this discrepancy are currently under review, as discussed in Section 7.2.7.

7.2.6 Source-specific recalculations

There has been one significant change to the UK landfill methane inventory for 2017, as follows:

- Based on advice from the regulatory authorities, the quantity of landfill methane flared at a small number of landfill sites between 2008 and 2016 was corrected. The regulatory authorities identified that a small number of operators had transposed data for landfill methane flaring and combustion in engines in their annual reports. Additionally, some reported quantities of landfill methane flared in 2015 had been incorrectly interpreted as referring to quantities of landfill gas. These figures were corrected, resulting in a small increase in calculated methane emissions for the years 2008 to 2016.

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.

7.2.7 Source-specific planned improvements

The Inventory Agency intends to conduct further QA/QC checks and to further evaluate model parameters against the IPCC (2006) default values.

Additionally, the Inventory Agency is working on improvements to the spatial distribution of landfill methane emissions data. This will enable verification of the calculated inventory against the InTEM field measurements to be carried out in more detail.

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)	T2	D
	Composting (household)	T2	D
	Anaerobic digestion (non-agricultural)	T2	D
	Mechanical biological treatment	T2	D
Gases Reported	CH ₄ , N ₂ O		
Key Categories	5B: Biological treatment of solid waste - CH ₄ (T1, T2, L2) 5B: Biological treatment of solid waste – N ₂ O (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	None.		

7.3.2 Methodological Issues

Emissions of methane and nitrous oxide from composting of MSW (Category 5.B.1) and anaerobic digestion and Mechanical Biological Treatment (MBT) (Category 5.B.2) are estimated using a Tier 2 methodology. This was identified as an appropriate approach in view of the scale of emissions from this sector (DECC, 2015b).

Activity data for composting and anaerobic digestion relies on the 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 MBT and whether the MBT is aerobic or anaerobic is based on annual organics recycling reports, published between 1998 and 2013 by: The Waste and Resources Action Programme (WRAP, 2009 to 2014), The Association for Organics Recycling (2006 to 2008), The Composting Association (1998 to 2005). Some extrapolation and interpolation is required to generate a complete and consistent time series.

Activity data for anaerobic digestion was derived from a site information database recorded in the National Non-Food Crops Centre (NNFCC 2018). The reported inputs to each site in NNFCC reflect the actual tonnes inputted by feedstock category.

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 CH₄ and N₂O emission factors proposed for composting and anaerobic digestion and it has been applied to the complete time series. CO₂, in line with the IPCC methodology, is not included in the Inventory calculation as it comes from a renewable source of organic matter. The emission factors for the anaerobic digestion 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 and Bermuda 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 Guernsey. Official statistics provide the amount of waste composted in Bermuda. IPCC 2006 default emission factors for both CH₄ and N₂O 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.

Time series consistency is based on activity data and is considered to be reasonably representative of activity in this sector between 1990 and 2017.

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 1.6**.

7.3.5 Source Specific Recalculations

The method for interpolating the quantities of MBT residues composted between historical data points was revised.

The methodology for calculating home composting quantities was revised following a re-evaluation of a reference which indicated larger quantities of materials diversion to home composting per household than had previously been identified. This resulted in an increase in

the quantity of waste assumed to be composted at domestic properties, and associated methane emissions.

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 carcasses 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	CS, D CR, D OTH, D CS, D CS CS OTH OTH OTH OTH OTH OTH OTH
Gases Reported	CO ₂ , CH ₄ , N ₂ O, 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 2017. A total of 33 incinerators regulated under the Industrial Emissions Directive (IED) have been identified as operating in 2017 - 5 burning sewage sludge, 16 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 were believed to be in use in the early 2002 (estimated in AEA Technology, 2002) and in the absence of updated data, we assume this is still the case. Animal carcass incinerators 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 290 in 2017 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 CO₂, CO, NO_x, SO₂, and VOC from chemical waste incinerators are estimated based on analysis of emissions data reported to the Pollution Inventory (Environment Agency, 2018), the Welsh Emissions Inventory (NRW, 2018) and the Northern Ireland Pollution Inventory (NIEA, 2018). 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 N₂O from chemical waste incinerators are estimated using the 100 g N₂O / 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 – 2017 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. The use of reported emissions data for pollutants other than N₂O avoids the need to rely upon the highly uncertain activity data.

Emissions of CH₄, CO, N₂O, SO₂ 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 N₂O 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)
2006-2016	Environment Agency, waste disposal data for individual sites in England
2004-2017	Inventory Agency estimates for Northern Ireland, based on design capacity of incinerator plant at only site.
2013, 2015-2017	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 CO₂, CH₄, CO, N₂O, NO_x, SO₂, and VOC from clinical waste incineration are estimated using literature-based emission factors. The factors for CO₂ and N₂O 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 <i>et al</i> , 1998
2002	Entec, 2003
2006-2017	Environment Agency, waste disposal data for individual sites in England and Wales
2004-13, 2015-17	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 plants. 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, SO₂ 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 (2017).

Emissions from MSW incineration for the period 1990-1996 are reported as a 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.

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; now called the Ministry of Housing, Communities, and Local Government). 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 in the Cayman Islands and the Falklands is provided by their respective local governments. 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 1.6**.

7.4.5 Source Specific Recalculations

We have corrected an error in the calculation of the split between MSW burnt with energy recovery, and that which is incinerated. This correction leads to revisions for 1990-1995 only with some fuel being re-allocated from 5C1 to 1A1a.

Estimates based on emissions data from regulators have been revised. The regulators' data does contain gaps, generally because operators consider that emissions are below reporting thresholds so need not report an actual emission. This does not mean that there are no emissions at all, just that they are less than the threshold. This year, we have improved the systems for processing all of the regulator data and for filling in these gaps and this has led to some relatively trivial revisions to UK GHGI estimates.

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 ₂ O		
Key Categories	5D: Wastewater Handling - N ₂ O (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	None		

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 CH₄ 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 since 2013 and extrapolated back to 1990;
 - **UK CH₄ 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 N₂O 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 (CH₄).** 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 CH₄ 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.

7.5.2.1.1 UK 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 plants 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.

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 no 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 are 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). Emissions of nitrous oxides are included in the company reported data; 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 removal 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, dewateres 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 (APD) 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.

Digestion 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.

7.5.2.1.2 Waste-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).

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), was the tool used by the water industry for reporting emissions to Defra and OFWAT. It 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, m³ for biogas use and kt tds otherwise); CH₄ and N₂O emissions were reported for the following:

- Mechanical treatment and short term storage of sludge (activity and CH₄ emissions only);
- Secondary treatment (activity and N₂O emissions only);
- Digestion (activity and CH₄ emissions only);
- Advanced digestion (activity and CH₄ emissions only);
- Composting (activity and CH₄ 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 CH₄ emissions only);
- Digested sludge to landfill (activity and CH₄ emissions only);
- Sludge to incineration (activity and N₂O 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 publicly 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. Northern Ireland Water, the sole provider of water and sewerage services in Northern Ireland have reported data for 2013 onwards. The Defra EPSIM statistics are used to provide activity data for the early part of the time series to 2005, whilst the gap between these data sets are 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.

7.5.2.1.3 Emission Estimation: Use of UK-specific Factors

The UK GHG inventory mostly follows the UK water industry GHG emission estimation methodology developed by UKWIR, 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. 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 3.5.2**.

7.5.2.1.4 Reporting 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 of sewage gas being produced are provided in DUKES (BEIS, 2017). 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.

7.5.2.2 5D1: UK CH₄ 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.

$$EF_j = B_0 * MCF_j$$

Where

EF_j = emission factor, kg CH₄/kg BOD (Biochemical Oxygen Demand)

j = each treatment/discharge pathway or system

B_0 = maximum CH₄ producing capacity, kg CH₄/kg BOD

MCF_j = methane correction factor (fraction), See Table 6.3 of the GLs.

Table 7.2 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 7.2 New emission factors added as a result of completeness checks

Parameter	Description	Units	Value
B ₀	Maximum CH ₄ producing capacity	kg CH ₄ /kg BOD	0.6
MCF	Methane correction factor	Fraction	0.5
EF	Emission factor	kg CH₄/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:

$$TOW = P \cdot BOD \cdot 0.001 \cdot I \cdot 365$$

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. Data on BOD values applied and estimated population connected to private waste water management systems are presented in **Annex 3.5.4**.

7.5.2.3 5D1: UK N₂O 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, 2017); see Table 7.3. For the latest year, data from the Expenditure and Food Survey is not available in time, and therefore the latest year is assumed to be the same as the year before. Population estimates are from the Office for National Statistics (ONS, 2018).

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 7.3 Per capita protein consumption in the UK (kg/person/yr), 1990-2017

Year	Protein consumption (kg/person/yr)
1990	27.9
1995	28.6
2000	29.9
2005	29.8
2010	28.7
2013	27.3

Year	Protein consumption (kg/person/yr)
2014	27.1
2015	27.3
2016	27.3
2017*	27.3

*previous year's data used, as latest data were not published in time for inventory compilation.

Nitrous oxide emissions are calculated by multiplying:

1. UK population;
2. annual total protein consumption per person;
3. the fraction of nitrogen in protein (0.16kg N/kg protein);
4. the fraction of municipal nitrogen load from unconsumed protein (1.16; Henze and Comeau, 2008); and,
5. the fraction of municipal nitrogen load 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.

7.5.2.3.1 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 does not account for losses (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, 2017). 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) has been 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 above, where large industrial sites that have on-site waste-water treatment plant are regulated under IPPC/EPR, 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 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.

7.5.2.4.1 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 gelatine 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 Defra⁶¹, 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.

⁶¹ <http://www.defra.gov.uk/publications/files/pb6655-uk-sewage-treatment-020424.pdf>

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 of activity statistics that reflect the changing fate of sewage sludge treatment and disposal; the UK 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 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 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 1.6**.

The 2016 UK GHGI reviews under the EU ESD and the UNFCCC Expert Review Team (ERT) 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 detailed.

The UK currently 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 country specific factor which accounts for several processes that occur at UK WWTPs including aerobic treatment⁶². Unfortunately, because it includes processes that are not included in the 2006 IPCC guidelines, it is not a like-for-like comparison. **Table 7.4** 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. Note that the conclusions of this verification should apply to the latest estimates as the methodology has not meaningfully changed since.

Table 7.4 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.

⁶² See the factor in **Table 7.4** for “Sewage treatment processes and the temporary storage and gravity thickening of sludge”

Source/Parameter	2006 IPCC Default Parameter	UK Parameter	Comments
Digestion (Chapter 5 of the 2006 IPCC guidelines)	0.48 kg per kg BOD		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.
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
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.
Total Emissions for 2015	16 to 594 kt	29 kt	The UK's estimate remains within the range of emissions estimates based in IPCC methodologies 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.

7.5.5 Source Specific Recalculations

A number of minor recalculations have occurred due to, for example, revisions in index of production data, 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 N₂O emissions from waste-water has been highlighted as a key category, and we are currently using a tier 1 method. It should also be 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 CO₂ and Nitrous Oxide Emissions

9.1 DESCRIPTION OF SOURCES OF INDIRECT EMISSIONS IN GHG INVENTORY

The calculation of indirect CO₂ and N₂O is not mandatory. The UK calculates indirect emissions of N₂O from emissions of NO_x and NH₃ from non-AFOLU sources. These are reported as a memo item.

The methods and data sources for the calculation of NO_x and NH₃ 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 N₂O are calculated using Equation 7.1 of Volume 1 of IPCC, 2006. EF₄ within the equation is the IPCC default of 0.01 kg N₂O-N/kg NH₃-N or NO_x-N emitted.

9.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

No formal uncertainty or trend analysis for indirect N₂O emissions has been carried out. Uncertainties and trends for NO_x and NH₃ 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. NH₃ 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

Indirect nitrous oxide emissions will change in line with changes made to the NO_x and NH₃ inventories. These are described in the IIR

9.6 CATEGORY-SPECIFIC PLANNED IMPROVEMENTS

Indirect nitrous oxide emissions will change in line with changes made to the NO_x and NH₃ 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 2018 NIR submission (1990-2016 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 1.6** 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 (for this submission, the IPCC 2006 guideline); 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 2016. This report gives emission estimates for 2016 and also includes estimates for the year 2017. 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 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 CO₂, CH₄, N₂O and F-gases since the 2018 NIR submission (1990-2016 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 (2016).

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 CO₂ in 1990 (kt CO₂)

IPCC category name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
1. Energy					
1.A. Fuel combustion activities					No significant recalculations
1.A.1. Energy industries					
1.A.2. Manufacturing Industries and construction					
1.A.3. Transport					
1.A.4. Other sectors					
1.A.5. Other					
1.B. Fugitive emissions from fuels					No significant recalculations
1.B.1 Solid fuels					
1.B.2 Oil and natural gas					
2. Industrial processes and product use					No significant recalculations
2. A. Mineral industry					
2. B. Chemical industry					
2. C. Metal industry					
2. D. Non-energy products from fuels and solvent use					
2. G. Other product manufacture and use					
2. H. Other					
3 Agriculture					
3.G. Liming					No significant recalculations

IPCC category name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
3.H. Urea application					No significant recalculations
4. Land use, land-use change and forestry					
4.A. Forestland	-17445.77	-15026.26	2419.51	-14%	Correction of double-counting of dead wood and litter and adjustment of average biomass densities due to error correction. Reconciliation of harvest volume and forest age data. Adjustment of turnover calculations.
4.B. Cropland	15033.60	14265.93	-767.67	-5%	Changes to the living biomass densities for cropland and grassland.
4.C. Grassland	-7756.55	-7111.03	645.52	-8%	Changes to the living biomass densities for cropland and grassland. Adjustment of average biomass densities for biomass burning due to error correction
4.E. Settlements	6901.20	7011.30	110.10	2%	Changes to the living biomass densities for cropland and grassland. Adjustment of average biomass densities for biomass burning due to error correction
4.G. Harvested wood products	-1614.71	-1639.08	-24.37	2%	Reconciliation of harvest volume and forest age data
5. Waste					
5.C. Incineration and open burning of waste	1363.29	1300.71	-62.59	-4.6	Reallocation between 1A1a and 5C

Table 10.2 Recalculations to CO₂ in 2016 (kt CO₂)

IPCC name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
1. Energy					
1.A.1. Energy Industries	110530.63	112012.49	1481.85	1.34	Revision to upstream oil and gas combustion estimates (new installation data added). Method change for Energy from Waste plant using revised UK energy statistics (fossil and biogenic split) and now applying IPCC default factors to those data.
1.A.2. Manufacturing Industries and construction	51076.12	51352.80	276.68	0.54	Revisions to natural gas use in energy statistics. Revision to UK off-road model for newer classes of machinery has also led to revisions in allocations of gas oil to mobile machinery in 1A2.
1.A.3. Transport	123110.31	123314.86	204.54	0.17	Small recalculations in 1A3 transport sector occur due to a combination of changes in different transport sub-sectors; 1A3aii: Increase in CO ₂ emissions is related to revised taxi-ing times, where more fuel and time is spent on the ground, and more specifically at lower thrust modes, than previously thought. 1A3b: Now containing fossil carbon content in biofuels.
1.A.4. Other sectors	92044.77	92376.25	331.48	0.36	No significant recalculations. Minor changes to energy statistics.
1.A.5. Other					
1.B.1. Fugitive Emissions from Fuel: Solid fuels					
1.B.2. Fugitive Emissions from Fuel: Oil and Natural gas	4115.18	4173.29	58.10	1.41	Revision to upstream oil and gas fugitive estimates (new installation data added).
2. Industrial Processes and product use					
2.A. Mineral Industry					
2.B. Chemical Industry	4522.54	4537.25	14.71	0.33	Revision to EU ETS-based estimates: we now include some further emissions reported in EU ETS within our estimate for 2B8g (petrochemical sector use of process off-gases).

IPCC name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
2.C. Metal Industry					
2.D. Non-energy products from fuel and solvent use	352.37	522.83	170.45	48.37	Various revisions, but most significant by far is an upward revision to the UK demand figure for petroleum coke in the UK energy statistics, which results in an increase in emissions from non-energy use of petroleum coke of 178 ktonnes CO ₂ .
3. Agriculture					
3.G. Liming					
3.H. Urea application					
4. Land use, Land-use change and forestry					
4.A Forestland	-24050.29	-18350.13	5700.16	24%	Correction of double-counting of dead wood and litter and adjustment of average biomass densities due to error correction. Reconciliation of harvest volume and forest age data. Adjustment of turnover calculations.
4.B. Cropland	11504.76	11059.73	-445.02	-4%	Changes to the living biomass densities for cropland and grassland. Adjustment to uncropped land area.
4.C. Grassland	-9371.91	-8654.53	717.38	8%	Changes to the living biomass densities for cropland and grassland. Adjustment of average biomass densities for biomass burning due to error correction. Changes to the average deforestation rate for soil CSC calculation
4.D. Wetlands	319.71	312.66	-7.05	-2%	Adjustment of total horticultural peat extraction area due to error correction

IPCC name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
4.E. Settlements	6422.08	6532.50	110.42	2%	Changes to the living biomass densities for cropland and grassland. Adjustment of average biomass densities for biomass burning due to error correction. Changes to the average deforestation rate for soil CSC calculation
4.G. Harvested wood products	-844.44	-2166.42	-1321.98	-157%	Reconciliation of harvest volume and forest age data
5. Waste					
5.C. Incineration and open burning of waste	283.37	267.20	-16.16	-5.70	Improvement to gap-filling approach for non-reporting sites.

Table 10.3 Recalculations to CH₄ in 1990 (kt CH₄)

IPCC name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
1. Energy					
1.A. Fuel combustion activities					
1.A.1. Energy Industries	198.65	204.00	5.36	2.70	Activity data revisions for the fossil and bio components of waste-derived fuels.
1.A.2. Manufacturing Industries and construction	113.98	116.67	2.69	2.36	Minor activity data revisions, including small changes to allocation of straw and wood use across the time series.
1.A.3. Transport					
1.A.4. Other sectors	1595.21	1568.92	-26.29	-1.65	Minor activity data revisions, including small changes to allocation of straw and wood use across the time series, changes to peat data also.
1.A.5. Other					
1.B. Fugitive emissions from fuels					No significant recalculations.
1.B.2. Fugitive Emissions from Fuels: Oil and Natural gas					
2. Industrial processes and product use					

IPCC name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
2.B. Chemical Industry	213.73	204.89	-8.84	-4.14	Minor revisions to the analysis of EU ETS data to assess the petrochemical and chemical industry use of waste gases.
3 Agriculture					
3.A. Enteric Fermentation	25992.58	25392.50	-600.08	-2.31	Correction to an error in the energy balance equations for other dairy cattle.
3.B. Manure Management	4863.97	4732.53	-131.44	-2.70	Correction to an error in the energy balance equations for other dairy cattle.
3.F. Field burning of agricultural residues					
4. Land use, land-use change and forestry					
4.A. Forestland	2.92	2.89	-0.04	-1%	Adjustment of average biomass densities due to error correction and hence adjustment to emissions from wildfires.
4.C.Grassland	10.00	9.97	-0.03	-0.3%	Adjustment of average biomass densities due to error correction and hence adjustment to emissions from controlled burning following deforestation.
4.E. Settlements	3.05	3.00	-0.05	-2%	Adjustment of average biomass densities due to error correction and hence adjustment to emissions from controlled burning following deforestation.
5. Waste					
5.B. Biological treatment of solid waste	5.48	18.13	12.65	230.78	Review of assumptions underlying household composting estimates.
5.C.Incineration and open burning of waste	137.63	134.83	-2.80	-2.03	Reallocation of AD between 1A1a and 5C
5.D.Waste water treatment and discharge					

Table 10.4 Recalculations to CH₄ in 2016 (kt CH₄)

IPCC name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
1. Energy					
1.A. Fuel combustion activities					
1.A.1. Energy Industries	355.87	348.32	-7.55	-2.12	DUKES revisions and exclusion of Ferrybridge MF - now understood to be an EFW plant.
1.A.2. Manufacturing Industries and construction	105.42	113.09	7.67	7.28	DUKES revisions and revisions to biomass AD time series - most of straw previously in 1A4c re-allocated to 1A2
1.A.3. Transport	112.04	111.49	-0.55	-0.49	"Small recalculations due to a combination of changes in different transport sub-sectors;
1.A.4. Other sectors	968.00	978.70	10.70	1.11	1A3aii: Increase in CH ₄ emissions is related to revised taxi-ing times, where more fuel and time is spent on the ground, and more specifically at lower thrust modes, than previously thought. This increase is offset by the small reduction in 1A3b sector.
1.A.5. Other					
1.B. Fugitive emissions from fuels					
1.B.2 Fugitive Emissions from Fuels: Oil and Natural gas	4863.35	4923.90	60.56	1.25	Updated emission estimates from fugitives and venting in the natural gas National Transmission System.
2. Industrial processes and product use					
2.B. Chemical Industry	73.02	71.67	-1.35	-1.85	Minor revisions to operator-reported estimates, gap-filling.
2.C. Metal industry	10.69	11.14	0.46	4.27	Revised operator-reported estimates, accessing data for more individual plant.
2.H. Other	5.99	0.00	-5.99	-100.00	Re-allocation, 2H to 2A
3 Agriculture					
3.A. Enteric Fermentation	21935.52	21385.99	-549.53	-2.51	Correction to an error in the energy balance equations for other dairy cattle.
3.B. Manure management	4322.83	4200.44	-122.39	-2.83	Correction to an error in the energy balance equations for other dairy cattle.
3.J. Other					
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	0.40	0.39	-0.01	-2%	Adjustment of average biomass densities due to error correction and hence adjustment to emissions from wildfires.
4.C. Grassland	23.63	22.80	-0.83	-4%	Adjustment of average biomass densities due to error correction and hence adjustment to emissions from controlled burning following deforestation.
4.E. Settlements	10.66	10.15	-0.51	-5%	Adjustment of average biomass densities due to error correction and hence adjustment to emissions from controlled burning following deforestation.
5. Waste					
5.A. Solid Waste disposal	14016.99	14129.53	112.54	0.80	Correction of mis-reported LFG flaring data for the years 2008-2016. Updated activity data for waste landfilled in NI in 2016. No change to methodology.
5.B. Biological treatment of solid waste	1070.53	1135.83	65.30	6.10	Revision to NNFCC data on anaerobic digestion, MBT and other waste treatment plant.
5.C. Incineration and open burning of waste	9.89	10.59	0.70	7.06	Reallocation of activity data between 1A1a and 5C.
5.D. Waste water treatment and discharge	3421.01	3366.64	-54.37	-1.59	Minor revisions to proxy data (e.g. Index of Production by sector) used for individual industry sector activity, which inform some waste water estimates.

Table 10.5 Recalculations to N₂O in 1990 (kt N₂O)

IPCC name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
1. Energy					
1.A.1. Energy Industries	1368.10	1370.01	1.91	0.14	No significant recalculations.
1.A.2. Manufacturing Industries and construction	1090.56	321.80	-768.75	-70.49	Correction of mobile machinery Efs. Revised N ₂ O EF for all (d) machinery types from 0.35 to 0.035 g/kWh to be more in line with other transport sources.

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.3. Transport	1475.02	1451.62	-23.40	-1.59	"1A3aii: Increase in N ₂ O emissions is related to revised taxi-ing times, where more fuel and time is spent on the ground, and more specifically at lower thrust modes, than previously thought. This increase is offset by the significant decrease in 1A3eii sector.
1.A.4. Other sectors	900.27	393.08	-507.19	-56.34	1A3eii: Revised N ₂ O EF for all (d) machinery types from 0.35 to 0.035 g/kWh to be more in line with other transport sources."
2. Industrial processes and product use					
					No significant recalculations.
3 Agriculture					
3.B. Manure management	3507.55	3442.70	-64.85	-1.85	Correction to an error in the energy balance equations for other dairy cattle.
3.D. Agricultural soils	13637.11	13610.39	-26.72	-0.20	Revised N excretion from other dairy cattle (due to energy balance equations correction). Revised urea fertiliser N use due to corrections to the emission factor calculation for ammonium sulphate and diammonium phosphate fertiliser types applied to grassland (across the time series). Also impacts from model corrections for laying hens and for nitrate leaching from cattle.
4. Land use, land-use change and forestry					
4.A. Forest Land	230.75	231.22	0.47	0.20%	Reconciliation of harvest volume and forest age data. Adjustment of average biomass densities due to error correction and hence adjustment to emissions from wildfires.
4.C.Grassland	10.36	10.33	-0.02	-0.2%	Adjustment of average biomass densities due to error correction and hence adjustment to emissions from controlled burning following deforestation. Changes to the average deforestation rate for soil CSC calculation.

IPCC name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
4.E. Settlements	584.71	584.68	-0.03	0.01%	Adjustment of average biomass densities due to error correction and hence adjustment to emissions from controlled burning following deforestation. Changes to the average deforestation rate for soil CSC calculation
5. Waste					
					No significant recalculations.

Table 10.6 Recalculations to N₂O in 2016 (kt N₂O)

IPCC name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
1. Energy					
1.A.1. Energy Industries	782.71	774.67	-8.04	-1.03	Exclusion of Ferrybridge MF, also revisions to EU ETS data
1.A.2. Manufacturing Industries and construction	805.76	231.60	-574.16	-71.26	Correction of mobile machinery EFs. Revised N ₂ O EF for all (d) machinery types from 0.35 to 0.035 g/kWh to be more in line with other transport sources. DUKES recalculations and reduction in estimates of agricultural straw used in biomass consumption.
1.A.3. Transport	1240.51	1186.46	-54.05	-4.36	1A3a _{ii} : Increase in N ₂ O emissions is related to revised taxi-ing times, where more fuel and time is spent on the ground, and more specifically at lower thrust modes, than previously thought. This increase is offset by the significant decrease in 1A3e _{ii} sector.
1.A.4. Other sectors	689.72	247.02	-442.70	-64.19	1A3e _{ii} : Revised N ₂ O EF for all (d) machinery types from 0.35 to 0.035 g/kWh to be consistent with other transport sources.
2. Industrial processes and product use					
2.B Chemical Industry					No significant recalculations.

IPCC name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
2.C. Metal industry					No significant recalculations.
2.G. Other product manufacture and use					No significant recalculations.
3 Agriculture					
3.B. Manure management	2886.99	2821.68	-65.32	-2.26	Correction to an error in the energy balance equations for other dairy cattle.
3.D. Agricultural soils	11263.87	11191.41	-72.46	-0.64	Revised N excretion from other dairy cattle (due to energy balance equations correction). Revised urea fertiliser N use due to: (i) corrections to the emission factor calculation for ammonium sulphate and diammonium phosphate fertiliser types applied to grassland (across the time series), and (ii) (specifically for 2016 only) a correction to the estimate of urea fertiliser N applied to tillage land. Also impacts from model corrections for laying hens and for nitrate leaching from cattle.
4. Land use, land-use change and forestry					
4.A. Forest land	152.39	147.62	-4.77	-3%	Reconciliation of harvest volume and forest age data. Adjustment of average biomass densities due to error correction and hence adjustment to emissions from wildfires.
4.B. Cropland	476.64	474.60	-2.04	-0.4%	Adjustment of average biomass densities due to error correction and hence adjustment to emissions from controlled burning following deforestation. Changes to the average deforestation rate for soil CSC calculation

IPCC name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
4.C.Grassland	37.62	36.75	-0.87	-2%	Adjustment of average biomass densities due to error correction and hence adjustment to emissions from controlled burning following deforestation. Changes to the average deforestation rate for soil CSC calculation
4.E. Settlements	526.89	527.17	0.28	0.1%	Adjustment of average biomass densities due to error correction and hence adjustment to emissions from controlled burning following deforestation. Changes to the average deforestation rate for soil CSC calculation
5. Waste					
5.B. Biological treatment of solid waste	657.72	695.38	37.66	5.73	Changed rate estimate of kg waste diverted per year per composting household to the estimate of total composted
5.C. Incineration and open burning of waste	41.33	41.43	0.10	0.24	No significant recalculations.
5.D. Waste water treatment and discharge	719.86	719.06	-0.80	-0.11	Update to use protein intake data for 2016 not available in time for the previous submission.

Table 10.7 Recalculations to SF₆ in base year (CO₂ 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	747.79	783.25	35.46	4.74	Review of switchgear data to use a time-series based on centrally reported OfGem data instead of data reported by each network operator and the national grid

Table 10.8 Recalculations to SF₆ in 2016 (CO₂ 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	298.25	281.81	-16.44	-5.51	Review of switchgear data to use a time-series based on centrally reported OfGem data instead of data reported by each network operator and the national grid

Table 10.9 Recalculations to HFC in base year (CO₂ 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.B.9. Fluorochemical production	17680.04	17670.77	-9.27	-0.05	HFC emissions associated with F-gas handling (rather than HFC or HCFC manufacture) reported by a UK manufacturer have been separated and reallocated to 2.F.6.b.
2.F.1. Refrigeration and air conditioning	531.19	531.30	0.11	0.02	Update to proxy data used to scale UK emissions for estimating Gibraltar emissions
2.F.2. Foam blowing agents	184.42	184.49	0.07	0.04	Update to proxy data used to scale UK emissions for estimating Gibraltar emissions
2.F.6. Other applications	27.61	36.88	9.27	33.58	HFC emissions associated with F-gas handling (rather than HFC or HCFC manufacture) reported by a UK manufacturer have been separated and reallocated from 2.B.9.

Table 10.10 Recalculations to HFC in 2016 (CO₂ 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					

IPCC name	Previous submission (CO ₂ eq., kt)	Latest submission (CO ₂ eq., kt)	Difference (CO ₂ eq., kt)	Difference %	Explanation for recalculations
2.B.9. Fluorochemical production	7.51	2.55	-4.97	-66.13	HFC emissions associated with F-gas handling (rather than HFC or HCFC manufacture) reported by a UK manufacturer have been separated and reallocated to 2.F.6.b.
2.F.1. Refrigeration and air conditioning	12649.02	12636.49	-12.53	-0.10	Update to proxy data used to scale UK emissions for estimating Gibraltar emissions
2.F.2. Foam blowing agents	425.72	425.74	0.02	0.00	Update to proxy data used to scale UK emissions for estimating Gibraltar emissions
2.F.3. Fire protection	331.73	324.90	-6.82	-2.06	Now using the latest EEA F-gas data for 2016
2.F.4. Aerosols	1725.97	1726.04	0.08	0.00	Update to proxy data used to scale UK emissions for estimating Gibraltar emissions
2.F.5. Solvents	78.62	20.17	-58.45	-74.34	Review of solvents estimates to be based on EU data on HFC-43-10mee, which is believed to be the only solvent used in the UK instead of the much higher estimates of F-gases allocated to the solvents sector
2.F.6. Other applications	53.74	58.71	4.97	9.25	HFC emissions associated with F-gas handling (rather than HFC or HCFC manufacture) reported by a UK manufacturer have been separated and reallocated from 2.B.9.

Table 10.11 Recalculations to PFC in base year (CO₂ 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 2016 (CO₂ 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 latest inventory year					

Table 10.13 Recalculations to NF₃ in base year (CO₂ 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 NF₃ in 2016 (CO₂ 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 latest inventory year					

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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

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GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
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
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	N	N	Chapter 5
D. Agricultural soils	Y	Y	Chapter 5
E. Prescribed burning of savannahs	N	N	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

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GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
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
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	

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GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
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 KP-LULUCF Activities

Justifications for the recalculations are given in Chapter 6, sections 6.2.7, 6.3.7 and 6.4.7.

Article 3.3 Afforestation has been affected by:

Carbon stock change: **Reconciliation of harvest volume and forest age data, Adjustment of turnover calculations and Correction of double-counting of dead wood**

CH₄ and N₂O emissions from drained and rewetted organic soils: **Reconciliation of harvest volume and forest age data**

N₂O emissions from N mineralization: **Reconciliation of harvest volume and forest age data**

HWP: **Reconciliation of harvest volume and forest age data**

Article 3.3 Deforestation has been affected by:

Carbon stock change: **Adjustment of average biomass densities due to error correction and Changes to the average deforestation rate for soil CSC calculation**

N₂O emissions from N mineralization: **Changes to the average deforestation rate for soil CSC calculation**

GHG emissions from biomass burning: **Adjustment of average biomass densities due to error correction.**

Article 3.4 Forest Management has been affected by:

Carbon stock change: **Reconciliation of harvest volume and forest age data, Adjustment of turnover calculations and Correction of double-counting of dead wood**

CH₄ and N₂O emissions from drained and rewetted organic soils: **Reconciliation of harvest volume and forest age data**

N₂O emissions from N mineralization: **Reconciliation of harvest volume and forest age data**

GHG emissions from biomass burning: **Adjustment of average biomass densities due to error correction**

HWP: **Reconciliation of harvest volume and forest age data**

Article 3.4 Cropland Management has been affected by:

Carbon stock change: **Changes to the living biomass densities for cropland and grassland and Adjustment to uncropped land area**

Article 3.4 Grazing Land Management has been affected by:

Carbon stock change: **Changes to the living biomass densities for cropland and grassland**

10.2 IMPLICATIONS FOR EMISSION LEVELS

10.2.1 GHG Inventory

Information at sector level is summarised in Table 10.1 to Table 10.14 above. The overall impact of all recalculations is an increase in net emissions of 0.42 Mt CO₂ equivalent in 1990, and an increase in net emissions of 5.51 Mt CO₂ equivalent in 2016

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.

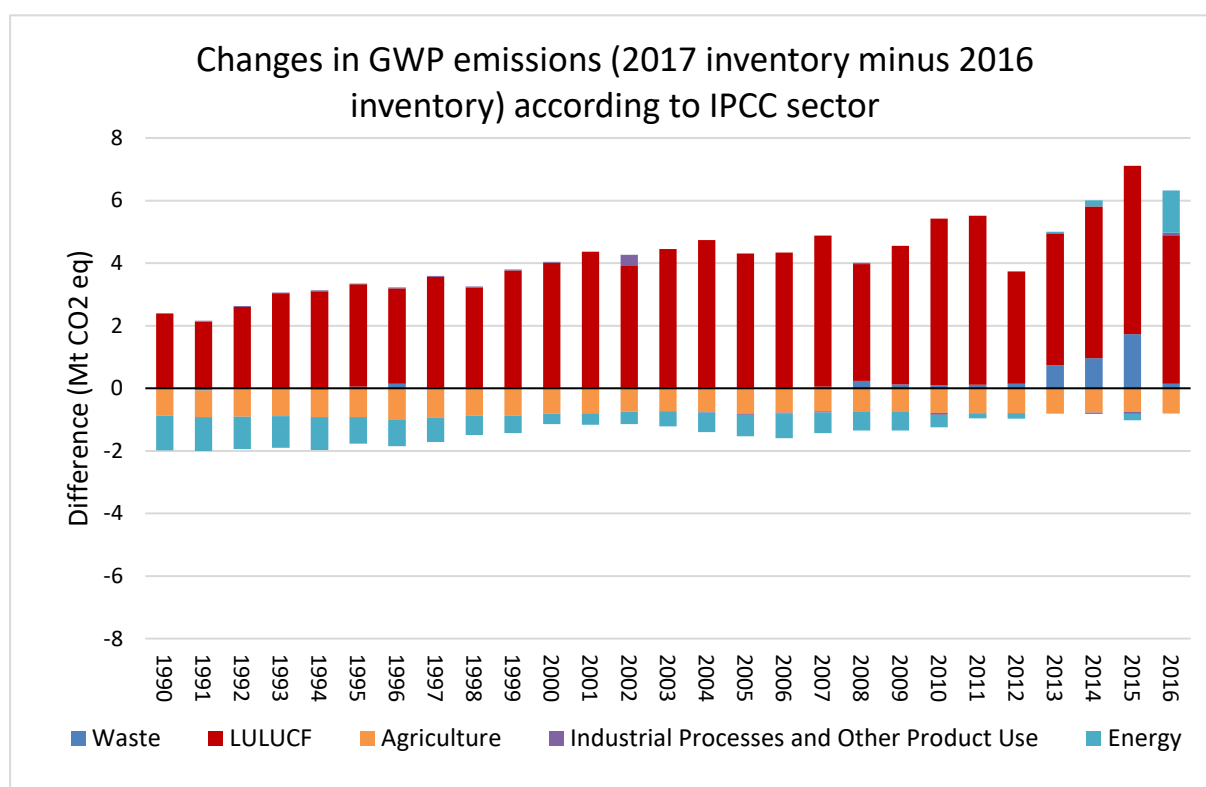
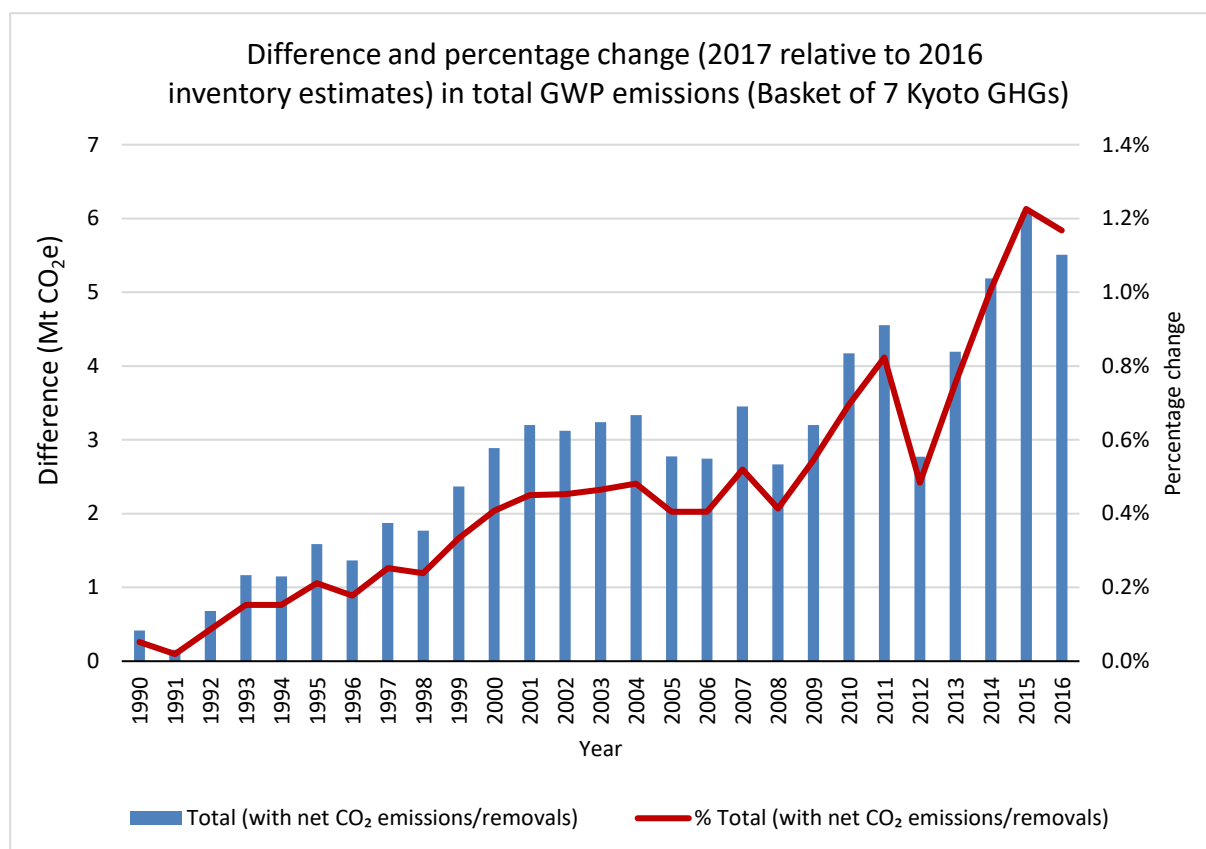


Figure 10.2 shows the net impact of all recalculations in absolute and percentage terms.

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 **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 the latest inventory year as a percentage difference is inappropriate.

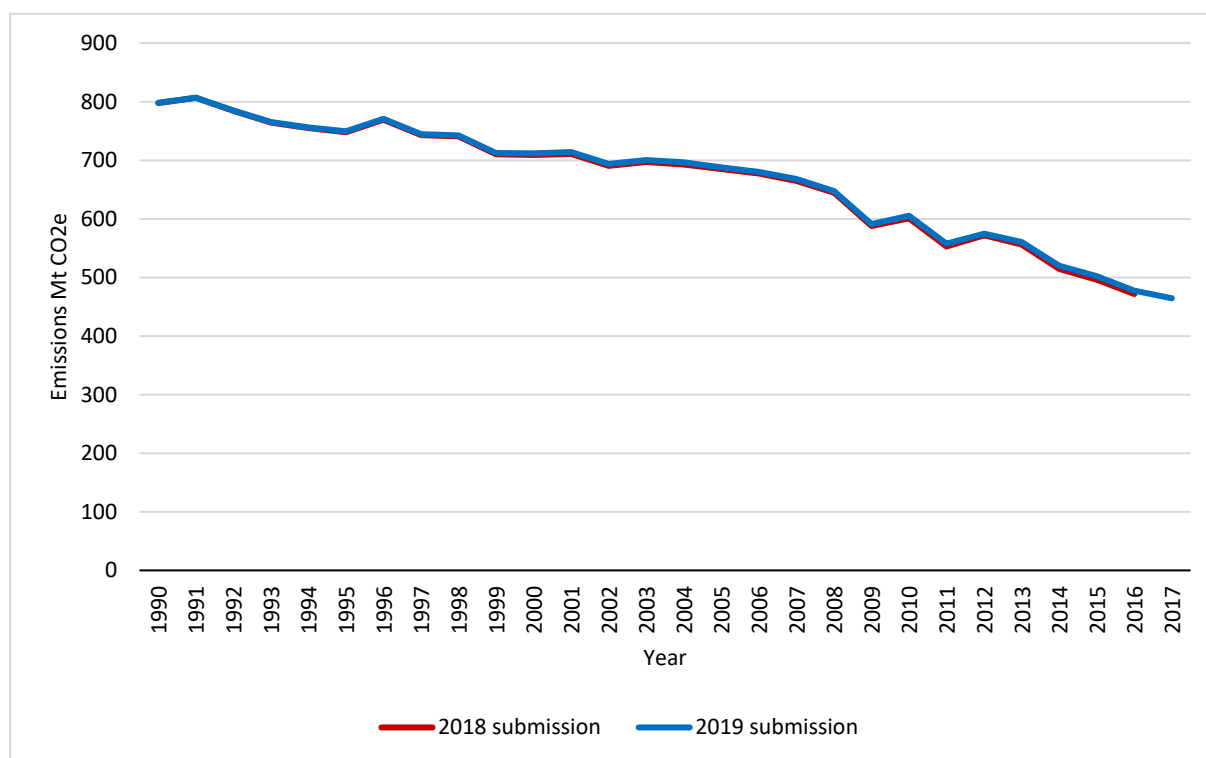
10.3 IMPLICATIONS FOR EMISSION TRENDS, INCLUDING TIME SERIES CONSISTENCY

10.3.1 GHG Inventory

There has been a very minor change in the reported trend in emissions. The reported trend from 1990 to 2016 in the 2018 inventory submission was a decrease of 40.9%. The recalculated trend from 1990 to 2016, as presented in the 2019 submission is a decrease of 40.2%.

The chart below displays the trend from both the 2018 and 2019 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 the latest reported inventory year..

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 to 8, and are summarised in **Table 10.1** to **Table 10.14**. 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 2016 greenhouse gas inventory submission (2016 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 (2016) submission. The review took place during September 2016 and the review report was published on December 4, 2017.

10.4.1 GHG Inventory Improvements**Table 10.16 Improvements to the UK GHG Inventory Submission in response to UNFCCC Review Findings**

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Recalculations	The ERT recommends that the United Kingdom continue to improve the transparency of reporting by providing explanations of recalculations in the NIR in accordance with paragraph 44 of the UNFCCC Annex I inventory reporting guidelines. The ERT also recommends that the Party improve the consistency in the reporting of recalculations between the NIR and CRF tables, providing in the NIR the explanations for differences therein shared with the ERT during the review (i.e. the differences in recalculations owing to different territorial coverage under the Convention and the Kyoto Protocol).	2017 ARR G.10	Resolved. The UK has reviewed the descriptions which are provided to explain the recalculations. The UK provides explanations for recalculations which are not insignificant. The differences in inventory data arising from changes in territorial coverage were an issue specific to the 2017 submission (and hence the 2017 ARR) due to the divergence of the UK's UNFCCC and KP territorial scopes. In the 2019 and future submissions, this issue is resolved..	Chapter 10.1
Feedstocks, reductants and other non-energy use of fuels - liquid fuels - CO ₂	There are six blank rows in CRF tables 1.A(b) and 1.A(d) corresponding to cells that should be labelled as "NO". The ERT recommends that the United Kingdom ensure reporting is complete as well as consistent between CRF tables 1.A(b) and 1.A(d) by reporting data or notation keys for other gaseous fuels in CRF table 1.A(b) and by using the same data or notation keys for other liquid fossil fuels, other gaseous fuels, other fossil fuels and other fossil fuels in CRF table 1.A(b) in the corresponding cells in CRF table 1.A(d).	2017 ARR E.13	Resolved. This notation key issue is due to an artefact of the CRF reporting software. In order to populate the CRF table with 'NO', it is necessary to manually generate nodes solely for the purpose of populating them with 'NO'. It is resource-intensive to present 'NO' in the CRF for all such cases for no impact on the final emissions data. Therefore the UK consider this to be disproportionate to improvement in inventory quality, given other improvement priorities, and therefore we clarify that these sources are Not Occurring in the NIR text, in section 3.2.3.	Chapter 3
1.A.1.c Manufacture of solid fuels and other energy industries - liquid fuels - N ₂ O	The ERT recommends that the United Kingdom justify in the NIR the application of high N ₂ O EFs (e.g. that they are informed by operator-reported data and are dominated by offshore combustion of natural gas).	2017 ARR E.15	Resolved. Text has been added to MS2, "Assumptions & Observations", to present the justification for the use of operator-reported emissions of N ₂ O from upstream oil and gas installations.	Chapter 3.4 MS 2

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
1.A.2.b Non-ferrous metals - solid fuels - CH ₄	The ERT recommends that the United Kingdom describe in the NIR the fluctuation in the CH ₄ IEF over the time series, especially between 2012 and 2015.	2017 ARR E.16	Resolved. Text has been added to MS3 to explain the trends in methane in those years.	Chapter 3.4 MS 3
1.A.3.a Domestic aviation - liquid fuels - CH ₄	The ERT recommends that the United Kingdom describe in detail in the NIR any changes in assumptions for the CH ₄ EF for aviation fuel to justify the unique trend in IEF between 2009 and 2010.	2017 ARR E.17	Resolved. Text has been added to the NIR "time-series consistency" in the MS7 to address the variation in CH ₄ IEF.	Chapter 3.4 MS7
1.A.4.a Commercial/institutional - biomass - N ₂ O	The ERT recommends that the United Kingdom ensure that the notation key "NO" is used for biomass combustion in CRF table 1.A(a)s4, and that a brief mention in the corresponding method statement in the NIR is made about this source not occurring.	2017 ARR E.18	Resolved. Text has been added to MS5 to explain that this source is Not Occurring in the UK, and also to explain that this notation key issue is caused by an artefact of the CRF reporting software, which means that in order to populate the CRF table with 'NO', it is necessary to manually generate nodes solely for the purpose of populating them with 'NO'. It is resource-intensive to present 'NO' in all such cases in the CRF for no impact on the final emissions data. Therefore, the UK consider this to be disproportionate to improvement in inventory quality, given other improvement priorities, and added text to the NIR to be transparent on this issue.	Chapter 3.4 MS5

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
1.B Fugitive emissions from fuels – all fuels – CO ₂ , CH ₄ and N ₂ O	<p>The ERT recommends that, where possible, the United Kingdom include all subcategory EFs for CO₂, CH₄ and N₂O and corresponding references for their sources for category 1.B (fugitive emissions from fuels) in the NIR or the accompanying background data file.</p> <p>Further, the ERT recommends that, for all subcategories where emissions are directly reported and EFs cannot be reported, the Party provide information in the NIR to clarify how the estimates are compiled from operator-reported data.</p>	2017 ARR E.20	<p>Resolved. We have addressed the omission in reporting within the supplementary background data file, such that all AD and EFs for fugitive emission sources are included, consistent with how the data were provided to the previous ERT during the 2017 submission review week.</p> <p>Further, we have added text to the MS18 to clarify the inventory method for those source categories where there are no AD and EFs but operator-reported estimates are aggregated and installation-level data checked between reporting systems.</p>	Chapter 3.4 MS18
1.B.1 Solid fuels - CH ₄	The ERT recommends that the United Kingdom elaborate on the method description in the NIR to explain that the estimates are complete and that, although EF data are not available for 2015, the EFs for 2013 and 2014 were applied to the complete and consistent AD time series of coal production.	2017 ARR E.21	Resolved. The UK has added additional details to MS17 in the NIR to clarify how it has ensured completeness and time-series consistency in estimates of CH ₄ emissions from deep-mined coal, coal storage and transport and open-cast coal.	Chapter 3.4 MS17
1.B.2 Oil and natural gas and other emissions from energy production - all fuels - CO ₂ , CH ₄ and N ₂ O	The ERT recommends that the United Kingdom describe in more detail the QC measures in place to verify the completeness of the onshore exploration and production given the incomplete (voluntary) nature of EEMS and EU ETS data.	2017 ARR E.24	Resolved. Further clarification is provided in the NIR in MS18 about the steps taken to ensure time-series consistency in the latest years of the inventory, when reporting to EEMS has been voluntary for onshore terminals. The NIR text very clearly states that the emission estimates are complete and consistent across the time series.	Chapter 3.4 MS18

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
1.B.2 Oil and natural gas and other emissions from energy production - all fuels - CO ₂ , CH ₄ and N ₂ O	<p>The ERT recommends that the United Kingdom enhance the transparency of the reporting on the coverage and allocation of fugitive emissions from oil and natural gas by including all IPCC subcategories in NIR table 3.5 as they are reported in CRF table 1.B.2 (e.g. if a subcategory is reported as "IE" in CRF table 1.B.2, include the respective IPCC category in the appropriate row of NIR table 3.5 where the emissions are reported).</p> <p>Further, the ERT recommends that the Party review all fugitive emissions from oil and natural gas that are reported as "IE" in the NIR but not able to be distinguished in the CRF tables owing to aggregation levels (i.e. the United Kingdom reports in the NIR subcategories under natural gas exploration) or not transparent in the NIR and report its findings in the NIR.</p>	2017 ARR E.25	<p>Resolved. NIR Table 3.5 has been updated with additional details to clarify the scope of methods for categories reported "IE".</p> <p>Resolved. Clarification has been added in MS18 to indicate that Natural Gas Production (1B2b2) is reported as IE, explaining the source data from EEMS and the limited data resolution for different fugitive emission sources.</p>	Chapter 3.4 MS18
1.B.2 Oil and natural gas and other – all fuels – CO ₂ and CH ₄	The ERT recommends that the United Kingdom describe in the NIR the coverage of the AD, methods and EFs for estimating emissions from well drilling, well testing and well completions in oil and natural gas exploration, and clarify whether these emissions are reported under category 1.A (fuel combustion activities) or 1.B (fugitive emissions from fuels).	2017 ARR E.27	Resolved. Additional details have been added to the NIR in MS18 outlining that emissions are taken from operator-reported data in EEMS and that activity data is derived through the assumption of that 1997 activity data is appropriate for all years from 1998 onwards, with emissions from well testing reported under 1B2. The findings of research and consultation regarding emissions from well drilling, completions and testing are also documented in MS18.	Chapter 3.4 MS18

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
1.B.2.a Oil - liquid and gaseous fuels - CO ₂	<p>The ERT recommends that the United Kingdom include in NIR table 3.17, under the methodological description for subcategory 1.B.2.c (flaring at upstream oil, gas facilities), the information that CO₂ emissions from refinery flaring are reported as "IE" under combustion-related emissions from petroleum refining (1.A.b).</p> <p>Further, the ERT recommends that the Party clearly note in the NIR under Method Statement 1 (Power stations, refineries and other energy industries (p.125)) – 1.A.1.b (petroleum refining) that fugitive CO₂ emissions from 1.B.2.a.4 (oil refining/storage) are reported with the corresponding combustion emissions from refining.</p>	2017 ARR E.28	<p>Resolved. The MS18 Table (now 3.16) has been amended to state clearly that all flaring emissions from refineries are reported in 1A1b.</p> <p>Resolved. MS1 has been updated to clarify that CO₂ emissions from flaring at oil refineries are included within the estimates reported under 1A1b.</p>	Chapter 3.4 MS1, MS18
1.B.2.b Natural gas - gaseous fuels - CO ₂ and CH ₄	The ERT recommends that the United Kingdom estimate and report CO ₂ and CH ₄ emissions from exploratory activities or, if the Party considers them insignificant, report them as "NE" and justify that the likely level of emissions is below the significance threshold established in paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.	2017 ARR E.29	Resolved. The NIR text (<i>Method Approach</i> section) now includes justification of reporting these emissions as "NE".	Chapter 3.4 MS18
2.A.2 Lime production – CO ₂	The ERT recommends that the United Kingdom collect lime production data so that it may be made available upon request to future ERTs in order to enable them to assess the accuracy, comparability and completeness of the emissions reported under this subcategory in accordance with the UNFCCC review guidelines.	2017 ARR I.14	Resolved. The inventory agency has researched additional AD from the Office of National Statistics and reported findings in NIR section 4.3.6.	Chapter 4.3
2.A.4 Other process uses of carbonates – CO ₂	The ERT recommends that the United Kingdom either estimate and include in the inventory the CO ₂ emissions associated with the non-glass use of soda ash or include in the NIR a justification, consistent with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines, for these emissions being considered insignificant.	2017 ARR I.15	Addressing. Research has been commissioned and is due to report during 2019 on the very low level of emissions from other process uses of carbonates. These new estimates will be reported in the 2020 submission of the UK GHGI, despite them falling well below the threshold of significance for the inventory.	Chapter 4.5

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
2.B.2 Nitric acid production - N ₂ O	The ERT recommends that the United Kingdom include information in the NIR on the abatement systems of the nitric acid production plants that were in operation in the country during the years 2012 to 2015 that justifies the low IEFs.	2017 ARR I.16	Resolved. The UK inventory agency has consulted with the operator and the regulator for the remaining UK nitric acid production sites and obtained information on the design and performance of the EnviNO _x SCR abatement systems in place since 2011, and this information is included in NIR section 4.7.2.	Chapter 4.7
2.B.2 Nitric acid production - N ₂ O	The ERT recommends that the United Kingdom update the uncertainty analysis to reflect that N ₂ O emissions from nitric acid production are based on continuous monitoring.	2017 ARR I.17	Resolved. The UK has reviewed and adjusted the uncertainty parameters used in the uncertainty analyses for N ₂ O from nitric acid in 1990 and in the latest inventory year. The UK has checked that the uncertainty data presented in the NIR are consistent with the data used in the uncertainty analysis.	Chapter 4.7, Annex 1, Annex 2
2.C.1 Iron and steel production - CO ₂	The ERT recommends that the United Kingdom update figure 3.1 in the NIR to clarify the subcategories under which CO ₂ emissions from sintering, blast furnaces and oxygen furnaces are reported.	2017 ARR I.18	Resolved. The figure 3.1 has been updated to present the correct source category allocations for emissions from sintering, blast furnaces and oxygen furnaces.	Chapter 3.4 MS 4
2.C.4 Magnesium production - HFCs and PFCs	The ERT recommends that the United Kingdom either estimate and include in the submission emissions of PFCs and/or HFCs that are the decomposition products from the use of FK 5-1-12 and HFC-134a by magnesium dye casters or include in the next NIR the information presented to the ERT during the review that justifies, in accordance with the UNFCCC Annex I inventory reporting guidelines, these emissions being considered insignificant.	2017 ARR I.19	Resolved. The NIR includes information as provided to the previous ERT to explain the existence of the source and the reason for the UK not estimating and reporting it, as it falls well below the threshold for reporting and is considered insignificant.	Chapter 4.19.2
2.D.2 Paraffin wax use - CO ₂	The ERT recommends that the United Kingdom examine the availability of paraffin wax AD for the entire time series (1990–2015). The ERT also recommends that the Party explain the differences between the data used from DUKES for the inventory and Eurostat data.	2017 ARR I.20	Resolved. The inventory agency has consulted with the UK energy statistics team, and now has access to a full, consistent time-series of paraffin wax consumption data. These new data have been used to replace the previous gap-filling approach based on total miscellaneous petroleum products, and further there is now no difference between the data used in the inventory and that reported to Eurostat.	Chapter 4.23

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
2.D.3 Other (non-energy products from fuels and solvent use) - CO ₂	The ERT recommends that the United Kingdom describe in the NIR that CO ₂ emissions from urea use in Euro VI standard HGVs and buses are included in the reported estimates from urea use in road transport catalysts, that fuel consumption data are determined using the same approach as is described in the NIR for Euro IV and V HGVs and buses, but, in accordance with the EMEP/EEA air pollution emission inventory guidebook 2016, a 3.5 per cent urea solution in fuel is considered, and that 100 per cent of Euro VI HGVs and buses are equipped with selective catalytic reduction abatement.	2017 ARR I.21	Resolved. The UK has updated the NIR description of the methodology for the estimation of emissions of CO ₂ from urea use in heavy duty vehicles to reflect that the UK inventory estimates also account for Euro VI vehicles using urea.	Chapter 4.24.2
2.F.I Refrigeration and air conditioning - HFCs	The ERT recommends that the United Kingdom include in the NIR the scaling factors (e.g. population, GDP) used to calculate emissions from refrigeration and air-conditioning equipment in OTs and CDs.	2017 ARR I.22	Resolved. The UK addressed this issue in the 2018 submission. The scaling factors are now reported annually in the NIR.	Chapter 4.29.2
2.F.I Refrigeration and air conditioning - HFCs	The ERT recommends that the United Kingdom improve the description in the NIR of the tier level of the methodology that is applied for the estimation of emissions from subcategory 2.F.1, noting a tier 2a method, in line with the 2006 IPCC Guidelines, has been implemented.	2017 ARR I.23	Resolved. The UK addressed this issue in the 2018 submission, describing the UK methodology as a Tier 2 modelling approach. [Note that the CRF software does not facilitate reporting a T2a or T2b methodology, only T2 can be entered.]	Chapter 4.29.2
2.G.2 SF ₆ and PFCs from other product use - SF ₆ and PCFs	The ERT recommends that the United Kingdom continue to include in its improvement plan the need for an update of the AD, based on actual consumption, for the estimation of SF ₆ and PFC emissions from semiconductor manufacture, and report any progress thereon in the NIR.	2017 ARR I.24	Addressing. As noted by the previous ERT, resolution of this issue is dependent on access to new activity data based on actual consumption which are not currently available. Therefore as recommended in ARR 2017, the issue remains on the UK's improvement programme and the UK will continue to report on any progress made in future submissions.	Chapter 4.37

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
3. General (agriculture)	The ERT recommends that the United Kingdom estimate and report emissions from categories 3.F, 3.G and 3.H for OTs and CDs or, if the Party considers them insignificant, report them as "NE" and provide a detailed explanation in the NIR on the likely level of emissions from categories 3.F, 3.G and 3.H for OTs and CDs in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.	2017 ARR A.6	<p>Addressing. 3F (Field burning): The inventory now includes estimates of field burning for Crown Dependencies, made by applying UK GHGI implied EFs to cropland and grassland land areas. As such, estimates are zero from 1994 onwards.</p> <p>No quantitative data are available from any Overseas Territory, but they are considered to be insignificant in the UK context and hence emissions from field burning in OTs are not currently estimated ("NE"). Efforts to improve data collection for this category are planned, subject to resource availability. In the Falklands, grass burning is undertaken by a "minority of farmers", according to the in-country contact, but there are no data available on areas burned. These improvements will be considered for future submissions as part of the prioritised inventory improvements, taking into account available resources. This explanation has been added into the NIR.</p>	3F (Field burning): Chapter 5, section 5.6.2.1
3. General (agriculture)	The ERT recommends that the United Kingdom estimate and report emissions from categories 3.F, 3.G and 3.H for OTs and CDs or, if the Party considers them insignificant, report them as "NE" and provide a detailed explanation in the NIR on the likely level of emissions from categories 3.F, 3.G and 3.H for OTs and CDs in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.	2017 ARR A.6 (continued)	<p>Addressing. 3G (Liming): No quantitative data on liming is available for Overseas Territories, but local expert input suggests that liming does not occur in the Falklands or Cayman Islands. In Bermuda, this category has not been estimated as no expert judgement is available. Efforts to improve data collection for this category are planned; however, it is thought that these emissions would be insignificant relative to total UK emissions. This improvement will be considered for future submissions as part of the prioritised inventory improvements, taking into account available resources. This explanation has been added to the NIR.</p>	3G (Liming): Chapter 5, section 5.7.2.1

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
3. General (agriculture)	The ERT recommends that the United Kingdom estimate and report emissions from categories 3.F, 3.G and 3.H for OTs and CDs or, if the Party considers them insignificant, report them as "NE" and provide a detailed explanation in the NIR on the likely level of emissions from categories 3.F, 3.G and 3.H for OTs and CDs in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.	2017 ARR A.6 (continued)	Addressing. 3H (Urea application): Emissions for the Falklands Islands and Bermuda were not estimated, due to lack of data availability. However, local expert judgement suggests that urea application in the Falkland islands is minimal, if not zero. Efforts to improve data collection for this category are planned; however, it is thought that these emissions would be insignificant relative to total UK emissions. This improvement will be considered for future submissions as part of the prioritised inventory improvements, taking into account available resources. This explanation has been added to the NIR.	3H (Urea application): Chapter 5, section 5.8.2.1
3.D.a Direct N ₂ O emissions from managed soils - N ₂ O	The ERT recommends that the United Kingdom provide in the NIR a complete reference to the data sources used, and a clear description of the method, assumptions and calculations used to calculate the country-specific EFs for inorganic fertilizer, animal manure applied to soils, and urine and dung deposited by grazing animals.	2017 ARR A.7	Resolved. As requested by the ERT, the UK has provided in the NIR a complete reference to the data sources used, and a clear description of the method, assumptions and calculations used to calculate the country-specific EFs for inorganic fertilizer, animal manure applied to soils, and urine and dung deposited by grazing animals.	Chapter 5.4.2
3.D.a.6 - Cultivation of organic soils (i.e. histosols) - N ₂ O	The ERT recommends that the United Kingdom provide in its NIR an explanation and further supporting evidence for the classification of organic soils in the Falkland Islands as unmanaged, and explain why the areas of organic soils in OTs and CDs are not included as a contributing source to N ₂ O emissions from the cultivation of organic soils.	2017 ARR A.8	Resolved. Information from the in-country contact and Falkland government website (http://www.fig.gov.fk/agriculture/) confirms that grassland on histosols is characterised as an extensive rangeland system, which receives no fertiliser, liming, cultivation nor drainage. Although this may technically qualify as "managed" under the IPCC definition as it is used for production, the rationale for calling it "unmanaged" is that there are no management activities that would lead to release of N ₂ O following loss of soil C. This explanation has been added to the NIR.	Chapter 5, Section 5.4.2.10

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
4. General (LULUCF)	The ERT recommends that the United Kingdom correct the inconsistencies identified within the NIR in the general and sector-specific sections and between the NIR and the CRF tables (i.e. ensure consistency in the reporting of the area of wetlands between NIR table 6.1 and CRF table 4.D and the reporting of the trends for the forest land and cropland categories, and include WDR among the activities elected under Article 3, paragraph 4, of the Kyoto Protocol).	2017 ARR L.14	Resolved. This issue was resolved in the 2018 submission. (a) the area of wetlands remaining wetlands in the OTs and CDs is now reported in both locations (b) LULUCF trends are now described only in section 2.3.4 (c) Inconsistencies have been corrected	(a) Chapter 6 section 6.9 (b) Chapter 2 (c) Chapter 2
4. General (LULUCF)	The ERT recommends that the United Kingdom implement a significance analysis to determine which carbon pools and subcategories are significant in each key category using the guidance provided in the 2006 IPCC Guidelines, and provide in the NIR detailed information on the results of the analysis.	2017 ARR L.15	Addressing. An improvement programme project to undertake a sensitivity analysis of the CARBINE model and update the LULUCF uncertainty analysis has started in early 2019. The UK intends to implement the significance analysis at the carbon pool level once that analysis is finished.	n/a

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Land representation	<p>The ERT recommends that the United Kingdom correct all inconsistencies with regard to the representation of land use and land-use changes. In particular, the ERT recommends that the Party:</p> <p>(a) Report, for all land-use categories, final land areas each year in CRF table 4.1 that equal initial land areas in the next year;</p> <p>(b) Report, for all land-use categories, final land areas for each year in CRF table 4.1 that equal the total land areas in the background sectoral CRF tables 4.A–4.F;</p> <p>(c) Report all land areas under their territorial coverage (United Kingdom, OTs and CDs) in CRF table 4.1 and the background sectoral CRF tables 4.A–4.F;</p> <p>(d) Ensure that the total country area reported in CRF table 4.1 and the background sectoral CRF tables 4.A–4.F remains constant throughout the time series.</p> <p>Further, the ERT recommends that the Party provide in the NIR detailed information on how the data sources have been combined to estimate land areas and on the methodology followed for the development of the land-use conversion matrix. The ERT encourages the United Kingdom to include in the NIR a complete set of both annual and 20-year land-use conversion matrices.</p>	2017 ARR L.16	<p>Resolved. The land use transition matrix was revised and made fully consistent in the 2018 submission.</p> <p>Resolved. Annual land use matrices and 20-year transition matrices are reported in the CRF and in section 6.9 for the OTs and CDs, with an explanation of their derivation included from the 2018 submission onwards. An equivalent table, table 6.3 in section 6.1.1, has been added for the UK in section 6.1 in the 2019 submission.</p>	Chapter 6
4.A Forest land - CO ₂	The ERT recommends that the United Kingdom obtain the necessary input data so as to be able to apply the CARBINE model for estimating carbon stock changes in forest land in OTs and CDs.	2017 ARR L.17	Not resolved. Transition to the use of CARBINE for the Overseas Territories and Crown Dependencies has been delayed to allow for further development (and documentation) of CARBINE that are likely to have a greater impact on the overall estimate.	n/a

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
4.A Forest land - CO ₂	The ERT recommends that the United Kingdom estimate and report carbon stock changes in biomass from forests not used for timber production in accordance with the 2006 IPCC Guidelines (volume 4, chapter 4) owing to biomass losses associated with harvesting and/or gathering (e.g. fuelwood) or provide transparent information justifying that such losses are not occurring.	2017 ARR L.18	Addressing. The carbon increment of forests not used for timber production is already estimated using the CARBINE model. No reliable estimates are currently available on the quantity of wood removed by gathering or disturbance. The second cycle of the National Forest Inventory (2015-2020) will provide additional information to resolve this issue.	Annex 3.4.1.2
4.A.1 Forest land remaining forest land - CO ₂	The ERT recommends that the United Kingdom adjust wood harvest data derived from the modelling of the management of forests to take into account data from recent forest inventories (NFI in 2011 and an inventory of the Public Forest Estate in 2014) in order to avoid an inconsistent time series, using the overlap or any other method consistent with those described in the 2006 IPCC Guidelines (volume 1, chapter 5).	2017 ARR L.19	Resolved. An automated algorithm (RECONCILE) has been introduced in the 2019 submission to adjust the assumed forest management to harmonise with the level of timber production, ensuring better time series consistency and accuracy.	Chapter 6, section 6.2
4.A.2.5 Other land converted to forest land - CO ₂	The ERT recommends that the United Kingdom develop the necessary AD for the original land-use category currently reported in other land converted to forest land and allocate these land areas to the appropriate land-use conversion category when developing the land-use conversion matrix, or alternatively, if this is not possible, reclassify this land-use change as grassland converted to forest land, given that the grassland category is used as the buffer category.	2017 ARR L.20	Resolved. This recommendation was implemented in the 2018 submission, with the small area of Other Land converted to Forest Land now re-allocated to Grassland converted to Other Land.	Chapter 6, section 6.2 (6.2.7)

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
4.B Cropland 4.C Grassland – CO ₂	The ERT recommends that the United Kingdom enhance the transparency and comparability of reporting in the LULUCF and agriculture sectors by: (a) Providing information in the NIR about areas of organic soils for all lands, separating drained and undrained cropland and grassland; (b) Reporting organic soils separately from mineral soils in CRF tables 4.B, 4.C and 4(II) for the United Kingdom, including its OTs and CDs; (c) Reporting CO ₂ emissions from organic soil drainage in CRF tables 4.B and 4.C, avoiding double counting of emissions in table 4(II); (d) Providing an explanation in the NIR for the discrepancies between areas of organic soils reported in CRF table 3.D and in CRF tables 4.B, 4.C and 4(II).	2017 ARR L.21	Addressing. This item is partially addressed in the 2019 submission. CO ₂ emissions from drainage on Cropland are now reported in 4.B and the area of organic soils is now consistently reported in the Agriculture and LULUCF sectors. There is an inventory improvement project in early 2019 to assimilate the activity data and emission factors from the Wetlands Supplement implementation project into the LULUCF inventory processes, which will enable further disaggregation of organic/mineral and drained/undrained soils in the CRF tables. Further work is underway to incorporate the results into the inventory, with the aim of implementation in the 2020 inventory submission.	Chapter 6, section 6.3 and 6.4
4..B. Cropland - CO ₂	The ERT recommends that the United Kingdom incorporate data from NIR table A.3.4.20 into the tables NIR A.3.4.15–A.3.4.18 and revise carbon stock changes in living biomass from land conversions to and from cropland.	2017 ARR L.22	Resolved. This item was addressed in the 2019 submission. The carbon stock changes arising from land use change and management now use the same set of UK-specific living biomass carbon densities.	Chapter 6, section 6.3, 6.4, 6.6
4.B.1 Cropland remaining cropland - CO ₂	The ERT recommends that the United Kingdom develop country-specific EFs for manure and residue inputs or continue to investigate the appropriateness of the application of default EFs to reference SOC stocks for 1 m layer soil.	2017 ARR L.23	Not resolved. The topic of soil carbon and stock change modelling for the UK is being kept under review with a view to inclusion in the improvement plan in the near future.	n/a
4.B.1 Cropland remaining cropland - CO ₂	The ERT recommends that the United Kingdom include in the NIR information on the calculation of carbon stock changes of different components of living biomass of cropland (e.g. transitions among orchards, annual cropland and shrubby perennial crops).	2017 ARR L.24	Resolved. Information on the calculation of carbon stock changes of different components of living biomass of cropland has been included in the text of the 2019 NIR submission.	Section 6.3 and Annex 3.4

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
4.C Grassland - CO ₂	The ERT recommends that the United Kingdom allocate rural hedges to settlements or grassland, ensuring time-series consistency of the accounting of these areas to a single land-use category, and clearly indicate in the NIR where they are included.	2017 ARR L.25	Not resolved. An analysis of the area of hedgerows in rural and urban areas shows that 93% of the national hedgerow area is within rural areas, so the difference from the recalculation will have a small impact and will be investigated further with a view to implementation in the 2020 submission.	n/a
4.C.2.1 Forest land converted to grassland - CO ₂	The ERT recommends that the United Kingdom report carbon stock changes from the dead organic matter and mineral soil pools.	2017 ARR L.26	Resolved. CSC in dead organic matter is now reported, CSC in mineral soil is reported as NO in the 2019 submission.	Section 6.9
4.C.2.3 Wetlands converted to grassland - CO ₂ , CH ₄ and N ₂ O	The ERT recommends that the United Kingdom include in the NIR detailed information on the methodology applied and assumptions used for classifying abandoned peat extraction sites as wetlands converted to grassland, noting that in accordance with the 2006 IPCC Guidelines (volume 4, section 7.2) GHG emissions from post-extraction lands continue and should be reported as long as the land is not converted to another use.	2017 ARR L.27	Resolved. Text in the NIR clarifying the methodology was updated in the 2018 submission.	Section 6.5 and Annex 3.4.8
4.D Wetlands - CO ₂ , CH ₄ and N ₂ O	<p>The ERT recommends that the United Kingdom collect the necessary data to enable it to report emissions/removals from peat extraction remaining peat extraction in OTs and CDs, and until then change the notation key in CRF table 4.D for the OTs and CDs from “NO” to “NE”.</p> <p>Further, the ERT recommends that the United Kingdom provide in its NIR detailed information to describe that land conversion to peat extraction in OTs and CDs is not occurring.</p>	2017 ARR L.28	<p>Addressing. The notation keys have been modified and additional text added to the NIR methodology Annex 3.4 for the 2019 submission.</p> <p>Not resolved. The update to the NIR to clarify the data, and present justification of “NO” for land conversion to peatland cannot be done until further work is completed.</p>	Annex 3.4.11

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
4.D.1 Wetlands remaining wetlands - CO ₂ , CH ₄ , N ₂ O	The ERT recommends that the United Kingdom report areas of flooded land remaining flooded land for OTs and CDs and the associated emissions, or, if that is not possible, report in the NIR on the progress in collecting suitable data in order to estimate emissions and removals from flooded land remaining flooded land for OTs and CDs.	2017 ARR L.29	Resolved. An assessment of the extent of flooded land has been undertaken for the OTs and CDs. No flooded land areas exceed the area threshold of 1 km ² used for the UK, so the notation key IE has been used where areas of flooded land remaining flooded land have been included with other wetland remaining other wetland.	Annex 3.4.11
4 (V) Biomass burning - CO ₂ , CH ₄ , N ₂ O	The ERT recommends that the United Kingdom assess the areas of and emissions from wildfires on forest land remaining forest land, land converted to forest land, grassland remaining grassland and land converted to grassland for all OTs and CDs.	2017 ARR L30	Resolved. The extent of biomass burning in the OTs and CDs has been estimated using the pro rata rates of burning on the different land cover types in the UK. The estimated emissions fall below the insignificance threshold for reporting, so the NE notation key will be retained and the notation key comment has been modified.	Annex 3.4.11
4.G Harvested wood products - CO ₂	The ERT recommends that the United Kingdom include in the NIR information on how the conversion factors for HWP are derived.	2017 ARR L.31	Resolved. The IPCC 2006 Guideline default values for HWP conversion have been used in the 2019 submission. Review of the basis for the previous UK data indicated a lack of sufficient data on the average density of harvested wood in the UK, with limited information across the time series. Therefore to improve transparency, the IPCC defaults have been used. We consider there to be no reduction in accuracy from this change in method to use defaults.	Section 6.8
4.G Harvested wood products - CO ₂	The ERT recommends that the United Kingdom correct the error in the HWP submodel in order to take into account the decay in HWP from the beginning of each year, and provide in the NIR detailed, transparent and verifiable information in the NIR in accordance with paragraph 41 of the UNFCCC Annex I inventory reporting guidelines.	2017 ARR L.32	Resolved. The error was corrected in the 2018 submission. More explanatory text has been added to the Annex 3.4 in the 2019 submission.	Section 6.8

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
5.A Solid waste disposal on land – CH ₄	The ERT recommends that the United Kingdom include in section 7.2.2 of the NIR how equations 3.1 to 3.6 from the 2006 IPCC guidelines (volume 5) are adapted for use in the MELMod model (i.e. provide more information on equation parameters removed or added) and how the Party conducts model verification in line with paragraph 41 of the UNFCCC Annex I inventory reporting guidelines on the verification of higher-tier methods and models.	2017 ARR W.11	Resolved. The information on adaptation of the 2006 IPCC Guideline calculation methods is provided in Section 7.2.2 from the 2018 NIR onwards in the format recommended. Further information on model verification in the context of the 2006 IPCC guidelines is provided in section 7.2.5 of the 2019 NIR	Section 7.2
5.A Solid waste disposal on land – CH ₄	The ERT recommends that the United Kingdom change the text in NIR table 5.A (p.414), which shows the improvements in the waste sector estimates, from “The methodology for calculating methane production in landfill sites has been updated” to “The input data and parameters for the MELMod model were updated based on new data” to reflect that updates in the MELMod model focused on input data and parameters and not on the methodology itself.	2017 ARR W.12	Resolved. Table 10.4 entry 5.A was updated in the 2018 NIR to reflect data and DA allocation changes, and does not imply landfill methane methodology change, as recommended by the ERT. The NIR states: “Changes due to MELMOD upgrade (move to 4 Devolved Administration specific models; incorporation of DA specific data).” Text has also been added to the methodology section 7.2.2, to explain this aspect of the development of the UK data and method.	Section 7.2
5.A Solid waste disposal on land – CH ₄	The ERT recommends that the United Kingdom include in the NIR information on energy recovered from landfill gas and a cross-reference to the category in the energy sector where emissions from CH ₄ recovered (from landfill gas) and used for power generation are reported.	2017 ARR W.13	Resolved. The NIR Chapter 3 section headed “Relevant fuels, activities” confirms that emissions from landfill gas combustion are included in Category 1A1a. This category includes both CH ₄ and N ₂ O emissions from landfill methane combustion both in power stations for energy recovery, and in flares. A cross-reference to 1A1a and MS1 has been added to section 7.2.1. Data on landfill gas used for energy recovery are provided in the 2019 NIR Appendix A3 Section A3.5.1.	Section 7.2 Annex A3.5.1
5.B. Biological treatment of solid waste – CH ₄ and N ₂ O	The ERT recommends that the United Kingdom provide in sections 7.3.2 and 7.3.5 of the NIR details on how AD are collected to enable the split of mechanical–biological treatment process emissions between composting and anaerobic digestion at biogas facilities.	2017 ARR W.14	Resolved. The UK has updated the methodology presented in the NIR for biological treatment of solid waste to present the source of MBT activity data and whether MBT is aerobic or anaerobic.	Section 7.3.2

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
5.D.1 Domestic wastewater – CH ₄	The ERT recommends that the United Kingdom report AD for domestic wastewater in BOD, and ensure that the organic product in private wastewater treatment systems is included in the total organic product.	2017 ARR W.15	Resolved. The United Kingdom has included organic product in private wastewater treatment systems in the total organic product reported in the CRF.	[CRF tables]
5.D.1 Domestic wastewater – N ₂ O	The ERT recommends that the United Kingdom include in CRF table 5.D the values of Fra _{CNON-CON} and Fra _{CIND-COM} applied.	2017 ARR W.16	Resolved. The United Kingdom include in CRF table 5.D the values of Fra _{CNON-CON} and Fra _{CIND-COM} applied.	[CRF tables]
5.D.1 Domestic wastewater – N ₂ O	The ERT recommends that the United Kingdom exclude N removed with sludge in the calculation of the emission estimates for the waste sector, as suggested by equations 6.7 and 6.8 in the 2006 IPCC Guidelines, and report the AD in the relevant CRF table.	2017 ARR W.17	Not resolved. This issue is being considered as part of a wider waste water improvement task for the UK GHGI improvement programme and will be implemented subject to priorities and available resources.	n/a
5.D.1 Domestic wastewater – CH ₄	The ERT recommends that the United Kingdom report CH ₄ recovery consistent with the United Kingdom's energy statistics.	2017 ARR W.19	Not resolved. This issue is being considered as part of a wider waste water improvement task for the UK GHGI improvement programme and will be implemented subject to priorities and available resources.	n/a
5.D.2 Industrial wastewater – CH ₄	The ERT recommends that the United Kingdom collect information on the proportions of aerobic and anaerobic treatment systems and revise the MCF used accordingly. Furthermore, the ERT recommends that the Party review whether the notation key "NA" is correctly used for CH ₄ recovery.	2017 ARR W.20	Not resolved. This issue is being considered as part of a wider waste water improvement task for the UK GHGI improvement programme and will be implemented subject to priorities and available resources. Resolved. The CRF notation keys have been updated in the 2019 submission.	n/a [CRF tables]

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
General (KP-LULUCF)	The ERT recommends that the United Kingdom revise the land areas reported in different CRF tables (in particular the areas of afforestation, deforestation and CM reported in CRF table NIR-2, the areas of CM and GM reported in CRF tables NIR-2, 4(KP-I)B.2 and 4(KP-I)B.3, and the total area of the country reported in CRF table NIR-2 as well as the total land area reported under the Convention and for KP-LULUCF activities) ensuring the consistency of the reported information among CRF tables as well as between the CRF tables and the NIR, and provide a transparent explanation for any differences remaining.	2017 ARR KL.15	Resolved. Inconsistencies in the land use and LUC matrices were corrected in the 2018 submission.	Chapter 11
General (KP-LULUCF)	The ERT recommends that the United Kingdom report information in CRF table NIR-1 consistently with the information reported in other sectoral tables, and enhance QA/QC procedures to avoid inconsistencies in the reporting of information between CRF tables in future submissions.	2017 ARR KL.16	Resolved. This inconsistency was corrected in the 2018 submission and a QA/QC check is now included for these tables.	Chapter 11
Deforestation - CO ₂	The ERT recommends that the United Kingdom estimate and report carbon stock changes from deforestation in below-ground biomass, litter, deadwood and soil organic matter in the OTs and CDs.	2017 ARR KL.17	Resolved. In the 2019 submission below-ground biomass is reported as IE (included with above-ground biomass), CSC in litter and deadwood is reported under litter, and CSC in soils is reported as NO. Explanatory text has been added to the NIR.	Chapter 11
Forest management - CO ₂	The ERT recommends that the United Kingdom estimate and report, in accordance with the 2006 IPCC Guidelines (volume 4, chapter 4), carbon stock changes in biomass from forests not used for timber production owing to biomass losses associated with harvesting and/or gathering (e.g. fuelwood) or provide transparent information justifying that such losses are not occurring.	2017 ARR KL.18	Resolved. Text in the NIR has been added to address this comment in Annex 3.4.1.2	Annex 3.4.1.2
Forest management - CO ₂	The ERT recommends that United Kingdom report separately carbon stock changes for above-ground and below-ground biomass.	2017 ARR KL.19	Resolved. These carbon stock changes are reported separately in the 2019 submission.	Chapter 11

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Forest management - natural disturbances	<p>The ERT recommends that the United Kingdom:</p> <p>(a) Estimate the background level and margin using a consistent and initially complete time series containing emissions for the period 1990–2009, in accordance with decision 2/CMP.7, annex, paragraph 33, using, if appropriate, methodologies from the 2006 IPCC Guidelines (e.g. volume 1, chapter 5);</p> <p>(b) Report in the NIR detailed information on the background level of emissions associated with annual natural disturbances that have been included in the FMRL, on how the background levels and margins for AR and FM have been estimated, on how the Party avoids the expectation of net credits or net debits during the commitment period, and on how the FMRL technical correction addresses emissions from natural disturbances for which the Party intends to apply the provision (e.g. substitution of natural disturbances emissions in the FMRL by the background level estimated);</p> <p>(c) Report the background level and margin estimated for AR and FM in CRF tables 4(KP-I)A.1.1 and 4(KP-I)B.1.3.</p> <p>Further, the ERT recommends that the United Kingdom provide detailed information on any recalculations performed in the time series of emissions from natural disturbance types for which the Party intends to apply the natural disturbances provision.</p>	2017 ARR KL.20	<p>Not resolved. The first recommendation is to use complete data from 1990-2009, but such data does not exist. We would welcome discussion with the next ERT to consider viable solutions here.</p> <p>The second recommendation refers to “<i>In the estimation of the background level and margin, emissions associated with drought have not been taken into account</i>”. We note that analysis of UK data shows that drought has no significant effect on UK forests, with even the severest droughts having negligible effect on mortality. There will be some effect on growth rate and this is implicitly included in the modelling for the FMRL (as this is based on regressions on data that will include drought effects), but is just as implicit in the carbon/ha used in the BL calculation.</p>	Chapter 11

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Cropland management Grazing land management	The ERT recommends that the United Kingdom: establish a hierarchy of elected activities under Article 3, paragraph 4; apply consistently the specified hierarchy to determine under which activity the land is to be reported in accordance with the Kyoto Protocol Supplement (section 1.2); in the cases in which a land falls into two activities, report over time that land under only one activity according to the established hierarchy; and provide detailed information in the NIR on the hierarchy and how it is consistently applied. Alternatively, in the cases of rotation of land between CM and GM, the United Kingdom may report all land subject to CM and GM under a single activity.	2017 ARR KL.21	Resolved. The UK notes that Parties are at liberty to decide the hierarchy of Cropland Management, Grazing Land Management and Revegetation. We have determined that CM and GM are equal in the hierarchy and have ensured that there is no risk of double-counting in our methods. We consider our approach to be consistent with IPCC guidance and the best use of the available data.	Chapter 11 (section 11.1.4)
Cropland management - CO ₂	The ERT recommends that the United Kingdom define the category of land under which hedges are to be accounted, ensure that corresponding GHG emissions and removals are estimated, and report consistently thereon for the entire time series.	2017 ARR KL.22	Resolved. Hedges are now included under GM only.	Chapter 11 (and Annex 3.4.3, also mentioned in Section 6.4.8)
Grazing land management - CO ₂	The ERT recommends that the United Kingdom report the same area of organic soils in grassland and GM in CRF tables 4(II) and 4(KP-I)B.3, respectively.	2017 ARR KL.23	Resolved. The same land area for organic soils in grassland and GM is now reported within CRF tables 4(II) and 4(KP-1)B.3.	[CRF tables]
Grazing land management - CO ₂ , CH ₄ and N ₂ O	The ERT recommends that the United Kingdom develop the necessary AD on controlled burning throughout the year and in land areas smaller than 1 ha, and estimate and report the associated CO ₂ and non-CO ₂ emissions for the entire territory.	2017 ARR KL.24	Not resolved. The required improvements have not yet been implemented. However, the UK has identified potential data sources for the estimation of controlled burning and is undertaking further analysis.	Chapter 11

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Wetland draining and rewetting - AD	<p>The ERT recommends that the United Kingdom:</p> <p>(a) Report the timetable for the ongoing project to incorporate WDR into the annual submission, including when the final results will be available for use in estimating CO₂ and non-CO₂ emissions from lands in the entire territory subject to WDR;</p> <p>(b) Follow, until the final results from the project are available, an interim approach (using alternative data sources) to obtain the necessary AD and use appropriate methodologies from the Wetlands Supplement to estimate CO₂ and non-CO₂ emissions for all the carbon pools from lands in the entire territory subject to WDR, noting the provisions of decision 2/CMP.7, annex, paragraph 26, decision 2/CMP.8, annex II, paragraph 2(a), (d) and (e), and decision 6/CMP.9, paragraph 10;</p> <p>(c) Report CO₂ and non-CO₂ emissions in CRF tables 4(KP-I)B.5, 4(KP-II)1, 4(KP-II)2 and 4(KP-II)4, and explain in the NIR how it has estimated them.</p>	2017 ARR KL.25	Not resolved. The required improvements have not yet been implemented. Further work on implementing the results of the research project will take place in 2019.	Chapter 11
Harvested wood products - CO ₂	The ERT recommends that the United Kingdom estimate the HWP contribution for HWP from deforestation on the basis of instantaneous oxidation.	2017 ARR KL.26	Resolved. This information has been included in the UK submission for many years, as communicated to the previous ERT. The method is clarified as "instantaneous oxidation" throughout section 11.3.1.	Chapter 11
Annual submission	Improve the transparency of the NIR by including sufficient information in the annual submission.	2017 ARR G.1	Resolved. The two outstanding items noted in item G.1 from the 2017 ARR are items (below) L.5 and W.1. Both of these are now resolved, and therefore this item G.1 is also resolved.	<p>L.5: Annex A3.4.1.2</p> <p>W.1: Annex table A3.5.5</p>

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Key Category Analysis	Provide justification for the level of category disaggregation used and the rationale for its use if there is any deviation from the level suggested by the 2006 IPCC Guidelines.	2017 ARR G.2	Resolved. The justification of the level of category disaggregation used in the UK KCA and explanations of deviations is provided in the NIR, with specific clarifications for LULUCF and agriculture included in Section A 1.3.	Annex A 1.3
Methods	Address the transparency issues identified in the previous review reports.	2017 ARR G.3	Resolved. This was a duplicate item for G.1, which in turn links to L.5 and W.1. All these are resolved.	See responses for G.1, L.5 and W.1
Uncertainty analysis	Include in the NIR a brief description of and reference to the information used to quantitatively assess the uncertainty for all categories where expert judgment was used.	2017 ARR G.5	Resolved. Justifications for uncertainty parameters are given in Tables A 2.3.1-2.3.4. We have prioritised documentation of parameters where the parameter has a significant impact on the KCA.	Annex A 2.3
Commitment period reserve	When preparing the NIR, compare the 90 per cent of assigned amount value against the total GHG emissions, excluding LULUCF, in the most recent year.	2017 ARR G.7	Resolved. The CPR calculation has been updated and is reported in the NIR, section 12.5, consistent with the approach recommended by the previous ERT.	Section 12.5
National system	Strengthen the national system in order to ensure the completeness of the coverage of the LULUCF and KP-LULUCF estimates of emissions and removals, and report on improvements made in the NIR.	2017 ARR G.8	Addressing. This issue relates to the completeness of reporting from OTs (items L.4 and KL.5), for which there is progress through development of institutional networks with both the Cayman Islands and Bermuda. This has led to access to new data, and resultant progress in a more complete national inventory and KP submission.	See responses for L.4 and KL.5.
General	Clearly indicate the geographical coverage of DUKES and demonstrate how fuel consumption data at the subcategory level for each OT and CD are obtained and incorporated into the national totals for that subcategory.	2017 ARR E.1	Resolved. DUKES coverage and the provision of AD from OTs and CDs is clarified in the 2019 NIR. Activity data for the OTs and CDs and their sources are included in Annex 3.6.	Section 1.1.2.2 Annex 3.6

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
General	Rectify the stock data in the energy statistics and implement relevant recalculations in the CRF tables, as necessary, and explain all the recalculations in the NIR.	2017 ARR E.2	Resolved. The energy statistics team have aligned stock changes reported in national energy statistics and the IEA returns for 2017 onwards, and these should remain largely consistent in future..	N/A
International navigation – liquid fuels – CO ₂ , CH ₄ and N ₂ O	Ensure the accuracy of the emission estimates for international navigation bunkers as well as the internal consistency between CRF tables 1.D and 1.A(b) by using the correct calorific values to convert activity from a mass basis to an energy basis.	2017 ARR E.5	<p>Resolved. The inventory agency has reviewed the available data and is satisfied that the approach to estimating and reporting data are consistent. The differences between the data reported in tables 1.D and 1.A(b) are primarily due to the use of independent simplified and weighted calorific values used in the reference approach compared to the source-specific calorific values in the sectoral approach.</p> <p>For Aviation fuels there is also an inconsistency in the structure of the CRF between the reference and sectoral approaches, meaning it is not clear where aviation spirit should be reported in the reference approach. The UK includes it with jet kerosene, which then results in a small discrepancy when compared to the jet kerosene data presented in the sectoral approach.</p> <p>The UK is satisfied that this doesn't represent an issue with emissions calculations.</p>	[CRF tables]

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
1.A.1.c Manufacture of solid fuels and other energy industries – liquid fuels – CO ₂ , CH ₄ and N ₂ O	Provide a clear and concise explanation that the estimates for AD and for CO ₂ , CH ₄ and N ₂ O emissions from subcategory 1.A.1.c.ii (oil and gas extraction) are complete, including relevant information (i.e. that the gap in data reporting applies to onshore terminals only and that the data from the EU ETS are very closely consistent with other reporting of emissions from the same installations under parallel regulatory mechanisms).	2017 ARR E.6	Resolved. This additional information is included within the full NIR of the 2019 submission, within the method approach, QAQC and improvements sections of MS 2. We clearly state that "It is important to note however that despite these different methods and data availability, the UK inventory agency does report in a time series consistent manner for each source, and that the UK inventory is complete for all emission sources in this Method Statement." Supporting information explains the data available across the time series, the specific known gaps and how they are addressed, and the QAQC section lists all of the specific quality checks that are conducted between different datasets for each installation.	MS 2
1.A.1.c Manufacture of solid fuels and other energy industries – liquid fuels – CO ₂ , CH ₄ and N ₂ O	Provide in the NIR up-to-date information on the consideration of, or progress made in, efforts to improve the energy statistics collection system for LPG and other petroleum gas fuels abstracted from upstream oil and gas exploration and production sources.	2017 ARR E.7	Resolved. The MS 2 section "Improvements" clearly presents up to date information to establish the status of this issue. The inventory is complete; the NIR is transparent in the UK approach to addressing a known data gap for LPG/OPG use at upstream oil and gas terminals.	MS 2
1.A.2.b Non-ferrous metals – solid fuels – CO ₂	Investigate the underlying cause of the drop in the CO ₂ EF for coal use in the Lynemouth aluminium smelter between 2003 and 2005 and report the findings of this investigation in the NIR.	2017 ARR E.9	Resolved. The "method approach" section of MS 3 explains the review of EU ETS data, the findings and the change in method to improve time series consistency that has been implemented to address this issue.	MS 3
2.D.2 Paraffin wax use – CO ₂	Examine possible sources of AD, especially the IEA (OECD), Eurostat and UNECE questionnaires.	2017 ARR I.10	Resolved. See also response to I.20. The UK energy statistics team have provided the petroleum wax-specific data used for IEA and Eurostat submissions to the inventory agency, and these data will be used in future.	Chapter 4.23

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
3.A Enteric fermentation – CH ₄	Implement the planned improvement of digestible energy data through the commissioned research projects.	2017 ARR A.1	Resolved. The UK has revised the methodology to implement the improvements derived from extensive UK research into this source category. This is explained in the NIR from the 2018 submission onwards.	Chapter 5
3.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.	2017 ARR A.2	Resolved. The UK has revised the methodology to move to higher tier methods for several livestock categories, including for sheep, in order to improve accuracy of the UK method, to better reflect UK-specific circumstances (e.g. housing, feed, livestock size / weight / breed type). This is explained in the NIR from the 2018 submission onwards, with supplementary reports detailing the UK research findings.	Chapter 5
3.A.4 Other livestock – CH ₄ and N ₂ O	Fully document in the NIR: (1) the method used to estimate the annual population of horses, deer and goats, including any adjustments to the original population data that the Party receives from national statistical agencies; and (2) the use of any additional data sources and estimations, as required by the 2006 IPCC Guidelines (volume 4, section 10.2.2 and equation 10.1).	2017 ARR A.3	Resolved. The UK has revised the methodology for estimating horse population and now presents details of how the AD are derived for all livestock types in the NIR from the 2018 submission onwards.	Chapter 5
3.B.4 Other livestock (horses) – N ₂ O	Make efforts to determine the number of horses in stabling and the corresponding type of manure management in order to determine the fraction of the total amount of N excretion for each manure management system for category 3.B.4 (manure management – horses).	2017 ARR A.4	Resolved. The UK has revised the methodology for estimating manure management from horses. This is explained in the NIR from the 2018 submission onwards.	Chapter 5
3.D.a.3 Urine and dung deposited by grazing animals – N ₂ O	Provide complete references for the data sources, a clear description of the method, assumptions and calculations used, and an explanation for the difference between the country-specific EF and the default EF from the 2006 IPCC Guidelines.	2017 ARR A.5	Resolved. All data references, and a full method description including assumptions, input data and calculation method are included in the NIR from the 2018 submission onwards.	Chapter 5

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
4. General (LULUCF) 4.B Cropland 4.C Grassland – CO ₂	Report mineral and organic soils separately under cropland and grassland.	2017 ARR L.1	Addressing. We are still working on the inclusion of the complete set of Grassland organic soils under table 4C.	Chapters 6.3 and 6.4.
4. General (LULUCF) 4.B Cropland 4.C Grassland – CO ₂	Assess the use of notation keys for the reporting of organic cropland and grassland soils, as appropriate.	2017 ARR L.2	Not resolved. We have no information yet on the extent of drained grassland in the Falkland Islands (where the organic soils are located within the OTs and CDs) but the land management is low intensity. Further research in the Falklands may resolve this issue.	Chapter 6.9.
Land representation – CO ₂	Provide estimates of emissions and removals for the missing land areas (Bermuda, Cayman Islands, Gibraltar and Montserrat).	2017 ARR L.4	Addressing. Gibraltar has been assessed as having zero LULUCF emissions and removals. The UK is working with the Cayman Islands and Bermuda governments to obtain activity data and estimate emissions and removals. Montserrat is not within the scope of UK GHGI reporting to the UNFCCC.	Annex 3.4 section 3.4.11.
4.A Forest land – CO ₂	Continue efforts to gather information on the management of privately owned forests and include in the NIR information on the management prescriptions and rotation ranges.	2017 ARR L.5	Resolved. Additional details are provided in the NIR Annex section A.3.4.1.2 from the 2018 submission onwards.	Annex 3.4 Section A3.4.1.2

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
4.A Forest land – CO ₂	Include additional information on the management of privately owned forests in the NIR, specifically that: (a) Privately owned forests are assigned a species based on the National Inventory of Woodland and Trees species survey, then mapped to species for which the United Kingdom has suitable growth models; (b) The distribution of growth rates for these species is assumed to be the same as on the public forest estates for each devolved administration (Scotland, Wales, Northern Ireland, England); (c) The overall percentage of woodland being managed for wood production is estimated so as to calculate wood production over the period that is consistent with the wood production statistics; (d) The rotation lengths are based on the age of maximum mean annual increment, with a range to match the given age distribution and planting records.	2017 ARR L.7	Resolved. The information on management of privately owned forests is documented in the National Forestry Accounting Plan, which is referenced in NIR Annex 3.4.12 and can be found at: https://www.gov.uk/government/publications/uk-national-forestry-accounting-plan-2021-to-2025 .	Chapter 6.2 Annex 3.4.
4.A Forest land	Include information in the NIR on how data for the areas of forest land remaining forest land and land converted to forest land for the period 1990–1999 were calculated, and provide a more concise description of how the areas for different categories (forest land remaining forest land and land converted to forest land) have been estimated for 1990 onward.	2017 ARR L.8	Resolved. The NIR Annex 3.4 provides the description of the derivation of land areas, and further information is provided in the National Forestry Accounting Plan, which is referenced in Annex 3.4 and can be found at: https://www.gov.uk/government/publications/uk-national-forestry-accounting-plan-2021-to-2025	Chapter 6.2 Annex 3.7
4.A Forest land – CO ₂	Include information in the NIR on the verification of all carbon stock changes estimated using tier 3 methods and/or models (CARBINE, C-Flow and BSORT models).	2017 ARR L.9	Addressing. A report has been prepared to verify the carbon stock changes of the soil component of the CARBINE model. We will investigate future inventory improvements to include more verification.	Annex 3.4
4.B Cropland – 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.	2017 ARR L.10	Resolved. This issue has been addressed, with text explaining the carbon stock changes over time within the NIR section 6.3.4.	Chapter 6.3

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
4.B Cropland – CO ₂	Report CO ₂ emissions from all organic cropland soils in CRF table 4.B.	2017 ARR L.11	Resolved. The reporting of CO ₂ emissions from organic cropland soils has been added into CRF Table 4.B, from the 2018 submission onwards.	CRF Table 4.B
4.G.3 Other (harvested wood products) – CO ₂	Include verifiable production data from the CARBINE model and the corresponding factors used to convert the production data to carbon, and report those data in CRF table 4.Gs2 to enable a more thorough verification of the HWP estimates.	2017 ARR L.13	Resolved. The UK has included this verifiable data by the improvement of wood products to semi-finished categories for HWP in the 1990-2016 inventory, the Reconcile improvement programme in the 1990-2017 inventory and improvements to the completeness of data reported in the CRF.	Table 4.Gs2 of the CRF
5.A Solid waste disposal on land – CH ₄	Implement the proposed improvements of the emission estimates for solid waste disposal sites in the OTs and CDs by providing further information on the methodologies used to estimate the emissions and by completing the CRF tables with specific parameters such as AD, MCF and DOC.	2017 ARR W.1	Resolved. Information on the landfill methodologies for OTs and CDs are presented in table A.3.5.5	Annex 3.5.1.3
5.A Solid waste disposal on land – CH ₄	Include in the NIR information on the parameters used in the MELMod model, including the exact figures and background information on their origin or method of derivation, and a weblink to the report on the review of landfill methane emissions modelling.	2017 ARR W.2	Resolved. From our records, the information requested by ARR was Methane Correction Factor; decay rates; DOC and DDOC for each waste stream; methane recovery; waste composition. The NIR includes the requested information as follows: Methane Correction Factor: Section 7.2.2 Decay rates: IPCC 2006 default values were used (confirmed in the 2018 NIR but not repeated in the 2019 NIR as this was not a change to the previous year and the IPCC 2006 default values were used) DOC and DDOC for each waste stream: Table A3.5.2 Methane recovery: Sections 7.2.3.1, 7.2.3.2, 7.2.3.3 and Table A3.5.4 Waste composition: Sections 7.2.3 and A3.5.1.1 and Table A3.5.1 A web link is provided to the review report in Section 17.6 as requested.	Sections 7.2.2, 7.2.3, 7.2.3.1, 7.2.3.2, 7.2.3.3, 17.6, A3.5.1.1 Tables A3.5.1, A3.5.2, A3.5.4

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
5.D.1 Domestic wastewater – CH ₄	Include information in the NIR on population number connected to a septic system, as well as the BOD values applied.	2017 ARR W.8	Resolved. This information is presented in the NIR, in Annex 3, Table A.3.5.12, and is outlined in Chapter 7.	Chapter 7 & Annex 3
5.D.1 Domestic wastewater – N ₂ O	In the NIR provide a detailed description and justification for the update of the fraction of N in protein (1.16) and the fraction of industrial and commercial co-discharged protein (1.25) and information on the consideration of sludge incineration and sludge spreading on agricultural lands, and update the CRF tables accordingly.	2017 ARR W.9	Resolved. The NIR section 7.5.2.3 presents the method description and justification for the factors applied in the UK. The fractions F _{NON-COM} and F _{IND-COM} were updated in the 2017 NIR; the CRF has since been updated to include these values as well.	Chapter 7
5.D.2 Industrial wastewater – CH ₄	Report on any progress in collecting the data needed to report AD and emissions from industrial wastewater separately from domestic wastewater.	2017 ARR W.10	Addressing. We will continue to maintain a watching brief on data available for this sector, but we do not have full access to complete data resolved sufficiently to address this recommendation.	n/a
General (KP-LULUCF)	Include specific information on how land under CM, GM and WDR is identified, especially related to the report developed as part of the ongoing project on areas of WDR.	2017 ARR KL.1	Addressing. The results of the project on wetland drainage and rewetting are in preparation for implementation in forthcoming inventories but additional information was included in the 1990-2017 inventory chapter 6 (Box in section 6.5.8) and section 11.1.3.	Chapters 6 and 11
General (KP-LULUCF)	Improve the QA/QC process and correct the inconsistency in the area of land converted to forest under the Convention and the Kyoto Protocol (i.e. the area of land converted to forest in CRF table 4.1 for 2014 (12.9 kha) does not match the area of AR (reported as 10.7 kha in table NIR-2)).	2017 ARR KL.2	Resolved. The inconsistencies in the area of land converted to forest under the Convention and the KP have been resolved, in CRF tables 4.1 and NIR-2.	CRF Tables 4.1 and NIR-2.
General (KP-LULUCF)	Include information in the NIR in accordance with decision 2/CMP.8, annex II, paragraph 5(c) and (e).	2017 ARR KL.4	Resolved. The relevant information has been added to the NIR from the 2018 submission onwards.	Chapter 11 sections 11.4 and 11.5

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
General (KP-LULUCF)	Provide estimates of emissions and removals for the Cayman Islands and Gibraltar.	2017 ARR KL.5	Resolved. The UK has contacted the Cayman Islands government to obtain activity data and estimate emissions and removals. We have researched the FAOSTAT dataset which indicates zero emissions from LULUCF from the Cayman Islands, and hence these are considered insignificant. Gibraltar have made their own calculations of their net LULUCF emissions (Annex 3.6) and these are determined to be zero, and therefore their KP emissions are also zero.	Annex 3.6
Deforestation – CO ₂	Find a method to verify that the carbon stocks in living biomass prior to deforestation are not underestimated.	2017 ARR KL.8	Not resolved. The UK will continue to investigate what data might be available to demonstrate that underestimation is not occurring. The UK currently has initiated a rolling programme of National Forest Inventories (NFIs) to provide accurate information about the size, distribution, composition and condition of the UK's forests and woodlands and to provide information about the changes taking place in UK's woodlands through time. Since land is only assigned as permanently deforested after 10 years, it would take until a possible 3rd cycle of the NFI to detect deforestation reliably. This issue therefore may take some time to resolve using the NFI alone.	n/a
Article 3.4 activities	Provide estimates of the carbon stock changes in: litter and deadwood for CM; litter, deadwood and organic soils for GM; and all carbon pools under WDR, and include a description of how these changes are estimated.	2017 ARR KL.9	Addressing. The results of the project on wetland drainage and rewetting are in preparation for implementation in forthcoming inventories but additional information was included in the 1990-2017 inventory (Box in section 6.5.8). As the UK has a forest area threshold of 0.1 ha, all tree-covered areas above this threshold are included under AR or FM. CM and GM are considered to only contain cropland or grassland vegetation respectively, and any litter or dead wood produced by these categories will decay within a single year and will not contribute to carbon stock change within the CM or GM categories.	Chapter 11

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter / section in the NIR
Forest management– CO ₂ , CH ₄ and N ₂ O	Correct the value of the FM cap in the CRF table “Accounting”.	2017 ARR KL.10	Resolved. The FM Cap was corrected from the 2018 submission onwards, within the CRF table “Accounting”, with details presented in NIR section 11.5.2.	Chapter 11 [CRF Tables]
Forest management – CO ₂	Include information in the NIR on the main changes in the inventory leading to the technical correction of the FMRL (including the inclusion of carbon emissions and removals from forest areas afforested prior to 1921, changes in the assumptions used for the species mix, growth rates and intensity of management).	2017 ARR KL. 11	Resolved. This issue was addressed from the 2018 submission onwards, with the information on main changes in the inventory leading to technical corrections of the FMRL presented in NIR section 11.5.2.	Chapter 11

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 ₂ O
Methods	As for LULUCF Sector 4
Emission Factors	As for LULUCF Sector 4
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	Activity data on historic forest planting rates have been adjusted after reconciliation of harvest levels from the published wood production statistics and forest age data. Improvements to the CARBINE model include: the correction of double-counting of deadwood in the year of harvest; disaggregated reporting of biomass, litter and deadwood carbon stock changes; and adjustment of turnover calculations to avoid double-counting. Average biomass densities for cropland and grassland used in the LUC model were changed to be consistent with those used in the cropland and grassland management calculations.

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, Sources chapter).

These single minimum values are used for reporting UK Forestry Statistics (see Annex 3.4 for details) and the UK's greenhouse gas inventory submitted under the UNFCCC. 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).

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 (reporting of which became mandatory in the second commitment period), 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 (DECC 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 CO₂ eq./yr, or -8.268 Mt CO₂ eq./yr when applying first order decay function for harvested wood products. The UK has calculated a technical correction to the FMRL which is -12.200 Mt CO₂ eq./yr, or -9.383 Mt CO₂ eq./yr when applying first order decay function for harvested wood products. This leads to a corrected FMRL of -15.642 Mt CO₂ eq./yr or 17.651 Mt CO₂ 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

11.1.3.1 Afforestation and Reforestation

Afforestation and reforestation are considered together and are consistent with the definition of forest given above. 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 replanted⁶³ or afforested post-1990. New forest area can result from planting, seeding or natural colonisation. The replanted area is estimated based on the wood production information and assigned to FM, and the remainder is assigned as Afforestation. Areas of forest planting are reported by calendar year for both 4A Forest Land and AR and FM. The area of forest established since 1990 for the latest inventory year is the same in both the UNFCCC GHGI and Article 3.3 Afforestation. It is assumed that none of the AR area has been subsequently deforested.

⁶³ Excludes re-stocking carried out as part of the cycle of sustainable forest management.

The area and carbon stock changes of KP AR and the area of 4A2 Land converted to Forest were identical at the end of 2009, at 459.47 kha and 409 Gg CO₂, as the area of 4A2 in 2009 will include all forest planting since 1990.

11.1.3.2 Deforestation

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 for the latest inventory matches the area reported under Article 3.3 Deforestation.

Forest Research has collated data from multiple sources: unconditional felling licences granted, differences between forest area maps (2006 and 2015 NFI and NIWT), 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 then that led 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.

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 more than a threshold volume of wood 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).

Activity data on the small area of deforestation (0.002 kha/yr) in the Overseas Territories and Crown Dependencies (Guernsey only) is obtained from two habitat surveys in 1999 and 2010, extrapolated forward to 2017. The change in forest cover is a result of the changed areas losing sufficient tree cover to be reclassified as dense scrub or parkland, rather than conversion to settlement land or agriculture.

11.1.3.3 Forest Management

The Forest Management area is the forest area established before the end of 1989 adjusted to reflect losses from deforestation (see Annex 3.4 for details). In the UNFCCC GHGI the Deforestation area is deducted from the 4A1 Forest remaining Forest Land area, and carbon stock changes are adjusted accordingly.

11.1.3.4 Cropland Management

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 UNFCCC methodology back-calculates from the 2015 cropland area, using Countryside Survey data for land use changes areas. This leads to a 2% difference in total areas in 2017. There are also small differences because (i) a small area of CM activity occurs on Deforested land and therefore this area and associated emissions and removals are reported under Deforestation; (ii) areas of CM land have been converted to Settlement. 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.

11.1.3.5 Grazing Land Management

The area of Grazing Land Management reported under KP is broadly consistent with that reported as Grassland under UNFCCC as all Grassland in the UK is considered to be grazed and managed to some degree. The area of Grassland in the UNFCCC inventory is the area remaining once all other land uses have been subtracted from the total country area, whereas the Grazing Land Management area uses the area of grassland in the Countryside Survey in 1990 as the starting point. This leads to a 2% difference in total area in 2017. The area of KP-GM land is also different from the UNFCCC Grassland area because (i) some KP-GM activity occurs on Deforested land 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. 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.

11.1.3.6 Wetland Drainage and Rewetting

BEIS commissioned a programme of research and methodological development to compile activity data and UK-specific emission factors for Wetland Drainage and Rewetting (WDR) activities. See box in section 6.5.8 for further details. Preliminary results show significant uncertainty in the areas assigned to different management actions around drainage and rewetting as well as on emissions factors for many peatland types. Further work is underway to incorporate the results into the GHGI methodology, with the aim of implementation in the 2020 inventory submission. The inclusion of some peatland condition categories may be delayed pending further work on reducing their associated uncertainties.

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 expect to 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 (for the GBE CRF submission) together with the combined area of the UK's Overseas Territories and Crown Dependencies (for the GBK and GBR CRF submissions). 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 Annex 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 6.1.1** 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 Forestry 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. The parameterisation of this algorithm to ensure the best fit between modelled wood production and the published wood production statistics has been automated for this inventory.

Areas planted since 1990 in this forest activity 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.

New planting in the UK is usually grant aided and it is a condition of these grants that the area of forest be maintained. 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 6** 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 Art 3.4 Cropland Management 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 Art. 3.4 Grazing Land Management 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 latest inventory. A programme of research and methodological development is in progress 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 2017 (UK only)

To current inventory year (2017)			Article 3.3 activities		Article 3.4 activities			Other	Total (beginning of year)	
From previous inventory year (2016)			Afforestation and Reforestation	Deforestation	Forest Management	Cropland Management	Grazing Land Management			
Article 3.3 activities	Afforestation and Reforestation	kha	540.4	0.0					540.4	
	Deforestation			64.0					64.0	
Article 3.4 activities	Forest Management			3.0	2957.0				2960.0	
	Cropland Management		0.7			5145.3	99.0		5245.1	
	Grazing Land Management		6.8			52.1	13638.5		13697.3	
Other			1.0			0.2	10.7	1919.8	1931.7	
Total (end of year)			548.9	67.0	2957.0	5197.6	13748.3	1919.8	24438.5	
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	540.4	0.0					540.4	

	Deforestation			64.0					64.0
Article 3.4 activities	Forest Management			3.0	2957.0				2960.0
	Cropland Management		0.7			5145.3	99.0		5245.1
	Grazing Land Management		6.8			52.1	13638.5		13697.3
	Other		1.0			0.2	10.7	1919.8	1931.7
Total (end of year)			548.9	67.0	2957.0	5197.6	13748.3	1919.8	24438.5

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 - 2017	New planting on previously non-forested land. Updated annually. Categorized into conifer and broadleaved woodland.
AR & FM	Annual restocking statistics	UK	1971 - 2017	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	2017	Information on the growth rate and management of the public forest estate. Used to estimate the distribution of tree species, growth rates and management of forests.
AR & FM	Timber production statistics	UK	1976 - 2017	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).
AR & FM	FAO Global Forest Resource Assessment	Overseas Territories and Crown Dependencies	2010	Areas of forest type and some management information.
D	Forestry Commission Unconditional Felling Licence data	England, Scotland, Wales	England: 1992-2013; Scotland: 1998-2013; Wales: 1996-2013	Licences 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
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	1990-2017	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.

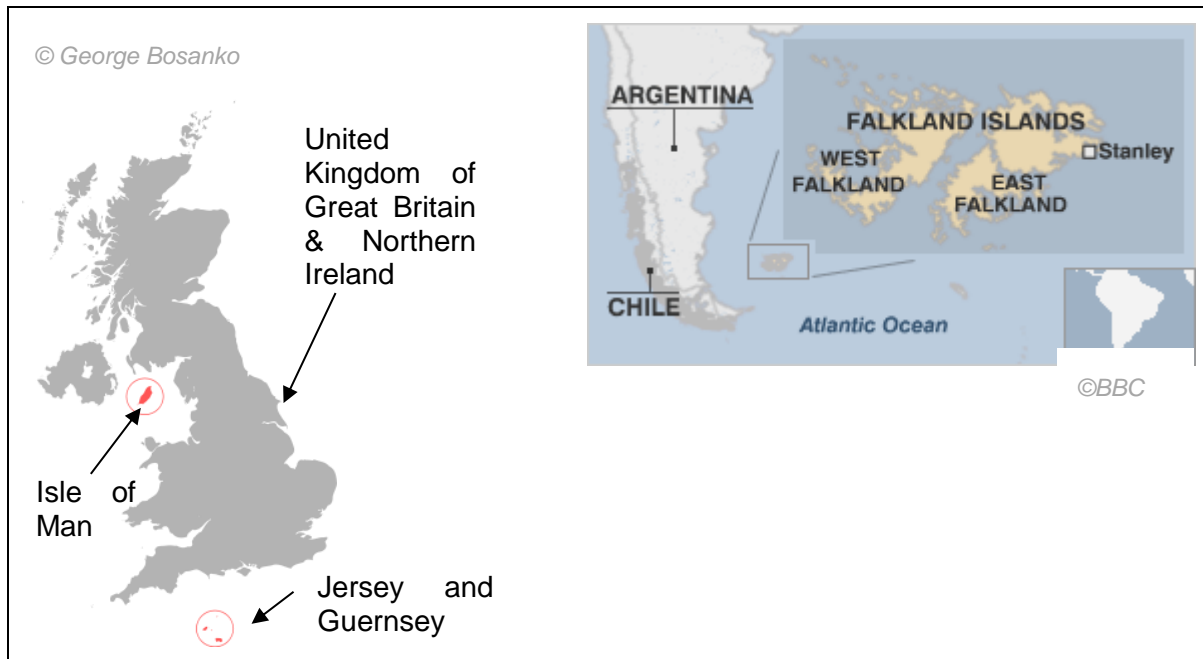
Activity	Dataset	Available scale	Time period	Details
D	Countryside Survey (CS) 1990, 1998, 2007	UK	1990-2007	Estimated areas of woodland converted to other land uses from CS data (1990, 1998, and 2007). The CS over-estimates the extent of woodland conversion compared with the extent estimated by the Forestry Commission. This is due to differences in woodland definitions, amongst other causes. The CS data is 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)	2000-2017	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 conversion 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, CM, GM	Habitat surveys, agricultural statistics and planting data	Overseas Territories and Crown Dependencies	1965-2017	Forest planting data for broadleaves and conifers was available for the Isle of Man. Habitat surveys and economic statistics were used to estimate forest, cropland, grassland and settlement 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 – 2017	Areas under different crops.
CM	British Survey of Fertiliser Practice	Great Britain (not Northern Ireland)	1992 – 2017	Percentage of crop residues incorporated to soil. Fertiliser and manure inputs to Cropland and Grazing Land.

Activity	Dataset	Available scale	Time period	Details
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)	2010-2017	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 11.1). 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. CEH is in discussion with the Cayman Islands to develop KP-LULUCF reporting for future submissions.

Figure 11.1 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

ARD and FM carbon stock changes

The 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 Tier 3 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 and below-ground biomass (gains and losses), litter and dead wood (net changes) and soils (net changes in mineral and organic soils).

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 CO₂, CH₄ and N₂O are reported in Table 5(KP-II)5. The remaining carbon stock in biomass is assumed to be immediately lost (instantaneous oxidation) (in UNFCCC reporting 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.

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 CARBINE 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, but has not yet needed to implement it. 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 (DECC 2016). No emissions have been excluded as being due to natural disturbances in the current 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 ₂ e/yr)	Margin (ktCO ₂ e/yr)	Disturbance provision threshold (ktCO ₂ e/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 calculated from 1960 onwards and reported from 1990.

CM and GM carbon stock changes

Changes in soil and biomass carbon due to LUC 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. 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 resulting from deforestation to cropland or grazing land are reported under KP-Deforestation.

Carbon stock changes in biomass as a result of agricultural management activities on cropland are calculated for annual crops, orchards, shrubby perennial crops, perennial grasses grown as biomass fuel, short rotation coppice, and set aside and fallow. Soil carbon stock changes are estimated using data on crop areas supplemented with data on residue removals and fertiliser and manure inputs methodology full description of these Tier 1 and 2 methodologies is given in **Annex 3.4**.

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 country-specific biomass carbon stocks (Tier 2). Details are given in **Annex 3.4**. The reporting of emissions from grazing land soils as a result of management activities is awaiting the outcome of further research in this area, as a literature review (Moxley et al, 2014a) suggested that Tier 1 emission factors were not appropriate for the high carbon organo-mineral soils underlying large areas of grazing land in the UK.

Other GHG emissions from KP-LULUCF

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 N₂O 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 and on grassland on organic soils (i.e. AR land) in the UK (see section 6.2) for more information). Indirect emissions from leaching and deposition of N fertiliser are calculated using a Tier 1 methodology.

Table 4(KP-II)2 CH₄ and N₂O emissions from drained and rewetted organic soils

The method used to estimate N₂O 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 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 CH₄ emissions from drainage and non-CO₂ emissions from rewetted soils at this time.

Table 4(KP-II)3 N₂O emissions from N mineralization/immobilization due to carbon loss/gain associated with land-use conversion and management change in mineral soils

Indirect emissions of N₂O from leaching of mineral soils as a result of N mineralization following land use change are calculated at Tier 1 methodology. Direct N₂O following deforestation to Cropland, Grassland and Settlement and with land use change between Forest Land, Cropland, Grazing Land and Settlement in the UK since 1990 are reported. N₂O 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 AR land and FM land on the basis of their proportion of the whole forest area. 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 of the incidence of wildfires on deforested areas but they do not occur every year. 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. 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 and progress has been made towards this goal.

Table 4(KP-I)A.1.1 Article 3.3 activities: Afforestation and Reforestation. Additional information: emissions and removals from natural disturbance

(GBE, GBR and GBK submissions) The UK has signed up to the provision to exclude emissions from natural disturbances with respect to Article 3(3) (Afforestation and Reforestation), but has not yet needed to implement it. 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 by the latest 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.

(GBR and GBK submissions) A small amount of deforestation in the Overseas Territories and Crown Dependencies on mineral soils is reported but limited data only allow Tier 1 estimation of carbon stock changes in biomass and litter. Other carbon stock changes are reported as Not Occurring. All emissions from deforestation in the Overseas Territories and Crown Dependencies fall well below the insignificance threshold of 500 Gg CO₂e (estimated to be 0.64 Gg CO₂ in 2017 if a similar rate of deforestation to the UK rate is assumed) but the UK will continue to report emissions from this activity that it has reported in previous years.

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

(GBE, GBR and GBK submissions) No emissions from natural disturbance above the disturbance provision threshold level have occurred in the period covered in the latest 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

(GBE, GBR and GBK submissions) 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. Deforestation to Cropland and Settlement does not occur in the Overseas Territories and Crown Dependencies.

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)

(GBE, GBR and GBK submissions) 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

(GBE, GBR and GBK submissions) No emissions from natural disturbance above the disturbance provision threshold level have occurred on Forest Management land in the period covered in the latest 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

(GBR and GBK submissions) 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, litter and dead wood are reported as Not Estimated (no guidance).

Table 4(KP-I)B.3. Elected Article 3.4 activities: Grazing Land Management

(GBR and GBK submissions) 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, litter and dead wood are reported as Not Estimated (no guidance).

Table 4(KP-I)B.5 Elected Article 3.4 activities: Wetland drainage and rewetting

(GBE, GBR and GBK submissions) UK-specific activity data and emission factors are still in development for this activity so all carbon stock changes are currently reported as Not Estimated.

Table 4(KP-I)C Carbon stock changes in the harvested wood products (HWP) pool

(GBE submission) HWP resulting from deforestation is assumed to be instantaneously oxidised and is reported as NA in this CRF table.

(GBK and GBR submission) There is a very small amount of HWP arising from timber harvesting in the UK's Overseas Territories and Crown Dependencies, with none (NO) arising from AR or D land. The small amount from FM land is assumed to all go into paper products for domestic consumption only, and all other products are reported as NO.

Table 4(KP-II)1 Direct N₂O emissions from N fertilization

(GBE, GBR and GBK submissions) It is assumed that nitrogen is only applied to newly planted forests on certain land use types in the UK, and therefore that no N fertilization occurs on Deforestation or Forest Management land (NO).

Table 4(KP-II)2 CH₄ and N₂O emissions from drained and rewetted organic soils

(GBE, GBR and GBK submissions) At present there is insufficient information to allow the estimation of CH₄ fluxes and non-CO₂ fluxes from drained and rewetted soils under CM, GM and WDR activities (Not Estimated). There are no known occurrences of rewetting on ARD and FM soils.

Table 4(KP-II) N₂O emissions from N mineralization/immobilization due to carbon loss/gain associated with land-use conversions and management change in mineral soils

(GBE, GBR and GBK submissions) There are no continuing carbon stock losses, and hence no N₂O emissions, associated with LUC from FM land in the UK or from ARD or FM land in the UK'S Overseas Territories and Crown Dependencies (Not Occurring).

Table 4(KP-II)4. GHG emissions from biomass burning

(GBE submission) There is no controlled burning for management in UK forests, so this is reported as Not Occurring for AR and FM. Controlled burning is prohibited on UK cropland (Not Occurring) but does occur on Grazing Land in the UK, particularly on heather moorland. However, these controlled burning events affect very small patches and occur intermittently and there is no activity data available on their occurrence and extent. At present, emissions for this activity have not been estimated (NE) but this is being kept under review.

Wildfires on Deforested land are infrequent and do not occur every year, so are reported using the notation key NO in most years.

(GBR and GBK submissions) There are no records of either controlled burning or wildfires in the UK's Overseas Territories and Crown Dependencies. These emissions are reported as Not Occurring, as estimated emissions (<0.3 Gg CO₂e), based on equivalent rates of controlled and wildfire burning in the territories as in the UK will fall below the insignificance level for reporting of 500 Gg CO₂e.

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, CO₂ 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).

11.3.1.4 Changes in data and methods since the previous submission (recalculations)

Details of recalculations are given in Table 11.4. Justifications for the recalculations are given in Chapter 6, sections 6.2.7, 6.3.7, 6.4.7 and 6.8.7 for the UK, and in Chapter 6, section 3.9.4 for the Overseas Territories and Crown Dependencies.

Table 11.4 Recalculations of previous emissions/removals in the latest KP-LULUCF submission

IPCC Category	Source Name	2018 Submission 2016	2019 Submission 2016	Units	Comment/Justification
UK					
KP.A.1	Afforestation and Reforestation-carbon stock change	-2491	-2241	Gg CO ₂	Reconciliation of harvest volume and forest age data. Correction of double-counting of dead wood. ⁶⁴
KP.A.1/(KP-II)1	Direct and indirect N ₂ O emissions from N fertilization	0.011	0.011	Gg N ₂ O	Reconciliation of harvest volume and forest age data ⁵
KP.A.1/(KP-II)2	CH ₄ and N ₂ O emissions from drained and rewetted organic soils	0.034	0.033	Gg N ₂ O	Reconciliation of harvest volume and forest age data ⁵
KP.A.1/(KP-II)3	N ₂ O emissions from N mineralization	0.481	0.460	Gg N ₂ O	Reconciliation of harvest volume and forest age data ⁵
KP.C	HWP from AR Land	-29	-49	Gg CO ₂	Reconciliation of harvest volume and forest age data ⁶⁵
KP.A.2	Deforestation- Carbon stock change	1173	1148	Gg CO ₂	Adjustment of average biomass densities due to error correction. ⁶⁶ Changes to the average deforestation rate for soil CSC calculation. ⁶⁷
KP.A.2/(KP-II)3	N ₂ O emissions from N mineralization	0.176	0.178	Gg N ₂ O	Changes to the average deforestation rate for soil CSC calculation. ⁹
KP.A.2/(KP-II)4	GHG emissions from biomass burning	382	364	Gg CO ₂	Adjustment of average biomass densities due to error correction. ⁸
		1.14	1.09	Gg CH ₄	
		0.063	0.060	Gg N ₂ O	
KP.B.1	Forest Management- carbon stock change	-21550	-16114	Gg CO ₂	Reconciliation of harvest volume and forest age data. ⁵ Correction of double-counting of dead wood ⁵⁶⁴

⁶⁴ See section 6.2.7 for justification

⁶⁵ See section 6.8.7 for justification

⁶⁶ See section 6.3.7 for justification

⁶⁷ See section 6.4.7 for justification

KP.B.1/(KP-II)2	CH ₄ and N ₂ O emissions from drained and rewetted organic soils	0.156	0.157	Gg N ₂ O	Reconciliation of harvest volume and forest age data. ⁵
KP.C	HWP from FM Land	-602	-1923	Gg CO ₂	Reconciliation of harvest volume and forest age data ⁶
KP.B.2	Cropland Management- carbon stock change	12227	11836	Gg CO ₂	Changes to the living biomass densities for cropland and grassland. ⁸ Adjustment to uncropped land area . ⁸
Overseas Territories and Crown Dependencies					
KP.A.2	Deforestation - Carbon stock change	0.85	0.25	Gg CO ₂ e	Changes to the living biomass densities for cropland and grassland
KP.B.2	Cropland Management - Carbon stock change	46.10	23.51	Gg CO ₂ e	Changes to the living biomass densities for cropland and grassland. Changes to cropland LUC time series in the Falkland Islands and Jersey.
KP.B.2/(KP-II)3	Emissions from N ₂ O mineralisation	0.018	0.008	Gg N ₂ O	Changes to cropland LUC time series in the Falkland Islands and Jersey
KP.B.3	Grazing Land Management - Carbon stock change	-3.44	4.03	Gg CO ₂ e	Changes to the living biomass densities for cropland and grassland Changes to cropland LUC time series in the Falkland Islands and Jersey
KP.B.2/(KP-II)3	Emissions from N ₂ O mineralisation	0.0145	0.0135	Gg N ₂ O	Changes to cropland LUC time series in the Falkland Islands and Jersey

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 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.

An uncertainty of 35% for Article 3.3 Afforestation/Reforestation and Article 3.4 Forest Management is 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, $\text{m}^3 \text{ha}^{-1} \text{yr}^{-1}$), 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 national forest estates. 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.

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, but has not yet needed to do so. 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 section 6.2 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 distribution as the FM area. It is unknown whether this assumption leads to an under- or over-estimate of emissions due to deforestation. We hope to investigate whether

Forestry Commission records can be used to characterise any of the deforestation on the national forest estates 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

Table 11.5: Areas converted to KP activities after 2013 (UK and OTs & CDs)

Year	Area converted to AR, kha	Area converted to D, kha	Area converted to CM, kha	Area converted to GM, kha
2013	17.80	2.55	52.68	109.92
2014	15.12	2.83	52.35	110.98
2015	6.91	2.48	53.33	110.00
2016	6.40	3.65	52.35	110.25
2017	8.51	2.97	52.35	109.85

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).

Information on deforestation is collated from multiple sources (see **Annex 3.4.4** for details), and remote sensing, all of which can 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. For the pre-2000 time series 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 time series extrapolation) are adjusted in order that deforestation is not over-estimated.

New data sources for the post-2000 time series have been used that clearly identify the post-deforestation land use. The estimation of areas of deforestation using analysis of aerial photographs to identify areas that have definitively changed is described in the report *Preliminary estimates of the changes in canopy cover in British woodlands between 2006 and*

2015 (Forestry Commission, 2016). Land is only classified as deforested 10 years after the removal of trees is first identified, unless there has been an irreversible change such as conversion to settlement or administrative records, for example the granting of an unconditional felling licence, indicates intent to convert to another non-forest land cover.

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 clear-felled 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 (not yet published) and 2020, which will give a more complete picture of the proportions of clear-felled 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 latest inventory.

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. In the event that the UK claims under the natural disturbance provisions, a technical correction will amend the FMRL to account for emissions associated with the natural 'factor' in question, to ensure the avoidance of net credits.

For Forest Management, carbon stocks and thus emissions (per hectare) are estimated on the basis of mean carbon stocks for conifers (295 tCO₂e/ha) and broadleaves (298 tCO₂e/ha), respectively, reported by the National Forest Inventory. 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 1,500-2,000 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 HWP pool (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). The HWP pool includes all domestically produced HWP 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) that have not been deforested since 1990 are included in Article 3.4 Forest Management. The CARBINE model is used to calculate emissions that have arisen from thinning, harvesting and restocking since 1990. 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 since 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

It is assumed that no emissions arise 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 CO₂ eq./yr, or -8.268 Mt CO₂ 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 for forest carbon stock changes and GHG emissions as the UNFCCC LULUCF inventory, the KP-LULUCF inventory and national projections of LULUCF emissions and removals. The methodology is described in **Chapter 6** and **Annex 3**. A technical correction to the FMRL was calculated for the latest 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 current 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 last inventory, since when the following changes in data and assumptions necessitate a new technical correction for the current submission:

- Adjustments to the activity data and forest management assumptions to better match reported wood production
- A correction to double counting in the calculation of deadwood
- Updated wildfire estimates.

The Technical Correction was calculated using the CARBINE model (**Annex 3.4.1**). 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 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 proportion of harvested wood products assigned to the HWP categories is fixed at the 2009 level to factors out the effects of post-2009 changes to policies affecting HWP.

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 CO₂, CH₄ and N₂O emissions from biomass burning in wildfires. Further details are given in **Annex 3.4**. 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.

Historical and projected emissions and removals from 1990 to 2020 are shown in Table 11.6. These are consistent with the national GHGI in the latest 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 3.4**. 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.

Table 11.6 Area under forest management and emissions/removals from forest management 1990-2020 (UK only, based on the latest 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 ₂ eq	Emissions/removals from HWP, Gg CO ₂	Net emissions/removals, Gg CO ₂ eq
1990	3023	-15189	42	-1554	-16700
1991	3022	-15961	73	-1230	-17119
1992	3021	-16549	19	-1154	-17685
1993	3020	-16915	33	-1289	-18170
1994	3020	-16945	27	-1422	-18340
1995	3019	-17219	214	-1616	-18621
1996	3018	-17676	113	-1595	-19159
1997	3017	-17888	150	-1833	-19571
1998	3016	-18385	85	-1754	-20054
1999	3015	-18544	14	-1972	-20503
2000	3012	-18874	49	-2003	-20828
2001	3008	-19160	67	-1987	-21080
2002	3005	-19373	57	-1958	-21274
2003	3000	-19354	49	-2063	-21368
2004	2997	-19249	64	-2199	-21383
2005	2993	-19333	120	-2102	-21315
2006	2991	-19378	119	-2002	-21261
2007	2987	-19107	107	-2124	-21124
2008	2984	-19475	99	-1763	-21138
2009	2981	-19331	87	-1600	-20844
2010	2978	-18866	43	-1857	-20680
2011	2975	-18254	58	-2217	-20413
2012	2972	-15968	271	-3599	-19296
2013	2969	-16703	67	-2460	-19095
2014	2967	-16616	72	-2117	-18660
2015	2964	-16229	0	-2030	-18259
2016	2960	-16080	6	-1923	-17997
2017	2957	-15672	34	-1845	-17484
2018	2955	-15216	34	-1871	-17053
2019	2952	-14695	34	-1903	-16564
2020	2949	-14206	34	-1927	-16100

* The OTs & CDs were not included in the original FMRL or the Technical Correction but would have an insignificant impact on the totals, with an increase of 4.5 kha, -40 Gg CO₂ from carbon stock changes, 0 Gg CO₂ from wildfires and -1.6 Gg CO₂ from HWP

For the business-as-usual projection standard management regimes (rotation lengths and thinning regime and felling regimes) are rolled forward, 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. It is assumed that there were no significant effects from post-2009 policies in the area and age distribution.

The Technical Correction was calculated as $FMRL_{corr} - FMRL_{orig}$ and is shown in Table 11.7.

Table 11.7: Forest Management Reference Levels and Technical Correction for the period 2013-2020.

	Assuming instantaneous Oxidation, Gg CO ₂ eq	With emissions/removals from HWP using first order decay functions, Gg CO ₂ eq
Submitted FMRL (FMRL_{orig})	-3442	-8268
Corrected FMRL (FMRL_{corr})	-15642	-17652
Technical Correction	-12200	-9384

11.5.2.4 Information related to the natural disturbances provision under Article 3.4

The information in section 11.4.4 also applies here.

11.5.2.5 Information on Harvested Wood Products under Article 3.4

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.

Carbon stocks in HWP are estimated by CARBINE based on the time of planting, species yield class and management regime (**Annex 3.4.1**). HWPs are generated for all woodland that has been harvested since 1990. 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 (see box in section 6.5.8).

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 (CO₂), Article 3.3 Deforestation (CO₂), Article 3.4 Forest Management (CO₂), Article 3.4 Cropland Management (CO₂), and Article 3.4 Grazing Land Management (CO₂). 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 based on level of emissions (including LULUCF).

Article 3.3 Afforestation and Reforestation (CO₂): The associated UNFCCC category 4A (-18 065 Gg CO₂e) is a key category and the AR component (i.e. its category contribution (-2 392 Gg CO₂e) is also larger than the smallest UNFCCC key category (1A3a Domestic aviation: Liquid fuels). 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 (CO₂): The associated UNFCCC categories (4B, 4C and 4E) are key categories (11 433, -8 811 and 6 985 Gg CO₂e respectively), although the Deforestation category contribution (1 439 Gg CO₂e) is not key on its own.

Article 3.4 Forest Management (CO₂): The associated UNFCCC category 4A is a key category (-18 065 Gg CO₂e). The Forest Management category contribution (-15 633 Gg CO₂e) is also greater than other categories in the UNFCCC key category analysis.

Article 3.4 Cropland Management (CO₂): The associated UNFCCC category 4B is a key category (11 433 Gg CO₂e). The Cropland Management category contribution (12 589 Gg CO₂e) is also greater than the smallest UNFCCC key category.

Article 3.4 Grazing Land Management (CO₂): The associated UNFCCC category 4C is a key category (-8 811 Gg CO₂e). The Grazing Land Management category contribution (-5 790 Gg CO₂e) 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 2018 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_2018_2_2.xls for commitment period 2 and RREG1_GB_2018_1_1.xls for commitment period 1.

12.2 SUMMARY OF INFORMATION REPORTED IN THE SEF TABLES

12.2.1 Commitment Period 2

At the end of 2018, the total CP2 holdings for the UK Registry was 25,939,911 CERs, of which 1,282,519 were in the voluntary cancellation account. There was also a total of 90,638,091 ERUs.

In total for 2018, the UK Registry received 7,762,983 CERs and 5,336,075 ERUs. Conversely, 11,249,038 CERs and 1 ERU was externally transferred to other national registries. No other CP2 units were transferred or acquired.

626,770 CERs and 498,162 ERUs were cancelled.

Full details are available in the SEF tables; the full tables are shown in **Annex 6**.

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://unionregistry.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 2018 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_2018_2_2.xlsx (Commitment Period 2 only). SEF_RREG1_GB_2018_1_1.xlsx (Commitment Period 1 only).

Annual Submission Item	Reporting Guidance
	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	<p>No discrepant transactions occurred in 2018.</p> <p>This is confirmed in the table named “R2” in the Excel file included, SIAR Reports 2018-GB v1.0.xls</p> <p>The contents of the Report R2 can also be found in Annex 6 of this document.</p>
15/CMP.1 annex I.E paragraph 13 & 14: List of CDM notifications	<p>No CDM notifications occurred in 2018.</p> <p>Refer to Separate Electronic Attachment “SIAR Reports 2018-GB v1.0.xls” Worksheet R3.</p> <p>The contents of the Report R3 can also be found in Annex 6 of this document.</p>
15/CMP.1 annex I.E paragraph 15: List of non-replacements	<p>No non-replacements occurred in 2018.</p> <p>Refer to Separate Electronic Attachment “SIAR Reports 2018-GB v1.0.xls” Worksheet R4.</p> <p>The contents of the Report R4 can also be found in Annex 6 of this document.</p>

Annual Submission Item	Reporting Guidance
15/CMP.1 annex I.E paragraph 16: List of invalid units	No invalid units exist as at 31 December 2018. Refer to Separate Electronic Attachment “SIAR Reports 2018-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 Publicly accessible information	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 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.
	<u>Account Information (Paragraph 45)</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 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. <u>Jl projects in UK (Paragraph 46)</u>

Annual Submission Item	Reporting Guidance
	<p>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</p> <p><u>Paragraph 47 a/d/f - Holding and transaction information of units</u></p> <p>Holding and transaction information is provided on a holding type level, due to more detailed information being declared confidential by EU Regulation.</p> <p>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..”</p> <p><u>Paragraph 47c</u></p> <p>The United Kingdom is not hosting domestic JI projects as per paragraph 46 above.</p>
	<p><u>Paragraph 47e</u></p> <p>The United Kingdom is currently not participating in any LULUCF projects for 2018.</p> <p><u>Paragraph 47g</u></p> <p>No ERUs, CERs, AAUs and RMUs have been cancelled on the basis of activities under Article 3, paragraphs 3 and 4 to date.</p> <p><u>Paragraph 47h</u></p> <p>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.</p> <p><u>Paragraph 47j</u></p> <p>No ERUs and CERs have been retired in 2018 for CP2.</p>

Annual Submission Item	Reporting Guidance
	<p><u>Paragraph 47k</u></p> <p>85,302,015 ERUs and 25,882,305 CERs have been carried over from CP1 to CP2.</p> <p><u>Account holders authorised to hold Kyoto units in their account (Paragraph 48)</u></p> <p>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.</p>

12.5 CALCULATION OF THE COMMITMENT PERIOD RESERVE (CPR)

15/CMP.1 annex I.E paragraph 18 CPR Calculation	<p>The Annex to Decision 11/CMP.1 (paragraph 6) specifies that: <i>'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 eight times its most recently reviewed inventory, whichever is lowest'.</i></p> <p>Therefore the UK's commitment period reserve is calculated as:</p> <p>Either</p> <table><tr><td>UK's Adjusted Assigned Amount</td><td>x</td><td>90%</td></tr><tr><td>2,746,287,369</td><td>x</td><td>0.90</td></tr><tr><td colspan="3">= 2,471,658,632 assigned amount units</td></tr></table> <p>Or</p> <table><tr><td>2016 Total Emissions*</td><td>x</td><td>Total years of the second commitment period</td></tr></table>	UK's Adjusted Assigned Amount	x	90%	2,746,287,369	x	0.90	= 2,471,658,632 assigned amount units			2016 Total Emissions*	x	Total years of the second commitment period
UK's Adjusted Assigned Amount	x	90%											
2,746,287,369	x	0.90											
= 2,471,658,632 assigned amount units													
2016 Total Emissions*	x	Total years of the second commitment period											

	$486,269,620 \quad \times \quad 8$ $= 3,890,156,960 \text{ assigned amount units}$ <p>*Emissions total is taken from Table A1.3.4 – Approach 1 Key Category Analysis for the latest reported year based on level of emissions (excluding LULUCF) of the 2018 NIR and are shown in tonnes CO₂ equivalent.</p> <p>Our rationale for using this figure is that the Report on the individual review of the annual submission of the United Kingdom of Great Britain and Northern Ireland submitted in 2016, para G.11 on page 19 states:</p> <p>“The ERT recommends that the United Kingdom, when preparing the NIR, compare the 90 per cent of assigned amount value against the total GHG emissions, excluding LULUCF, in the most recent year.”</p> <p>The lower of the two numbers is that calculated as 90 per cent of the UK’s assigned amount.</p> <p>The UK’s Commitment Period Reserve is therefore 2,471,658,632 tonnes of CO₂ equivalent (or assigned amount units).</p>
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13 Information on Changes to the National System

13.1 CHANGES TO THE NATIONAL SYSTEM

No significant changes have been made to the UK's National Inventory System since the previous inventory submission.

As part of the functioning of the National Inventory Steering Committee, there are now also bi-annual meetings (teleconferences) between BEIS and the devolved Governments of Scotland, Wales and Northern Ireland, in advance of each NISC. These additional meetings have been established to facilitate discussion and agreement between inventory stakeholders at the UK and sub-national level, regarding: (i) priorities for inventory improvements in future cycles, and (ii) communication of changes to inventory data, including from improvements implemented in the latest national inventory dataset. These new meetings reflect the continued development of GHG mitigation targets by the devolved Governments, the different policy and evidence priorities at different spatial scales within the UK, and the increased scrutiny on both UK and sub-UK GHG emissions data.

14 Information on Changes to the National Registry

The following changes to the national registry of United Kingdom have therefore occurred in 2018. Note that the 2018 SIAR confirms that previous recommendations have been implemented and included in the annual report.

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	<p>The versions of the EUCR released after 8.0.8 (the production version at the time of the last Chapter 14 submission) introduced minor changes in the structure of the database.</p> <p>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 is provided in Annex A.</p> <p>No change to the capacity of the national registry occurred during the reported period.</p>
15/CMP.1 annex II.E paragraph 32.(d) Change regarding conformance to technical standards	<p>Changes introduced since version 8.0.8 of the national registry are listed in Annex B.</p> <p>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).</p> <p>No other change in the registry's conformance to the technical standards occurred for the reported period.</p>

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	No changes regarding security occurred during the reported period.
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 reported period.
15/CMP.1 annex II.E paragraph 32.(h) Change of Internet address	The registry internet address changed during the reported period. The new URL is https://unionregistry.ec.europa.eu/euregistry/XX/index.xhtml
15/CMP.1 annex II.E paragraph 32.(i) Change regarding data integrity measures	No change of data integrity measures occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(j) Change regarding test results	Changes introduced since version 8.0.8 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.

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 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.

At the latest Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Katowice, Poland in December 2018, Parties reached agreement on a rulebook to support the implementation of the Paris Agreement. Together, the Paris Agreement and the associated rulebook sets out clearly Parties' collective commitment to a just transition towards a low-carbon future, requiring unprecedented action and highest possible ambition from all countries – both developed and developing.

The UK played a key role in facilitating agreement at COP24 - through our role in the European Union, engagement in informal multilateral fora and wider climate diplomacy – and is committed to bringing what was agreed in Paris and Katowice to life.

Central to this commitment is a continuation of the UK's ambitious domestic record of reducing our emissions while growing our economy, as well as our world-leading support for developing countries as they look to pursue low greenhouse gas emissions and climate resilient development.

The UK's Clean Growth Strategy sets out our policies and proposals for decarbonising the UK economy through the 2020s. What's more, following publication of the IPCC special report on global warming of 1.5°C, the UK Government commissioned our independent advisors, the Committee on Climate Change, for their advice on the implications of the Paris Agreement for the UK's long-term targets.

On international support, the UK remains committed to helping others to implement ambitious clean growth policies, whilst building resilience to the impacts of climate change. We have pledged to spend at least £5.8bn international climate finance from 2016-2020. The UK's International Climate Finance (ICF) portfolio has already: helped 47m people cope with the impacts of climate change; provided 17m people with improved access to clean energy; reduced/avoided 10.4m tonnes of GHG emissions (tCO_{2e}); and supported the installation of 590 MW of clean energy capacity.

Whilst the UK is unwavering in our commitment to climate action, we look to implement policies and measures in such a way as to maximise the positive and minimise the negative impact on our international partners – in line with obligations under Article 3, paragraph 14 of the Kyoto Protocol, and consistent with paragraph 4.15 of the Paris Agreement. This chapter sets out the steps we take in this regard.

This chapter has been updated for the 2019 NIR submission. Changes include:

- An update on research programmes in 15.2.1;
- An update on International Climate Finance in 15.2.3;
- An update on Knowledge Transfer in 15.2.4;
- An update on Research Collaboration in 15.2.5;
- An update on Capacity Building and Technology Transfer projects on Renewable Energy and Energy Efficiency in 15.2.6;
- An update on capacity building projects on adapting to climate change in 15.2.7; and
- An update on Energy Market Reforms in 15.2.8;

15.2 UNDERSTANDING IMPACTS OF RESPONSE MEASURES

Understanding the impacts of response measures is a key step to minimising the adverse impacts. The UK continues to undertake assessments, reviews and analysis 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 the UK and through our international engagement to minimise 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.

- BEIS recently published a review of the available scientific evidence to assess the co-benefits and possible adverse side effects of climate change mitigation⁶⁸. BEIS recently funded two major programmes of research to produce research to feed into the IPCC Special Report on Global Warming of 1.5°C. This included analysis of 1.5 degree pathways and the limitations and possible impacts of 1.5 degree consistent mitigation options (for example widespread deployment of Bioenergy and Carbon Capture and Storage⁶⁹). The UK continues to fund a major programme of research into greenhouse gas removal technologies, which includes an exploration of the challenges and limitations of such technologies⁷⁰.

To support the UK 2050 Pathways Analysis the Department for Business, Energy and Industrial Strategy (BEIS) developed a 2050 Energy and Emissions Calculator model. The Calculator is an award-winning, user-friendly model that allows the user to create their own UK emissions reduction pathway, and see the impact using real scientific data. This model is currently being updated and will have new functionality added. Over the last five years, BEIS 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.

⁶⁸ <https://www.gov.uk/government/publications/climate-change-mitigation-the-co-benefits-and-possible-adverse-side-effects>

⁶⁹ <http://iopscience.iop.org/article/10.1088/1748-9326/aaaa02/meta>

⁷⁰ <https://nerc.ukri.org/research/funded/programmes/ggr/>

- An International Climate Finance 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 have also adopted the model, for example China, Japan and Austria.
- There is evidence that the models have had 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.
- BEIS is now extending this programme, providing an additional £3.5 million over three years. This will allow a further five countries to create their own Calculator models, and support updates to Calculators in developing countries that have already been developed.
- BEIS, working in collaboration with a number of other organisations, built a Global Calculator in 2015, which enables users to explore the options for reducing global emissions, and the impacts of climate change associated with them.⁷¹

Following on from the Gallagher review in 2008, the UK Department for Transport (DfT) has and continues to lead work into understanding Indirect Land Use Change (ILUC) impacts from biofuels. For example, on the basis of the review and emerging evidence, the UK decided to promote the transition from crop-based to waste-derived biofuels, including double rewards for waste-based biofuels and a cap on crop-based biofuels. DfT continues to review evidence and support research into the area to ensure we promote biofuels with the highest possible greenhouse gas savings, including when indirect land use change impacts are taken into account.

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 exports⁷².

This year’s output from the monitoring, in the Official Statistics Release, is published online⁷³. The UK continues to take an active part in the EU’s Strategic Energy Technology Plan, the technology element of Energy Union and the EU’s Horizon 2020 research and development funding programme.

15.2.2 Actions to minimise 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

⁷¹ <http://tool.globalcalculator.org>

⁷² <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>

⁷³ <http://www.defra.gov.uk/statistics/environment/green-economy/scptb01-ems/>

helping the poorest and most vulnerable to curb emissions whilst developing and to 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 minimise adverse impacts in accordance with article 3, paragraph 14 through its International Climate Finance (ICF) and other international action.

15.2.3 International Climate Finance

Recognising the growing importance and urgency of tackling climate change and its impact on growth and poverty reduction, the UK invested £3.87 billion in International Climate Finance (ICF) from 2011-2016 (financial years 2011/12 to 2015/16). The UK has committed to provide at least a further £5.8 billion from 2016-2020 (financial years 2015/16 to 2020/21). This was a 50% uplift on 2011-15 and a doubling in 2020 of our 2014 spend, placing the UK amongst the largest providers of climate finance. Recognising that adaptation is a priority for many developing countries, the UK aims for an even split in its adaptation and mitigation spend and achieved this aim in 2016 and 2017. This commitment reflects our view that climate change is the biggest threat to the long-term eradication of global poverty, and that the impacts of climate change will hit the poorest hardest.

The UK's ICF is supporting a portfolio of investments managed by the Department for International Development (DFID), BEIS, and Defra. It aims to support international poverty eradication now and in the future by helping developing countries to manage risk and build resilience to the impacts of climate change, take up low-carbon development at scale, and manage natural resources sustainably.

To achieve this, the UK ICF delivers transformational change through well-targeted finance. For example, it helps to pay the incremental cost of making infrastructure investments climate smart and avoid lock-in of high carbon technologies. It also incentivises countries to reduce deforestation and promote sustainable land use. This demonstrates that low-carbon, climate resilient development paths are viable and compatible with economic growth and poverty alleviation.

Cumulative data that we collect show that, between 2011/12 and 2017/18, UK ICF programmes have:

- Supported 47 million people to cope with the effects of climate change;
- Provided 17 million people with improved access to clean energy;
- Reduced or avoided 10.4 million tonnes of greenhouse gas (GHG) emissions (tCO₂e);
- Installed more than 590 MW of clean energy capacity; and
- Mobilised £3.3 billion public and £910 million private finance for climate change purposes in developing countries.

Through its ICF, the UK is supporting a number of bilateral and multilateral programmes, including (but not limited to) the following examples:

The Green Climate Fund – Since becoming operational in 2015 the Green Climate Fund (GCF) has become the key 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'. The UK is a strong supporter of the GCF, having committed £720 million for the initial resource mobilisation period, and is committed to ensuring that the GCF delivers maximum impacts in the developing countries it supports.

The GCF funds transformational projects with a strong focus on leveraging private finance, with a commitment to provide 50% of its resources for mitigation and 50% for adaptation. At least 50% of its adaptation support will be provided to particularly vulnerable countries including Least Developed Countries (LDCs), Small Island Developing States (SIDS) and

African States. In the past year, the GCF has made significant progress in terms of programming, tightening its policy framework, and building the Secretariat's capacity. So far, the GCF has committed \$4.6 billion of funding to 93 projects, representing a balanced geographical and thematic split, with over 50% of funds going to private sector projects, and \$520 million to Small Island Developing States.

The Nationally Appropriate Mitigation Action (NAMA) Facility is a bilateral programme supported by the UK, working in partnership with the German Federal Ministry for the Environment (BMUB), Denmark and the European Commission. **NAMAs** refer to any action that reduces emissions in developing countries and is prepared under the umbrella of a national governmental initiative. They can be policies directed at transformational change within an economic sector, or actions across sectors for a broader national focus. The Facility seeks to support and fund the implementation of the most transformational parts of the NAMAs. It has an open application process, welcoming projects across a diverse range of sectors and geographies.

Since 2012, 20 climate mitigation projects across 16 countries have been supported, with each project chosen for its ability to catalyse change in the sector. To support this demand the UK has committed £185 million into the Facility, of which £45 million has been allocated to the 6th Call of the Facility, launched at Cop24.

Climate Investment Funds (CIF)- The UK is the largest investor in the \$8.5 billion Climate Investment Funds (CIFs), having invested around \$2.5 billion since 2008, to pilot low-emission and climate resilient development through projects implemented by the multilateral development banks. The CIFs now operate across 72 countries and have a total portfolio of 310 projects. CIF finance is enabling the construction of the equivalent of over a quarter of the current globally installed geothermal and concentrated solar power. The projects are unlocking finance flows in the green markets of developing countries and are expected to generate \$58 billion of co-financing.

CIFs: The Clean Technology Fund (CTF) - Of the four funds that sit under the Climate Investment Fund, the UK has contributed £701 million, between 2011/12 and 2016/17, to the Clean Technology Fund (CTF). The CTF provides concessional finance and technical assistance in 21 countries, delivering significant development benefits, such as increased energy security, reduced local air pollution, and job opportunities. It has supported national governments to identify and implement ambitious low carbon investment plans and helped demonstrate technologies and create markets. South Africa's KaXu Solar One Concentrated Solar Power project, with funding from the Clean Technology Fund, has recently been awarded a *Momentum for Change Award* by the UNFCCC for its innovative and game-changing approach to climate change and wider economic, social and environmental challenges.

CIFs: The Scaling up Renewable Energy Programme (SREP) is another of the four Climate Investment Funds. The UK has provided £268m to SREP, which aims to stimulate energy access and economic activity by working with governments to build renewable energy markets and support productive uses of energy at the household level. As of June 2017, SREP had endorsed investment plans for 19 pilot countries. Expected results under these plans, and the Fund's Private Sector Set Aside, include an estimated 6,686 gigawatt hours (GWh) of electricity to be generated annually from renewable energy sources (equivalent to the annual electricity production of Armenia) and new or improved access to clean, modern energy services for 17.3 million people (approximately the population of Malawi). The total estimated greenhouse gas (GHG) emissions to be avoided are approximately 5.4 million tons CO₂e/yr.

CIFs: Pilot Programme for Climate Resilience (PPCR) - The UK is the largest contributor to the \$1.2 billion Pilot Programme for Climate Resilience (PPCR), one of the four Funds that sit under the CIFs. The PPCR assists governments with the integration of climate resilience into development planning and pilots innovative public and private solutions to climate-related risks, primarily in Least Developed Countries or Small Island Developing States. For example,

a \$15.75 million project in Mozambique will develop climate resilient infrastructure to improve the ability of 8,200 farming families to withstand extreme weather events.

Least Developed Countries Fund (LDCF) - The UK is also a long-standing contributor to the Least Developed Countries Fund (LDCF), which supports LDCs in developing their National Adaptation Programmes of Action (NAPAs) and funding the resultant programming. Through our most recent contribution of £30 million, the UK is aiming to help nearly a million people become more resilient to climate change, and to bring approximately 200,000 hectares of land under more sustainable management. This was the fourth contribution that the UK has made to the LDCF – total contributions amount to £122 million since 2006. The most recent Annual Review, covering results up to June 2017, demonstrated that the 86 projects in the active LDCF portfolio had already reached more than 4.4 million direct beneficiaries, brought around 1.5 million hectares of land under more climate-resilient management, and trained some 358,000 people in various aspects of climate change adaptation.

Reduce Emissions from Deforestation and forest Degradation (REDD+) is a framework agreed under the UNFCCC to *Reduce Emissions from Deforestation and forest Degradation* and enhance forest carbon stocks (+) in developing countries. It aims to demonstrate the potential of a new land-use paradigm that delivers large-scale forest protection alongside sustainable agricultural intensification. The UK will continue to support “jurisdictional” REDD+ results-based finance that unlocks key barriers in the enabling environment and mobilises private finance, including the examples below:

- The UK has committed £141.5 million to the Forest Carbon Partnership Facility Carbon Fund, the world’s biggest fund for forest carbon. It is a payment for results mechanism, designed to incentivise ambitious actions to reduce deforestation through payments for verified emission reductions generated by jurisdictional REDD+ programmes. There are currently 19 country programmes accepted, or provisionally accepted, into the Carbon Fund Pipeline.
- The UK also supports the BioCarbon Fund with £115 million. This fund combines upfront technical assistance with results-based finance, rewarding countries which implement landscape-level approaches that reduce emissions from agriculture, forests and other land use. It also aims to catalyse investments from the private sector, recognising that many companies along the supply chain of commodities (such as palm oil) have committed to zero-deforestation sourcing.

REDD for Early Movers (REM) - The UK has committed £73 million to the **REDD for Early Movers (REM)** programme which is an accelerator for the most ambitious and committed countries to reduce emissions from deforestation. REM rewards countries that are already successful in driving down deforestation trends, with finance re-invested in agreed activities to deliver further results. UK support focusses on Colombia’s goal to stabilise deforestation in its Amazon region, as well as programmes to decouple increases in production from forest loss in two Brazilian States – Acre and Mato Grosso.

The £104 million **Partnerships for Forests (P4F)** programme, focusing in South America, West, Central and East Africa, and Southeast Asia, brings together the private sector, governments, and local communities to create market-ready partnerships for sustainable forestry and land-use.

The Sustainable Infrastructure Programme - In 2017 the UK established the Sustainable Infrastructure Programme (SIP) in Latin America in partnership with the Inter-American Development Bank. The purpose of the programme is to enable and accelerate the implementation of the Nationally Determined Contributions in Latin America, initially Brazil, Colombia, Mexico and Peru, focusing on supporting and catalysing private sector investments in low carbon infrastructure. The UK will provide up to £177.5 million from its ICF budget over 5 years to provide technical and financial support. This can include technical assistance to governments to help them shape their regulatory frameworks in a way that is attractive to

private investors, support the development of local capital markets, while also investing in a few demonstration projects to show commercial viability.

UK Climate Investments - UKCI is a joint venture between the Green Investment Group and the UK Government Department for Business, Energy and Industrial Strategy. UKCI invests in renewable energy and energy efficiency projects across sub-Saharan Africa and India to demonstrate that low carbon development is possible, replicable at scale, commercially viable and capable of supporting economic growth, poverty reduction and lowering carbon emissions. UKCI is mandated to invest up to £200m of UK International Climate Finance over an initial investment period of 2015-2019. The fund provides late-stage minority equity investments on a commercial basis to help get projects off the ground that would not otherwise reach financial close.

Completed investments to date include a 60GW utility-scale solar project in Maharashtra, India and India's first renewable yield company (or yieldco), an innovative financial structure that pools solar energy assets to provide secondary market funding and free up developers' capital for new renewable energy projects.

The Renewable Energy Performance Platform (REPP) - The REPP seeks to mobilise private sector development activity and investment in small and medium scale renewable energy projects (up to 25MW, or up to 50MW for wind power) in sub-Saharan Africa. REPP aims to increase the number of sound 'bankable' smaller renewable energy projects by assisting project proponents throughout the project development stage by providing technical assistance, access to risk mitigation instruments, and pre-construction finance, and providing post-construction finance where needed. The UK made an initial commitment of £48 million in 2015 and has recently committed an additional £100m to the programme to 2023.

The Climate Public Private Partnership (CP3) a £130 million programme that aims to support clean energy and demonstrate the commercial viability of investments in climate-related businesses in emerging markets. By anchoring two private equity funds – i.e. providing committed investment into these funds to help attract additional investors – the programme mobilised private climate finance of \$279 million and kick-started the largest private equity climate fund in Asia. The funds have so far invested in 73 businesses and renewable energy developers across developing countries in Asia, Africa and South and Central America. CP3 is expected to avoid 57.4m tonnes of CO₂ equivalent over its lifetime (to 2026).

The **Climate Leadership in Cities (CLIC) Programme** is a £27.5 million UK Government initiative launched at the end of 2017, which supports developing country cities to unlock ambitious climate action. The programme was developed in recognition of the fact that, with the majority of the world's population living in urban areas, and cities accounting for more than 70% of global CO₂ emissions, climate leadership in cities is critical in delivering the Paris Agreement. The programme contains three components:

- Technical assistance for 15 megacities in Latin America and Asia to develop ambitious climate action plans consistent with the Paris Agreement, delivered by C40.
- Expanding the C40 Cities Finance Facility, jointly implemented by C40 and GIZ, through which cities bid for technical assistance to develop investable business cases for climate action.
- Global research and national advocacy (with country programmes in China and Mexico) to help remove barriers to city action, delivered by the Coalition for Urban Transitions.

The **Global Climate Partnership Fund (GCPF)** uses a £49 million investment by the UK, combined with investments from other donor governments, as a risk cushion so that it can raise capital from development institutions, institutional investors and the private sector. To date it has raised over \$600 million. The GCPF then provides lines of credit to local banks in developing countries so they can on-lend to their clients for renewable energy and energy

efficiency investments. The clients are small and medium-sized enterprises and households and their investments range from high-efficiency household appliances to light industrial equipment. GCPF can also invest directly in larger sale projects.

The UK also funds the GCPF's technical assistance facility with £6m, which supports the local banks to open up new green lending markets, establish CO₂ reporting facilities and so on. The GCPF has now invested in over 20 countries in Latin America, Africa and Asia. Its partners have issued over 55,000 sub-loans, amounting to over 10 million tonnes of CO₂ saved over the lifetime of the loans.

The **Market Accelerator for Green Construction (MAGC)** is a £106.1 million global programme launched at the end of 2018 in collaboration with the International Finance Corporation. The Fund aims to drive the financing and construction of more energy efficient buildings in emerging economies. Buildings account for around a fifth of global greenhouse gas emissions and improving building design and construction will play an important role in avoiding climate change and meeting our Paris Agreement goals.

By providing a package of technical assistance and blended finance, the programme will work with banks to establish new green construction finance services that will help crowd in private finance while encouraging developers to adopt greener construction practices, thereby developing clean growth markets in emerging economies. A significant research component will also aim to develop a robust evidence base that can be used to further enhance green building standards and motivate the wider uptake of green construction over conventional approaches.

UK PACT (Partnering for Accelerated Climate Transitions) - Set up in 2018, **UK PACT** is a £60 million technical assistance programme designed to support clean growth transitions in middle-income developing countries. Through demand-driven technical assistance projects, long term secondments and short-term skill shares, the programme works to increase capacity and capability in partner countries to reduce carbon emissions in line with their commitments under the Paris Agreement. UK PACT works in areas of UK low-carbon expertise, including green finance, climate legislation, and energy market reform. The programme is currently working in Colombia and Mexico across multiple demand-led areas, as well as in China (solely on green finance). UK PACT plans to expand to four new countries in Africa and Southeast Asia in the next two years.

In addition to the direct assistance the UK provides to developing countries through our climate finance programmes listed above, the UK recognises that the scale of the challenge will require a broader effort at all levels to align investment flows with the goals of the Paris Agreement. **Integrating climate and environmental factors into financial decision making** is essential to aligning financial flows with these goals and accelerating low-greenhouse gas and climate-resilient investment globally. The UK has played a leading role in this area becoming co-chair of the G20 Green Finance Study Group, established by China during its 2016 G20 Presidency.

The leadership of the Governor of the Bank of England, Mark Carney, is widely recognised, including his role in helping to establish the Financial Stability Board's industry-led Task Force on Climate-related Financial Disclosures (TCFD). In 2017 the UK became one of the first governments to formally endorse these recommendations, and we are working to promote their uptake internationally. The City of London has established formal relationships on **green finance** with major emerging market economies, including China, India and Brazil. These partnerships present opportunities for the UK to collaborate with key developing economies in a rapidly growing market and to share Britain's green finance expertise.

15.2.4 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 we are 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-funded Global Network of Climate Innovation Centres programme, which provides funding to the World Bank's Climate Technology Programme (CTP) to support the design, implementation, and international coordination of Climate Innovation Centres (CICs) in developing countries. The programme assists local entrepreneurs to develop innovative technology and business solutions to domestic energy, resource and environmental challenges.

The UK also supports CICs in Ethiopia and Vietnam through bi-lateral programmes, while there are additional non-DFID supported CICs in South Africa, the Caribbean, Ghana and Morocco. The programme helps gather evidence on climate technology innovation in developing countries, enabling national CICs to respond to technology trends.

- DFID has committed approximately £103m to the Climate and Development Knowledge Network (CDKN) which is generating and sharing knowledge and building the capacity 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, research, capacity building, knowledge management and climate negotiation support 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 a detailed monitoring system in place for capturing results delivered through the ICF portfolio. ICF has a Monitoring, Evaluation and Learning programme that aims to further enhance the monitoring system and generate evidence and knowledge from the portfolio.

15.2.5 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. The UK continues to be an active participant in EU-based research and development initiatives through the EU's Strategic Energy Technology Plan, the EU's Horizon 2020 research and development funding

programme and through the International Energy Agency's Technology Collaboration Programmes. This UK commitment was further underlined at the COP21 climate change conference in Paris, where 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 the Mission Innovation "Innovation Challenges" and co-leads the affordable heating and cooling of Buildings Innovation Challenge alongside the European Commission and United Arab Emirates. These challenges are aimed at catalysing 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 DECC 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.

BEIS, in collaboration with 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, BEIS 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 Finance (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 CO₂ emissions from the energy sector in India and China to meet national 2050 emissions targets consistent with limiting global temperature rise to below 2°C. It then shared these results with Indian and Chinese officials at international workshops. The second phase of AVOID involved 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 leading role in supporting technical assistance on Carbon Capture, Usage & Storage (CCUS) to developing countries and emerging economies. The UK has committed up to £70 million of International Climate Finance since 2012 to raise the level of understanding of CCUS within fossil fuel-intensive countries, such as Mexico, South Africa, China and Indonesia. This funding is supporting the establishment of the necessary regulatory and policy frameworks, technical know-how and incentive structures to enable demonstration and ultimately accelerate the deployment of CCUS. UK funding is provided through the World Bank CCUS Trust Fund and the Asian Development Bank CCUS Fund to support technical assistance activities, such as feasibility studies, pilot projects, developing regulatory and policy

frameworks, establishing CCUS Centres of Excellence, running training workshops, and facilitating knowledge-sharing activities.

The UK is an active member of key international CCUS fora: the CCUS Initiative under the Clean Energy Ministerial, the Carbon Sequestration Leadership Forum (CSLF), the IEA Greenhouse Gas R&D programme, and co-leads the CCUS Challenge under Mission Innovation (alongside Mexico and Saudi Arabia). The UK also co-hosted the International CCUS Summit and Conference with the IEA in November 2018 and hosted a CCUS side event in the UK Pavilion at COP 24.

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.

15.2.6 Capacity Building and Technology Transfer projects on Renewable Energy and Energy Efficiency

The world needs increasing energy supplies to sustain economic growth and development. However, energy resources are under pressure and CO₂ emissions from today's energy use are already changing the climate. It is necessary to accelerate the deployment of low carbon energy technologies and increase energy efficiency to address the global challenges of energy security, climate change and economic development. The following are some examples of the technology transfer activities that the UK undertakes:

- **Carbon Capture, Usage and Storage (CCUS):** Since 2012, the UK has provided £70 million to support developing countries and emerging economies to build the technical and institutional knowledge necessary to enable the deployment of CCUS technologies. CCUS development and deployment is crucial for meeting the 'well-below' 2°C target set out under the Paris Agreement. The programme aims to raise the level of knowledge of CCUS in key countries, such as Mexico, South Africa, China and Indonesia, leading to the establishment of the necessary regulatory and policy frameworks to support CCUS demonstration and ultimately accelerate the deployment of CCUS.
- **The Clean Technology Fund (CTF),** to which the UK is the largest contributor (providing £701 million), has demonstrated and deployed low carbon technologies at scale across 21 countries. Examples include supporting the first generation of utility scale Concentrated Solar Power (CSP) plants to be built in developing countries, with the plant in South Africa now providing power to 80,000 people and winning a Momentum for Change award from the UNFCCC. CTF finance for the Noor CSP complex in Morocco has helped to bring down technology costs and overall CTF has supported around a fifth of global CSP deployment to date. The fund has dramatically scaled up geothermal development across multiple countries, as well as a wide range of other renewable and clean transport technologies.
- **Capacity Building and Transparency:** As agreed by COP21, the Capacity Building Initiative for Transparency (CBIT) was established by the Global Environment Facility (GEF) in 2015 to support developing countries to meet new reporting requirements under the enhanced transparency framework of the Paris Agreement. The UK is the second largest donor (behind the US) to CBIT to date, committing £10 million from the ICF and £1 million from the Scottish Government.
- **The Asian Development Bank (ADB)'s Clean Energy Fund** was set up to improve energy access, energy security and the transition to low-carbon technologies through

cost-effective investments. The UK's contribution of £10 million is specifically used to fund the technical assistance elements of the fund.

- **Climate Innovation Centres Programme:** The UK-funded Global Network of Climate Innovation Centres programme provides funding to the World Bank's Climate Technology Programme (CTP). This supports to support the design, implementation, and international coordination of Climate Innovation Centres (CICs) in developing countries. The programme assists local entrepreneurs develop innovative technology and business solutions to domestic energy, resource and environmental challenges.

The UK has continued to leverage the collective commitment of the international community in other key fora and institutions to deliver policy interventions and high-level actions that encourage the promotion of low carbon technologies, including:

International Renewable Energy Agency (IRENA) - The UK supports IRENA's mission to promote widespread and sustainable use of renewable energy through its role as a centre of excellence for energy transformation, a global voice for renewables, a network hub for international collaboration, and a source of support and advice. The UK has been an IRENA Council member for 2016-2017 and has helped to drive forward IRENA's medium-term strategy which is consistent with UK government objectives regarding energy security and decarbonisation.

International Partnership for Energy Efficiency Co-operation (IPEEC) - The UK is working in 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. This identifies 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. The UK is also working with members of the G20, IPEEC and the International Energy Agency (IEA) to establish an "Energy Efficiency Hub", to help coordinate international efforts to drive forward energy efficiency improvements.

15.2.7 Capacity building projects on adapting to climate change

UK ICF investments aim to support international poverty reduction now and in the future by helping developing countries manage risk and build resilience to the impacts of climate change, take up low-carbon development at scale, and manage natural resources sustainably. The poorest and most vulnerable people in the world will be hit first and hardest by the impacts of climate change. This is why the UK aims to spend half of its climate finance on adaptation.

We support capacity-building to assist developing countries to better:

Adapt to long-term impacts well in advance, for example by changing or diversifying livelihoods and ensuring infrastructure is fit for purpose.

Anticipate and reduce the impact of climate variability and extremes, for example through effective forecasting and preparedness measures.

Absorb the effects of climate extremes and disasters - for example through effective and rapid response that enables people to cope with disaster and recover quickly.

Adapt

- The Building Resilience and Adaptation to Climate Extremes and Disasters (BRACED) programme is helping people become more resilient to climate extremes in South and Southeast Asia, as well as in the African Sahel and neighbouring countries. It does this through improved integration of disaster risk reduction and climate adaptation methods into

development approaches, influencing local, national and international policies and practices.

- The Blue Forest programme is introducing models for the sustainable management of mangroves in Madagascar and scaling these models in Indonesia and South East Asia to help increase coastal adaptation and resilience. The £10.1 million project, involving fisheries management and mangrove livelihood diversification, is expected to protect 20,000 hectares of mangrove forests and benefit over 100,000 people. Key progress made on livelihood adaptation includes the creation and implementation of 11 sustainable community-owned mangrove forestry management plans, and the development and integration of multiple alternative livelihoods, including bee keeping and sea cucumber farming.

Anticipate

- UK Aid funds the Weather and Climate Information and Services for Africa (WISER) programme. Its mission is to deliver transformational change in the quality, accessibility and use of weather and climate information services at all levels of decision making for sustainable development in Africa. It is strengthening the capacity of the national and regional mandated organisations and channels in order to deliver weather and climate services which support poverty reduction, directed by user needs.
- UK Aid also funds the Future Climate for Africa (FCFA) research programme, which aims to enhance the scientific understanding and prediction of climate variability and change in Africa and, at the same time, is working with stakeholders to bring this information into use in adaptation planning. FCFA includes 11 pilot studies, building capacity across sub-Saharan Africa in using climate information to inform decisions, including infrastructure development, climate-smart agriculture, and urban and national planning.

Absorb

- The UK is a major contributor to African Risk Capacity (ARC) which strengthens African governments' understanding of drought risk and enables them to buy insurance that will pay out after harvest failures due to droughts. Senegal, Mauritania and Niger received payments totalling \$26.5 million after poor rains in 2014, providing food aid, animal fodder and other assistance to 1.3 million people. Malawi received a payment of \$8.1 million in 2016, which they have used for emergency cash transfers to affected people and to replenish the national strategic grain reserve. Five countries are currently insured.

15.2.8 Energy Market Reforms – responding to energy market imperfections

Launched in 2013, 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 electricity and reliable supplies, while minimising costs to consumers.

CfDs are long term (15 year) contracts between CfD generators and the Low Carbon Contracts Company (LCCC), a government-owned company. Contracts are designed to give greater certainty and stability of revenues to electricity generators by reducing their exposure to volatile wholesale prices, whilst protecting consumers from paying for higher support costs when electricity prices are high. A CfD generator is paid the difference between the 'strike price' (a price for electricity reflecting the cost of investing in a particular low-carbon technology) and the "reference price" (a measure of the average market price for electricity).

Investment contracts (and early form of CfD) were awarded to eight projects in 2014, and two competitive allocation rounds have been held since then in 2015 and 2017. Projects currently supported by the CfD scheme are expected to provide around 10GW of new renewable

electricity capacity by 2023. Eleven projects have so far been commissioned, providing a combined capacity of over 2.4 GW of renewable electricity. Details of CfD projects are available on the CfD Register published by the LCCC at www.lowcarboncontracts.uk.

The government confirmed in its Clean Growth Strategy in October 2017 that up to £557 million (in 2011/12 prices) of annual support will be available for further CfDs, with the next auction planned to open by May 2019. Further allocation rounds will be held around every two years after that. Depending on the price achieved, these auctions will deliver between 1 to 2 gigawatts of offshore wind each year in the 2020s.

Four main Capacity Market auctions have been completed so far. These auctions have secured supplies up to 2021/22. However, the Capacity Market is currently standstill, following the judgment of the General Court of the Court of Justice of the European Union in Case T-793/14. The UK government is working closely with the European Commission on the necessary steps for the GB Capacity Market (CM) scheme to be reinstated as quickly as possible. During this standstill period no further auctions can take place nor any capacity payments made.

The most recent main auction concluded in February 2018, for delivery in 2021/22. This secured 50.4GW of capacity.

The UK is continuing to reduce its reliance on coal and is bringing innovative and low-carbon technologies into its energy mix, as part of a cleaner, more flexible energy system. The Government has confirmed 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. References in this document refer to correct name at the time of original publication.

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17.11 ANNEX 3, SECTOR 3

See references under **Chapter 5**

17.12 ANNEX 3, SECTOR 4

See references under **Chapter 6**

17.13 ANNEX 3, SECTOR 5

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Table 18.1 Contributors to this National Inventory Report and the CRF

Person	Technical work area and responsibility
<i>Main authors</i>	
Broomfield, Mark	Sector expert for solid waste disposal on land. Author of landfill, biological treatment of waste, and sections within Annex 3.
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Cardenas, Laura ⁷⁵	Sector expert for agriculture; author of sections of the NIR and other reporting requirements on agriculture.
Choudrie, Sarah	Inventory compilation lead; author of executive summary, Cpt 1, contribution to other chapters.
Jones, Luke	Contributor to Cpts 1, 3, 4, 5, 7, Annexes 1, 2, 4, 7, and 9. Compiled attached emission factors tables.
Karagianni, Eirini	Author of road transport, off-road machinery.
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 ⁷⁶	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.
Turtle, Lara	UK Greenhouse Gas Inventory Report Manager. Author of Cpt 2 and Annex 8.
Wakeling, Daniel	Author of road transport, off-road machinery, shipping and fishing.
<i>Contributors</i>	
Bradley, Sam	BEIS GHGI improvement programme lead

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⁷⁶ Centre for Ecology & Hydrology

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Glendining, Margaret ⁷⁵	Contributions to agriculture inventory compilation and text
Gluckman, Ray ⁷⁷	Author of the section on f-gases in Cpt 4.
Hampshire, Kathryn ⁷⁸	Responsible for compilation of emission estimates for the OTs and CDs, and report text relating to this
Henshall, Paul ⁸⁰	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 ⁷⁸	Compilation of rail emissions estimates and text for this sector
Malcolm, Heath ⁷⁶	CEH project manager for the LULUCF inventory team. Contribution to LULUCF QA/QC.
Manning, Alistair ⁷⁹	Verification of the UK greenhouse gas inventory (Annex 6)
Matthews, Robert ⁸⁰	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
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Milne, Alice ⁷⁵	Contributions to agriculture inventory compilation and text
Misselbrook, Tom ⁷⁵	Contributions to agriculture inventory compilation and text
Murrells, Tim	NAEI transport manager. Technical Director of NAEI Programme. Contributing author to all sections on transport
Pearson, Ben	Methodological development of the Monte Carlo model
Penistone, Amanda	BEIS GHGI and statistics lead
Thistlethwaite, Glen	Inventory QA/QC manager. Author of QA/QC section.
Walker, Charles	Sector expert for aviation in the NAEI. Author of aviation sections.
Watterson, John	Review of LULUCF chapters and Annex. Contribution to Cpt 10.
<i>Additional assistance</i>	
Aston, Clare	Data acquisition, report printing
National Inventory Steering Committee	Suggestions and improvements to draft versions of the NIR
Kilroy, Eleanor Richardson, Joe Richmond, Ben Sheldon, Dominic Stewart, Robert Webb, Nicola	NAEI compilation

⁷⁷ Gluckman Consulting

⁷⁸ Aether

⁷⁹ The Met Office

⁸⁰ Forest Research

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).
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.