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UK Greenhouse Gas Inventory, 1990 to 2021

Annual Report for Submission under the Framework Convention on Climate Change

Main authors Brown P, Cardenas L, Del Vento S, Karagianni E, MacCarthy J, Mullen P, Passant N, Richmond B, Thistlethwaite G, Thomson A, Wakeling D, Willis D

With contributions from Anthony S, Aston C, Broomfield M, Buys G, Carnell E, Clilverd H, Dragosits U, Gibbs, M, Gilhespy S, Glendining M, Gluckman R, Gorji S, Hampshire K, Henshall P, Hobson M, Kelsall A, King K, Lambert N, Levy P, Malcolm H, Manning A, Matthews R, Milne A, Misra A, Misselbrook T, Murrells T, Nickerson R, O'Doherty S, Pang Y, Pearson B, Pitt J, Quinn P, Raine B, Redington A, Richardson J, Sandars D, Skirvin D, Stanley K, Stewart R, Szanto C, Thornton A, Tomlinson S, Walker C, Watterson J, Williams A, Wong J, Young D, Young H

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Peter Brown
Ricardo Energy & Environment
The Gemini Building, Fermi Avenue
Harwell
Didcot
Oxfordshire, OX11 0QR, UK.

Telephone: +44 1235 75 3273
Facsimile: +44 1235 75 3001

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Lead Author	Name	Peter Brown
Approved by	Name	Glen Thistlethwaite
	Signature	
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Preface

This is the United Kingdom's National Inventory Report (NIR) submitted in 2023 to the United Nations Framework Convention on Climate Change (UNFCCC). It contains national greenhouse gas emission estimates for the period 1990-2021, and descriptions of the methods used to produce the estimates.

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 Energy Security and Net Zero (DESNZ) for the Science and Innovation for Climate and Energy (SICE) Directorate, by Ricardo Energy & Environment. We acknowledge the positive support and advice from DESNZ 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 DESNZ or otherwise.

Units and Conversions

Emissions of greenhouse gases presented in this report are normally given in Gigagrams (Gg), Million tonnes (Mt) and Teragrams (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 Gigagram (Gg) = 1 kt

1 Teragram (Tg) = 1 Mt

Conversion of carbon emitted to carbon dioxide emitted

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

Conversion of Gg of greenhouse gas emitted into Gg CO_2 equivalent

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

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

Abbreviations for Greenhouse Gases and Chemical Compounds

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

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

IPCC categories

IPCC Category	Source Description
1	**Energy**
1A	**Fuel Combustion Activities**
1A1	**Energy Industries**
1A1a	Public Electricity and Heat Production
1A1ai	Electricity Generation
1A1aiii	Heat Plants
1A1b	Petroleum refining
1A1c	Manufacture of Solid Fuels and Other Energy Industries
1A1ci	Manufacture of solid fuels
1A1cii	Oil and gas extraction
1A1ciii	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	Off-road vehicles and other machinery
1A2gviii	Other
1A3	**Transport**
1A3a	Domestic Aviation
1A3b	Road Transportation
1A3bi	Cars
1A3bii	Light duty trucks
1A3biii	Heavy duty trucks and buses
1A3biv	Motorcycles
1A3bv	Other
1A3c	Railways
1A3d	Domestic Navigation
1A3e	Other Transportation (to be specified)
1A3ei	Pipeline Transport
1A3eii	Other
1A4	**Other sectors**

IPCC Category	Source Description
1A4a	Commercial / Institutional
1A4ai	Stationary combustion
1A4b	Residential
1A4bi	Stationary combustion
1A4bii	Off-road vehicles and other machinery
1A4c	Agriculture / Forestry / Fishing
1A4ci	Stationary
1A4cii	Off-road vehicles and other machinery
1A4ciii	Fishing
1A5	**Other (not elsewhere specified)**
1A5a	Other, Stationary (including Military)
1A5b	Other, Mobile (including military)
1B	**Fugitive Emissions from Fuels**
1B1	**Solid Fuels**
1B1a	Coal Mining and Handling
1B1a1	Underground Mines
1B1a1i	Mining Activities
1B1a1ii	Post-Mining Activities
1B1a1iii	Abandoned Underground Mines
1B1a2	Surface Mines
1B1a2i	Mining Activities
1B1a2ii	Post-Mining Activities
1B1b	Solid fuel transformation
1B1c	Other (to be specified)
1B2	**Oil and natural gas**
1B2a	Oil
1B2a1	Exploration
1B2a2	Production
1B2a3	Transport
1B2a4	Refining / Storage
1B2a5	Distribution of Oil Products
1B2a6	Other
1B2b	Natural gas
1B2b1	Exploration
1B2b2	Production
1B2b3	Processing
1B2b4	Transmission and storage
1B2b5	Distribution
1B2b6	Other
1B2c	Venting and flaring
1B2c1	Venting
1B2c1i	Venting - Oil
1B2c1ii	Venting - Gas
1B2c1iii	Venting - Combined
1B2c2	Flaring
1B2c2i	Flaring - Oil
1B2c2ii	Flaring - Gas
1B2c2iii	Flaring - Combined
1B2d	Other
2A	**Mineral Products**
2A1	Cement Production
2A2	Lime Production
2A3	Glass Production
2A4	Other Process uses of Carbonates
2A4a	Ceramics

IPCC Category	Source Description
2A4b	Other uses of Soda Ash
2A4c	Non-metallurgical Magnesium Production
2A4d	Other
2B	**Chemical Industry**
2B1	Ammonia Production
2B2	Nitric Acid Production
2B3	Adipic Acid Production
2B4	Caprolactam, Glyoxal and Glyoxylic Acid Production
2B4a	Caprolactam
2B4b	Glyoxal
2B4c	Glyoxylic Acid
2B5	Carbide production
2B5a	Silicon Carbide
2B5b	Calcium Carbide
2B6	Titanium Dioxide Production
2B7	Soda Ash Production
2B8	Petrochemical and Carbon Black Production
2B8a	Methanol
2B8b	Ethylene
2B8c	Ethylene Dichloride and Vinyl Chloride Monomer
2B8d	Ethylene Oxide
2B8e	Acrylonitrile
2B8f	Carbon Black
2B8g	Other
2B9	Fluorochemical Production
2B9a	By-product emissions
2B9a1	Production of HFC-22
2B9b	Fugitive Emissions
2B9b1	Production of HFC-134a
2B9b2	Production of SF_6
2B9b3	Other
2B10	Other
2C	**Metal Production**
2C1	Iron and Steel production
2C1a	Steel
2C1b	Pig Iron
2C1c	Direct Reduced Iron
2C1d	Sinter
2C1e	Pellet
2C1f	Other
2C2	Ferroalloys Production
2C3	Aluminium Production
2C3a	CO_2 Emissions
2C3b	By-Product Emissions
2C3c	F-gases used in foundries
2C4	Magnesium Production
2C5	Lead Production
2C6	Zinc Production
2C7	Other (to be specified)
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

IPCC Category	Source Description
2E2	TFT Flat Panel Display
2E3	Photovoltaics
2E4	Heat Transfer Fluid
2E5	Other
2F	**Product Uses as Substitutes for ODS**
2F1	Refrigeration and Air Conditioning
2F1a	Commercial Refrigeration
2F1b	Domestic Refrigeration
2F1c	Industrial Refrigeration
2F1d	Transport Refrigeration
2F1e	Mobile Air-Conditioning
2F1f	Stationary Air-Conditioning
2F2	Foam Blowing Agents
2F2a	Closed Cells
2F2b	Open Cells
2F3	Fire Protection
2F4	Aerosols
2F4a	Metered Dose Inhalers
2F4b	Other
2F5	Solvents
2F6	Other Applications
2F6a	Emissive
2F6b	Contained
2G	**Other Product Manufacture and Use**
2G1	Electrical Equipment
2G2	SF_6 and PFCs from Other Product Use
2G2a	Military Applications
2G2b	Accelerators
2G2e	Other
2G3	N_2O from Product Uses
2G3a	Medical Applications
2G3b	Other
2G4	Other
2H	**Other**
2H1	**Pulp and paper**
2H2	**Food and beverages industry**
2H3	**Other**
3	**Agriculture**
3A	**Enteric Fermentation**
3A1	Cattle
3A2	Sheep
3A3	Swine
3A4	Other livestock
3B	**Manure Management**
3B1	CH_4 Emissions
3B11	Cattle
3B12	Sheep
3B13	Swine
3B14	Other livestock
3B2	N_2O and NMVOC Emissions
3B21	Cattle
3B22	Sheep
3B23	Swine
3B24	Other livestock
3B25	Indirect N_2O Emissions

IPCC Category	Source Description
3C	**Rice Cultivation**
3D	**Agricultural Soils**
3D1	Direct N_2O Emissions From Managed Soils
3D11	Inorganic N Fertilizers
3D12	Organic N Fertilizers
3D12a	Animal Manure Applied to Soils
3D12b	Sewage Sludge Applied to Soils
3D12c	Other Organic Fertilizers Applied to Soils
3D13	Urine and Dung Deposited by Grazing Animals
3D14	Crop Residues
3D15	Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter
3D16	Cultivation of Organic Soils
3D17	Other
3D2	Indirect N_2O Emissions From Managed Soils
3D21	Atmospheric Deposition
3D22	Nitrogen Leaching and Run-off
3E	**Prescribed Burning of Savannas**
3F	**Field Burning of Agricultural Wastes**
3F1	Cereals
3F11	Wheat
3F12	Barley
3F13	Maize
3F14	Other
3F2	Pulses
3F21	Other
3F3	Tubers and Roots
3F31	Other
3F4	Sugar Cane
3F5	Other
3G	**Liming**
3G1	Limestone CaCO3
3G2	Dolomite CaMg(CO3)2
3H	**Urea Application**
3I	**Other Carbon-containing Fertilisers**
3J	**Other**
4	**Land-use, land-use change and forestry**
4A	**Forest Land**
4A1	Forest Land Remaining Forest Land
4A2	Land Converted to Forest Land
4B	**Cropland**
4B1	Cropland Remaining Cropland
4B2	Land Converted to Cropland
4C	**Grassland**
4C1	Grassland Remaining Grassland
4C2	Land Converted to Grassland
4D	**Wetlands**
4D1	Wetlands Remaining Wetlands
4D2	Land Converted to Wetlands
4E	**Settlements**
4E1	Settlements Remaining Settlements
4E2	Land Converted to Settlements
4F	**Other Land**
4F1	Other Land Remaining Other Land
4F2	Land Converted to Other Land

IPCC Category	Source Description
4G	**Harvested Wood Products**
4H	**Other**
5	**Waste**
5A	**Solid Waste Disposal**
5A1	Managed Waste Disposal Sites
5A1a	Anaerobic
5A1b	Semi-aerobic
5A2	Unmanaged Waste Disposal Sites
5A3	Uncategorized Waste Disposal Sites
5B	**Biological Treatment of Solid Waste**
5B1	Composting
5B1a	Municipal Solid Waste
5B1b	Other
5B2	Anaerobic Digestion at Biogas Facilities
5B2a	Municipal Solid Waste
5B2b	Other
5C	**Incineration and Open Burning of Waste**
5C1	Waste Incineration
5C11	Biogenic
5C11a	Municipal Solid Waste
5C11b	Other
5C12	Non-biogenic
5C12a	Municipal Solid Waste
5C12b	Other
5C2	Open Burning of Waste
5C21	Biogenic
5C21a	Municipal Solid Waste
5C21b	Other
5C22	Non-biogenic
5C22a	Municipal Solid Waste
5C22b	Other
5D	**Wastewater Treatment and Discharge**
5D1	Domestic Wastewater
5D2	Industrial Wastewater
5D3	Other
5E	**Other**
6	**Other**

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Executive Summaries

ES 1 BACKGROUND INFORMATION

ES 1.1 Climate Change

The Climate Change Act became UK Law on 26 November 2008. This legislation introduced a 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 Climate Change Committee (CCC) was set up to provide independent advice the UK Government on the setting and meeting of UK carbon budgets, as well as monitoring progress against them. In June 2019, the UK government furthered this by setting a legally binding target to achieve net zero greenhouse gas emissions across the UK economy by 2050. The UK was the first major economy in the world to legislate for a net zero target.

Reporting under the Paris Agreement is expected to start in 2024, and therefore this report (for the 2023 submission) does not yet include any reporting specifically related to the Paris Agreement.

Countries that have signed and ratified the Kyoto Protocol were legally bound to reduce their greenhouse gas emissions by an agreed amount. The first commitment period of the Kyoto Protocol was from 2008 to 2012. A single European Union (EU) 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 second commitment period of the Kyoto Protocol was for 2013 to 2020 inclusive. For this second commitment period, the EU, the Member States and Iceland 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 was based on the understanding that it would be fulfilled jointly by the European Union, the Member States, the UK and Iceland. Under the terms of the Withdrawal Agreement, the UK remained committed to its shared target and reporting with the EU under the Kyoto Protocol, including any further requirements for the conclusion of the true up period. The EU2020 target is unconditional and supported by EU legislation in place since 2009 (The EU Climate and Energy Package). This Kyoto target included the UK, and the relevant Crown Dependencies (CDs) and Overseas Territories (OTs) for whom the ratification is extended.

Further information on Kyoto Protocol reporting can be found in the final submission relating to the 2nd commitment period in the 2022 submission[1].

Further information on the UK Devolved Administrations (DAs) action to tackle climate change can be found on the CCC's website[2]. Information on climate adaptation can be found on the UK Government's topic page[3].

[1] The 2022 submission of the NIR can be found here https://naei.beis.gov.uk/reports/reports?report_id=1108

[2] The Climate Change Act 2008 (2050 Target Amendment) Order 2019. https://www.legislation.gov.uk/ukdsi/2019/9780111187654

[3] Climate change adaptation Guidance and regulation, https://www.gov.uk/environment/climate-change-adaptation

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 2023 to the UNFCCC. It contains national greenhouse gas emission estimates for the period 1990-2021, and the descriptions of the methods used to produce the estimates. The report is prepared in accordance with decision 24/CP.19[4]. Note that decision 24/CP.19 paragraph 2 dictates that AR4 Global Warming Potentials (GWPs) should be used "until a further decision is adopted", and decision 7/CP.27[5] is a further decision that adopts AR5 GWPs for reporting under the Paris Agreement, and hence AR5 GWPs are used in this report.

The UK Greenhouse Gas Inventory is compiled and maintained by a consortium led by Ricardo Energy & Environment – the **Inventory Agency** – under contract to DESNZ. 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 OTs and CDs. Ray Gluckman (Gluckman Consulting) advises on F-gas emissions.

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 (UKCEH), both partners within the consortium. Agricultural sector emissions estimates (CRF sector 3) are produced by a consortium led by Rothamsted Research, under contract to the UK Department for Environment, Food and Rural Affairs (Defra).

DESNZ, Defra and the 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 (**Section 1.2.1.1**).

'The inventory covers the seven direct greenhouse gases in the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention. These are as follows:

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

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

- Nitrogen oxides (NO_x);
- Carbon monoxide;

[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

[5] FCCC Decision 7/CP.27. Common metrics used to calculate the carbon dioxide equivalence of anthropogenic greenhouse gas emissions by sources and removals by sinks https://unfccc.int/resource/ldc/documents/13a04p6.pdf

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

Emissions of indirect N_2O from emissions of NO_x and NH_3 are 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 towards the UK Government's own Carbon Budgets and to meet commitments as a Party to the UNFCCC. Geographical coverage for these two purposes differs to some extent, because of the following:

1) 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.
2) The UK Government Carbon Budgets apply to the UK only, and exclude all emissions from the UK's Crown Dependencies and Overseas Territories.

Emissions data for the first geographical coverage (Coverage 1) is used for the data in the CRF tables submitted to the UNFCCC under the Convention. **Table ES 1** and **Table ES 2** show CO_2 and the direct greenhouse gases, disaggregated by gas and by sector for geographical Coverage 2. Coverage 2 are reported for information and to facilitate comparison between different publications. Table 3.3 in the UK Greenhouse Gas statistics[6] includes further detail of how emissions between scopes compare.

Table ES 3 has data on indirect greenhouse gas emissions, for geographical Coverage 1.

[6] https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2021

ES 2 SUMMARY OF NATIONAL EMISSION AND REMOVAL RELATED TRENDS

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, 1990-2021. (Mt CO_2 Equivalent)

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021	% change 1990 - 2021
CO_2 (Inc. net LULUCF)	607.3	569.2	569.7	568.4	508.6	417.9	375.1	361.7	321.4	342.6	-44%
CO_2 (Exc. net LULUCF)	603.7	567.7	570.5	572.1	513.8	423.8	380.6	366.9	327.2	348.4	-42%
CH_4 (Inc. net LULUCF)	150.9	144.2	124.3	101.3	75.7	63.0	60.9	60.4	58.0	57.4	-62%
CH_4 (Exc. net LULUCF)	145.3	138.6	118.8	95.7	70.1	57.3	55.2	54.7	52.3	51.7	-64%
N_2O (Inc. net LULUCF)	44.4	35.7	26.9	23.3	20.7	20.1	19.8	19.9	18.7	19.2	-57%
N_2O (Exc. net LULUCF)	42.5	33.9	25.2	21.7	19.3	18.7	18.5	18.6	17.4	17.9	-58%
HFCs	12.1	15.6	7.0	8.7	11.5	13.3	13.0	12.3	11.5	10.8	-10%
PFCs	1.5	0.5	0.5	0.4	0.3	0.3	0.1	0.2	0.2	0.2	-87%
SF_6	1.2	1.3	1.9	1.1	0.7	0.4	0.6	0.5	0.4	0.4	-66%
NF_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	207%
Total (Inc. net LULUCF)	817.5	766.5	730.2	703.1	617.5	515.0	469.4	455.1	410.2	430.7	-47%
Total (Exc. net LULUCF)	806.3	757.6	723.9	699.6	615.7	513.9	467.9	453.2	409.0	429.5	-47%

1. One Mt equals one Tg, which is 10^{12} g (1,000,000,000,000 g) or one million tonnes
2. Net Emissions are reported in the Common Reporting Format
3. Geographical coverage of this table includes the Crown Dependencies and the Overseas Territories which are 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 CO_2, which contributed 80% to total net emissions in 2021. Methane emissions account for the next largest share (13%), and N_2O emissions make up a further 4%. Emissions of all these gases have decreased since 1990, contributing to an overall decrease of 47%.

ES 3 OVERVIEW OF SOURCE AND SINK CATEGORY EMISSION ESTIMATES AND TRENDS

Table ES 2 details total net emissions of GHGs, aggregated by IPCC sector.

Table ES 2 Aggregated emission trends per source category, including all estimated GHG emissions from the Crown Dependencies and selected relevant Overseas Territories (Mt CO_2 equivalent)

Source Category	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
1. Energy	602.9	558.6	553.8	550.3	498.9	404.7	366.9	352.7	312.9	335.0
2. Industrial Processes and Product Use	80.0	73.6	53.4	49.7	41.0	43.1	36.1	35.7	34.1	32.3
3. Agriculture	50.8	49.9	48.6	46.4	43.8	44.4	43.6	43.8	42.5	43.1
4. LULUCF	11.2	8.8	6.3	3.5	1.8	1.1	1.5	1.8	1.3	1.2
5. Waste	72.5	75.6	68.2	53.2	31.9	21.7	21.3	21.0	19.5	19.1
Total (net emissions)	**817.5**	**766.5**	**730.2**	**703.1**	**617.5**	**515.0**	**469.4**	**455.1**	**410.2**	**430.7**

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 2021 this contributed 78% to the total net emissions. Emissions of CO_2, CH_4 and N_2O all arise from this sector, but CO_2 is the dominant gas consisting of 97% of emissions. Since 1990, emissions from the energy sector have declined by 44%.

The second largest source of greenhouse gases is the agricultural sector, contributing 10% in 2021. Emissions from this sector are mostly CH_4 and N_2O, contributing 65% and 32% respectively. Only a small amount of CO_2 is emitted in comparison. Since 1990, emissions from this sector have declined by 15%.

Industrial processes and product use make up the third largest sector for greenhouse gas emissions in the UK, contributing 8% to the national total in 2021. Emissions of all seven direct greenhouse gases occur from this sector. Since 1990, emissions from this sector have declined by 60%.

Land-Use, Land-Use Change, and Forestry contains sinks as well as sources of CO_2 emissions. LULUCF was a net sink in 2021. Emissions from this sector occur for CO_2, N_2O and CH_4.

The remaining sector that contributes to direct greenhouse gas totals is waste. In 2021 this contributed 4% to the national total. This sector leads to emissions of CO_2, CH_4 and N_2O, with emissions occurring from waste incineration, solid waste disposal on land and wastewater handling. CH_4 is the dominant gas consisting of 90% of all emissions. Emissions from this sector have declined and in 2021 were 74% below 1990 levels.

ES 4 OTHER INFORMATION

Table ES 3 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 result in an increase in tropospheric ozone concentration, increasing radiative forcing. Sulphur oxides are included because they contribute to aerosol formation.

Table ES 3 Emissions of Indirect Greenhouse Gases in the UK, 1990-2021 (in kt).

Gas	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
NO_x	2861	2467	1984	1752	1251	1020	848	794	685	689
CO	7725	6357	4888	3266	1978	1608	1491	1423	1292	1312
NMVOC	2760	2279	1710	1241	914	824	842	824	799	783
SO_2	3591	2541	1305	789	467	270	177	157	134	127

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 NO_x, CO and SO_2 is the energy sector, with 80% of emissions or more arising from activities within this sector. For NMVOC, 58% of emissions are from the industrial processes and product use sector, with other significant contributions from the energy sector.

Contacts

This work is delivered for the Department for Energy Security and Net Zero. The Land-Use Change and Forestry estimates were provided by the UK Centre for Ecology and Hydrology (UKCEH) in Edinburgh with the support of Forest Research. Rothamsted Research provide the estimates of agricultural emissions.

DESNZ Contract Officer:

Tom Forrest

Department for Energy Security and Net Zero

1 Victoria Street

London

SW1H 0ET

E-mail: tom.forrest@beis.gov.uk

Technical enquiries should be directed to:

Peter Brown

Ricardo Energy & Environment

The Gemini Building, Fermi Avenue

Harwell

Didcot

Oxfordshire OX11 0QR

UK

Tel: +44 (0) 1235 753273

E-mail: peter.brown@ricardo.com

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

1 Introduction

This is the UK's 2023 National Inventory Report (NIR). The NIR is one element of the annual greenhouse gas inventory (GHGI) that is compulsory to submit to the UNFCCC by signatories to the Convention on 15 April of each year. The NIR is compiled in accordance with the revised UNFCCC reporting guidelines, see decision 24/CP.19[7]. Note that decision 24/CP.19 paragraph 2 dictates that AR4 Global Warming Potentials (GWPs) should be used "until a further decision is adopted", and decision 7/CP.27[8] is a further decision that adopts AR5 GWPs for reporting under the Paris Agreement, and hence AR5 GWPs are used in this report.

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. Under the Kyoto Protocol, the UK has been obliged to report supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol[9] for each year of both commitment periods, alongside the inventory submission due under the Convention, in accordance with paragraph 3(a) of decision 15/CMP.1. This edition of the NIR is no longer within the Kyoto Protocol reporting period, as such elements relating to the Kyoto Protocol are not included in this edition.

1.1 BACKGROUND INFORMATION ON GREENHOUSE GAS INVENTORIES, AND CLIMATE CHANGE

1.1.1 Background Information on Climate Change

The Climate Change Act[10] became UK Law on the 26 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 Climate Change Committee (CCC) was set up to advise the UK Government on setting and meeting of UK carbon budgets, as well as monitoring progress against them. In June 2019, the UK Government furthered this ambition by setting a legally binding target to achieve net-zero greenhouse gas emissions across the UK economy by 2050[11]. The UK was the first major economy in the world to legislate for a net-zero target.

[7] 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

[8] FCCC Decision 7/CP.27. Common metrics used to calculate the carbon dioxide equivalence of anthropogenic greenhouse gas emissions by sources and removals by sinks https://unfccc.int/resource/ldc/documents/13a04p6.pdf

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

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

[11] The Climate Change Act 2008 (2050 Target Amendment) Order 2019. Available at: https://www.legislation.gov.uk/ukdsi/2019/9780111187654

Further information on the UK's action to tackle climate change can be found on the Department for Energy Security and Net Zero's website[12]. Information about climate adaptation can be found on the UK Government's topic page[13].

Countries that signed and ratified the Kyoto Protocol were legally bound to reduce their GHG emissions by an agreed amount. A single European Union Kyoto Protocol reduction target for GHG 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% relative to the base year. The first commitment period of the Kyoto Protocol was from 2008 to 2012.

The second commitment period of the Kyoto Protocol (the Doha Amendment) ran for eight years, from 2013 to 2020 inclusive. For this second commitment period, alongside the EU and its Member States, the UK communicated an independent quantified economy-wide emission reduction target of a 20% emission reduction by 2020 compared with 1990 levels (base year). The target for the European Union, its Member States and Iceland is based on the understanding that it will be fulfilled jointly with the European Union, its Member States and Iceland. The 20% emission reduction target by 2020 is unconditional and supported by legislation in place since 2009 (Climate and Energy Package). This Kyoto target covered the UK, and the relevant Crown Dependencies and Overseas Territories to whom ratification was extended. The UK and the EU formally ratified the Doha Amendment on 17 November 2017, and 21 December 2017, respectively. The Doha Amendment entered into force on 31 December 2020. Under the terms of the Withdrawal Agreement, the UK remained committed to its shared target with the EU under the Kyoto Protocol.

1.1.2 Background Information on Greenhouse Gas Inventories

1.1.2.1 Reporting of the UK Greenhouse Gas Inventory

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

The UK's NIR is prepared in accordance with Decision 24/CP.19[14]. 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 the Department for Energy Security and Net Zero (DESNZ). Full details of the institutional arrangements for the preparation of the GHG inventory are explained in **Section 1.1.**

This report and corresponding CRF tables provide annual emission estimates submitted by the UK to the UNFCCC for the period 1990 to 2021. The geographical coverage of this submission is as follows:

1. **UNFCCC** Coverage Includes UK, Crown Dependencies (Jersey, Guernsey, Isle of Man) and the Overseas Territories (Bermuda, Cayman Islands, Falkland Islands, Gibraltar).

[12] Department for Energy Security and Net Zero, available at: https://www.gov.uk/government/organisations/department-for-energy-security-and-net-zero

[13] Climate change adaptation, available at: https://www.gov.uk/environment/climate-change-adaptation

[14] 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

The main section of this report presents GHG emissions for the years 1990-2021, discusses the reasons for the trends, and documents any changes in the estimates due to revisions made since the last inventory submission. 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[15] 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 accompanies this report and is available on the NAEI website[15].

1.1.2.2 Geographical coverage of UK emissions

For the 2023 submission, the UK is reporting only one set of CRF tables. The tables previously reported (under the KP, and for the EU) are no longer necessary. From 2024, the UK will need to report under the Paris Agreement, which may necessitate a second set of CRF tables going forward.

A major source of activity data (AD) for the UK inventory is provided through the publication of the Digest of UK Energy Statistics (DUKES) (see **Table 1.5**). The geographical coverage of DUKES is the United Kingdom (BEIS, 2022). 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 for DUKES accords with that of the "economic territory of the United Kingdom" used by the UK Office for National Statistics (ONS), 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 the:

- **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.
- **Overseas Territories (OTs)** (formerly called Dependent Territories)
  The relevant Overseas Territories are the Cayman Islands, Bermuda, Falkland Islands, and Gibraltar. Other Overseas Territories have not signed up to the UNFCCC and are not included in the NIR. Overseas Territories are constitutionally not part of the United Kingdom and have separate constitutions, and most have elected governments with varying degrees of responsibilities for domestic matters. The Governor, who is appointed by, and represents, His Majesty the King, retains responsibility for external affairs, internal security, defence, and in most cases the public service.

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

[15] UK NAEI - National Atmospheric Emissions Inventory, available at: https://naei.beis.gov.uk/

1.1.2.3 Greenhouse Gases Reported in the UK Inventory

The greenhouse gases reported are:

- **Direct greenhouse gases**
  - Carbon dioxide (CO_2);
  - Methane (CH_4);
  - Nitrous oxide (N_2O);
  - Hydrofluorocarbons (HFCs);
  - Perfluorocarbons (PFCs);
  - Sulphur hexafluoride (SF_6); and,
  - Nitrogen trifluoride (NF_3).
- **Indirect greenhouse gases**
  - Nitrogen oxides (NO_x, as NO_2);
  - Carbon monoxide (CO);
  - Non-Methane Volatile Organic Compounds (NMVOCs); and,
  - Sulphur oxides (reported as SO_2).

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

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

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

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

1.1.2.4 Global Warming Potentials (GWPs) of the Greenhouse Gases

The direct greenhouse gases have different effectiveness in radiative forcing. The GWP is a means of providing a simple measure of the relative radiative effects of the emissions of the various gases. The index is defined as the cumulative radiative forcing between the present and a future time horizon caused by a unit mass of gas emitted now, expressed relative to that of CO_2. It is necessary to define a time horizon because the gases have different lifetimes in the atmosphere. **Table 1.1** shows GWPs defined on a 100-year horizon without climate-carbon feedback, according to the Fifth Assessment Report (IPCC, 2014). These are the GWP values that are required for reporting under the Paris Agreement and the UNFCCC from 2024. The UK has adopted these from the 2023 submission. 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.

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	28
Nitrous oxide	N_2O	265
Sulphur hexafluoride	SF_6	23,500
Nitrogen trifluoride	NF_3	16,100

Hydrofluorocarbons		
HFC-23	CHF_3	12,400
HFC-32	CH_2F_2	677
HFC-41	CH_3F	116
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1,650
HFC-125	C_2HF_5	3,170
HFC-134	$C_2H_2F_4$	1,120
HFC-134a	$C_2H_2F_4$	1,300
HFC-143	$C_2H_3F_3$	328
HFC-143a	$C_2H_3F_3$	4,800
HFC-152	CH_2FCH_2F	16
HFC-152a	$C_2H_4F_2$	138
HFC-161	CH_3CH_2F	4
HFC-227ea	C_3HF_7	3,350
HFC-236cb	$CH_2FCF_2CF_3$	1,210
HFC-236ea	CHF_2CHFCF_3	1,330
HFC-236fa	$C_3H_2F_6$	8,060
HFC-245ca	$C_3H_3F_5$	716
HFC-245fa	$CHF_2CH_2CF_3$	858
HFC-365mfc	$CH_3CF_2CH_2CF_3$	804
Perfluorocarbons		
Perfluoromethane	PFC-14 -CF_4	6,630
Perfluoroethane	PFC-116 - C_2F_6	11,100
Perfluoropropane	PFC-218 - C_3F_8	8,900
Perfluorobutane	PFC-3-1-10 - C_4F_{10}	9,200
Perfluorocyclobutane	PFC-318 - c-C_4F_8	9,540
Perfluouropentane	PFC-4-1-12 - C_5F_{12}	8,550
Perfluorohexane	PFC-5-1-14 - C_6F_{14}	7,910
Perfluorodecalin	PFC-9-1-18b - $C_{10}F_{18}$	>7,190
Perfluorocyclopropane	c-C_3F_6	>9,200

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 DESNZ (formerly BEIS). Ricardo Energy & Environment is responsible for producing the emissions estimates for CRF categories of 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 Centre for Ecology and Hydrology (UKCEH) with the support of Forest Research. 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)

Figure 1.1 summarises the key organisational structure of the UK National Inventory System (NIS) and **Section 1.2.2** 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

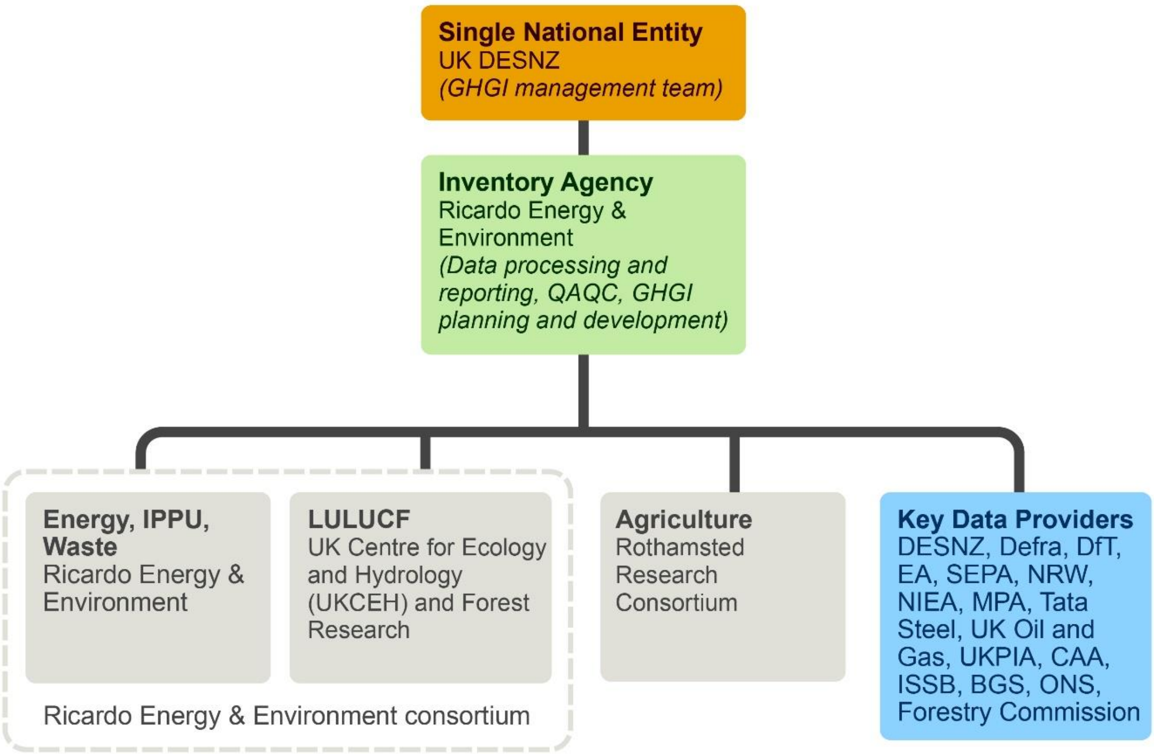
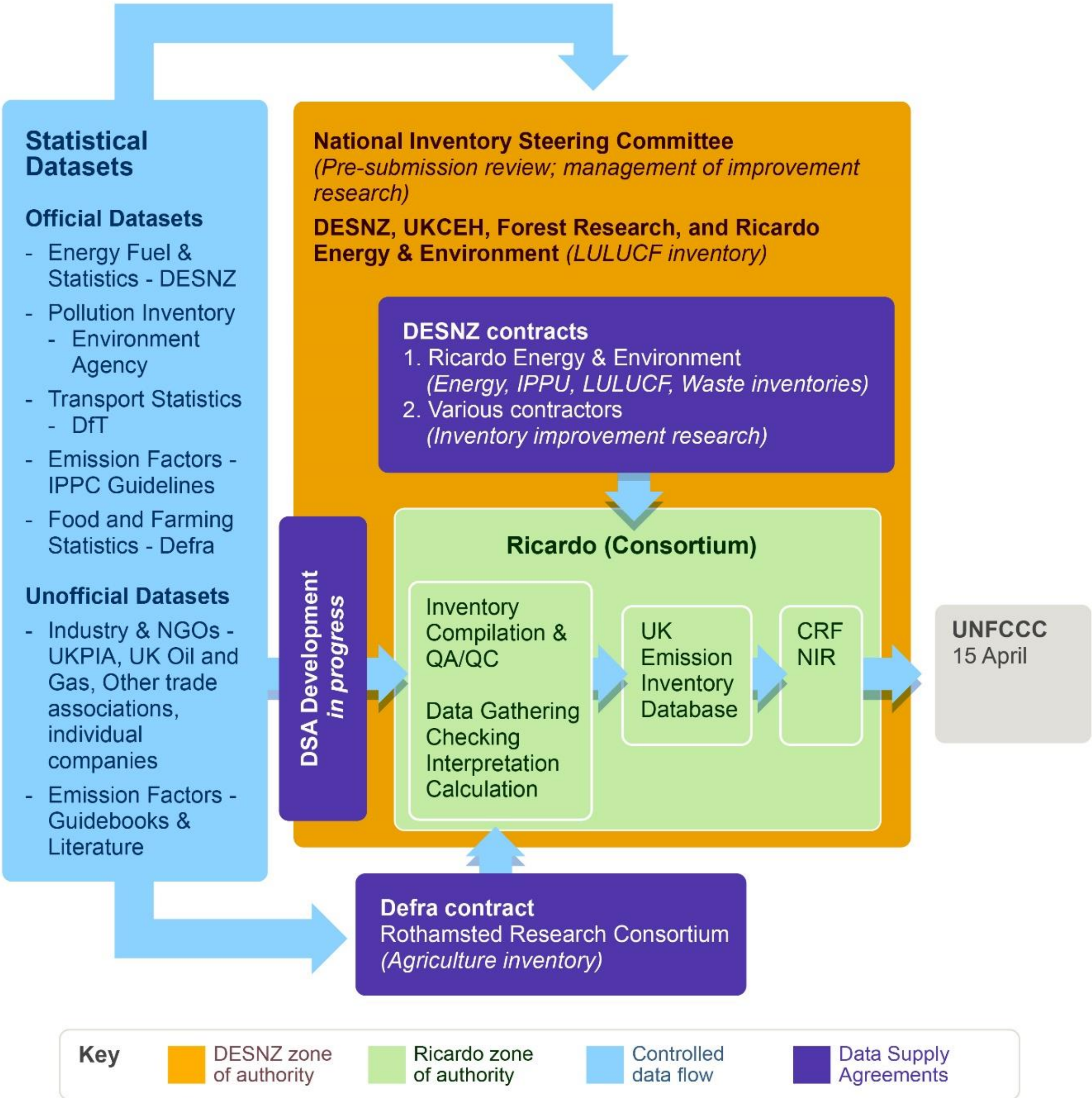


Figure 1.2 shows the main elements of the UK National Inventory System. DESNZ (formerly BEIS) is the Single National Entity responsible for submitting the UK's GHGI to the UNFCCC. The Inventory Agency compiles the GHGI on behalf of DESNZ and produces disaggregated estimates for the Devolved Administrations (DAs) within the UK.

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



The National Inventory Steering Committee (NISC) is formed of two groups, the Advisory Body and the Executive Body. Both groups meet twice per year, in April and November. The Advisory Body brings together technical experts on the inventory while the Executive Body membership consists of government stakeholders and end users of inventory data. The purpose of the Advisory Body is to advise on how proposed changes to the inventory should be prioritised and delivered, discussing any risks to the data supply chain as well as reviewing the inventory to identify any potential issues. The Executive Body reviews and discusses modifications to the inventory methodology and resulting recalculations, making recommendations as to whether these modifications should be accepted. It also advises the DESNZ Greenhouse Gas Inventory Team on how improvements to the inventory should be prioritised. The Executive Body aims to ensure that a rigorous science and evidence base remains central to decision-making on the future of the inventory, and stakeholders remain up to date with any significant risks to the Inventory.

1.2.1.2 Legal Framework

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

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

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

To meet the standards required under the Kyoto Protocol, the UK introduced legislation specifically for national inventory purposes which took effect from November 2005[16]. These standards are maintained beyond the end of the KP commitment periods. This legislation makes provision for DESNZ'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. To ensure that the system works most effectively and to minimise the need for legislative action, DESNZ establishes 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 NISC (see **Section 1.2.2.4** below).

There are currently DSAs in place with the Scottish Government, the Scottish Environment Protection Agency, the Northern Ireland Environment Agency, Natural Resources Wales and DfT.

1.2.2 Overview of Inventory Planning

As summarised in **Section 1.1**, 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 – DESNZ

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 His Majesty's Government and the Devolved Administrations (Das) (Wales, Scotland, and Northern Ireland).

At the time of preparing this report, a new government department – the Department for Energy Security and Net Zero (DESNZ) has been formed, which will take on the Single National Entity role. This will be communicated to the UNFCCC Executive Secretary once the legal transition is completed. DESNZ (formerly BEIS) is responsible for the institutional, legal, and procedural arrangements for the national system and for the strategic development of the national inventory.

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

Within DESNZ, 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, and the IPCC 2006 Guidelines.

As the designated Single National Entity for the UK GHG NIS, DESNZ 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 4-year contract was established for the Inventory Agency in 2020 following a competitive tendering exercise. Ricardo Energy & Environment leads the consortium responsible for compiling the inventory, under contract to DESNZ (formerly BEIS). Ricardo Energy & Environment is responsible for all aspects of national inventory preparation, reporting and quality management. The current consortium consists of:

- Ricardo Energy & Environment – lead contractor;
- UKCEH – overall responsibility for the LULUCF estimates.
- Forest Research – responsible for forestland estimates that feed into the 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.

Ricardo Energy & Environment together with the project partners prepares the NAEI which is the core air emissions database from which the 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 UNFCCC on behalf of DESNZ.

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 DESNZ 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.

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

The Rothamsted Research consortium includes:

- Rothamsted Research – lead contractor, dairy, pig, poultry and other livestock estimates;
- ADAS – Modelling and database management, Sheep and grassland estimates;
- Cranfield University – Beef and arable estimates
- UKCEH - sector-wide data analysis and high resolution mapping
- SRUK – research support
- Ricardo Energy & Environment – QA/QC support

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 DESNZ, 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 DESNZ (formerly 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 DESNZ Offshore Petroleum Regulator for Environment & Decommissioning (DESNZ 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 Environmental Permitting Regulations (EPR). 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 UK Emissions Trading System (UK ETS), from detailed annual operator returns to the UK regulators of UK ETS (EA, SEPA, NRW, NIEA, DESNZ OPRED)[17]. These data are used by the Inventory Agency and the DESNZ 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 Centre for Ecology and Hydrology (UKCEH) 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.

[17] The UK Emissions Trading Scheme (UK ETS) replaced the UK's participation in the EU ETS on 1 January 2021. UK based operators (except for electricity generators in Northern Ireland, who will remain in EU ETS in accordance with the terms of the Northern Ireland Protocol (or Protocol on Ireland/Northern Ireland to the Withdrawal Agreement, depending on how formal the publication is)) will now report their emissions under the UK ETS. For the purposes of calculating UK emissions statistics, teams should use EU ETS data for emissions arising up to December 31st, 2020, and use UK ETS data for emissions emitted from 1st January 2021. As the UK ETS was initially designed to provide a smooth transition for relevant sectors from the EU to the UK scheme, the two data sets will be compatible.

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 DESNZ 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 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 DESNZ, 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 DESNZ.

Final technical sign-off of inventory outputs rests with the Inventory Agency, as part of the governance procedures agreed with DESNZ 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 1.2 and **Table 1.3** 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 DESNZ, 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, as well as sector-specific peer- or bilateral review findings are also considered to guide decisions on UK GHGI improvement priorities.

A qualitative uncertainty analysis of the inventory is 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 UNFCCC ERTs.

In spring each year, DESNZ and the Inventory Agency hold a review meeting, at which the findings of the UN reviews, other peer reviews commissioned by DESNZ, 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 1.2 UK GHG National Inventory Steering Committee composition and responsibilities

Organisation	Role in relation to NISC	Key NISC responsibilities
DESNZ (formerly BEIS) – Science and Innovation for Climate and Energy (SICE) Directorate	• GHG inventory manager • Manager of GHG research contracts • DESNZ annual climate change statistics and indicators	• Administer functions of Single National Entity for the UK National Inventory System • Overall responsibility for inventory development, compilation, and reporting • Manage GHG inventory research contracts • Act as NISC Chair • Ensure that UK GHGI conforms to UN international standards and requirements
Defra – Air Quality & Industrial Emissions Team in the Environmental Quality Directorate	• Air quality (AQ) inventory manager • Manager of AQ research contracts	• Ensure that UK AQ inventory conforms to UN international standards and requirements • Overall responsibility for AQ inventory development, compilation, and reporting • With DESNZ, ensure coordinated approach to improvements across GHG and AQ inventories, where relevant.
Defra	• Liaison between Defra and NISC	• Provide an analytical overview of all relevant Defra sectors • Provide link with Defra climate change mitigation team
DESNZ (formerly BEIS) – Carbon Budgets	• UK Climate Change Programme • Climate Change Act • Carbon budgets	• Inform NISC of UK programme developments • Explore links between inventory and carbon budgets and potential requirements for either area
DESNZ (formerly BEIS) – Industrial Energy	• UK Emissions Trading System (UK ETS) • UK ETS Registry	• Provide UK ETS fuel use and fuel characterisation datasets for determining industrial fuel use statistics and GHG emission from combustion sources • Improve links between UK ETS registry and GHG inventory
DESNZ (formerly BEIS) – International Climate and Energy (ICE)	• International negotiations • UNFCCC • Paris Agreement	• 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

Organisation	Role in relation to NISC	Key NISC responsibilities
DESNZ (formerly BEIS) – SICE	• LULUCF Inventory manager	• Provide LULUCF inventory data that conforms to UNFCCC international standards and requirements • Work with the NISC to ensure highest quality data
Defra – Farming and Food Science	• Agriculture Inventory Manager	• Providing agriculture inventory data that conforms to UN international standards and requirements • Work with the NISC to ensure highest quality data
Defra – Waste	• Waste	• To provide waste policy expertise to the inventory, including landfill waste • To assist in improving landfill waste data quality
DESNZ (formerly BEIS) – Energy Statistics (DUKES)	• Energy statistics	• Annual publication of Digest of UK Energy Statistics (DUKES) • Providing energy statistics to inform the UK inventory
Regulators: • Environment Agency for England • Natural Resources Wales • Scottish Environment Protection Agency • Northern Ireland Environment Agency	• Pollution inventory • UK ETS Registry	• 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 UK ETS
DESNZ (formerly BEIS) OPRED	• Offshore oil and gas regulator (EEMS, UK ETS) and technical expertise	• 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 Environmental and Emissions Monitoring System (EEMS) of environmental emissions from that sector
Department for Transport (DfT)	• Transport	• Publication of transport statistics each year • Providing transport statistics to inform the UK inventory
Devolved Administrations	• Inventories for Devolved Administrations	• General review function for completeness and accuracy of UK inventory from a devolved perspective, including ensuring the integration of local datasets and specific research where appropriate.

Organisation	Role in relation to NISC	Key NISC responsibilities
	• Devolved administration climate change legislation and statutory GHG targets	• Aid NISC in understanding the implications of the UK inventory for the devolved administration inventories, legislation, GHG targets and other relevant context.
GHG inventory contractor (Ricardo Energy & Environment)	• UK greenhouse gas inventory compilation and development	• Contractor responsible for the UK GHG inventory; activity data, methods, emission factors, emissions estimation, reporting and archiving • Compile the annual National Inventory Report (NIR) and Common Reporting Format (CRF) submission to the UN • Participate in sectoral expert panels as required
GHG inventory project partners (Aether)	• Inputs to GHG inventory compilation and development	• Contractor responsible for emissions from railways, and from Overseas Territories and Crown Dependencies • Joint role in managing the inventory improvement programme and development of QA/QC procedures
GHG inventory project partners (UKCEH)	• LULUCF inventory •	• Contractor responsible for LULUCF inventory, activity data, methods, emission factors and removals estimation • Prepare and develop LULUCF inventory of emissions and removals and deliver on time for incorporation into the national inventory • Participate in sectoral expert panels as required
GHG inventory project partners (Forest Research)	• LULUCF inventory (forestry component)	• Contractor responsible for forestry elements of the LULUCF inventory • Participate in sectoral expert panels as required
Agricultural inventory contractor (Rothamsted)	• Agriculture Inventory compilation and development	• Contractor responsible for agriculture inventory; activity data, methods, emission factors and emission estimation • Prepare and develop agriculture inventory and deliver on time for incorporation into national inventory • Participate in sectoral expert panels as required
DESNZ (formerly BEIS) – Analysis	• Energy modelling and projections	• Produce UK CO_2 projections
Defra – Stratospheric Ozone and Fluorinated Gases	• F-gases	• To provide F-gas policy expertise to the inventory • To assist in improving F-gas data quality

Table 1.3 Special Advisors to the UK GHG National Inventory Steering Committee

Organisation	Role in relation to NISC	Key NISC responsibilities
Met Office/University of Bristol	• Atmospheric measurements and interpretation at Mace Head, Ireland, and other tall tower sites.	• Provide atmospheric measurements and interpretation of these data collected at Mace Head, for use in inventory data verification • Prepare comparison between estimated and observed emissions for the NIR
External reviewers	• Representation of industries, industry organisations and independent experts in the development of the national inventory	• Other experts or representatives may be asked to participate in sectoral expert panels or to review key sources or sources where significant changes to methods, activity data or emission factors have occurred e.g. ONS, UKPIA, Offshore Energies 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 – the European Monitoring and Evaluation Programme, which sits under the Convention on Long Range Transboundary Air Pollution (CLRTAP), the European Environment Agency (EEA) and the US Environmental Protection Agency (EPA), or from specific research programmes sponsored by DESNZ and other UK Departments.

The UK NIS has a formal Inventory Improvement Programme, overseen 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[18]. 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 several 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

For details of inventory preparation, see **Section 1.2**.

The Environment Agency was appointed as the UK Registry Administrator for the Kyoto Registry and EU ETS (until the UK left the latter scheme at the end of the transition period on 31 December 2020) by BEIS. The Environment Agency remains the administrator for the UK ETS and the KP registry. 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.

[18] As detailed in chapter 6.5 of the 2006 IPCC Guidelines. Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_6_Ch6_QA_QC.pdf

Responsibilities of the Environment Agency are 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/Meeting of the Parties (MOP) decisions as implemented by the UNFCCC;
- Conform to the EU Registries Regulations as amended from time to time;
- Allow access for authorised users[19].
- 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 1990-2021 was compiled in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). As discussed in paragraph 12 (a) in the fifty-second to fifty-fifth session of the UNFCCC Subsidiary Body for Scientific and Technological Advice[20], while the IPCC have since published a refinement to the 2006 IPCC guidelines (IPCC, 2019), these are yet to be adopted for use in historic inventory reporting under the UNFCCC, but can be used in some cases if specifically justified.

1.3.2 Data collection, processing, and storage

The data acquisition task provides the fundamental activity data from which the GHGI 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, European Commission reviews, peer reviews, bilateral reviews and relevant research sponsored by DESNZ, 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.

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

[20] https://unfccc.int/sites/default/files/resource/sbsta2021_inf04.pdf

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).

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 DESNZ. 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 QA/QC procedures outlined in Volume 1, Chapter 6 of IPCC, 2006.

Rothamsted Research and UKCEH, who are the sector experts for agriculture and 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 UKCEH 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 6.11** and **Chapter 5**, **Section 5.11** 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 1.4 provides a summary of the methods used to estimate UK GHG emissions, which are described in more detail in the subsequent Chapters and Appendices.

Table 1.4 Summary of methods used to estimate emissions of the direct greenhouse gases

CRF sector	Comments on methods
1A	• Basic combustion module (fuel use * emission factor); • Transport models (see **MS 6 to MS 10**); and, • Carbon balance approach (See **MS 4**).
1B	• Carbon Balance approach (See **MS 4**); • BEIS EEMS inventory (See **Annex 3.1.2.2**); and, • Gas leakage data from network operators (See **MS 19**).
2A	• Cement production: IPCC Tier 2 approach (see **Section 4.2.2**); • Lime production: Approach is comparable to IPCC Tier 2, although the Tier 1 default factor is used in the reporting of emissions; • Glass: IPCC Tier 2 approach, UK-specific factors from UK and EU ETS; • Brickmaking: IPCC Tier 2 approach, UK-specific factors from UK and EU ETS; and, • Other carbonates – FGD: Tier 1 approach for earlier part of time-series, Tier 2 for years covered by UK and EU ETS.
2B	• Emissions calculated based on emissions data from industry, UK and EU ETS, and the environmental regulators' inventories, except for: • Use of EU and other MS statistics to estimate methanol manufactured in the UK • Use of IPCC default factors for CH_4 from ethylene oxide, acrylonitrile, carbon black in years where no environmental regulators' inventories data available; and, • Use of IPCC default factor for CO_2 from ethylene dichloride across full time-series.
2C	• Iron and Steel - 2 stage carbon balance and UK and EU ETS/operator carbon factors for carbonate use and arc furnaces (see **MS 4**); • Spreadsheet model and operator reported emissions for aluminium and magnesium production; and, • Tier 1 approach for non-ferrous metal production.
2D	• Emissions calculated based on IPCC defaults for non-energy use of fuels; and, • IPCC method based as a proportion of the amount of fuel consumed for urea consumption in road transport.
2E, 2F	• Spreadsheet models to estimate emissions of F-gases.
2G	• Spreadsheet models to estimate emissions of F-gases; • NHS research into anaesthetic use; • Pollution inventory data for other uses of N_2O; and, • Statistics on cream consumption and Danish inventory assumptions for N_2O as a propellant for whipped cream.

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

The sources of data used are documented in the relevant sections of this NIR. Much of the activity data are taken from the key publications listed in **Table 1.5**. All sources are updated annually. References to these sources are hereafter abbreviated as shown in **Table 1.5**.

Table 1.5 Summary of sources of activity data used to estimate greenhouse gas emissions

Source **(and publisher)** ***Short name/acronym***	Relevant activity data contained in the source
Digest of UK Energy Statistics (UK Department for Energy Security and Net Zero, formerly Department for Business, Energy, and Industrial Strategy) *DUKES*	• Energy statistics for the UK (imports, exports, production, consumption, demand) of liquid, solid and gaseous fuels; and, • Calorific values of fuels and conversion factors.
Emissions Trading Scheme (UK ETS regulatory agencies in the UK; data supplied via UK Department for Business, Energy, and Industrial Strategy) *UK and EU ETS*	• Emissions from installations and characteristics of fuels consumed; • Energy data are aggregated by sector and used to inform inventory estimates; and, • Fuel quality data are used to derive up to date carbon emission factors for major fuels in energy intensive sectors. • The UK was part of the EU ETS up until 2020, and from 2021 onwards formed the UK ETS. Both

Source (and publisher) *Short name/acronym*	Relevant activity data contained in the source
	sources are used across the time series within the inventory, and therefore there are references to both within this report.
Transport Statistics GB (UK Department for Transport) *TSGB*	• Vehicle km according to vehicle type and road type; • Vehicle licensing statistics (split in vehicle km by fuel type); and, • Selected domestic and international civil aviation aircraft km flown.
Northern Ireland Statistics: Inventory of Statutory Releases, transport data (NI Department of Agriculture, the Environment and Rural Affairs, NI Department for Regional Development) *ISR*	• Traffic count and vehicle km data for Northern Ireland; and, • Information on regulated processes in NI.
Civil Aviation Authority *CAA*	• Detailed domestic and international civil aviation aircraft km flown.
Pollution Inventory (Environment Agency and Natural Resources Wales) *PI*	• Information on emissions from regulated processes in England and Wales.
Scottish Pollutant Release Inventory (Scottish Environment Protection Agency) *SPRI*	• Information on regulated processes in Scotland.
United Kingdom Petroleum Industry Association *UKPIA*	• Refinery emissions; and • Lead and sulphur contents of fuels, benzene content of petrol, RVP of petrol.
Environmental Emissions Monitoring System (EEMS) (DESNZ OPRED) *EEMS*	• Detailed inventory of oil and gas emissions.
UK Iron and Steel Industry Annual Statistics (International Steel Statistics Bureau) *ISSB*	• Energy production and consumption in the Iron and Steel industry; and, • Other statistics regarding the Iron and Steel industry.
United Kingdom Minerals Yearbook (British Geological Society)	• Statistical data on minerals production, consumption, and trade.

Source **(and publisher)** ***Short name/acronym***	Relevant activity data contained in the source
UKMY	
Department for Transport *ANPR*	• Automatic Number Plate Recognition (ANPR) data used to help define fleet composition on different road types in the UK.

Key data sources within the Energy sector are further elaborated in **Annex 3**. These include the annually updated data sets EEMS, the PI, SPRI and ISR listed above, and other one-off studies that are used across several 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, in terms of the absolute level of the emissions, uncertainty or the trend. **Table 1.6** to **Table 1.9** 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.

Note that **Table 1.6** to **Table 1.9** indicate key source categories only for the submission to the Convention (UNFCCC scope).

A key category ranking has been carried out, this is set out in **Table A 1.5.1**, and is explained below; it is referred to in **Table 3.1** when referencing which categories are or contain key categories within the energy sector.

The Key Category Analysis (KCA) ranking system is an additional tool that the UK has developed to aid in the prioritisation of improvement work. The KCA ranking system works by allocating a score based on how high categories rank in the base year and most recent year level assessments and the trend assessment for the approach 1 KCA including LULUCF. For example, if CO_2 from road transport liquid fuel use is the 4th highest by the base year level assessment, 3rd highest by the most recent year level assessment and has the 5th highest trend assessment then its score would be 4+3+5=12. The categories are then ranked from lowest score to highest, with draws in score resolved by the most recent year level assessment. The assessments excluding LULUCF are ignored for this exercise, as the LULUCF sectors would only be included in half of the assessments and would therefore give an unrepresentative weighting.

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

Table 1.6 Key Source Categories for the latest reported year (including LULUCF) – UNFCCC scope

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: solid fuels	CO_2	L1, T1
1A1	Energy industries: liquid fuels	CO_2	L1, T1
1A1	Energy industries: gaseous fuels	CO_2	L1, T1
1A1	Energy industries: other fuels	CO_2	L1, T1
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	N_2O	L2
1A2	Manufacturing industries and construction: solid fuels	CO_2	L1, T1
1A2	Manufacturing industries and construction: liquid fuels	CO_2	L1
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	L1, T1
1A3b	Road transportation: liquid fuels	CO_2	L1, T1
1A3b	DERV	CO_2	L2, T2
1A3b	Gasoline/ LPG	CO_2	L2
1A3b	DERV	N_2O	L2, T2
1A3d	Domestic Navigation: liquid fuels	CO_2	L1, L2
1A4	Other sectors: solid fuels	CO_2	L1, T1
1A4	Other sectors: liquid fuels	CO_2	L1, T1
1A4	Other sectors: gaseous fuels	CO_2	L1, T1
1A5	Other: liquid fuels	CO_2	L1, T1
1B1	Coal mining and handling	CH_4	T1, T2

IPCC Code	Category	Greenhouse Gas	Identification Criteria
1B2	Oil and gas extraction	CO_2	L1
1B2	Oil and gas extraction	CH_4	L1, T1
1B2	Natural Gas Transmission	CH_4	T2
2A1	Cement production	CO_2	L1
2B	Chemical industries	CO_2	L2
2B	Chemical industries	N_2O	T2
2B	Chemical industries	HFCs	T2
2B2	Nitric acid production	N_2O	T1
2B3	Adipic acid production	N_2O	T1
2B8	Petrochemical and carbon black production	CO_2	L1, T1
2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3	T1
2C1	Iron and steel production	CO_2	L1, T1
2F	Product Uses as Substitutes for ODS	HFCs	L2, T2
2F1	Refrigeration and air conditioning	HFCs, PFCs, SF_6 and NF_3	L1, T1
2G	Other Product Manufacture and Use	N_2O	L2, T2
3A	Enteric Fermentation	CH_4	L2, T2
3A1	Enteric fermentation from Cattle	CH_4	L1, T1
3A2	Enteric fermentation from Sheep	CH_4	L1, T1
3B1	Manure management from Cattle	CH_4	L1, T1
3B2	Manure management from Sheep	N_2O	L1
3D	Agricultural soils	N_2O	L2, T2, L1, T1
4A	Forest land	CO_2	L2, T2, L1, T1
4B	Cropland	CO_2	L2, T2, L1, T1
4C	Grassland	CO_2	L1, T1

IPCC Code	Category	Greenhouse Gas	Identification Criteria
4C	Grassland	CH_4	L2, T2, L1, T1
4C	Grassland	CH_4	L1, T1, L2, T2
4D	Wetlands	CH_4	L1, T1, L2, T2
4D	Wetlands	CO_2	L2, T2
4E	Settlements	CO_2	L2, T2, L1
4G	Harvested wood products	CO_2	L1, T1
5A	Solid waste disposal	CH_4	L2, T2, L1, T1
5B	Biological treatment of solid waste	CH_4	T1, L2, T2
5B	Biological treatment of solid waste	N_2O	T2
5C	Waste Incineration	CO_2	L2, T2
5D	Wastewater Handling	CH_4	L1
5D	Wastewater Handling	N_2O	L2, T2

Table 1.7 Key Source Categories for the base year (including LULUCF) – UNFCCC scope

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: solid fuels	CO_2	L1
1A1	Energy industries: liquid fuels	CO_2	L1
1A1	Energy industries: gaseous fuels	CO_2	L1
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	N_2O	L2
1A2	Manufacturing industries and construction: solid fuels	CO_2	L1
1A2	Manufacturing industries and construction: liquid fuels	CO_2	L1

IPCC Code	Category	Greenhouse Gas	Identification Criteria
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	L1
1A3b	Road transportation: liquid fuels	CO_2	L1
1A3b	DERV	CO_2	L2
1A3b	Gasoline/ LPG	CO_2	L2
1A3b	Gasoline/ LPG	CH_4	L2
1A3b	Gasoline/ LPG	N_2O	L2
1A3d	Domestic Navigation: liquid fuels	CO_2	L1, L2
1A4	Other sectors: solid fuels	CO_2	L1
1A4	Other sectors: liquid fuels	CO_2	L1
1A4	Other sectors: gaseous fuels	CO_2	L1
1A5	Other: liquid fuels	CO_2	L1
1B1	Coal mining and handling	CH_4	L1, L2
1B2	Oil and gas extraction	CH_4	L1
1B2	Oil and gas extraction	CO_2	L1
1B2	Natural Gas Transmission	CH_4	L2
2A1	Cement production	CO_2	L1
2B	Chemical industries	CO_2	L2
2B	Chemical industries	N_2O	L2
2B	Chemical industries	HFCs	L2
2B2	Nitric acid production	N_2O	L1
2B3	Adipic acid production	N_2O	L1
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
2G	Other Product Manufacture and Use	N_2O	L2

IPCC Code	Category	Greenhouse Gas	Identification Criteria
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
3B2	Manure management from Sheep	N_2O	L1
3D	Agricultural soils	N_2O	L1, L2
4A	Forest land	CO_2	L1, L2
4B	Cropland	CO_2	L1, L2
4C	Grassland	CH_4	L2
4D	Wetland	CH_4	L2
4E	Settlements	CO_2	L1, L2
5A	Solid waste disposal	CH_4	L1, L2
5C	Waste Incineration	CO_2	L2
5D	Wastewater Handling	N_2O	L2

Table 1.8 Key Source Categories for the latest reported year (excluding LULUCF) – UNFCCC scope

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: solid fuels	CO_2	L1, T1
1A1	Energy industries: liquid fuels	CO_2	L1, T1
1A1	Energy industries: gaseous fuels	CO_2	L1, T1
1A1	Energy industries: other fuels	CO_2	L1, T1

IPCC Code	Category	Greenhouse Gas	Identification Criteria
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	CH_4	L2
1A1 & 1A2 & 1A4 & 1A5	Other Combustion	N_2O	L2
1A2	Manufacturing industries and construction: solid fuels	CO_2	L1, T1
1A2	Manufacturing industries and construction: liquid fuels	CO_2	L1
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	L1, T1
1A3b	Road transportation: liquid fuels	CO_2	L1, T1
1A3b	DERV	CO_2	L2, T2
1A3b	Gasoline/ LPG	CO_2	L2
1A3b	DERV	N_2O	L2, T2
1A3d	Domestic Navigation: liquid fuels	CO_2	L1
1A3d	Marine fuel	CO_2	L2
1A4	Other sectors: solid fuels	CO_2	L1, T1
1A4	Other sectors: liquid fuels	CO_2	L1, T1
1A4	Other sectors: gaseous fuels	CO_2	L1, T1
1A5	Other: liquid fuels	CO_2	L1, T1
1B1	Coal mining and handling	CH_4	T1, T2
1B2	Oil and gas extraction	CO_2	L1
1B2	Oil and gas extraction	CH_4	L1, T1
1B2	Natural Gas Transmission	CH_4	L2, T2
2A1	Cement production	CO_2	L1
2B	Chemical industries	CO_2	L2
2B	Chemical industries	N_2O	T2
2B	Chemical industries	HFCs	T2

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

Table 1.9 Key Source Categories for base year (excluding LULUCF) – UNFCCC scope

IPCC Code	Category	Greenhouse Gas	Identification Criteria
1A	(Stationary) Oil	CO_2	L2

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

IPCC Code	Category	Greenhouse Gas	Identification Criteria
2B	Chemical industries	HFCs	L2
2B3	Adipic acid production	N_2O	L1
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
2G	Other Product Manufacture and Use	N_2O	L2
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_2O	L2, L1
5A	Solid waste disposal	CH_4	L2, L1
5C	Waste Incineration	CO_2	L2
5D	Wastewater Handling	N_2O	L2

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 IPCC Good Practice Guidance (IPCC, 2006) and also includes a range of bespoke sector specific QA/QC activities that 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 is required 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 Energy Security and Net Zero (DESNZ) and the Department for Environment, Food and Rural Affairs (Defra). Ricardo Energy & Environment prepares the GHG submission 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 several other organisations: ADAS, Cranfield University, the Centre for Ecology and Hydrology (UKCEH) and Scotland's Rural College (SRUC).
- The Centre for Ecology and Hydrology (UKCEH) 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, UKCEH, 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 the UK Government or for trade associations. Several of these data provider organisations (e.g. DESNZ, the Department for Transport, Defra, the Office of National Statistics and British Geological Survey) qualify as UK National Statistical Agencies (as defined in UN Guidance[21]) and abide by strict statistical QA/QC standards.

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 UK ETS or the Environmental Permitting Regulations (EPR)) 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).

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

[21] See: https://unstats.un.org/unsd/methods/statorg/

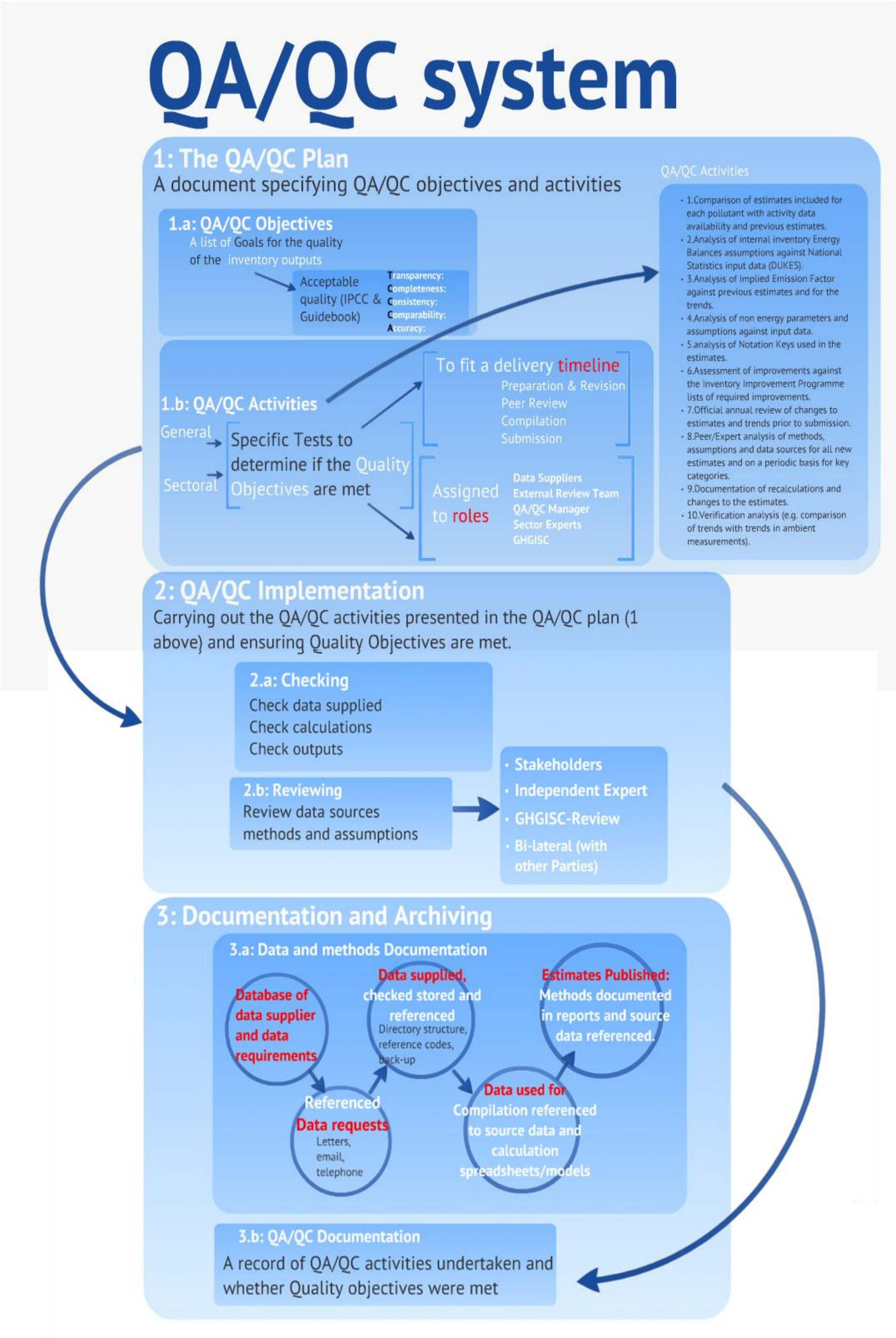
- inventory planning tasks, including: review of historic data and methods, identification of improvement priorities, data and method selection, inventory team training and development;
- inventory compilation and reporting tasks, including: management and documentation of data flows from raw data through 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 presented 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 timeframe. 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 1.2: ISO 9001:2015 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, the international standard that specifies requirements for a quality management system. 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 15 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 October 2022. Ricardo Energy & Environment successfully passed the recertification, with no major non-compliances, and a new Ricardo Group certificate was issued in February 2023. 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 ISO 4500:2018 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 (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 subject to continuous 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 (HM Treasury Aqua Book[22]). 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 UKCEH to generate the LULUCF estimates, and during 2017 HM reviewed a sample of models used to process point source data for the national inventory. In 2020 HM undertook a quality review of the Power Station model. The findings of these reviews have underpinned QA system improvements over recent submission cycles; further model-specific QA improvements may be implemented in future, subject to priorities and resources available. In 2021, Det Norske Veritas (DNV) were awarded the contract to provide independent QA/QC of

[22] The Aqua Book: guidance on producing quality analysis for government (2015), available at: https://www.gov.uk/government/publications/the-aqua-book-guidance-on-producing-quality-analysis-for-government

the NAEI. As part of their contract, DNV has reviewed two batches of models that underpin the inventory. These reviews have not found any errors in the inventory, but have concluded that there are changes that could be made to the models to improve transparency and reduce the risk of errors.

Improvements made to the inventory QA/QC system during the 2023 submission cycle included:

- Completion of data logs for the inventory compilation workbooks to improve documentation and transparency.
- Completion of assumption logs for the inventory compilation workbooks, to help identify risks, and dated assumptions.
- Removal of hard coded values within calculations in the inventory compilation workbooks, to reduce the risk of errors and improve transparency.
- Continued roll out of the NAEI Data Portal to facilitate pollutant-specific and activity data checking, building up the data set on known trend changes as well as facilitating checks. The new NAEI Data Portal also allows more focussed checking with the more significant changes more easily identified.
- Implementation of the new road transport model
- Improvements to the NRMM model to apply best practice digital principles, largely around documentation and reproducibility of the code.

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 IPCC[23] and CLRTAP[24]. The inventory data quality objectives are to achieve the principles of Transparency, Completeness, Consistency, Comparability and Accuracy (TCCCA):

- **Transparent in:**
    - 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 assumptions (e.g. source category detail and the split between UK ETS and non-UK 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.).
    - 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.

[23] 2006 IPCC Guidelines for National Greenhouse Gas Inventories: http://www.ipcc-nggip.iges.or.jp/public/2006gl/

[24] Guidelines for reporting emissions and projections data under the Convention (2013 EB Decision: ECE/EB.AIR/122/Add.1, 2013/3 and 2013/4): https://www.ceip.at/ms/ceip_home1/ceip_home/reporting_instructions/

- **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 UK ETS and non-UK ETS sources, scenarios, units for parameters and of input parameters (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 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 DESNZ 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 the 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.

- **External Review Experts:** Provide expert/peer review of emissions and 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.

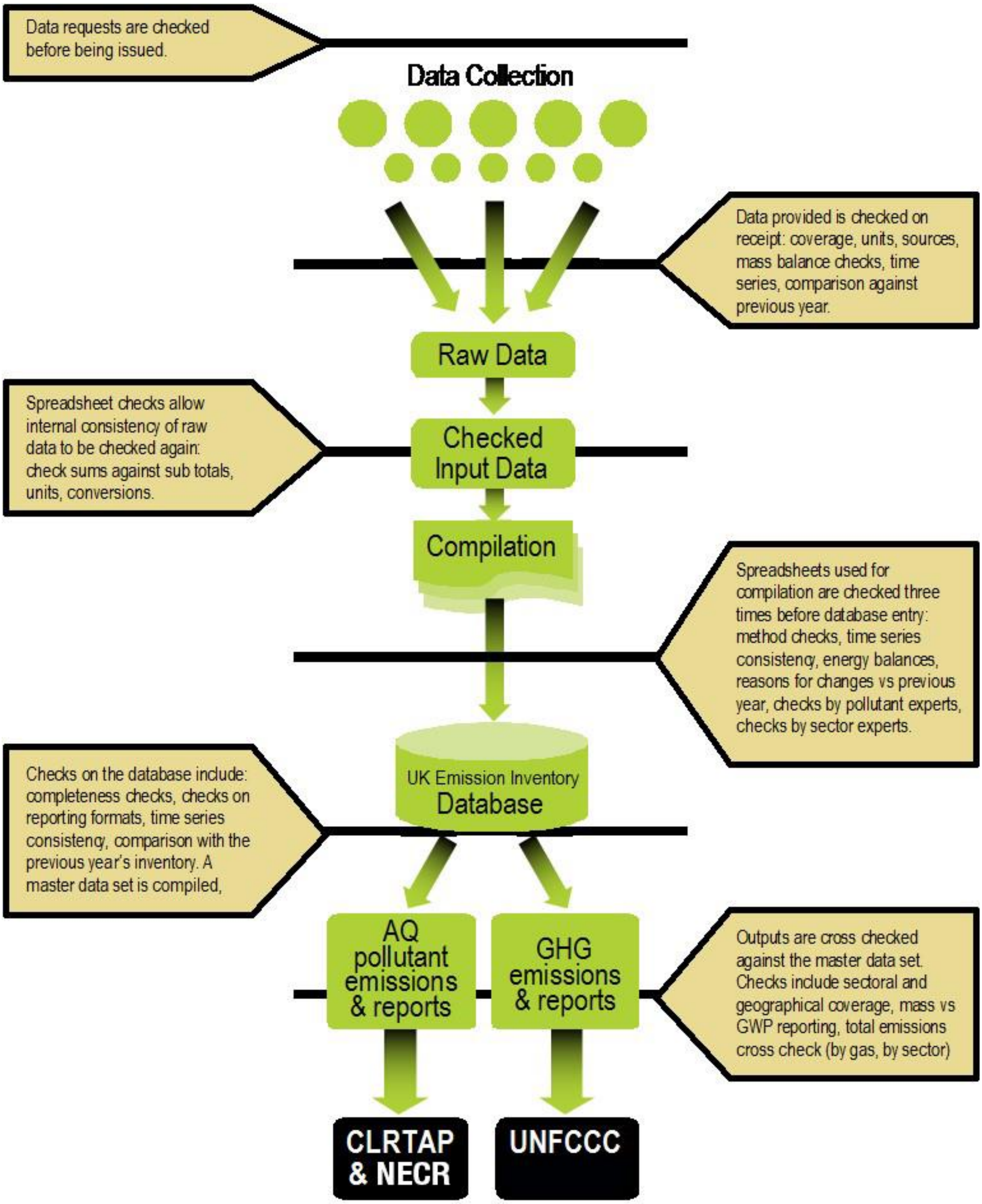
1.6.2.4 Quality Control and Documentation

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 EPR and UK 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. **<u>A database of contacts</u>** 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 UNFCCC reporting (including CRF population), responding to ad-hoc queries or deriving other downstream estimates (e.g. emissions by Devolved Administration and emissions by Local Authority). The detailed Activity Data and Emission Factor components for each source or sink category estimate are held within the NAEI database and include all sources, activities, gases/pollutants (GHGI and AQPI), 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. Several 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)[25];

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 the UK ETS and Environmental Permitting Regulations (EPR). 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. CO_2, 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 NFR 2020 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 in North Wyke) is backed up daily on their network storage system. This system is mirrored with the Rothamsted Research Harpenden site, comprising an offsite backup.
    - At UKCEH, 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

[25] 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.

UKCEH 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 UKCEH 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 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) reviews 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 (DESNZ) (see Institutional Arrangements section), who understand 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 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 1990-2021 inventory submission include:

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- The Inventory Agency are part of the stakeholder group for UK Energy statistics, which includes regular meetings with the DUKES team. The stakeholder group works to provide independent QA/QC of energy stats updates, feedback our requirements as users of energy stats, and ensure that any revisions in the DUKES data are reflected appropriately in the inventory. Other engagement happens throughout the year based on need, for example, so that time series recalculations are made in consultation with the DUKES team. This year there was some specific engagement with the DUKES team to support in the revisions to the gas oil reconciliation process for the inventory.

- Consultation with 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.

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.
- Consultation with industry regulators such as OFGEM and UREGNI has helped to improve the quality of data used for gas use and fugitive emission estimates from the gas network.
- Consultation with industry regulators to understand outliers in reported electrical gas insulation emissions.

Other data providers

- Ongoing consultation with TechWorks provided qualitative information on trends the fed into the new upgraded semiconductor model.
- Ongoing consultation with Water UK and Ofwat to improve the quality of data supply.
- Consultation with MoD to provide updated AWACS data.
- Consultation with the Iron and Steel Statistics Bureau (ISSB) to access more detailed statistics than are available through publications and to confirm the reporting of energy units;
- Consultation with the Department for Transport (DfT) to discuss the potential use of MOT data for improving the relative mileage with age assumption for road transport and to discuss the methodological approach applied for the analysis of ANPR data to develop the fleet composition;
- Discussion with the Environmental Analysis team at DfT about fleet modelling assumptions;
- Chemical Industries Association (chemicals manufacture), British Coatings Federation (manufacture of paints and inks), Euromonitor (non-aerosol personal care and household products) British Aerosol Manufacturers Association (BAMA) and the European Solvents Industry Group (solvent manufacture and use). New data from these trade bodies led to revisions mainly to the UK NMVOC inventory.

1.6.2.5.3Expert, 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, with the most recent in 2018.

Since 2002, the UK has implemented a programme of peer reviews by experts outside of the organisation responsible for the estimates. 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 1.10 Summary of Expert, Peer and Bilateral review activities

Review description	**Summary**
2022/2023: Rapid reviews of the Energy and IPPU sectors	DESNZ (then BEIS) commissioned a team of international experts to conduct a rapid review of the Energy and IPPU categories, with a focus on future requirements as well as consideration of the current methods and data. The outcomes from this review will feed into the improvement programme.
2022: Annual review of the National Greenhouse Gas Inventory Data	An individual review of the annual submission of the United Kingdom of Great Britain and Northern Ireland submitted in 2022. The ARR has been published and the actions planned or taken as a result of these findings is set out in chapter 10.
2021: Annual Review of National Greenhouse Gas Inventory Data	A 2021 annual review of national greenhouse gas inventory data by the European Environment Agency. The review considered the transparency, accuracy, consistency, comparability and completeness of the national GHG inventory. Reviewers raised a number of issues, all of which were clarified and resolved. No recommendations were made.
2021: Individual review of the annual submission of the United Kingdom of Great Britain and Northern Ireland submitted in 2021	An individual review of the annual submission of the United Kingdom of Great Britain and Northern Ireland submitted in 2021 was undertaken by the UNFCCC review team, and the findings have fed into the improvement programme.
2020: Comprehensive Review of National Greenhouse Gas Inventory Data under the Effort Sharing Decision	A 2020 comprehensive ESD review by the European Environment Agency. The review considered the transparency, accuracy, consistency, comparability and completeness of the national GHG inventory. Reviewers raised a number of issues and provided recommendations for 4 of these, which the UK accepted. These have fed though to the 2021 submission.
2006 - 2019: 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. In October 2019, the UK hosted an In-Country Review.
2019: Bilateral review of the	The UK and German inventory experts for the agriculture sector met in Germany during May 2019 to conduct a review of the new K methods and

Review description	Summary
agriculture sector with Germany	documentation. The findings of the review have fed into the inventory improvement plan for the sector.
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 an experienced UNFCCC reviewer to conduct a focussed expert review of the new UK methods. This was conducted during autumn 2018 and the findings from the review fed into the inventory improvement plan.
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.
2015: Review under the Effort Sharing Decision	Although a full review for all Member States was not conducted, the UK volunteered for the second stage of the review to consider any potentially significant issues. None were found with the UK submission.
2015: Bilateral review with Denmark, focussing on energy and IPPU sectors.	Bilateral review with Denmark, focusing on energy, and industrial processes and product use. Also considered the changes made to the UK NIR for the 2015 submission, in the absence of a formal UNFCCC review. The findings of the review fed into the compilation of the 2016 inventory submission.
2015: Multi-lateral review with Germany, France, Netherlands, Denmark, on QA/QC.	The UK participated in a multi-lateral review workshop hosted by the German UBA inventory team, to consider the IPCC 2006 Guidelines on QA/QC and review implementation across all participating countries to exchange best practice, identify any areas of ambiguity and/or difference in Member State approach to QA implementation. The findings fed into a paper submitted by UBA to the EU Working Group 1 for inventory agencies.
2014: Independent Review of the UK 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	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

Review description	Summary
Technical Expert Review Team	by this review for lime production and burning of biomass for energy to address underestimates, and for dairy cattle to address an overestimate.
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, UKCEH 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 UKCEH 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 (Regulation MMR) 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). In the past, some were 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. UKCEH participation in annual yearly knowledge sharing with European LULUCF inventory compilers at EU Joint Research Council LULUCF meetings.
2. Knowledge sharing with the Vietnam inventory team.
3. Capacity building workshop with Balkan EU accession countries on National System development.
4. Study visit by delegation from the Chinese National Centre 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.

5. Knowledge sharing between UKCEH LULUCF inventory compilers and Maltese LULUCF inventory compilers in 2016.
6. 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.
7. The UK experts on inventory verification and the InTEM (Inversion Technique for Emission Modelling) 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. This was 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.
8. NAEI experts provided capacity building project in the Kyrgyz Republic funded by the World Bank in 2018 (Ricardo with UKCEH).
9. The UK Partnering for Accelerated Climate Transitions (UK PACT) programme. UK The inventory team has several staff on the programmes roster of experts. Eligible countries can request support on GHG inventories via the British Embassy or High Commission in their country, as described at Skill-Shares and Secondments (ukpact.co.uk).
10. The DESNZ team and the Inventory Agency attended the most recent IG3IS summit on verification Geneva in February 2023

1.6.3 Verification

DESNZ has a research programme that derives independent emission estimates for the UK using in-situ high-precision high-frequency atmospheric observations of the UNFCCC gases and a range of other trace gases at the Mace Head Atmospheric Research Station on the west coast of the Republic of Ireland and a network of tall tower sites around the UK. 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, 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 sites across the UK, at Angus (north of Dundee, decommissioned in 2015), Talcolneston (Norfolk), and Ridge Hill (Herefordshire), to create the UK DECC (Deriving Emissions linked to Climate Change) Network. Two additional stations, **Heathfield (HFD)** in Southern England and **Bilsdale (BSD)** in North Yorkshire, were established through the NERC GAUGE (Greenhouse Gas UK and Global Emissions) programme. BSD replaced TTA in 2015 in the UK DECC network and is funded by BEIS. A fire at BSD in August 2021 destroyed the tower and measurements have therefore been discontinued until a replacement tower is available. HFD is supported by the National Physical Laboratory (NPL). 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 overestimating 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 online[26].

1.6.4 Treatment of Confidentiality

NAEI input data from some sources are subject to commercial confidentiality, notably where the production data and/or activity data for a specific installation or company are identifiable. For example, there are confidential data indicating the plant production capacity for specific industrial plant (e.g. cement kilns, chemical plant), annual sales data of specific commodities (e.g. sporting goods) and also details of fuel use for specific installations (e.g. plant-level data from UK ETS-regulated installations).

It is important therefore that in the management of these data within the NAEI system, and in the publication of emission estimates (and other data) relating to these data sources, that the NAEI does not disclose such commercially sensitive information.

There are several mechanisms that the Inventory Agency, Ricardo Energy & Environment, and the wider inventory compilation teams (e.g. Rothamsted Research) deploy to ensure that disclosure of confidential data does not occur:

- The provision of sensitive raw data to the Inventory Agency, if not through direct communication with the data source organisations, is managed via Defra or DESNZ using file encryption with password protection;
- Confidential data, such as the UK ETS dataset, is managed by the Inventory Agency on a password-protected secure server which has limited access rights, i.e. access is limited to the relevant compilers and checkers only;
- Within the NAEI database tables, there are specific data fields to identify confidential data. These are applied to cover all the associated data, such as emissions, AD and EFs, to minimise the risk of mistakenly releasing sufficient information that the confidential data can be inferred. These database data fields then enable ease of identification of risk of data disclosure in any NAEI database output (e.g. data at different spatial scales, such as for a specific Local Authority or in mapping outputs);
- Confidential data assignations are periodically reviewed, and in every routine data request for input data for the NAEI the organisation providing the data is given an opportunity to identify confidential data;
- Where data outputs use the confidential data, the data are reported at an aggregated level – either with other sources (e.g. in the case of sporting goods), or over a larger geographical area (e.g. in the case of emissions mapping outputs which are usually at 1km x 1km resolution, data for some sources are aggregated and smeared over a larger area, typically 10km x 10km). This may mean that the UK cannot report exactly

[26] www.metoffice.gov.uk/atmospheric-trends

in line with the expected level of sectoral resolution as defined in the CRF reporting format for GHGs, but this is considered an acceptable trade-off that is necessary to protect sensitive data.

The UK National Inventory Reports from the 1999 NIR onwards, and estimates of emissions of GHGs, are all publicly available on the NAEI website[27].

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 5.0% in 1990 and 2.5% in 2021. The trend in the total GWP weighted emissions expressed as the fall between 1990 and 2021 is -47%, with a 95% confidence interval of between -53% and -43%.

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

1.8 GENERAL ASSESSMENT OF COMPLETENESS

The UK GHG inventory aims to include all anthropogenic sources of GHGs. This section discusses sources of greenhouse gases not currently included in reporting.

1.8.1 Sources Reported as 'Not Estimated'

The below table summarises sources that are reported as not estimated in the inventory, what their expected level of emissions would be relative to the national total, and the UK's justification for not estimating these sources. Section 37(b) of the UNFCCC reporting guidelines on annual greenhouse gas inventories stipulates that Parties may report emissions as not estimated if an activity occurs in the Party, and either:

- The 2006 IPCC Guidelines do not provide methodologies to estimate the emissions/removals; or,
- A disproportionate amount of effort would be required to collect data for a gas from a specific category that would be insignificant in terms of the overall level and trend in national emissions.
- Where an emission should only 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 CO_2 eq.

The total national aggregate of estimated emissions for all gases and categories considered insignificant shall remain below 0.1 per cent of the national total GHG emissions. The below table summarises sources that are known to be not estimated in the inventory, and what their expected level of emissions would be relative to the national total.

[27] http://naei.beis.gov.uk/

Table 1.11 Summary of Not Estimated (NE) Sources[28]

Source	No 2006 IPCC guidelines methodology	Explanation for not estimating	Estimate of Emission (Mt CO_2e)	% of national total[29]	Comments on how this estimate was determined
2.C.4 Magnesium Production - PFCs	TRUE	It is estimated that the decomposition of 1 t FK 5-1-12 generates about 400 t CO_2 eq PFCs. As this product is used only at one small magnesium production plant and has been trialled at one larger plant, total emissions in the United Kingdom due to the decomposition of FK 5-1-12 could be up to about 2 kt CO_2 eq per year since 2012 and zero before 2012.	0.0020	0.000%	Based on consultation with the small number of magnesium manufacturers in the UK.
2.E.2 TFT Flat Panel Display		When deriving an estimate of emissions based on the IPCC default methodology and using the largest of the 2003-5 UK production capacities given in Table 6.7 of Volume 3 in the 2006 IPCC guidelines the estimate of emissions is smaller than the thresholds (both as a percentage of national emissions and as an absolute value of emissions) to be considered insignificant. Consultation with industry has indicated that current UK production capacity is zero	0.0084	0.002%	Based on data for 2003-5, no other data identified
2.E.3 Photovoltaics		When deriving an estimate of emissions based on the IPCC default methodology and using the 2003 UK production capacity given in Table 6.8 of Volume 3 in the 2006 IPCC guidelines the estimate of emissions is 3 orders of magnitude smaller than the thresholds (both as a percentage of national emissions and as an absolute value of emissions) to be considered insignificant. Consultation with industry has indicated that current UK production capacity is smaller than in 2003, and the limited remaining production processes do not require any F-Gases	0.0004	0.000%	Based on data for 2004, no other data identified
2.E.4 Heat Transfer fluid		Very small quantities of PFCs are sold in the UK market for this application, but it is believed that these are sold exclusively for hermetically sealed applications and products that are sold on to outside the UK.	0.0020	0.000%	This is a conservative assumption that the upper limit of PFC sales to the UK is entirely used and emitted within the UK for heat transfer fluids, although our understanding is that the majority of this PFC is emitted outside the UK.

[28] Where IE means “included elsewhere”

[29] Specifically the lowest national total annual emissions excluding LULUCF since 1990

Source	No 2006 IPCC guidelines methodology	Explanation for not estimating	Estimate of Emission (Mt CO_2e)	% of national total[29]	Comments on how this estimate was determined
3.D Agricultural Soils - CH_4	TRUE	Not estimated due to insufficient data. Emissions are expected to be very small	NE	NE	No suitable data identified to generate even an indicative value.
3.F Field burning - Overseas Territories		Data on Overseas Territory activity for this source are not available.	0.0005	0.000%	Estimate is made by applying the highest annual UK emissions from this source to the ratio of UK and OT and CD cropland areas.
3.G Liming - Overseas Territories		Data on Overseas Territory activity for this source are not available.	0.0025	0.001%	Estimate is made by applying the highest annual UK emissions from this source to the ratio of UK and OT and CD cropland areas.
3.H Urea application - Overseas Territories		Data on Overseas Territory activity for this source are not available.	0.0007	0.000%	Estimate is made by applying the highest annual UK emissions from this source to the ratio of UK and OT and CD cropland areas.
Drained Organic Soils/Overseas Territories and Crown Dependencies		Insufficient information for reporting.	NE	NE	The UK is developing an approach to estimating emissions from this source, but do not currently have suitable data to present.
Peat Extraction Lands/Overseas Territories and Crown Dependencies		Insufficient activity data for reporting.	NE	NE	The UK is developing an approach to estimating emissions from this source, but do not currently have suitable data to present.
1.B.1.a.1 Underground Mines - CO_2	TRUE	There are no data available on CO_2 content of coal mine methane in the UK, and therefore we have considered the 2006 Guidelines, section 4.1.2: "The following sections focus on methane emissions, as this gas is the most important fugitive emission for coal mining. CO_2 emissions should also be included in the inventory where data are available". CO_2 from combustion of coal mine methane is included in the UK GHGI under 1A1c and 1A2g.	0.0041	0.001%	This is the highest value since 1990 when estimated by assuming that colliery methane has a similar CO_2 content to natural gas.

Source	No 2006 IPCC guidelines methodology	Explanation for not estimating	Estimate of Emission (Mt CO_2e)	% of national total[29]	Comments on how this estimate was determined
2.D.3 Other/Solvent use	TRUE	Indirect CO_2 emissions from the oxidation of VOCs are not mandatory for reporting under the UNFCCC reporting guidelines.	0.1843	0.045%	Estimate of emissions due to abatement of NMVOC by oxidation presented. This estimate is based on the differences in emissions of NMVOC reported for 2017 for each source category within 2D3 compared with emissions reported for 1990 (when solvent emissions will not have been abated). For almost all source categories, NMVOC emissions are lower in 2017 than in 1990 and expert judgement was applied as to what proportion of the reductions in each category was driven by sector decline, reformulation of products, changes in practices to minimise solvent requirement, recovery or destruction by oxidation. Emissions from oxidation of solvents may have been higher in some years in the past but only from the late nineties onwards (since most processes did not abate emissions before then). Since total emissions were also significantly higher in the past, we believe that it is likely that emissions from abatement of NMVOC would represent a similar % of total emissions in those earlier years.

Source	No 2006 IPCC guidelines methodology	Explanation for not estimating	Estimate of Emission (Mt CO_2e)	% of national total[29]	Comments on how this estimate was determined
2.H.2 Food and beverages industry - CO_2	TRUE	No appropriate data available	NE/IE	NE/IE	Use of CO_2 by-products from industrial processes (e.g. ammonia production) in the food and drink industry (e.g. carbonated drinks). For simplicity, the UK currently includes all CO_2 by-product from UK ammonia production in the national total, but this estimate is not necessarily the same as UK final consumption of products containing CO_2 by-product. In order to generate an accurate and complete estimate of UK emissions of CO_2 from by-products we would need to estimate the imports and exports of CO_2 by-product and imports and exports of products containing by-product CO_2. There are also sources of CO_2 of biogenic origin in this source, but these would not contribute to the national total, so have not been considered.
4.B and 4.C/4(V) Biomass Burning/Wildfires - CO_2		Assumed to be replaced by re-growth within the year.	0	0.000%	Assumed to be replaced by re-growth within the year. No evidence of wildfires on permanent crops.
5.A Solid Waste Disposal - CO_2	TRUE	Emissions of CO_2 are biogenic and therefore are excluded.	0	0.000%	As sources of non-LULUCF CO_2 of biogenic origin are not included in the national total, the impact on the national total is 0.
Total			**0.205**	**0.050%**	
Total excluding sources for which there is no 2006 IPCC guidelines methodology			**0.014**	**0.004%**	

This summary confirmed that there are no sources for which emissions are not estimated which would be expected to be above 0.05% of the UK national total in any year, and that the sum of the sources is estimated to be under 0.1%. Note that many of the sources included are reported as

“NE” due to there not being a suitable methodology to generate an estimate, when including only sources for which are not reported due to insignificance, the likely proportion of emissions omitted is much lower than 0.1% of the UK national total in any year. Therefore, the UK inventory’s use of ‘NE’ in the CRF is compliant with section 37(b) of the UNFCCC reporting guidelines on annual greenhouse gas inventories.

1.8.2 Sources Outside the Scope of the National Total

The following sections discuss sources of emissions relating to UK activities relevant to climate change which are excluded from the national total due to being outside of the scope of greenhouse gas inventory reporting requirements.

1.8.2.1 International Aviation and Shipping

International shipping and aviation refer to emissions associated with travel from a location within the geographic scope of the inventory to a location outside that scope. The approach adopted by the UNFCCC is that combustion emissions from these journeys are to be reported as 'memo items' but not included in Party's national totals. The UNFCCC separately engages with the Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) regarding these emissions[30].

Emissions from processes other than fuel combustion can occur on these international journeys (e.g. fugitive emissions of HFCs used in refrigeration or air conditioning in shipping), however these emissions are comparatively small, and many of these source are likely to be indirectly captured by territorial emissions estimates for those sources.

In accordance with UNFCCC reporting requirements, the UK GHGI reports emissions and activity relating to due to fuel combustion in international aviation and shipping as a 'memo item' in CRF Table1.D, and the methodology is presented in **MS 7** and **MS 13**, but these are not included in national totals. The UK does not make specific estimates of, or report emissions of sources that occur on international journeys other than fuel combustion and lubricant use.

1.8.2.2 Aviation-Induced Radiative Forcing

Almost all anthropogenic emissions occur at or near ground level, and therefore emissions are reported using Global Warming Potentials (GWPs) that reflect how pollutants contribute to global warming when released at ground level. However, emissions that are emitted at high altitudes (i.e. fuel combustion emissions from the cruise stage of flights) contribute to atmospheric chemistry differently to ground level emissions due to contrails and their impact on cloud formation, although precisely how strong this effect is sensitive to a number of factors, and remains uncertain[31].

The UK GHGI reports emissions and activity from emissions due to aviation cruise in CRF Table1.A(a)s3 and Table1.D and the methodology is presented in **MS 7**. However, these emissions reported do not account for the aviation-specific impact as there is no approach to account for this in the 2006 IPCC guidelines and it is not facilitated in the reporting mechanisms adopted by the UNFCCC.

1.8.2.3 Carbon Dioxide of Biogenic Origin

Carbon dioxide contributes to the greenhouse gas effect independently of whether originating from a mineral (e.g. fossil fuels) or biogenic (e.g. wood burning) origin. The main difference between mineral and biogenic carbon is that without anthropogenic intervention, mineral carbon generally remains stored in a solid form and does not interact with atmospheric chemistry, whereas without anthropogenic intervention, biogenic carbon is part of a natural cycle where some is released to the atmosphere as CO_2, and CO_2 is absorbed from the atmosphere to be stored in organic matter. Because of this, anthropogenic activity contributes to higher levels of CO_2 from these sources differently; i.e. anthropogenic mineral CO_2 sources are effectively increasing the total carbon in circulation, whereas anthropogenic contribution

[30] https://unfccc.int/topics/mitigation/workstreams/emissions-from-international-transport-bunker-fuels#eq-2

[31] https://www.ipcc.ch/site/assets/uploads/2018/03/TAR-06.pdf

of biogenic CO_2 are a shifting of the split in the carbon cycle to have a higher proportion in the atmosphere.

One approach to estimate the net change to carbon in the atmosphere is to estimate the changes in carbon stored in vegetation, soils and other organic matter. This approach accounts for emissions of CO_2 by assuming that carbon in vegetation removed is eventually emitted via combustion, animal consumption and respiration, or decomposition, and simultaneously accounts for CO_2 sequestered and stored by vegetation. The 2006 IPCC guidelines sets out a methodology to account for carbon stock changes in this way, and the UNFCCC agreed that this method should be used, the net carbon stock change reported against Land Use, Land Use Change and Forestry (LULUCF) and included in Party's national totals.

The approach for accounting for carbon stock changes in land means that including estimates of emissions of CO_2 from fuels of biogenic origin at the point of release would be a double count of this carbon stock approach, and therefore estimates of CO_2 of biogenic origin at the point of release is excluded from national totals, but can be reported as a 'memo item'.

The UK uses the UNFCCC agreed LULUCF approach for accounting for CO_2 of biogenic origin, which is reported in CRF Table4 to Table4(IV) and the methodology is discussed in **Section 6**. The UK also reported CO_2 of biogenic origin from fuel use or incineration against the various sectors in which they are combusted as 'memo items' the total of which is presented in CRF Table10s1, but these values are not included in the national total.

1.8.2.4 Ozone Depleting Substances (ODS) regulated under the Montreal Protocol

These substances are explicitly excluded from requirements to report under UNFCCC. As stated at https://unfccc.int/process-and-meetings/transparency-and-reporting/methods-for-climate-change-transparency/methodological-issues-relating-to-fluorinated-gases:

- "The UNFCCC agreed that all Parties shall develop national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases (GHGs) not controlled by the Montreal Protocol..."; and,

Where the Montreal Protocol is a UN agreement for the control of ODS.

Many ODS are additionally potent greenhouse gases, for which we estimate peak emissions in the 90s to be over 20Mt CO_2e. Almost all emissive uses of ODS have been discontinued, many using HFCs as a substitute (also potent greenhouse gases, but with zero ozone depleting potential).

ODS emissions are not reported in the UK Greenhouse Gas inventory, but some ODS use is modelled as part of understanding emissions of ODS-substitutes.

1.8.2.5 Other Substances with Non-Zero GWPs

These substances are not included in the products required to be reported under UNFCCC or otherwise. Most of these products are believed to be only used in small quantities, have modest GWPs, or both. For example, key substitutes for high GWP HFCs include hydrofluoroolefins, or hydrocarbons, which typically have GWPs two orders of magnitude smaller than the HFC being replaced. It is estimated that in recent years total emissions from these pollutants exceed 0.1 Mt CO_2e.

Emissions of these products are not reported in the UK Greenhouse Gas inventory, but some use is modelled as part of understanding emissions of products they are used to substitute.

1.8.2.6 Water Vapour

Water vapour is abundant in the atmosphere, significantly contributes to the Earth's Greenhouse effect, and there are anthropogenic sources of water vapour (e.g. from the combustion of most fossil fuels). However, it is believed that atmospheric concentrations of water vapour are primarily driven by temperature (warmer air can maintain higher humidity, and warmer water evaporates at a greater rate)[32], and anthropogenic emissions do not contribute significantly[33]. Because of this, water vapour is key to understand for climate modelling, including how water vapour can contribute to a warming feedback loop, but not important for estimating anthropogenic emissions in greenhouse gas inventories. Therefore, no estimate is made or reported for water vapour emissions in the UK GHGI.

1.8.2.7 Indirect Greenhouse Gases

In addition to the direct GHGs, scientists also consider the effects of indirect GHGs on the radiative forcing of the atmosphere. Although they are not included in GWP weighted greenhouse gas emissions totals, these indirect GHGs affect the overall radiative balance of the atmosphere. There are four indirect GHGs which must be reported under the UNFCCC, and estimates of their emissions are reported in across the CRF tables, and the NIR against the various sources where these pollutants arise. They are:

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

The effects of these gases on radiative forcing are complex. CO, NO_X and NMVOC control in part the abundance of ozone (O_3) and the oxidising capacity (OH) of part of the upper atmosphere called the troposphere. These pollutants act as indirect greenhouse gases through their influence on atmospheric chemistry; for example, through the formation of tropospheric O_3 or changing the lifetime of CH_4. The emissions of NO_x and CO are dominated by human activities[34]. Sulphate aerosols, formed from releases of SO_2 which because of their small size are effective scatterers of sunlight and have long lifetimes, are responsible for radiative forcing. Volcanic eruptions that inject substantial amounts of SO_2 gas into the stratosphere are the dominant natural cause of externally forced climate change on annual and multi-decadal time scales[35].

A reduction in SO_2 emissions leads to more warming. NO_X emission control has both a cooling (through reducing of tropospheric ozone) and a warming effect (due to its impact on methane lifetime and aerosol production)[35].

1.8.2.8 Other Climate Forcing Pollutants

Particulate matter also plays a part in radiative forcing. The colour or reflectivity of the particles is important and the effects on forcing are complicated. Air pollution control measures to limit the levels of particulate matter emitted in turn will affect the emissions and atmospheric

[32] https://www.nasa.gov/topics/earth/features/vapor_warming.html

[33] IPCC FAQs, Q1-2-3 at https://www.ipcc-nggip.iges.or.jp/faq/faq.html.

[34] https://www.ipcc.ch/site/assets/uploads/2018/03/TAR-04.pdf "Atmospheric Chemistry and Greenhouse Gases" Executive Summary

[35] https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf. Chapter 8 Anthropogenic and Natural Radiative Forcing. Section 8.4.2 Volcanic Radiative Forcing. FAQ 8.2 | Do Improvements in Air Quality Have an Effect on Climate Change?

concentrations of several pollutants, including: NO_X, NMVOCs, ammonia, black carbon, organic carbon, and SO_2. In some cases, this can result in both heating and cooling effects.

Aerosol cooling occurs through aerosol–radiation, and, aerosol–cloud interactions. On the other hand, black carbon (BC) or soot, absorbs heat in the atmosphere leading to radiative forcing. When BC is deposited on snow, it reduces its or ability to reflect sunlight. Reductions of BC emissions can therefore have a cooling effect, but the additional interaction of black carbon with clouds is uncertain and could lead to some counteracting warming.

Some couplings between the air quality pollutant emissions and climate are still poorly understood or identified, including the effects of air pollutants on precipitation patterns, making it difficult to fully quantify these consequences[35].

Particulate emission and black carbon are not included in the GHGI, but are reported in the UK submissions under the Convention on Long-range Transboundary Air Pollution (CLRTAP).

1.8.2.9 Carbon fluxes from underwater terrain

Currently, carbon dioxide fluxes (i.e. sequestration or emissions) from sea, lake and river beds (also referred to as ‘blue carbon’) are not included in the UK national atmospheric emissions inventory. This is primarily driven by the omission of a methodology for estimating these in the IPCC guidelines (the methodological guidance for national inventory reports adopted by the UNFCCC), where the omission of the methodology means that national inventories are not required to generate an estimate. Countries would have to go out of their way to develop the evidence based upon which to make an estimate if they wanted to include it.

The UK can and does estimate emissions and sinks from sources not included in the IPCC guidelines where suitable data and methodologies are identified, and in some cases conduct research to develop those data and methodologies. In this case, our understanding is that doing so for underwater terrain would be complicated by:

a) the high uncertainty in estimates for CO_2 fluxes (e.g. the chemistry is fundamentally different to above water fluxes, as water absorbs atmospheric CO_2, so the location in the water column would impact the quantity eventually released to the atmosphere, but it would also indirectly impact the atmospheric CO_2 which can be absorbed by water);

b) the challenge in understanding what proportion of these fluxes are anthropogenic (we consider all on land fluxes in the UK to be anthropogenic as the entirety of the UK is populated, but this is less clear for underwater terrain);

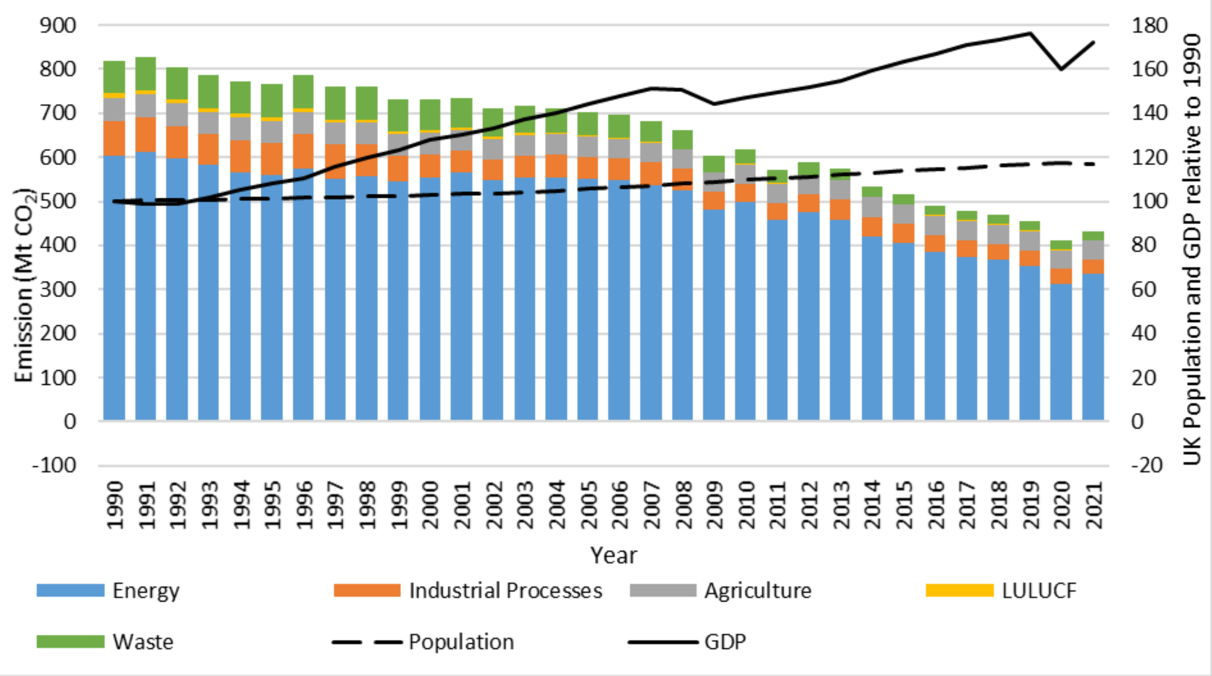
c) the question of territorial boundaries, noting that UK fishing vessels operate outside UK waters, and non-UK fishing vessels operate within UK waters; and,

d) the reporting systems for inventory reporting do not provide a framework for reporting such fluxes (it would most naturally fit with Land Use, Land Use Change and Forestry, but there are no reporting categories for non-land).

Some of these are less of an issue for coastal wetlands, and therefore inclusion of these is more likely that other underwater terrain fluxes.

2 Trends in Greenhouse Gas Emissions

Figure 2.1 Total GWP weighted emissions by sector[36]



[1] Population and GDP figures from ONS

Figure 2.2 Trends in emissions by sector relative to 1990[37]

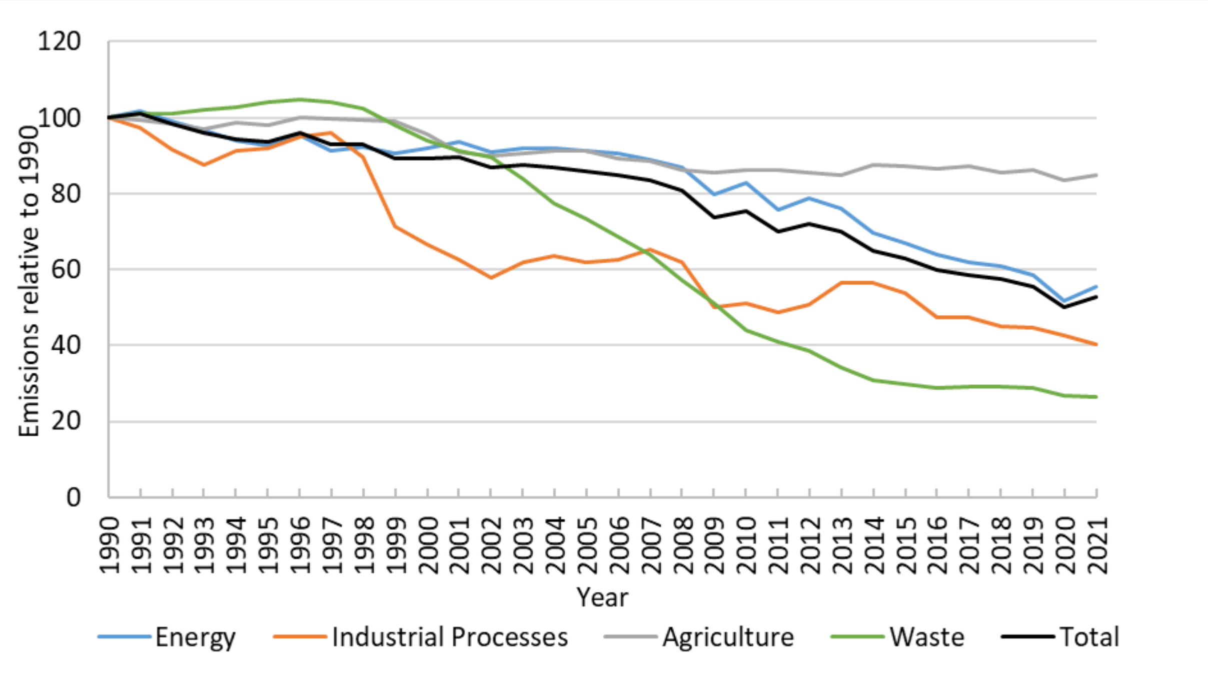
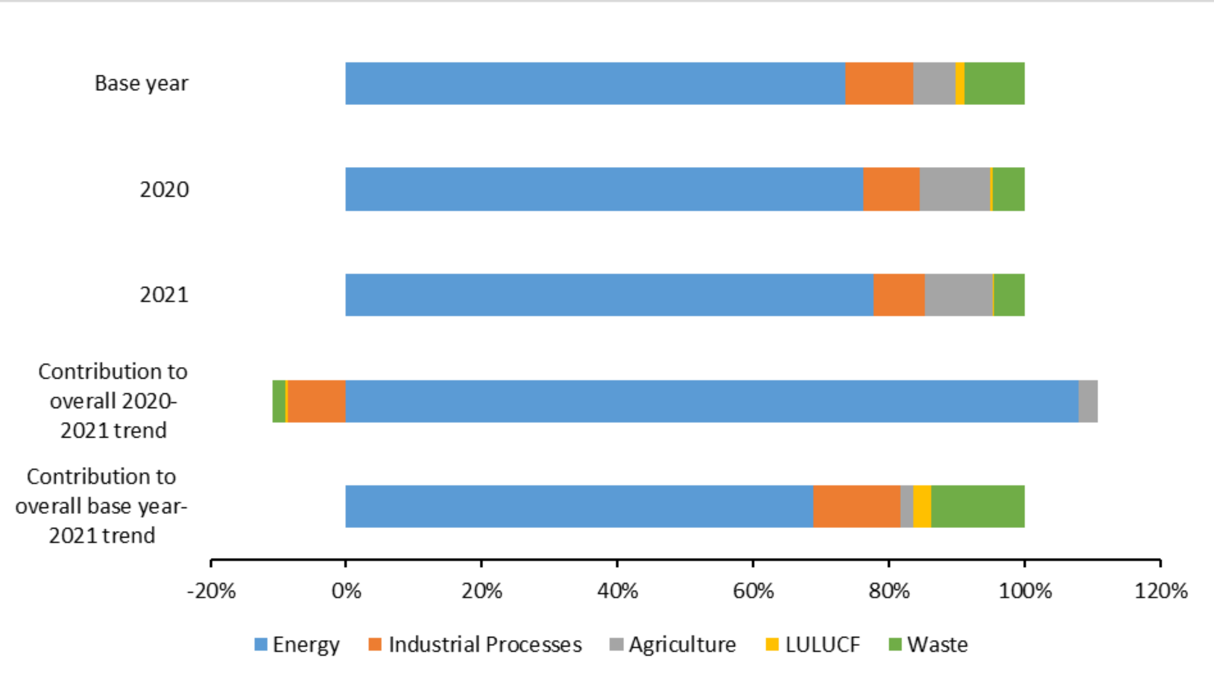


Figure 2.3 Contribution to National totals in the selected years and to overall trends between selected years by sector[38]



[37] 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.

[38] 'Base year' refers to 1990 for CO_2, CH_4 and N_2O, or 1995 for F-gases. F-gases are fluorine containing compounds which are potent greenhouse gases, including: Sulphur Hexafluoride (SF6), Nitrogen Trifluoride (NF3), Perfluorocarbons (PFCs) and Hydrofluorocarbons (HFCs).

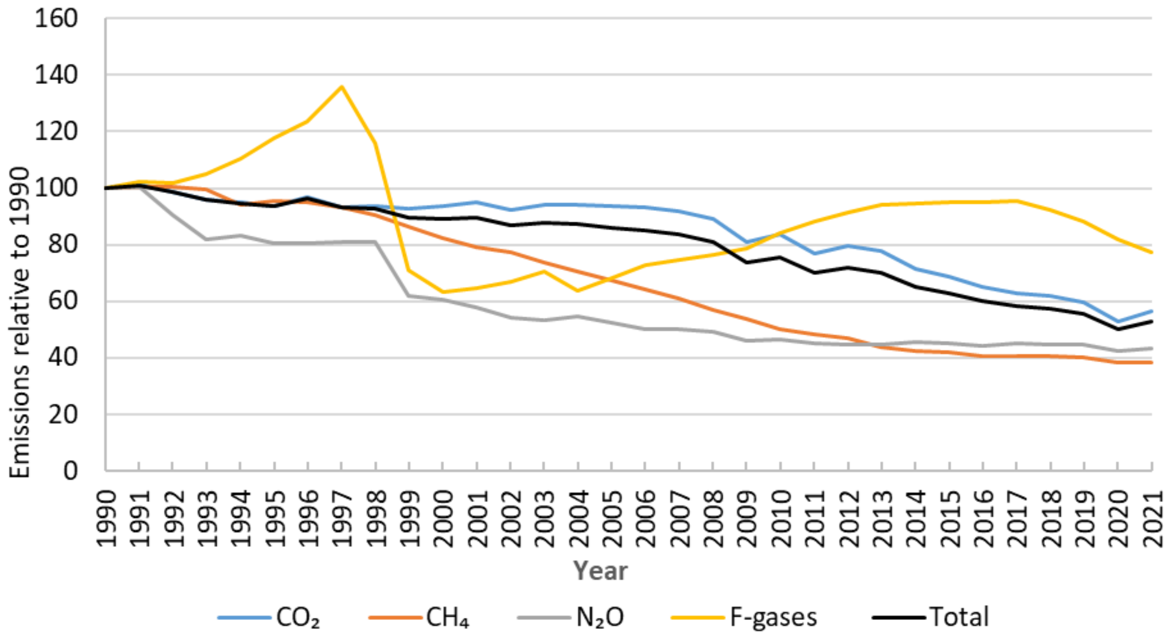
As shown in **Figure 2.1** and **Figure 2.2**, total emissions of direct GHGs have decreased since 1990. **Figure 2.3** illustrates that this decline is driven predominantly by a decrease in emissions from the energy sector – particularly from power stations The increase between 2020 and 2021 is due to the increase in activity following the restrictions caused by the COVID-19 pandemic. 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 LULUCF.

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.

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.

Figure 2.4 Trends in emissions by gas relative to 1990[39]



[39] F-gases are fluorine containing compounds which are potent greenhouse gases, including: Sulphur Hexafluoride (SF_6), Nitrogen Trifluoride (NF_3), Perfluorocarbons (PFCs) and Hydrofluorocarbons (HFCs).

Figure 2.5 Contribution to National totals in the selected years and to overall trends between selected years by gas

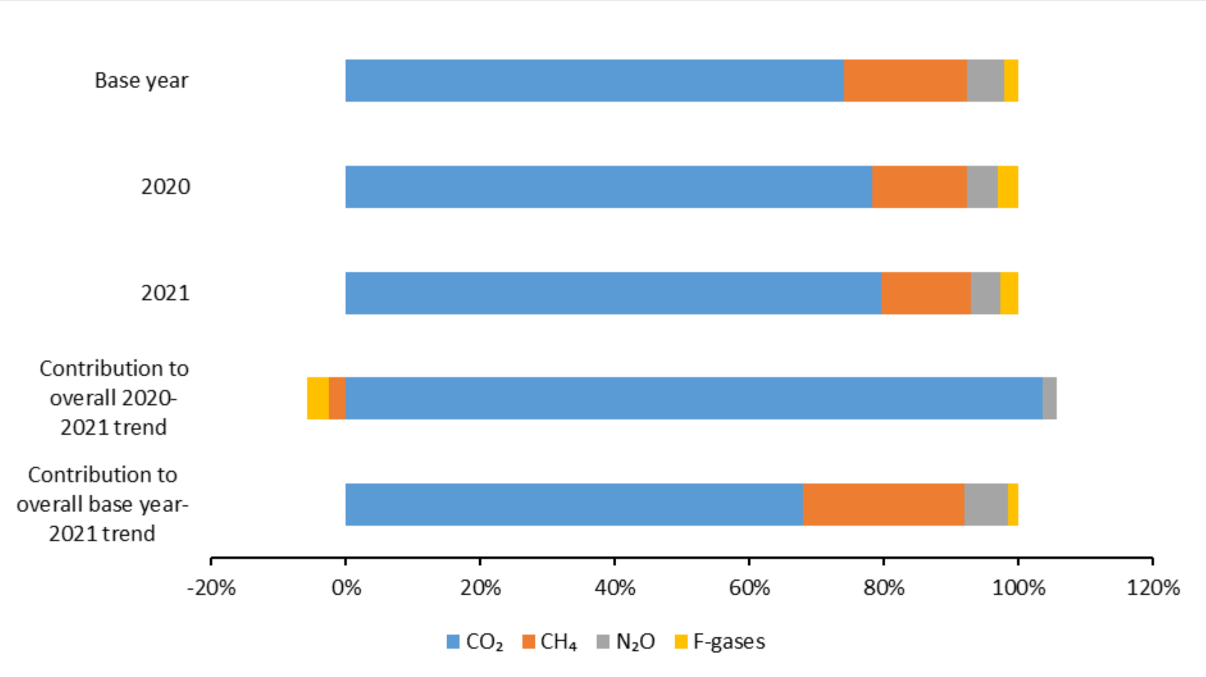


Figure 2.5 presents the contribution of each GHG to the UK emissions trend:

- Emissions of CO_2 are by far the largest component of total GHG emissions, of which the largest sources are power generation and road transport. Emissions have reduced across the time series due to fuel switching, structural change, and improvements in end-use efficiency. The strong link between power generation and CO_2 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 (CH_4)**. Annual emissions of CH_4 have reduced by over half since 1990. The main sources of CH_4 are agriculture, waste disposal, leakage from the gas distribution system and coal mining. Reductions in CH_4 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 (N_2O)** have also reduced by over half since 1990. Most N_2O emissions are generated from the agriculture sector, Agriculture sector N_2O emissions have decreased primarily due to reduced emissions from synthetic fertiliser application. N_2O is also released during the production of nitric and adipic acid, a significant source in 1990 contributing to approximately half of all N_2O emissions. Due to a decline in production together with the installation of abatement equipment, the Industrial Processes and Other Product Use (IPPU) sector now only contribute around 4% of N_2O emissions.
- The smallest percentage reduction in emissions across the time series is for the **F-gases:** HFCs, PFCs, NF_3 and SF_6. All F-gas emissions are accounted for under the 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 to some extent 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 2.6 Total GWP weighted emissions in the energy sector compared to primary energy demand

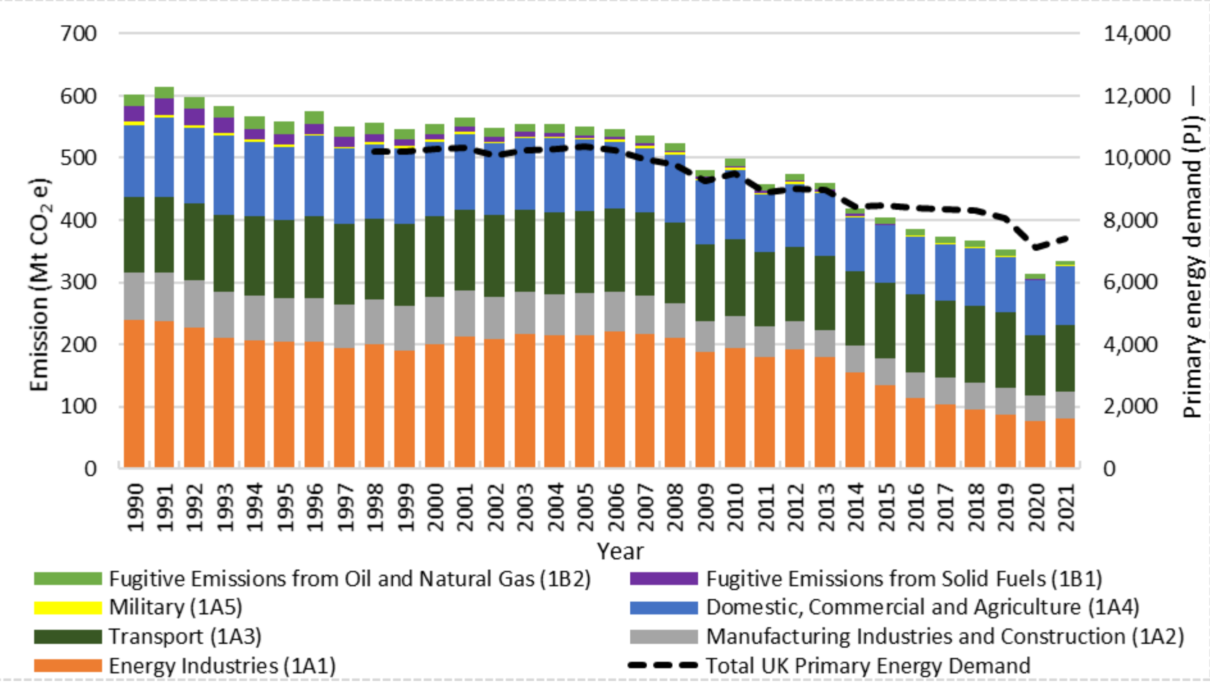


Figure 2.7 Trends in Energy emissions by sub-sector relative to 1990

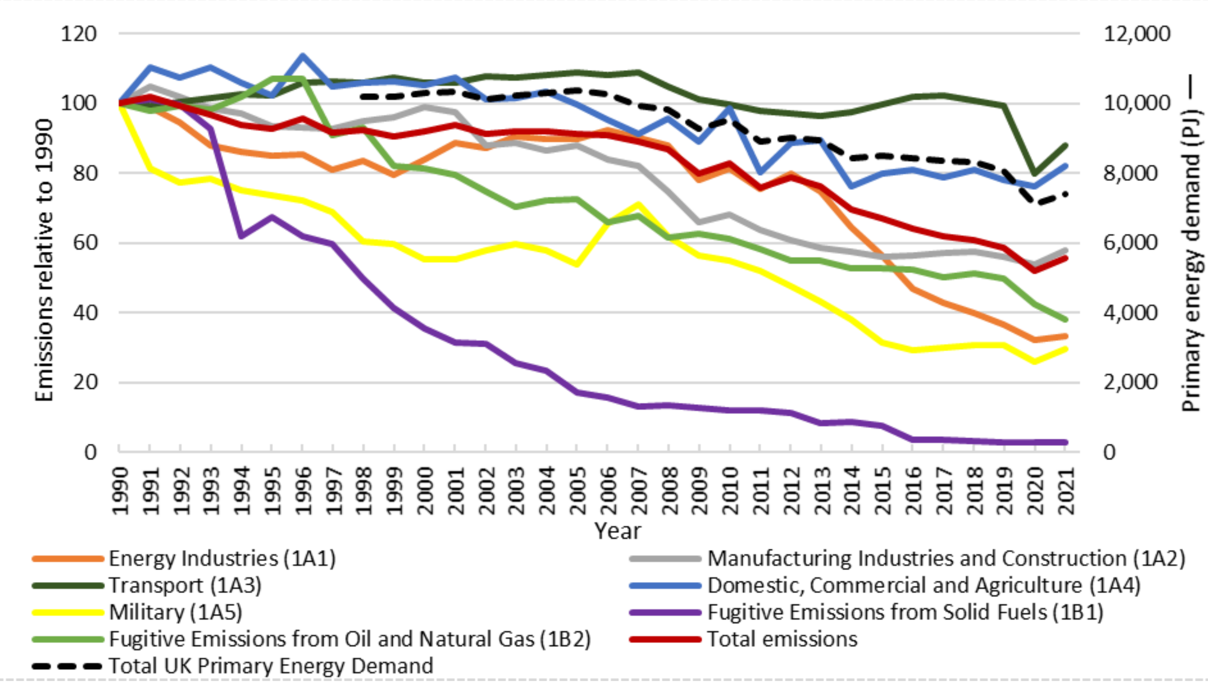
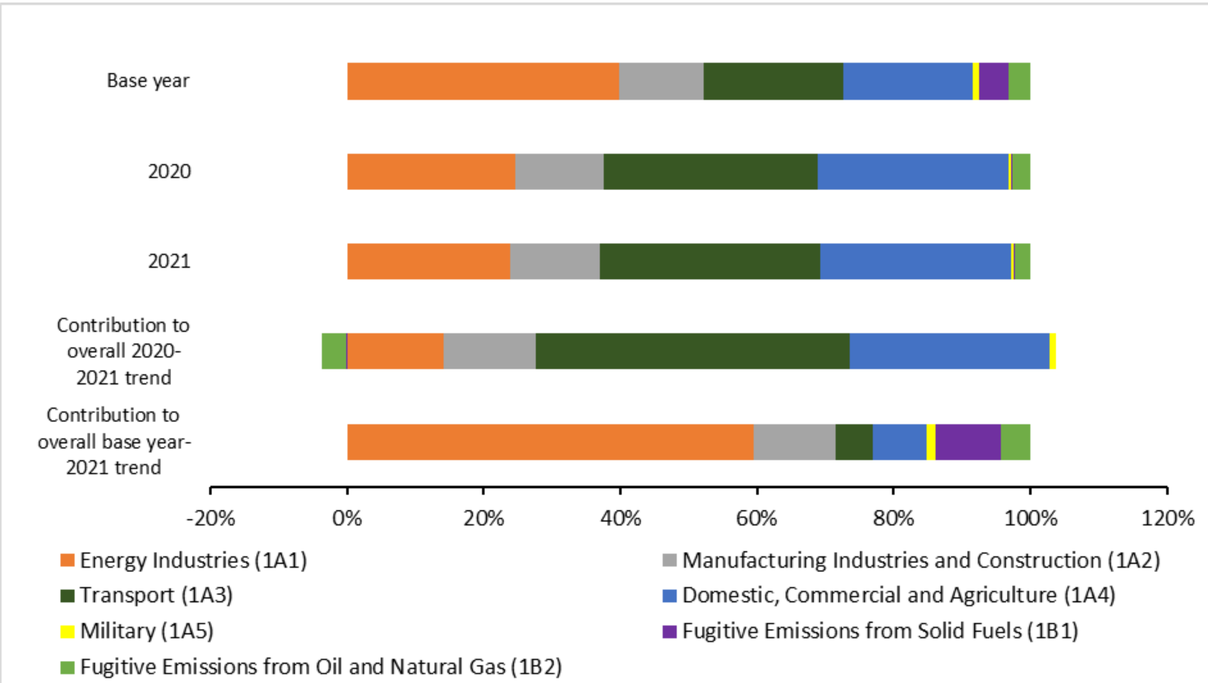


Figure 2.8 Contribution to totals in the selected years and to overall sectoral trends between selected years by sub-sector for Energy



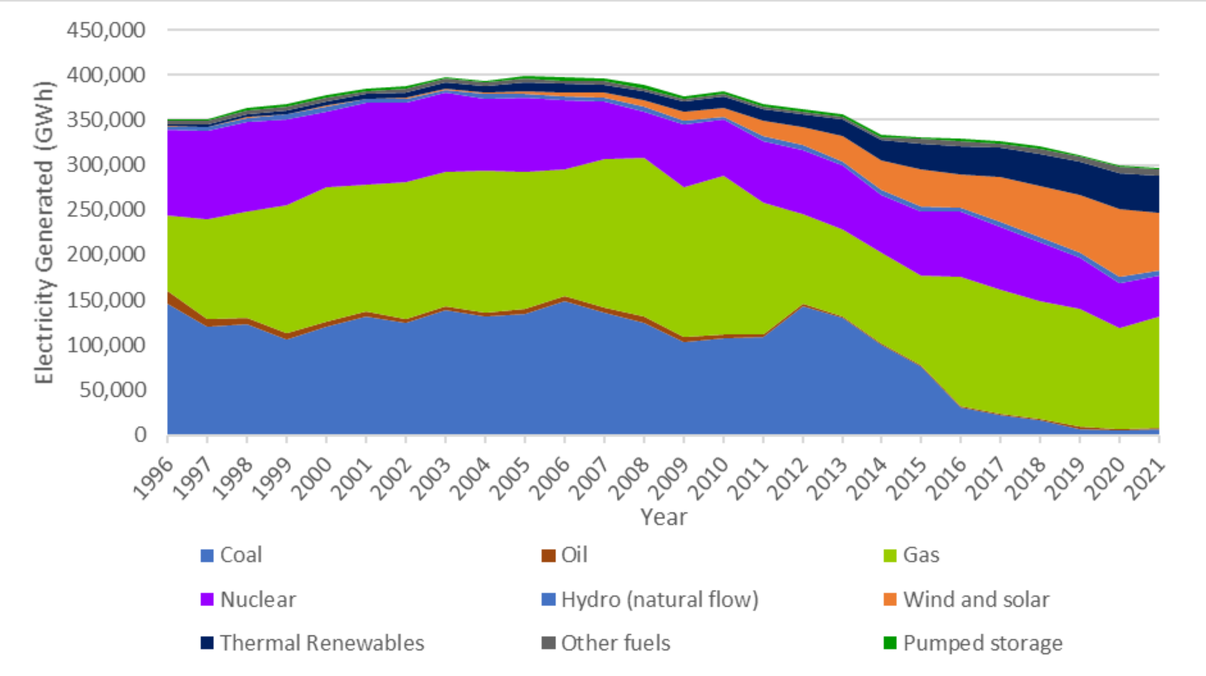
The energy sector GHG emissions are primarily CO_2 from fossil fuel combustion in power generation, transport, manufacturing and construction, and other stationary and mobile fuel combustion. The supply of fossil fuels also leads to significant emissions of CH_4 from fugitive emission sources, such as from coal mining, oil and gas extraction and from the natural gas transmission and distribution system.

Figure 2.7 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 proportional use of natural gas, nuclear power, and renewables. There have also been large reductions in fugitive CH_4 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 2.9 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 2018 they operated on average at 48.9% efficiency, whilst coal-fired stations operated on average at 34.1% 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.

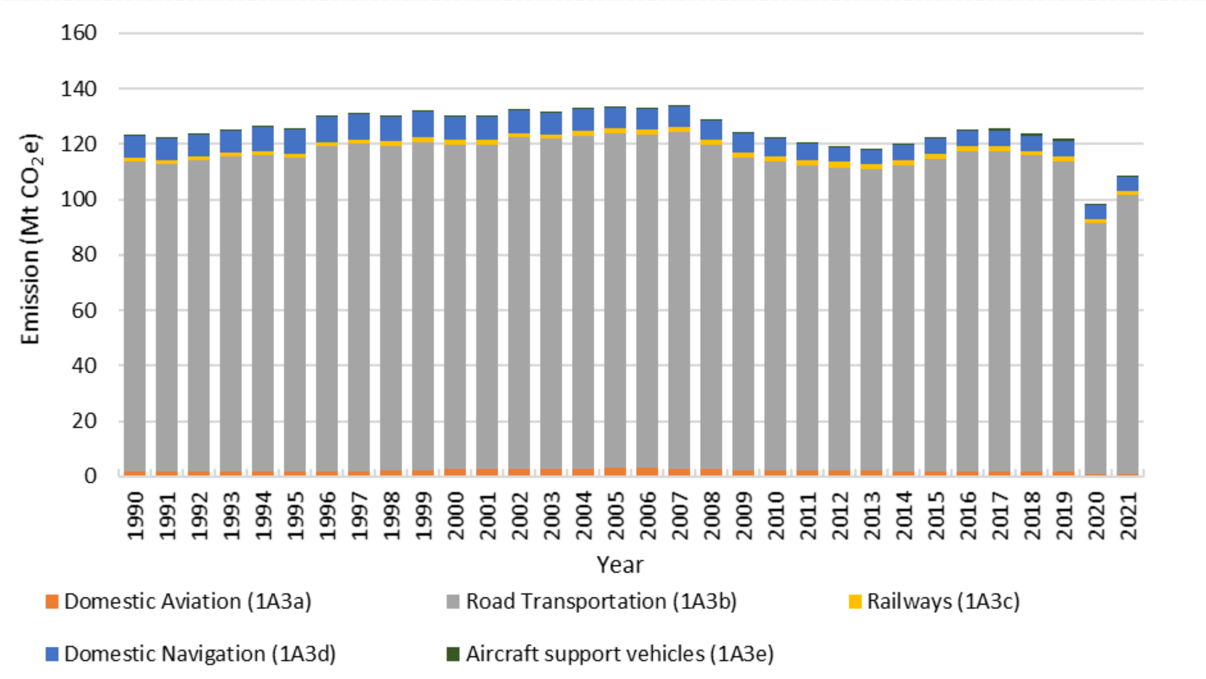
2.1.2.2 Manufacturing Industries and Construction

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 over 40% 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 2.10 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 2019 were just below 1990 levels. Emissions increased in 2021 after a large decrease in 2020 due to the COVID-19 pandemic. This trend prior to 2020 was 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 N_2O 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 CO_2 emissions from the consumption of biofuels are not included in the UK totals[40].

[40] 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**.

Emissions from domestic aviation increased between 1990 and 2005 but have subsequently decreased to levels comparable to 1990 by 2019. This is because of a move to use more fuel-efficient aircraft in 2006 and a lower number of air miles being flown. There was an increase in emissions from domestic aviation in 2021 after a large reduction in air travel in 2020 due to the COVID-19 pandemic.

Shipping emissions in the UK peaked in the late 1990s and have decreased since then. 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. Shipping emissions increased in 2021 after a notable drop in 2020 due to the COVID-19 pandemic.

2.1.2.4 Domestic, Commercial and Agriculture

Emissions from domestic fuel combustion dominate 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 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.

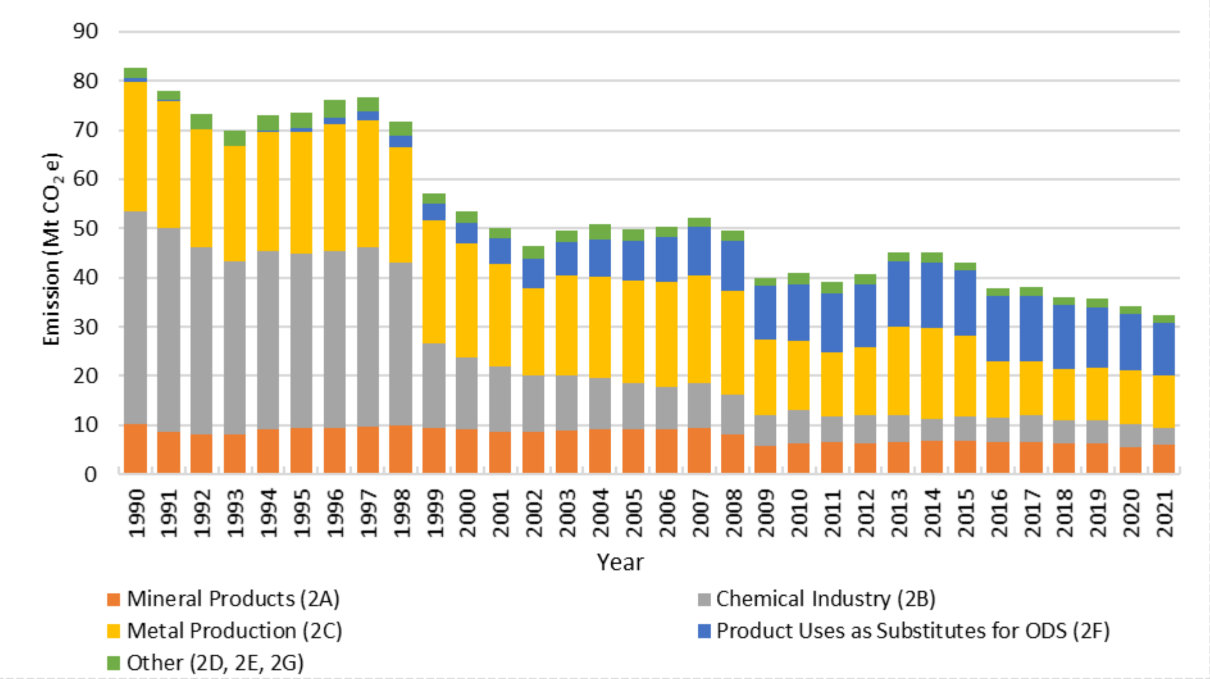
2.1.2.5 Fugitives (Energy exploration, production, and distribution)

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 pipework 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 2.11 Total GWP weighted emissions in the Industrial Process and Product Use sector[41]



[41] Other includes 2D – Non-energy Products from Fuels and Solvent Use, 2E – Electronics Industry, and 2G – Other Product Manufacture and Use.

Figure 2.12 Trends in emissions from Industrial Processes and Product Use by sub-sector, relative to 1990[42]

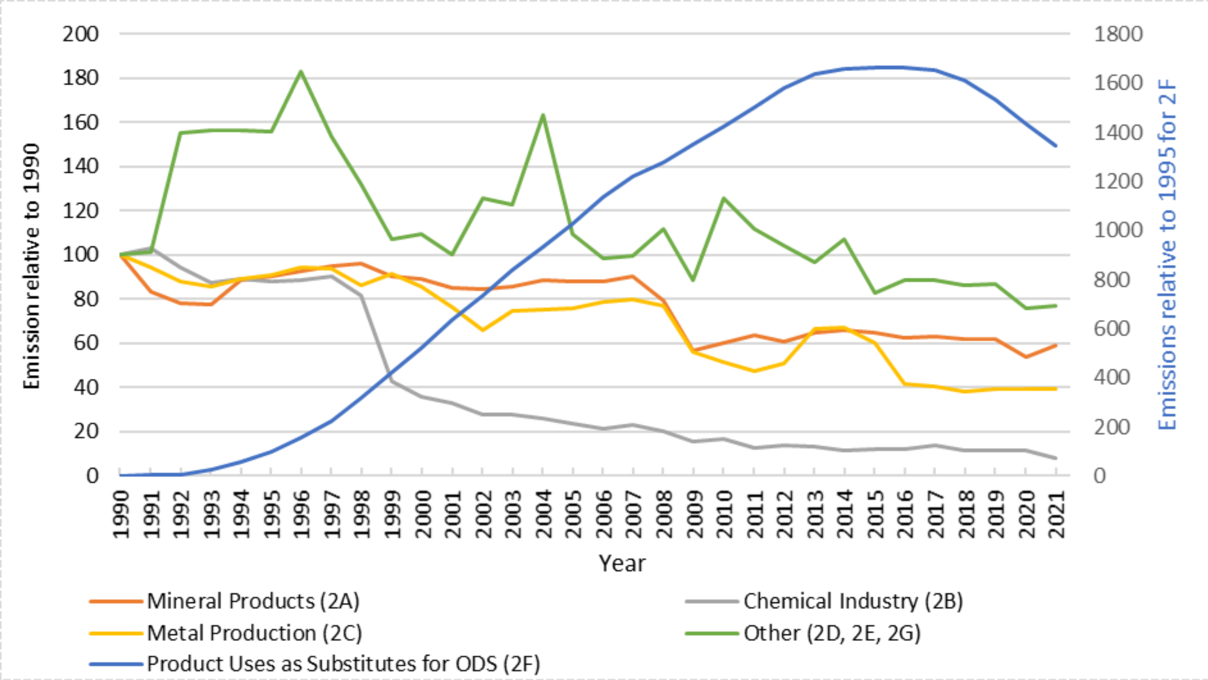
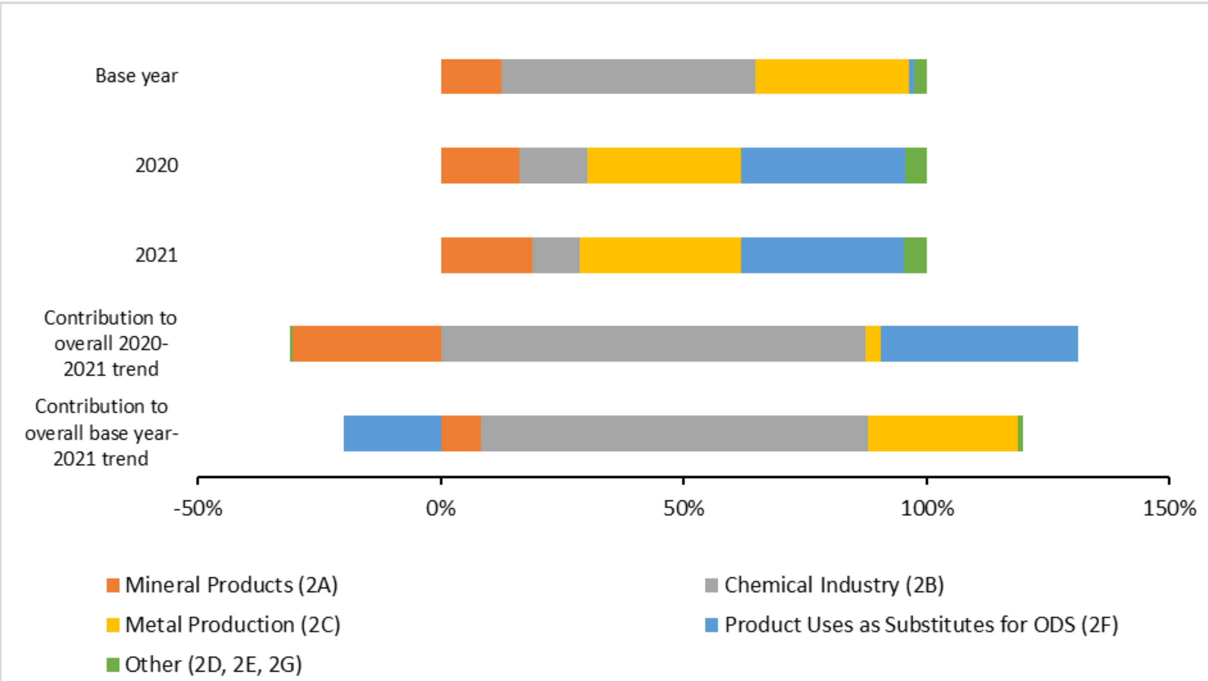


Figure 2.13 Contribution to totals in the selected years and to overall sectoral trends between selected years by sub-sector for Industrial Processes and Product Use



[42] Emissions from sector 2F 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 sources[43] and product use including solvents. Just under half of IPPU emissions are now CO_2, although this only contributes to small proportion of total CO_2 emissions. All F-gas emissions are generated from IPPU sources, and there are small quantities of CH_4 and N_2O emissions.

The number of industrial process sites in the UK have been declining since 1990 (see **Figure 2.14** - **Figure 2.16**). The declining trend in IPPU emissions in the UK (see **Figure 2.11**) 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 N_2O 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.

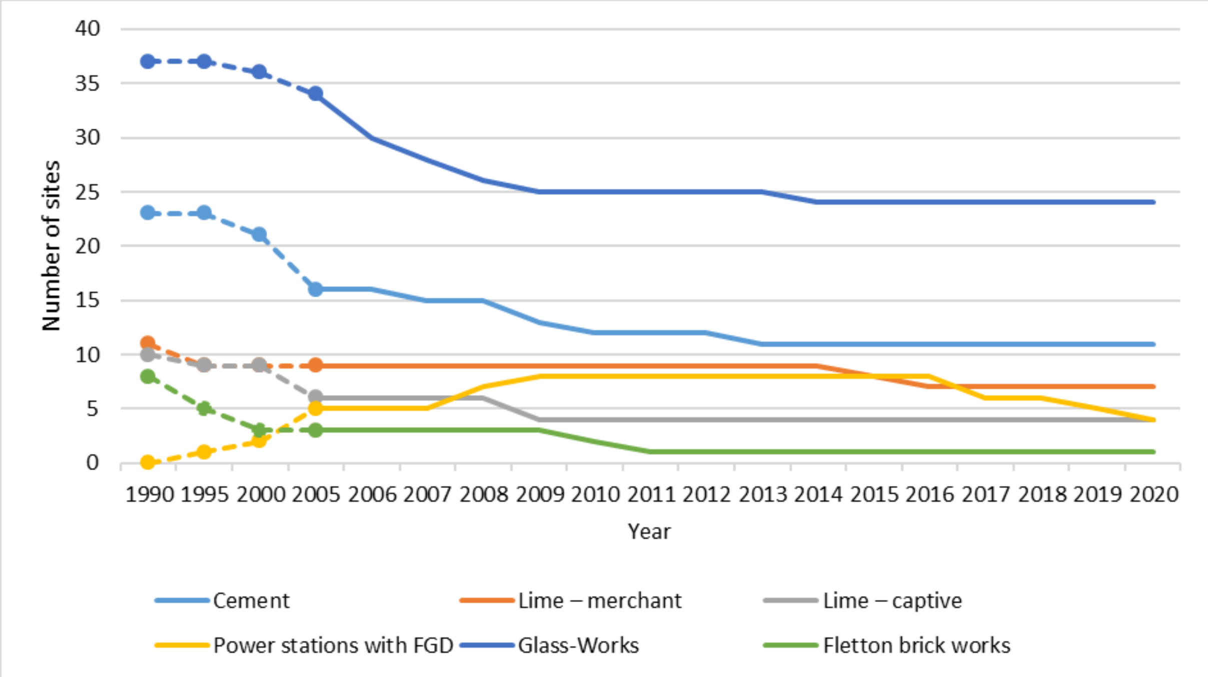
Since 2008 an increasing number of applications have been restricted from using higher GWP HFCs by EU regulation of F-gases. EU regulation has also become more stringent regarding the management of HFCs and HFC-using systems, and since 2015 a quota system was introduced, limiting the total HFC (on a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

Further discussion of these trends, including how they compare to atmospheric measurements, and other European countries subject to HFC-quota systems can be found in **Section 4.29.4**.

[43] 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 2.14 Trends in the number of mineral process sites[44]



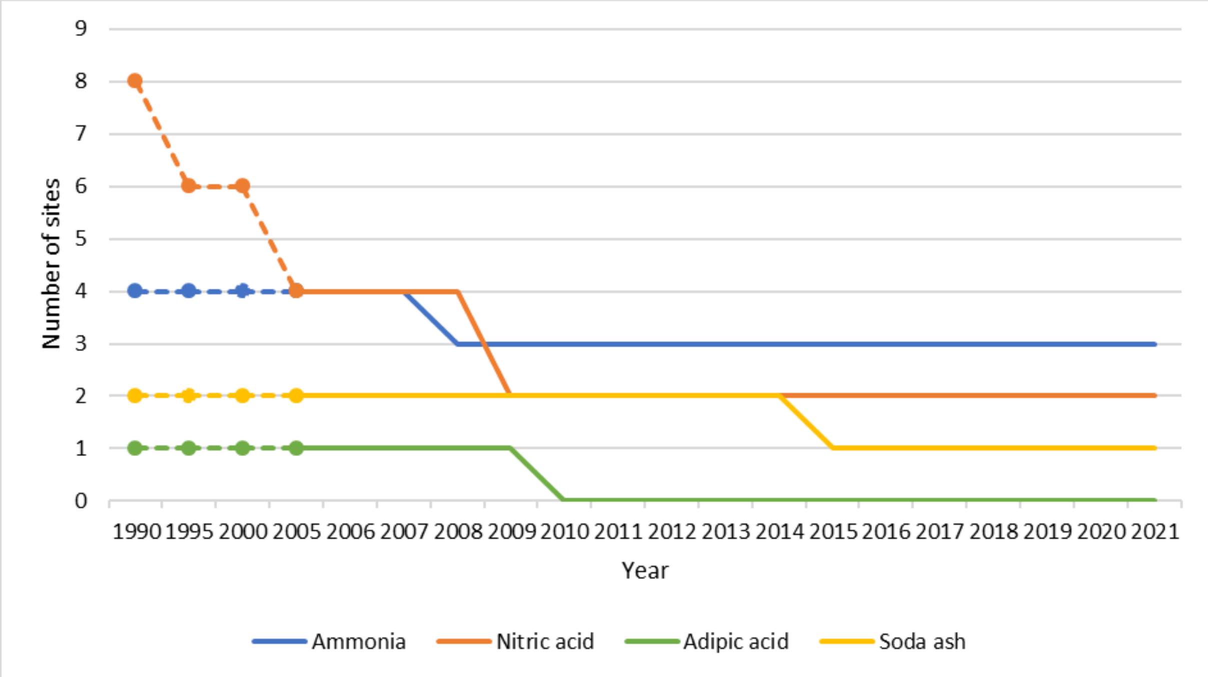
Annual CO_2 emissions from cement manufacture comprised 69% of total mineral sector CO_2 emissions in 2021 but have fallen by 42% since 1990 due to the closure of many kilns and decreasing UK clinker production. Emissions fell to a low point of 3.7 $MtCO_2$ in 2009 due to the impact of the recession in 2008-2009, and then increased again and have stabilised in recent years at around 4.0 to 4.5 $MtCO_2$.

Other mineral source categories don't have a significant impact on the UK GHG trends; lime production and CO_2 emissions has reduced by around 18% since 1990, glass production emissions are down by around 17%; brick manufacturing emissions are down by 62%.

[44] Merchant refers to sites selling lime and emitting CO_2, captive refers to sites using lime and CO_2 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 2.15 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.

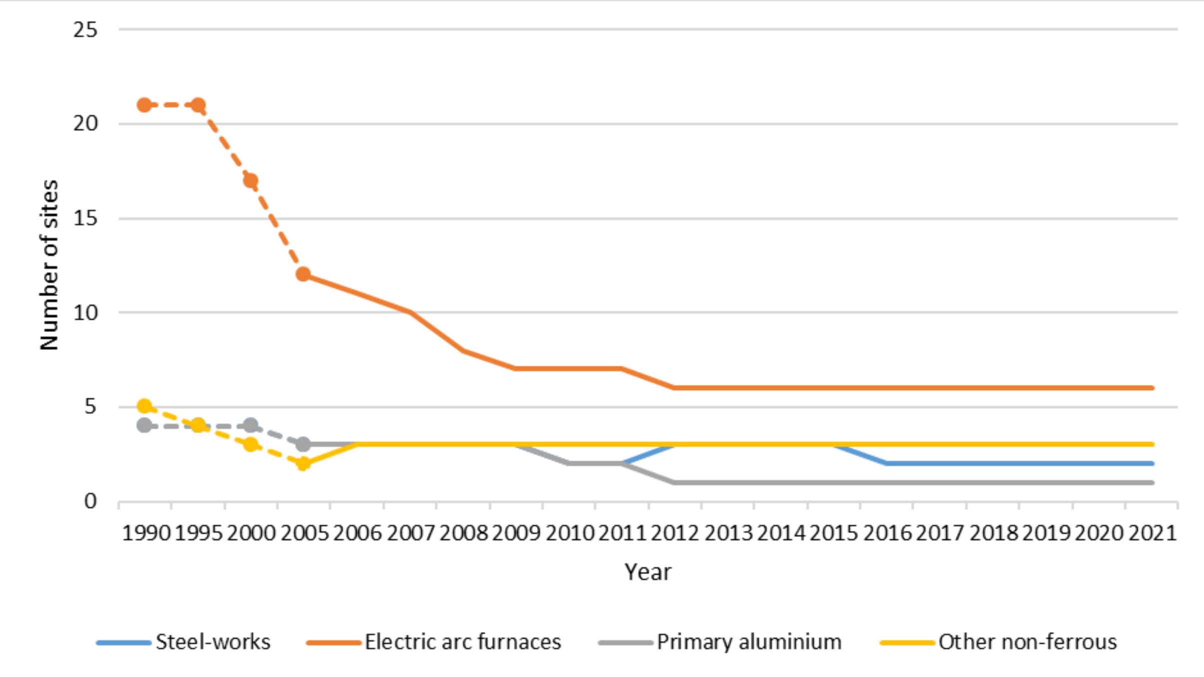
By-product emissions from the manufacture of HFCs and HCFCs have decreased to zero since 1990, due to plant closures and the installation of abatement equipment. Approximately half of the fall in chemical sector emissions in 1999 emissions was due to the installation of a thermal oxidiser at the UK's 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.

N_2O emissions from nitric acid manufacture show falls due to the closure of 4 plants between 2000 and 2008 and due to the installation of abatement technology in the larger of the remaining plants in 2011.

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 2.16 Trends in the number of metal process sites[45]



GHG emissions from across the UK metal production sector have fallen by around 61% 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 CO_2 emissions decreasing by 55% (across 2C1a-2C1d), which accounts for 88% of the total UK metal production sector CO_2 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 27% reduction in CO_2 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 31% decline in CO_2 emissions in 2015-2016, with total I&S IPPU emissions (2c1a-2C1d) thereafter stabilizing at around 10 to 11 $MtCO_2$.

The production of primary aluminium has also declined significantly across the time series, with CO_2 emissions down by 87% 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 $MtCO_2$.

There are no other primary non-ferrous metal processes in the UK since the closure of a large zinc and lead smelter complex in 2003; this one site closure accounts for 9% of total metal sector IPPU CO_2 emission reductions in the UK since 1990. A number of secondary lead processes are in operation but these merely recover lead from batteries and clean scrap and there is no evidence of any process emissions of CO_2 from any of them.

[45]'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 2.17 Total GWP weighted emissions in the Agriculture sector[46]

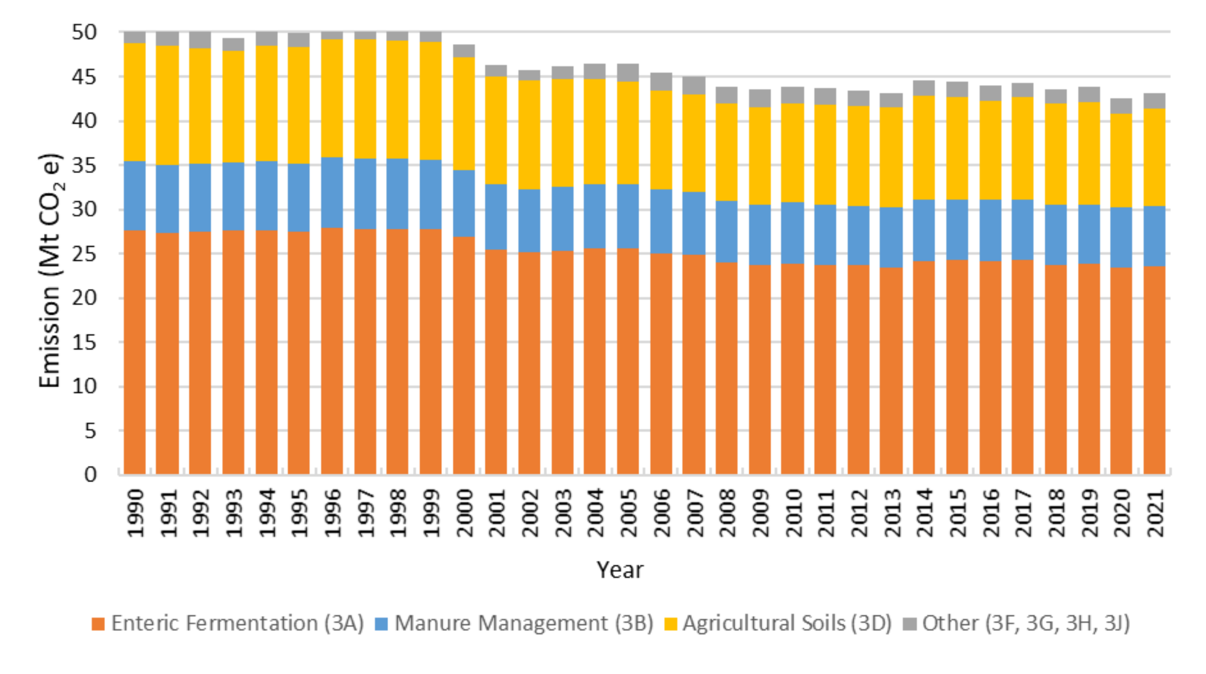
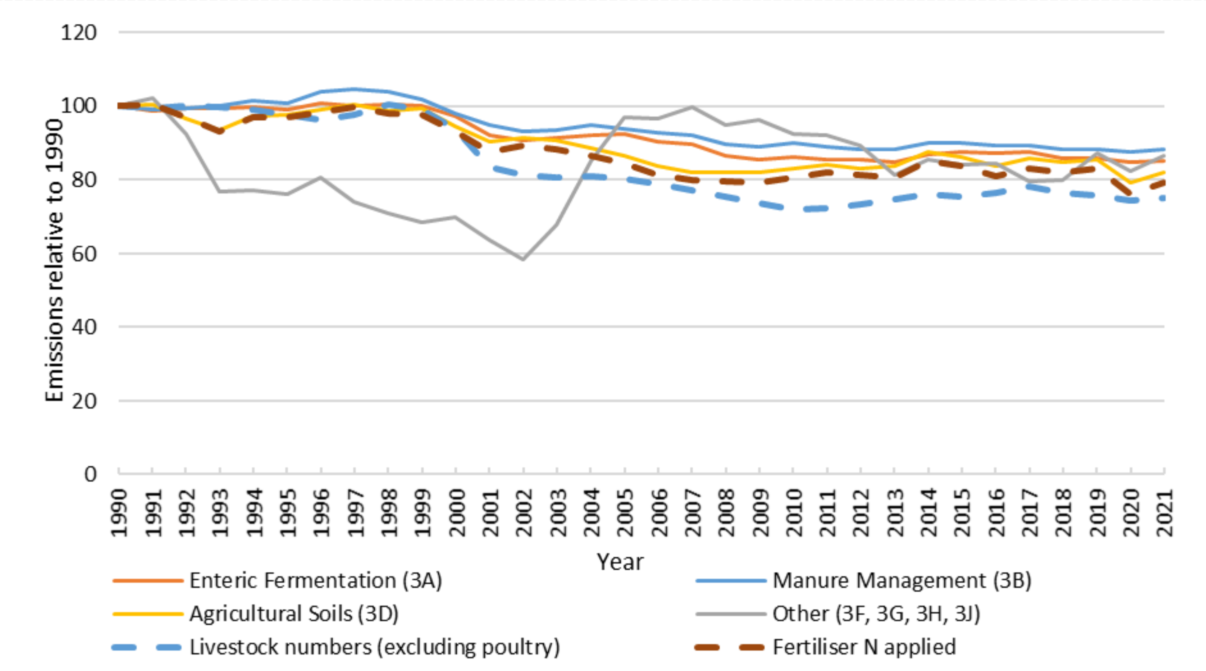
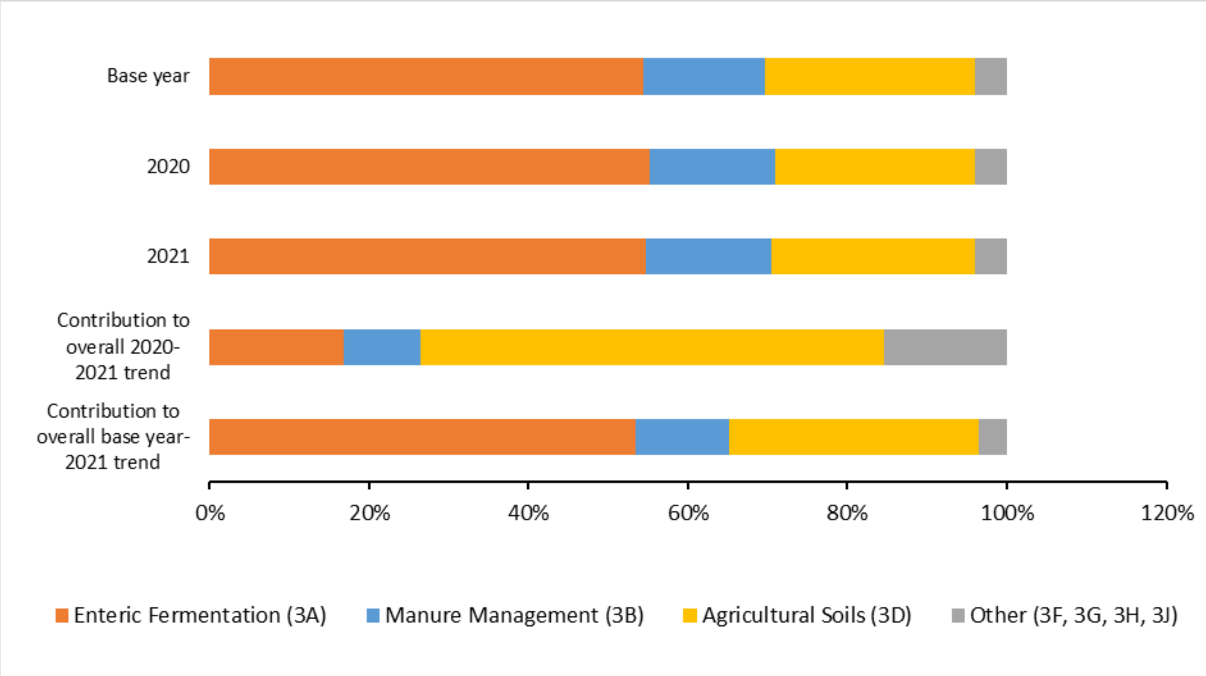


Figure 2.18 Trends in emissions from Agriculture by sub-sector, relative to 1990[46]



[46] '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 2.19 Contribution to totals in the selected years and to overall sectoral trends between selected years by sub-sector for Agriculture[46]



In the UK, the Agriculture sector is dominated by CH_4 emissions from livestock generated through enteric fermentation (animal digestion processes) and N_2O 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 (CH_4) (3A) and manure (N_2O) (3B) from cattle. This is, in turn, due to decreased cattle numbers.

2.3.2.2 Agricultural Soils

Annual emissions from fertiliser use (3H) have declined by 14% 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 2.20 Total GWP weighted emissions in the LULUCF sector

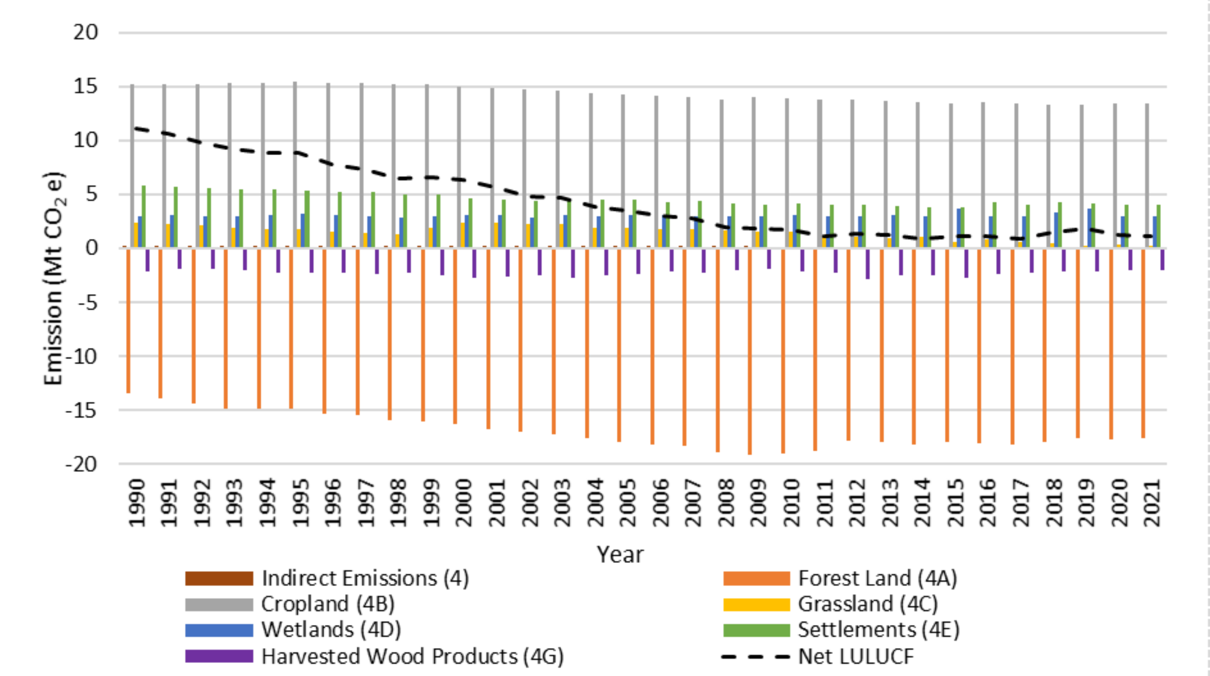
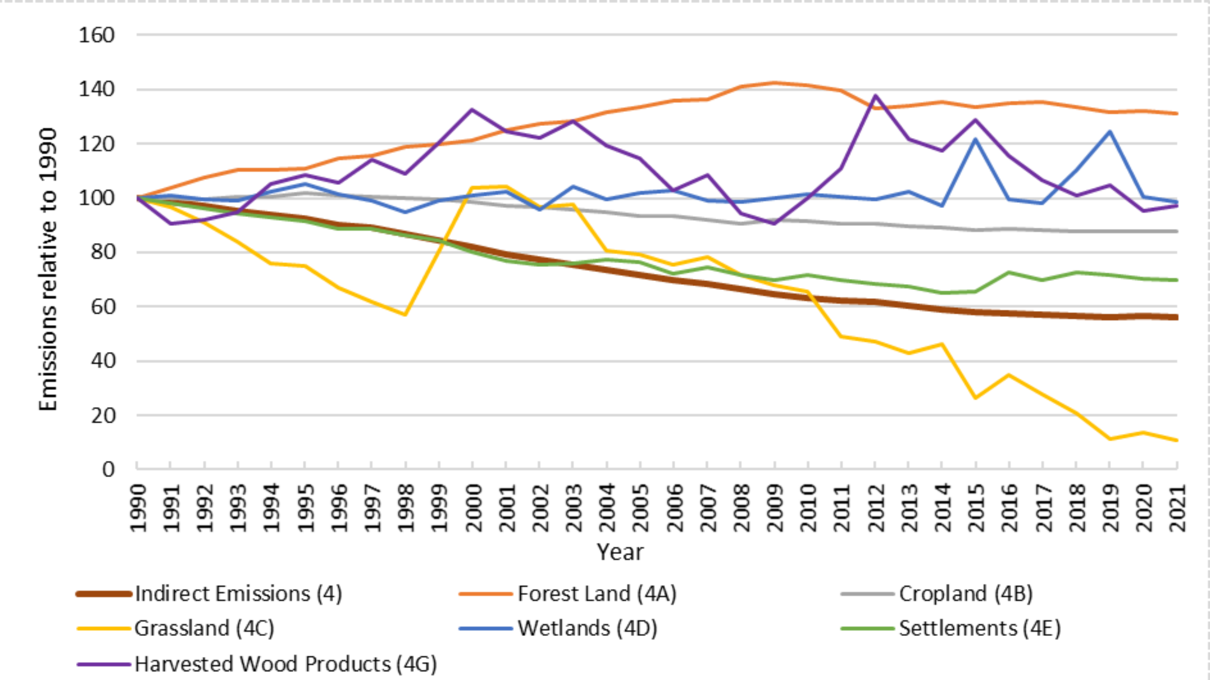


Figure 2.21 Trends in net emissions/removals from LULUCF by sub-sector, relative to 1990[47]



[47] Some of these are trends in the size of the net removals rather than net emissions.

The Land Use, Land-Use Change and Forestry (LULUCF) sector is the only sector within the national GHG inventory which reports both emissions and removals. Removals are from carbon stock gains in above- and below-ground biomass, soils and harvested wood products, emissions are from carbon stock losses and GHG emissions from LULUCF activities. The sector is currently a net source across the time series.

The LULUCF sector covers emissions and removals of direct GHGs under six categories, of which Forest Land and Harvested Wood Products are net sinks, and Cropland, Grassland, Wetlands, and Settlements are net sources (**Figure 2.21**) , and indirect emissions of N_2O from the whole LULUCF sector The UK does not report any emissions or removals from the Other Land category. Emissions from the LULUCF sector have shown an overall decrease since 1990, largely driven by an increase in the Forest Land net sink and a reduction in the Cropland, Grassland and Settlement net sources.

2.4.1.1 Forest land

Annual removals from Forest land increased significantly by 43% between 1990 and 2009 but have levelled off to around 30% above the 1990 level since 2012. 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 CO_2 removals) up to 2009 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 young trees have much lower rates of carbon sequestration than the mature trees they have replaced. 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 reduced substantially since 1990 but have started to increase in recent years.

2.4.1.2 Cropland, grassland and settlements

Annual emissions from Cropland have decreased by 12% since 1990. Net emissions from the Grassland category decreased between 1990 and 1998, returned to 1990 levels 2000-2001, and have decreased steadily since then to 11% of 1990 net emissions. Annual emissions from Settlements have decreased by 30% relative to 1990. The changes in these categories are due to lower rates of land use conversion since 2000, compared to rates of conversion before 2000).

2.4.1.3 Wetlands

The Wetlands category is stable until 2015, when it shows spikes in 2015 and 2018-19. These result from emissions associated with felling of forests for peatland habitat restoration and rewetting.

2.4.1.4 Harvested wood products

Annual removals due to harvested wood products (HWP) are variable over time. This is 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 2.20**). The large spike in removals in 2012 is an artefact of the modelling approach and is small in absolute terms. The carbon gains in the HWP pools are consistent with the carbon losses from Forest Land. Both are estimated using the CARBINE model with tree carbon losses on harvest transferred to the HWP, litter and deadwood pools and modelled accordingly.

2.5 WASTE

2.5.1 Overview

Figure 2.22 Total GWP weighted emissions in the Waste sector

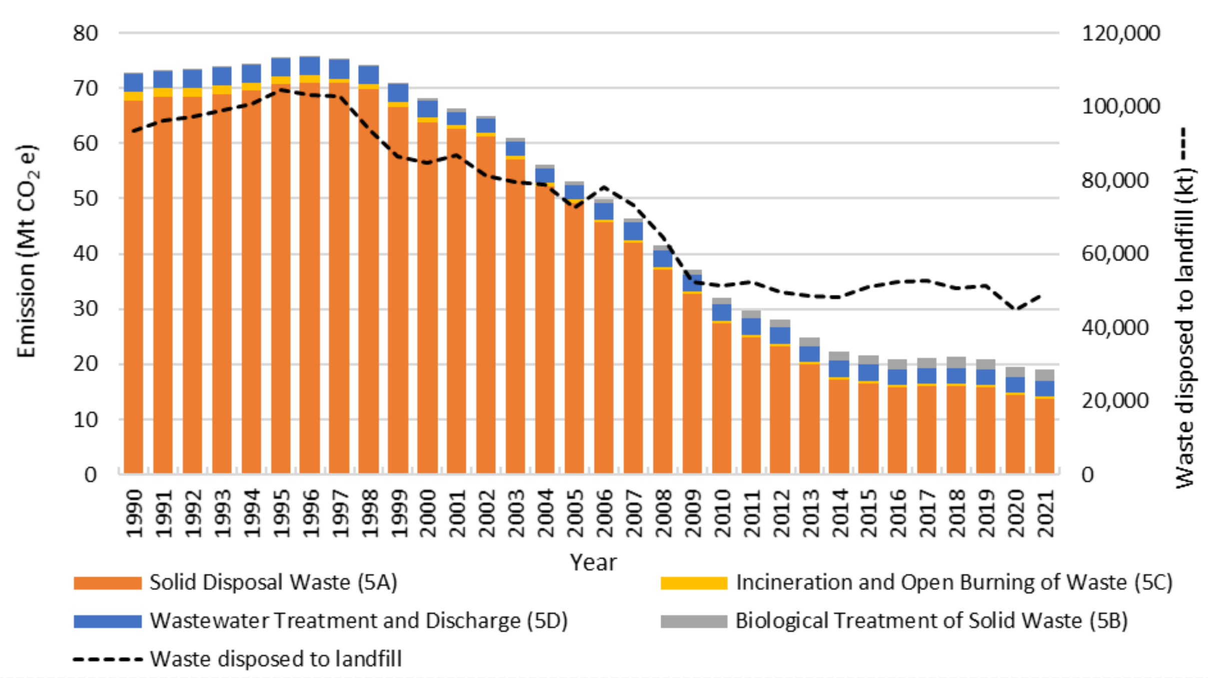


Figure 2.23 Trends in emissions from Waste by sub-sector, relative to 1990

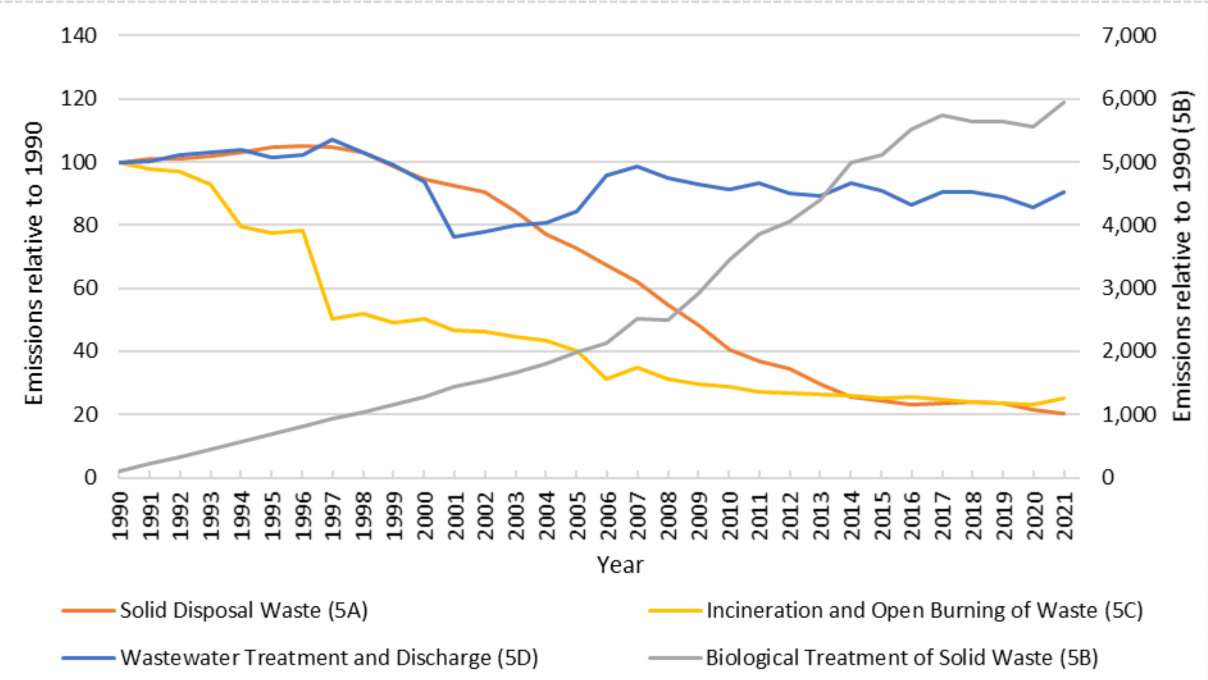
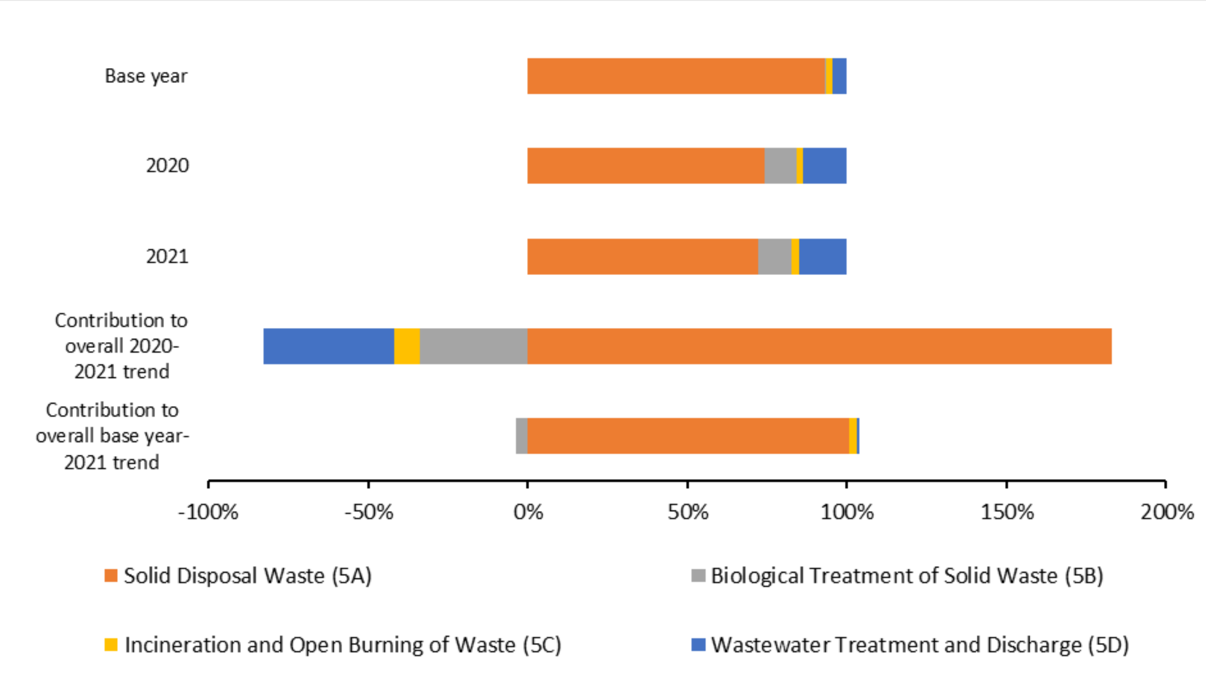


Figure 2.24 Contribution to totals in the selected years and to overall sectoral trends between selected years by sub-sector for Waste



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 CH_4 emissions from landfill sites.

Overall, annual emissions from the waste sector have decreased significantly since 1990 but have flattened out in recent years (**Figure 2.23**).

2.5.2 Emission trends in Waste 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 CH_4 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, CH_4 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 retrofitting 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.

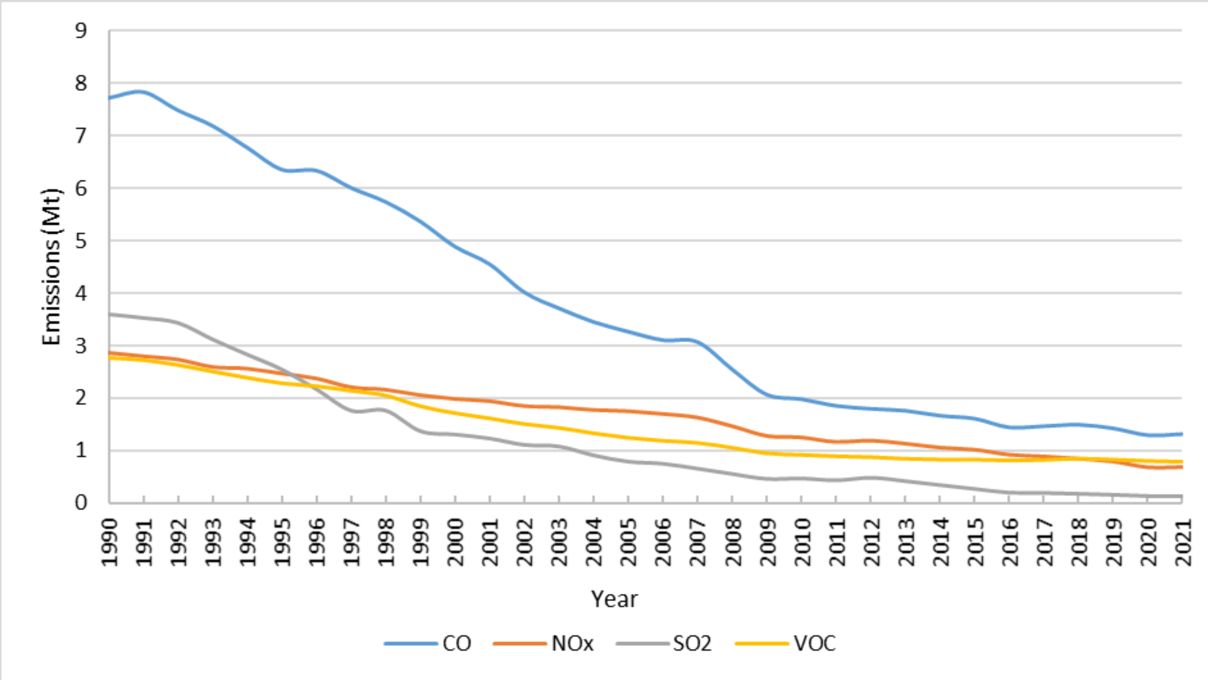
2.5.2.4 Biological treatment of solid waste

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 SO_2

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 (SO_2). Of these, NO_x, CO and NMVOC can increase tropospheric ozone concentration and hence radiative forcing. SO_2 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 2.25**. Significant reductions of all indirect GHGs and SO_2 have occurred since 1990.

Figure 2.25 UK Emissions of Indirect Greenhouse Gases



2.6.1 Carbon Monoxide

Annual emissions of CO have decreased by 83% since 1990. In 2021 80% of UK emissions of CO were from the energy sector, with 20% of emissions in this sector from transport. Since 1990, annual emissions from transport have decreased by 96%. This 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 contributed 32% of total CO emissions in 2021. Emissions from within this category mostly come from biomass combustion and off-road vehicles used in manufacturing and construction.

2.6.1 Nitrogen Oxides

Annual emissions of NO_x have decreased by 76% since 1990. In 2021, 94% of NO_x emissions in the UK came from the energy sector with the greatest contribution from road transport. 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 contributed 20% of total NO_x emissions in the UK in 2021. Since 1990, annual emissions from this sector have decreased by 84% 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 fallen by 61% 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.

2.6.2 Non-Methane Volatile Organic Compounds

Annual emissions of NMVOCs have decreased by 72% since 1990. In 2021, 58% of emissions were from industrial processes and other product use. Around 70% of emissions in this sector were 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.

In 2021, 24% of NMVOC emissions originated from the energy sector. Of these, the largest contribution arose from the fugitive emissions of oil and natural gas which comprised 54% of NMVOC emissions from the sector. Fugitive emissions of oil and natural gas includes emissions from gas leakage along with the transportation, refining, and storage of oil

2.6.3 Sulphur Dioxide

Since 1990, total annual emissions of SO_2 have decreased by 96%. In 2021, 88% of SO_2 emissions originated from the energy sector, with the greatest contribution from Domestic, Commercial and Agriculture. Since 1990, emissions from power stations have declined by almost 100%. This decline has been due to the increase in the proportion of electricity generated CCGT stations, other gas fired plants, the increase in the proportion of electricity generated in nuclear plants, and the application of Flue Gas Desulphurisation abatement equipment on several of the largest coal-fired power stations in the UK. CCGTs run on natural gas and are more efficient than conventional coal and oil stations and have negligible SO_2 emissions.

Emissions from Manufacturing, Industry and Construction were responsible for 25% of UK SO_2 emissions in 2021. Since 1990, emissions from this category have declined by 92%. 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 1990-2021 and 2020-2021. A description of the trends and the main drivers behind these can be found in **Chapter 2**

Table 3.1 Energy Sector Overview

Energy GREENHOUSE GAS SOURCE AND SINK CATEGORIES	KCA Rank (UNFCCC) scope	Uncertainty (MC)	Latest year total	1990-Latest year trend	Last 2 yr trend	Recalculation-: 2020	Recalculation-: 1990	Methodology reference (NIR Section)
Total Energy			**335**	**-44%**	**7%**	**0%**	**0%**	
A. Fuel combustion activities (sectoral approach)			**327**	**-41%**	**8%**	**0%**	**0%**	
1. Energy industries			**80**	**-67%**	**4%**	**0%**	**0%**	
a. Public electricity and heat production	3, 5, 7, 29	3%	56	-73%	9%	0%	0%	MS 1
b. Petroleum refining	3, 5, 7, 29	14%	11	-38%	0%	0%	0%	MS 1
c. Manufacture of solid fuels and other energy industries	3, 5, 7, 29	2%	13	-22%	-12%	0%	0%	MS1, MS 2, MS 4, MS 20
2. Manufacturing industries and construction			**44**	**-42%**	**7%**	**3%**	**-2%**	
a. Iron and steel	6, 8, 10	5%	1	-68%	7%	17%	2%	MS 4
b. Non-ferrous metals	6, 8, 10	5%	1	-84%	8%	0%	1%	MS 3
c. Chemicals	6, 8, 10	5%	5	-59%	-5%	8%	2%	MS 3
d. Pulp, paper and print	6, 8, 10	6%	1	-72%	-1%	1%	1%	MS 3
e. Food processing, beverages and tobacco	6, 8, 10	5%	4	-48%	4%	-1%	3%	MS 3
f. Non-metallic minerals	6, 8, 10	11%	3	-62%	8%	1%	0%	MS 3
g. Other (*please specify*)	6, 8, 10	5%	29	-20%	11%	3%	-7%	MS 3, MS 6
3. Transport			**108**	**-12%**	**10%**	**1%**	**0%**	
a. Domestic aviation	32	20%	1	-52%	28%	2%	0%	MS 7
b. Road transportation	1	2%	101	-10%	11%	1%	1%	MS 8
c. Railways		16%	2	6%	9%	0%	0%	MS 9
d. Domestic navigation	20	18%	5	-36%	2%	0%	0%	MS 10, MS 11, MS 12
e. Other transportation		16%	0	32%	-16%	-72%	-56%	MS 6
4. Other sectors			**94**	**-18%**	**7%**	**-2%**	**2%**	

Energy GREENHOUSE GAS SOURCE AND SINK CATEGORIES	KCA Rank (UNFCCC) scope	Uncertainty (MC)	Latest year total	1990-Latest year trend	Last 2 yr trend	Recalculation-: 2020	Recalculation-: 1990	Methodology reference (NIR Section)
a. Commercial/institutional	2, 12, 15	3%	19	-33%	7%	-3%	13%	MS 5
b. Residential	2, 12, 15	4%	69	-15%	7%	-2%	0%	MS 5, MS 6
c. Agriculture/forestry/fishing	2, 12, 15	31%	6	17%	17%	0%	-19%	MS 5, MS 6, MS 10, MS 13
5. Other *(as specified in table 1.A(a) sheet 4)*			**2**	**-70%**	**14%**	**-2%**	**0%**	
a. Stationary	N/A	N/A	IE	N/A	N/A	N/A	N/A	
b. Mobile	25	7%	2	-70%	14%	-2%	0%	MS 15, MS 16
B. Fugitive emissions from fuels			**8**	**-82%**	**-9%**	**1%**	**0%**	
1. Solid fuels		13%	**1**	**-97%**	**-1%**	**0%**	**0%**	
a. Coal mining and handling	18		1	-98%	-3%	0%	0%	MS 17
b. Solid fuel transformation	18		0	-88%	3%	0%	0%	MS 4, MS 20
c. Other *(as specified in table 1.B.1)*	N/A	N/A	NO	N/A	N/A	N/A	N/A	
2. Oil and natural gas and other emissions from energy production		21%	**7**	**-62%**	**-10%**	**1%**	**0%**	
a. Oil	17, 23		0	-90%	-1%	-4%	0%	MS 5
b. Natural gas	17, 23		4	-67%	-4%	2%	0%	MS 5, MS 20
c. Venting and flaring	17, 23		3	-45%	-17%	0%	0%	MS 5
d. Other *(as specified in table 1.B.2)*	N/A	N/A	NO	N/A	N/A	N/A	N/A	
C. CO_2 Transport and storage	**N/A**	**N/A**	**NO**	**N/A**	**N/A**	**N/A**	**N/A**	
1. Transport of CO_2	N/A	N/A	NO	N/A	N/A	N/A	N/A	
2. Injection and storage	N/A	N/A	NO	N/A	N/A	N/A	N/A	
3. Other	N/A	N/A	NO	N/A	N/A	N/A	N/A	
Memo items:(1)	**N/A**	**N/A**	**22**	**-10%**	**-6%**	**-4%**	**6%**	
International bunkers	**N/A**	**N/A**	**22**	**-10%**	**-6%**	-4%	**6%**	
Aviation	N/A	N/A	13	-15%	-11%	-5%	7%	MS 7
Navigation	N/A	N/A	9	-1%	2%	-4%	5%	MS 14
Multilateral operations	**N/A**	**N/A**	**NE**	**N/A**	**N/A**	**N/A**	**N/A**	
CO_2 emissions from biomass	**N/A**	**N/A**	**48**	**842%**	**4%**	**-32%**	**-51%**	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 CO_2 emissions described in **Section 3.4**, The Reference Approach is a ‘top down’ approach for estimating energy CO_2 emissions using national fuel statistics that acts as a verification tool for the Sectoral Approach.

The RA-SA comparison shows very close consistency between the two datasets (once the major known differences are accounted for) for the UK and provides verification of the reported SA emission estimates for 1A. The UK greenhouse gas inventory is compiled using a detailed Sectoral Approach methodology, to produce sector specific- inventories of the 7 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 and the more aggregated approach to applying emission factors to activity data across fuel types.

More data on the RA, SA and RA-SA comparison can be found in CRF Table1.A(b), Table1.A(c), and Table1.A(d).

3.2.1.1 Discrepancies between the IPCC Reference and Sectoral Approach

The IPCC Reference Approach total can be compared with the IPCC Table 1A total for all fossil fuels, and under the new 2006 GLs approach the Reference Approach (RA) CO_2 estimates for the UK range between **0.8% lower** and **1.3% higher** than the comparable bottom-up emission totals of the Sectoral Approach (SA).

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

3.2.1.1.1 Statistical Differences in Energy Balance Data

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

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

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

3.2.1.1.3 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.

3.2.1.1.4 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.

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

Table 3.3 shows the percentage differences in CO_2 emissions from fuel combustion sources between the IPCC Reference Approach and the UK GHGI (Sectoral Approach) IPCC sector 1A, for each year since 1990 and the resulting comparison when we have accounted for most of the known differences. **Table 3.2** gives a summary of the RA-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]
Liquid Fuels	1.015	0.959	0.986	1.6%
Solid Fuels	1.297	0.971	1.044	4.8%
Gaseous Fuels	1.025	0.987	1.000	0.6%
Total	**1.008**	**0.987**	**0.999**	**0.4%**

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

It can be seen in **Table 3.2** that the reference approach for liquid fuels is generally lower (on average 1.4%[48]) than the sectoral approach; there are some years with larger deviations, the highest being a 4.1% deviation in 1997.

For solid fuels, the RA is within 4% of the SA for 1990-2014, with a divergence of up to 30% for recent years. We are continuing to investigate this divergence but note that this is exaggerated by a rapid decline in coal used in power stations; the 30% deviation seen for 2021 is not outside the range of deviations seen for years where those deviations represent <4% when expressed as Mt CO_2.

The RA for gaseous fuels, which is based on supply statistics, only deviates from the SA by more than 1% in four years after 1996, for earlier years the relationship is less consistent.

While there are ‘other fossil fuels’ included in the overall SA-RA comparison, these are not presented as a separate comparison in **Table 3.2**, as the contribution to the overall RA-SA is minor. When expressed as a %, the differences between the RA and SA are much larger than the other fuel groups, although these are larger % of a much smaller total quantity. Other fossil fuel mostly consists of wastes, but the nature of waste means that three is a lot of scope for differences in choices of calorific values, gross-net conversions, biogenic/non-biogenic splits, carbon contents, and what is classified as waste (e.g., the Inventory Agency is aware that in earlier years UK energy stats excludes some scrap tyres, but in more recent years they are included). These parameters can additionally vary by end use. The Inventory Agency have not yet managed to fully trace how each of these differences might be contributing to the observed differences between the RA and SA for other fossil fuels in CRF Table1A(c).

The overall comparison between the Reference Approach (RA) and the Sectoral Approach (SA) indicates that on average the RA estimates are 0.1% lower than the SA estimates.

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

[48] Note that the average deviation (in this case 1.6%) is the average of the absolute values of (RA/SA-1) for each year, whereas the average % difference (in this case 1.4%) 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 and IPCC Reference Approach (total CO_2)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Sectoral Approach 1A (Mt CO_2)	550.9	561.4	546.5	532.9	524.0	514.6	533.0	512.8	520.3	513.6
Reference Approach (Mt CO_2)	546.7	561.8	551.0	532.9	524.6	515.5	532.3	510.5	519.1	515.4
RA/SA %	-0.8%	0.1%	0.8%	0.0%	0.1%	0.2%	-0.1%	-0.4%	-0.2%	0.4%
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Sectoral Approach 1A (Mt CO_2)	523.8	536.1	521.7	529.9	530.3	527.8	525.9	516.0	504.8	462.5
Reference Approach (Mt CO_2)	527.3	533.8	518.6	527.1	528.8	529.8	527.4	515.1	504.7	460.4
RA/SA %	0.7%	-0.4%	-0.6%	-0.5%	-0.3%	0.4%	0.3%	-0.2%	0.0%	-0.5%
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Sectoral Approach 1A (Mt CO_2)	480.5	440.2	457.4	442.8	403.6	389.1	371.3	359.4	352.8	338.9
Reference Approach (Mt CO_2)	477.6	434.2	455.5	443.1	402.7	391.1	372.3	360.0	352.7	338.1
RA/SA %	-0.6%	-1.3%	-0.4%	0.1%	-0.2%	0.5%	0.3%	0.2%	0.0%	-0.3%
	2020	**2021**								
Sectoral Approach 1A (Mt CO_2)	300.7	323.5								
Reference Approach (Mt CO_2)	298.8	323.1								
RA/SA %	-0.6%	-0.1%								

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 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 (BEIS, 2022a) 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 DESNZ as of 2023; also was BEIS between 2016 and 2023) 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., UK 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 (and therefore CO_2) 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.

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, 2022a), hereafter referred to as DUKES. This annual publication gives detailed sectoral energy consumption broken down by fuel type, covering the entire 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 distinct types of appliances have to be separately reported in the inventory and furthermore they may exhibit very different combustion characteristics (for non-CO_2 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 UK ETS 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 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 DESNZ (formerly BEIS) energy statistics team to derive a defensible historic time series back to at least 1990 for use in the UK inventory.

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 modifications by fuel 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 are 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 UK Emissions Trading System (UK ETS) (BEIS, 2022b), which has been analysed and compared with the data from DUKES. Further details of the analysis of the UK 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, 2022) and from data supplied by the UK Mineral Products Association (MPA, 2022), and from the UK solid fuel supply sector (CPL, 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 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 many source sectors.

Greenhouse gas emissions including CO_2 are estimated for these fuels and presented in the relevant sections of the CRF. The CO_2 emissions from biomass are, however, not included in the total UK emissions from fuel combustion and are instead recorded as a memo item.

Emissions of N_2O and CH_4 from biomass combustion are included within the UK inventory totals although in the case of emissions from use of biofuels in road transport or biogases blended with natural gas, the emissions are not reported separately, and are instead included in the emissions reported for the primary fuel these are blended with (such as petrol for bioethanol, or natural gas for biogases).

For fuels that contain both fossil carbon and biogenic carbon, the CO_2 emissions are reported to reflect the split between these components. The details for the relevant fuels are set out below.

- MSW: CO_2 emissions are split between *other fossil fuels* and *biomass*. CH_4 and N_2O, and the total activity data, are reported as *other fossil fuels*.
- Natural gas: A small percentage of biogas is incorporated into the UK natural gas grid. The CO_2 emissions are split between the *gaseous fuels* and *biomass* categories within the CRF. All activity data and non-CO_2 emissions are reported in the *gaseous fuels* category.
- Fossil component of liquid biofuels: there is a fossil-carbon component of some liquid biofuels (e.g., the methyl group in FAME is derived from fossil feedstock). The activity

data, and CO_2 from biomass are reported under *biomass* and the fossil CO_2 emission is reported under *other fossil fuels.*

The impact of biomass use on carbon stocks in the UK is recorded in the LULUCF sector; biomass imported into the UK will affect the LULUCF sector in the country from which the biomass is imported.

3.2.6 Unoxidized Carbon

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

In the UK Inventory, it is assumed that unoxidized carbon is only significant for solid fuels. For gaseous and liquid fuels, although some carbon might not be oxidized fully during combustion (for example emitted as VOC or particulate matter), based on discussions with fuel suppliers, it is assumed than any indefinite storage of unoxidized carbon will be sufficiently trivial to be ignored. For solid fuels, UK-specific assumptions are employed, either based on expert judgements provided by UK industry, or based on UK 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	Unoxidized carbon in the UK GHGI[c]	IPCC default for unoxidized carbon
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%
Solid	Coal	1A1a	2005	1.8%[b]	0%
Solid	Coal	1A1a	2006	2.0%[b]	0%
Solid	Coal	1A1a	2007	1.7%[b]	0%
Solid	Coal	1A1a	2008	2.0%[b]	0%
Solid	Coal	1A1a	2009	1.9%[b]	0%
Solid	Coal	1A1a	2010	1.9%[b]	0%
Solid	Coal	1A1a	2011	1.8%[b]	0%
Solid	Coal	1A1a	2012	1.7%[b]	0%
Solid	Coal	1A1a	2013	1.8%[b]	0%
Solid	Coal	1A1a	2014	1.8%[b]	0%
Solid	Coal	1A1a	2015	1.8%[b]	0%
Solid	Coal	1A1a	2016	1.8%[b]	0%
Solid	Coal	1A1a	2017	1.6%[b]	0%
Solid	Coal	1A1a	2018	1.5%[b]	0%
Solid	Coal	1A1a	2019	1.7%[b]	0%
Solid	Coal	1A1a	2020	1.5%[b]	0%
Solid	Coal	1A1a	2021	1.7%[b]	0%
Solid	Coal	1A2f	All	0%	0%
Solid	Coal	1A4b	All	0%	0%
Solid	Coal	All others	All	0%	0%
Solid	Anthracite	1A4b	All	0%	0%

Fuel Type	Fuel sub-type	Source Sector	Years	Unoxidized carbon in the UK GHGI[c]	IPCC default for unoxidized carbon
Solid	Coke, solid smokeless fuel	1A4b	All	0%	0%
Solid	Coke, solid smokeless fuel	All others	All	0%	0%

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

[b] Calculated from site-specific UK and 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 CO_2 TRANSPORT AND STORAGE

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

3.4 METHOD STATEMENTS

The rest of the energy chapter is structured using a series of inventory compilation method statements in order to group together categories where the source data and methods are similar, minimising unnecessary repetition of method descriptions and improving the clarity of the NIR. The method statements are numbered, 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, mobile combustion and fugitive sources.

Table 3.5 Method Statement Scope: IPCC and Source Categories

MS number	IPCC categories	Source categories
Stationary combustion		
MS 1	1A1ai, 1A1iii, 1A1b, 1A1ciii	Power stations, Public heat production, refineries (*including emissions from flaring at refineries*) and other energy industries (collieries, gas production, nuclear fuel production).
MS 2	1A1cii	Upstream oil and gas production - combustion
MS 3	1A2	Manufacturing industries and construction (excluding iron and steel use of derived fuels, and off-road machinery)
MS 4	1A1ci, 1A2a, 1B1b, 2C1	Iron and steel, and coke manufacture
MS 5	1A4ai, 1A4bi, 1A4ci	Other stationary combustion
Mobile combustion		
MS 6	1A2gvii,1A3eii,1A4bii, 1A4cii	Off-road machinery
MS 7	1A3a,	Aviation,

MS number	IPCC categories	Source categories
	Memo item	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	*Memo item*	International shipping
MS 14	1A5b	Naval Shipping
MS 15	1A5b	Military aircraft
Fugitive sources *(Except 1B1b – see 0)*		
MS 16	1B1ai, 1B1aii, 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). *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.* *Note that emissions for 1B2c1iii and 1B2c2iii, venting or flaring for oil and gas combined are reported as 'IE' and aggregated in reporting in oil or gas venting or flaring (1B2c1i, 1B2c1ii, 1B2c2i, 1B2c2ii).*
MS 19	1B2biv, 1B2bv	Natural Gas leakage – transmission, distribution, point of use
MS20	1A1ci, 1B1b	Solid smokeless fuel production, charcoal production

MS 1 Power stations, refineries, and other energy industries

Relevant Categories, source names

1A1ai: Power stations

1A1aiii: Public heat production

1A1b: Refineries

1A1ciii: Collieries, gas production and nuclear fuel production

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

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

Note that 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, public heat production, 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 2021 was 2.0% from coal and 40.7% from gas. Nuclear stations generated a further 14.1%, and almost all of the remainder was generated from renewables or non-thermal sources such as wind and hydro (43.2%).

Biomass is being burnt at an increasing number of power generation sites to help electricity generators meet Government targets for renewable energy production. These sites use poultry litter, straw, or wood as the main fuel, whilst many coal-fired power stations have increased the use of biofuels such as short-rotation coppice to supplement the use of fossil fuels. Electricity is also generated in a large number of engines running on biogas at landfill sites and sewage treatment works. CO_2 emissions associated with biofuel combustion are estimated and reported as memo items, but not included 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

Year	Coal	Fuel oil	Gas oil	Gas	Waste	Biomass	Biogas	Nuclear Fission
2005	16	4	14	50	20	19	461	13
2010	16	3	14	59	24	21	554	10
2012	15	3	14	63	26	19	565	10
2013	14	3	14	57	28	22	621	10
2014	12	2	14	57	34	24	628	10
2015	12	1	14	57	35	25	633	9
2016	12	0	14	58	39	26	642	9
2017	9	0	14	57	40	26	658	9
2018	8	0	14	56	45	27	654	9
2019	7	0	14	56	49	33	650	8
2020	6	0	13	50	51	30	650[b]	8
2021	4	0	19	48	52	33	650[b]	7

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

[b]Figure for 2021 not published in DUKES, estimated equal to previous year

Table 3.7 shows how the numbers of refineries vary over the period covered by the inventory. The UK had 8 operating refineries during 2021, 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

Year	Crude oil refineries	Specialist refineries
2013	7	3
2014	7	2
2015-2021	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 1** 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 2016-2021. Emissions from combustion at UK collieries are covered in this MS. Fugitive emission estimates from these mining and extraction activities are included in **MS 15** and **MS 18.**

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

Key Data sources

Activity data: DUKES (BEIS, 2022a), UK and EU ETS (BEIS, 2022b)

Emission Factors: Carbon factors are predominantly derived from UK and EU ETS data (2005 onwards), from refinery sector reporting (UK Petroleum Industry Association, 2022) and from the 2004 Carbon Factors Review (Baggott et al., 2004), with some solid fuel factors derived from UK research (Fynes and Sage, 1994); non-CO_2 EFs are predominantly IPCC defaults (IPCC, 2006).

*An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]. The justification for use of several references, such as UK and EU ETS, the 2004 Carbon Factors Review and Fynes and Sage, are presented in **Annex 3.1.3**.*

***Table 1.5** gives additional information for common activity data sources.*

Method approach

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

UK Emissions = EF x AD

The sources of emission factors and activity data are summarised under "key data sources" above, with a full list of emission factors set out in *"Energy_background_data_uk_2023.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

[49] This can be found as one of the additional documents to the NIR https://naei.beis.gov.uk/reports/reports?report_id=1108

. Note that there can be a delay between the NIR being published on the NAEI website after official submission.

Inventory Agency or via the UK Emissions Trading System (UK 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 UK 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%. The factors presented in *"Energy_background_data_uk_2023.xlsx"* are the factors including consideration of the oxidation factor. The data for recent years is taken from installation-specific analysis through UK 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 is 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 UK ETS data. These UK 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 UK ETS and DUKES. Based on data from UK 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 2013-2020 are based on UK 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 UK 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 UK ETS and applying the EF for petroleum coke provided by UKPIA; UK ETS data are higher (and therefore used in the GHGI, deviating from DUKES) for all years 2005 to 2010 and again in 2013 and 2015-2018. In 2011, 2012, 2014, and 2019-21 the DUKES data are higher than UK 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 UK ETS totals in 2012. The Inventory Agency retains this approach in order to use UK 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 UK ETS figures for 2005: this is because DUKES reports higher consumption of other fuels (including fuel oil and natural gas) than given in UK ETS, rather than due to differences for OPG and petroleum coke as in 2012.

- Public Heat Production – Data for landfill gas and sewage gas combustion, reported in DUKES under the categories unclassified, and public administration, respectively, are allocated to public heat production for the NAEI.

Recalculations

Activity data revisions include:

- Revisions to DUKES in 2019 and 2020. No method changes have been made and none of the DUKES revisions are notable.

For emission factors:

- No notable revisions

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 UK 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 UK ETS data against the installation-wide total emissions reported to the EU Transaction Log and UK Compliance Reports, 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 DESNZ energy statistics team and (where necessary) the UK 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*[50]. The UK ETS data, is subject to its own QA process, defined and managed by the competent authority and compliant with UK 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 UK 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.

[50] Available from https://www.statisticsauthority.gov.uk/code-of-practice

For some sources and fuels, carbon emission factors are taken from Baggott et al., for the period 1990-2003, and from UK and EU 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 UK ETS. Therefore, whilst the UK 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 CO_2 emissions accurately. Non-CO_2 emissions are dependent on a greater number of parameters and are largely based on defaults. As such, the uncertainties are higher, but since the emissions are smaller, this does not have a significant impact on the overall uncertainty of total GHG emissions.

MS 2 Upstream oil and gas production – fuel combustion

Relevant Categories, source names

- Upstream oil production: fuel combustion
- Oil terminal: fuel combustion
- Upstream gas production: fuel combustion
- Gas terminal: fuel combustion

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Gas oil, Fuel gas[51] ('Natural Gas')

Background

This source category comprises emissions from the combustion of all fuels (excluding fuel used for vessel propulsion) including producers' own fuel gas and purchased fuels such as diesel, through all phases of exploration, development, production and decommissioning for all upstream oil and gas installations on the UK Continental Shelf (UKCS) and onshore, i.e. including at offshore assets (platforms, Floating Production Storage and Offloading vessels -

[51] In UK upstream facilities where fuel gas is used, the gas is predominantly methane and similar in composition to natural gas but also typically contains more higher-chain hydrocarbons (e.g. ethane, propane, butane, C5 and above) and often also higher levels of CO_2 and sulphur compounds compared to natural gas that is provided to downstream users via the National Transmission System (NTS) after processing at gas terminals.

FPSOs, and Mobile Offshore Drilling Units - MODUs), at onshore terminals and at onshore production sites.

The UK has been producing oil and gas, predominantly offshore in the North Sea, for decades, and there are several hundred oil and gas platforms that have been operating across the time series. As they have high power demands to run the exploration and production operations, most platforms include large gas turbines that are run off a proportion of the fuel gas produced on-site, with smaller supplementary engines, heaters and other units that may burn fuel gas and/or diesel.

UK GHGI methods are implemented to derive separate estimates for:

(i) onshore terminals; and
(ii) offshore platforms, FPSOs and MODUs.

The different methods per installation type reflects the difference in source datasets between onshore and offshore facilities due to different regulatory systems in the UK for the respective installations. Each installation is allocated to either *upstream oil* or *upstream gas* production according to the North Sea Transition Authority (NSTA) definitions of the fields/terminals producing/treating the oil or gas.

Key Data sources

Activity Data:	Gas oil data are primarily taken from DUKES (BEIS, 2022a); fuel gas ('natural gas') data are derived from operator reporting to the UK ETS (2005-) (BEIS, 2022b) and EEMS (1998-) (BEIS OPRED, 2022) reporting systems and quality checked against UK energy statistics in DUKES (BEIS 2022a). Fuel use estimates for pre-EEMS years, i.e. 1990-1997, are derived from sector data submitted to UK Government based on operator reporting (UKOOA, 2005).
Emission Factors:	Carbon factors for fuel gas ('natural gas') are derived from operator-reporting to UK ETS (BEIS, 2022b) and EEMS (BEIS OPRED, 2022), supplemented by operator data for the earlier years in the time-series (UKOOA, 2005); the carbon factor for gas oil is derived from the 2004 Carbon Factors Review (Baggott et al, 2004). Methane and nitrous oxide EFs are based on operator reporting via EEMS from 1998 onwards; these EFs are also extrapolated back to 1990.

An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[52]. ***Table 1.5*** *gives additional information for common activity data sources.*

Method approach

The Inventory Agency has researched and analysed all available activity and emissions data for the UK upstream oil and gas sector across the time series during a recent inventory improvement project (Thistlethwaite et al, 2022). The inventory method for 1A1cii draws upon the best available data from the sector, through a range of reporting mechanisms that have been developed by UK regulatory agencies across the time series.

[52] This can be found as one of the additional documents to the NIR https://naei.beis.gov.uk/reports/reports?report_id=1108

Note that there can be a delay between the NIR being published on the NAEI website after official submission.

*A more detailed summary of the oil and gas sector analysis is presented in **Annex 3.1.6**. The methods developed impact both fuel combustion emissions in 1A1cii and all upstream oil and gas fugitive emission sources reported in 1B2 (see **MS 18**).*

Across all years of the time series, the fuel use estimates presented in DUKES are incomplete and operator-reported data are used to deliver a complete and accurate inventory estimate. (*For further details see the section below: 'Assumptions and Observations'.*)

The key activity and emissions datasets used across the time series are:

- **1990-1997**: Inventory agency estimate derived from the UKOOA 2005 aggregated estimates of GHG emissions presented for all offshore and onshore production emissions. AD estimated from the emissions data, assuming that the sector-wide EFs from 1998 are representative for earlier years for all fuels (diesel, fuel gas);
- **1998-2003**: EEMS operator-reported fuel combustion emission and activity estimates per installation, from all offshore mobile and fixed installations and all onshore terminals, supplemented by analysis of the UK ETS National Allocation Plan (NAP) data;
- **2004**: EEMS operator-reported fuel combustion emission and activity estimates per installation, offshore and onshore;
- **2005-2010**: UK ETS (CO_2) and EEMS (all GHGs) operator-reported fuel combustion emission and activity estimates per fixed installation, offshore and onshore. EEMS data for all mobile offshore units;
- **2010-Current**: UK ETS (CO_2) and EEMS operator-reported fuel combustion emission and activity estimates per fixed offshore installation; EEMS data for all mobile offshore units; UK ETS (CO_2) operator-reported fuel combustion emission and activity estimates per onshore terminal.

Since 1998 there are installation-level data reported to UK Government, including fuel combustion estimates that are based predominantly on installation-specific carbon emission factors for fuel gas; this is therefore a Tier 3 method using the aggregate of reported data across all UK installations, and based on a large dataset of fuel compositional analysis and operator reported emission estimates.

Prior to 1998 the source data reported to Government are more aggregated, based on sector surveys and (in some years) the use of proxy data (oil and gas production statistics) to estimate the activity data. An industry submission to Government in 2005 (UKOOA, 2005) provided a comprehensive estimate of sector emissions from 1990 to 2003 based on aggregated UK operator reporting, and hence this is a Tier 2 method.

Since 2005, the activity and emissions data for combustion are primarily derived from UK ETS (BEIS, 2022b) reporting for those installations that report to UK ETS, and from EEMS (BEIS OPRED, 2022) data for the sites that fall below the reporting threshold for UK ETS. Analysis has shown that there is a small systematic under-report for fuel gas use by the oil and gas sector for recent years of the time series in the UK energy statistics, DUKES (BEIS, 2022a). Where the fuel combustion emissions are reported for an installation via both EEMS and UK ETS, the UK ETS data are regarded as better quality as they are subject to Third Party verification, as part of the requirements of the trading scheme. However, the scope of reporting under UK ETS is not as complete as EEMS; mobile offshore units (e.g. drilling units) do not fall within UK ETS scope and a number of smaller offshore platforms also report only to EEMS as they do not meet the UK ETS threshold for combustion unit capacity.

Onshore oil and gas terminal operators reported fuel combustion estimates via EEMS from 1998 to 2010. Since 2010, terminal operators are not mandated to report to EEMS and most have ceased to do so, as they are already required to report installation-wide annual emission estimates under the IED/PPC reporting systems to onshore regulators. The UK ETS data provide complete estimates for fuel use at all onshore oil and gas terminals from 2005 onwards.

The UK ETS CO_2 data for high emitting source streams are based on source-stream-specific fuel analysis (i.e. compositional analysis to derive carbon content, NCV) and the assumption that the fuel is 100% oxidised; for example on most oil and gas platforms the estimates of emissions from fuel gas use within turbines, engines, heaters and other units are based on sampling and analysis of the carbon content of the fuel gas. As such the UK ETS data are considered highly accurate; they provide a rich and detailed dataset that exhibits a range of variability in the fuel gas across installations and across the time series.

For 1998 to 2004 inclusive, the combustion activity and emissions were reported by all upstream oil and gas installations, offshore and onshore, via EEMS (BEIS OPRED, 2022). The oil and gas operators subsequently conducted more detailed analysis, to review activity data and carbon emission factors, in the course of developing the National Allocation Plans (Phase I NAP, Defra 2005)[53], in the years leading up to the EU ETS. The accuracy of the 1998-2003 data was improved through this process in order to ensure accurate emission allocations per installation in the first phase of EU ETS which ran from 2005 to 2007. To derive the UK GHGI estimates for combustion in 1998 to 2004, the Inventory Agency has reviewed the EEMS and NAPs data during the recent oil and gas improvement project and used the best available data per installation.

For 1990 to 1997 there are more aggregated data available from industry reporting (UKOOA 2005) that are used to inform the UK GHGI estimates. The 1990 and 1991 CO_2 estimates are based on company reported data, with CH_4 and N_2O estimates derived by the Inventory Agency, applying EFs from operator reporting in later years (under EEMS). Data for 1995 to 1997 were compiled from operator reporting under a system with a similar reporting structure to EEMS, but data are only available from across the whole industry, rather than per installation, and hence are somewhat less transparent. The sector estimates for 1992 to 1994 are based on modelling by the oil and gas trade association, using oil and gas production data as a proxy, scaling emissions between the reported data in 1991 and 1995.

The fuel combustion in the sector is a minor source of emissions of methane and nitrous oxide. Operators report estimates to EEMS, predominantly applying defaults from operator guidance for fuel gas combustion or gas oil combustion. The inventory estimates are based on the operator-reported estimates from EEMS for 1998 onwards; the estimates in 1990-1997 are based on EFs rolled back from EEMS 1998 data.

Assumptions & observations

The DUKES commodity balance tables are regarded as high quality and complete for most fuels and sectors, where the fuel allocations are based on fuel sales data (from tax records, from annual and periodic surveys), surveys of fuel suppliers and producers, import and export data. However, for the upstream oil and gas sector a high proportion of fuel use (and hence combustion emissions) arise from operators' own use of fuels (mainly fuel gas, a mixture of methane and other hydrocarbons) that are generated and used on site and are therefore not 'bought and sold' (unlike most fuel use across the UK economy), nor are they metered or

[53] EU Emissions Trading Scheme, Approved Phase I National Allocation Plan 2005-2007, Defra (2005) https://webarchive.nationalarchives.gov.uk/ukgwa/20121024153024/http://www.decc.gov.uk/en/content/cms/emissions/eu_ets/phase_1/phasei_nap/phasei_nap.aspx

delivered through a system (e.g. pipeline network) where inputs and outputs are routinely monitored to track fuel use / sales to recharge the suppliers.

The DUKES long-term trends in producers' own fuel gas use by the upstream sector[54] exhibit a ~20% single year step-change from the year 2000 to 2001 that the UK Government (then DECC) energy statistics team confirmed was due to the more complete data capture after the Petroleum Production Reporting System (PPRS) was implemented (DECC, 2012. Personal communication) and was not a 'real' change in fuel use. Prior to PPRS the data capture mechanisms in place under-reported the sector fuel use, with data gaps indicated by UK Government energy statisticians for fuel gas use at gas terminals and at oil terminals. This has informed our method choice to deviate from UK energy statistics and to use the industry reported data for emission estimates in the 1990s (i.e. the UKOOA 2005 dataset) in preference as they are the more accurate, complete dataset.

Further, the UK energy statistics are still incomplete in recent years for fuel gas use, as confirmed during the oil and gas improvement project through analysis of the own gas use reported by UK terminals and consultation with the BEIS energy statistics team. Consultation with BEIS energy statistics (BEIS, 2021. Personal communication) has confirmed that the fuel gas use reported within PPRS and UK ETS from oil terminals is not included in the DUKES data for 'oil and gas extraction' use of 'natural gas'. Hence the UK GHGI method deviates from DUKES, using the operator-reported (and Third Party verified) UK ETS data on fuel gas use as it is regarded as the most complete and accurate dataset for the oil and gas sector. *This is a continuation of the method from the 2021 submission*.

DUKES (BEIS, 2022a) reports gas oil use for the upstream oil and gas sector since 2005 but not for earlier years in the time series; the operator data from EEMS (1998-2004) and from UKOOA (1990-1997) shows that gas oil has been used by the sector throughout the time series. Therefore, the UK GHGI uses the operator-reported estimates directly for 1990-2004 and the DUKES data for 2005 onwards, which are based on operator returns to EEMS.

We note that when the operators' own **fuel gas** is the primary fuel for generating heat and power in upstream facilities, it is formed predominantly of methane and has a similar composition to **natural gas** processed at gas terminals and provided to downstream users in the UK via the National Transmission System (NTS). However, fuel gas frequently has a greater proportion of higher-chain hydrocarbons (e.g. ethane, propane, butane, C5 and above) than natural gas, as well as higher levels of CO_2 and sulphur compounds. Tables in **Annex 3.1.6** set out the fuel compositional data for the fuel gas, illustrating the variability of CEFs, densities and NCVs of the fuel gas across the UK upstream oil and gas sector. All of the emissions are reported under 'natural gas' use in 1A1cii, reflecting the allocation of the fuel gas to the natural gas commodity balance in DUKES.

Emissions from OTs and CDs are 'Not Estimated' for this source. There is no oil or gas production in any of the OTs and CDs, and only limited well drilling and initial exploration activity (i.e. well testing) in waters around the Falklands Islands in 1998, in 2010, 2012 and 2015. There are no fuel use estimates specific to those exploration activities; it is assumed that any fuel use is accounted for within the Falklands energy balance data.

Emission factors for N_2O 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

[54] UK energy statistics, DUKES Table 4.2 Natural Gas Production and Supply. Producers own use is reported in GWh for 1999-2000-2001-2002 thus: 64,634 – 65,555 – 78,457 – 79,364. The step change 2000 to 2001 is a 19.7% apparent increase, but reflect better data capture (Personal communication: BEIS, 2012)

are considered to be more representative of combustion emissions at UK installations than the IPCC defaults.

Recalculations

There have been no major recalculations to estimates.

Improvements (completed and planned)

The oil and gas sector improvement project (Thistlethwaite *et al*, 2022) has assessed all available UK data to improve the quality of the UK GHGI submission across 1A1cii and 1B2, and is described in more detail in **Annex 3.1.6**.

Emission factors and activity data remain under review.

Further improvements may be achieved if it becomes possible to obtain more resolved data on fuel gas quality per installation, to improve the assumptions for NCVs and density of fuel gas. The current method applies the best available data from PPRS but this is a separate data reporting mechanism to the EEMS and UK ETS datasets. If a more comprehensive NCV dataset directly from e.g. the UK ETS data reporting, were to become available, this may help to improve data quality. However, we note that this would **not alter the emission totals**, but it would slightly improve the accuracy of the AD and EFs.

We note that the recent oil and gas improvement project has fully explored all available data for the early part of the time series and we see no practicable opportunity to improve the estimates for the 1990s.

QA/QC

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

- The comparison of the reference/sectoral approach;
- Comparison of EEMS, UK ETS and DUKES activity data for fuel (natural) gas combustion. The data underpinning DUKES estimates are gathered via the PPRS which presents facility-level activity data that are compared against EEMS and UK ETS to identify and reconcile any data inconsistencies;
- Comparisons between EEMS and UK 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 UK ETS as a de-minimis. The UK 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 of total emissions data reported by each onshore oil and gas installation via the Regulatory Inventories (RIs) to assess time-series consistency and completeness of reporting, comparing CO_2 emissions data against those presented in UK ETS (and EEMS if the terminal reports to EEMS also).

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

Time-series consistency

The method is compromised by the lack of source-specific data for the 1990-1997 period, where only aggregate emissions data across all sources in 1A1cii and 1B2 are available from the industry submissions to UK Government; this coincides with a period where consultation with the BEIS energy statistics team has confirmed that that the UK energy statistics were not gathering complete data for all oil and gas terminals. Wherever possible the Inventory Agency has filled data gaps with operator-reported estimates and applied IPCC good practice gap-filling methods to ensure that the time series consistency is as good as practicable given the available data; this is possible as there are a defined number of installations that are active in this sector and their activities (and emissions) are generally well documented with gaps in data being relatively minor.

Further, the Inventory Agency has conducted time series consistency checks between the aggregated emissions reported in the 1990-2003 data submission (UKOOA 2005) and the installation-level EEMS and NAPs data (BEIS OPRED, 2022), across the overlap years of 1998 to 2003. This analysis shows close consistency, indicating that the scope of reporting in the UKOOA 2005 dataset is consistent with the later installation-level EEMS data. *Further details are presented in **Annex 3.1.6**.*

In order to validate the data estimates, the Inventory Agency has derived estimates of *fuel gas use per unit production* for oil production and gas production back to 1990. There is a general trend to higher fuel gas use per unit production across the time series, reflecting the higher energy demands to extract materials from increasingly depleted oil and gas fields, although this trend is not always continuous year to year as some fields cease production and others come on stream. The total fuel gas use is 1.54 TJ net per kt crude oil production and 0.841 TJ net per Mm^3 gas production in 1990 whereas by the end of the 1990s the figures are 1.56 and 0.842 in 2000, with increases evident to over 1.60 and around 1.00 by 2002. These figures can only be regarded as indicative given the variability in emissions intensity production evident across the UKCS and limited data resolution in the early 1990s, but they do indicate that the derived estimates of fuel use for 1990 are lower than data for later years and of a similar order of magnitude, which is as expected.

We further note that whilst the emission estimates specific to fuel combustion in 1990-1997 are uncertain, that the total emissions across all upstream oil and gas sources (∑1A1cii, 1B2) in the UK GHGI are aligned with the industry submission to UK Government (UKOOA, 2005) and hence are regarded as the most accurate data available.

Uncertainties

Uncertainties for both activity and emission factors are based on expert judgement, informed by the understanding of the available data, the level of uncertainty that is accepted within the reporting systems (e.g. UK ETS) and the likelihood of error compensation across the UK installations.

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 above) that there are known data gaps in national statistics across the time-series and less detailed emissions data available for the 1990-1997 period, and hence uncertainties for the estimates in 1990 are higher than for recent years where much more detailed and complete operator-reporting of activity and emissions are evident. The carbon emission factors are based on UK specific data. Since there is a direct link between the carbon emitted and the carbon content of the fuel, it is possible to estimate CO_2 emissions accurately. Non-CO_2 emissions are dependent on a greater number of parameters and are largely based on defaults. As such, the uncertainties are higher, but since the emissions are smaller, this does not have a significant impact on the overall uncertainty of total GHG emissions.

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

Relevant Categories, source names

1A2a – Iron and Steel (combustion)

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

1A2gviii - Other industrial combustion, Autogeneration - exported to grid (gas), Autogenerators (gas)

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

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

Background

This MS covers the use of fossil fuels for heat and power production in industry. Estimates cover fuel used throughout industry and including from both large and small installations. Larger installations are included in the UK ETS (2021) and EU ETS (2008 – 2020), 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, 2022a), cement sector fuel use estimates (MPA, 2021) and, installation-specific activity data from UK ETS e.g. for lime kilns (EA, SEPA, NRW, NIEA, all 2022).

Emission Factors: Where available, operator-reported EFs from UK ETS are used for high-emitting source sectors. Other UK CS CEFs are taken from the 2004 Carbon Factors Review (Baggott et al., 2004). Defaults for non-CO_2 gases are derived from IPCC (IPCC 2006).

An accompanying document "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references. ***Table 1.5*** *gives additional information for common activity data sources.*

Method approach

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

DUKES provides most of the energy activity statistics. The full breakdown is available for all categories under 1A2 for coal, natural gas, fuel oil and gas oil. Other fuels such as LPG, coke and burning oil cannot be split within 1A2 and are therefore allocated solely under 1A2g due to a lack of any data on sectoral use in DUKES. A number of approaches are used to fine tune the allocation of energy use under the different subcategories to maximise consistency with other datasets such as UK 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 and UK ETS data. All lime kilns are included in the scope of EU ETS from 2008 – 2020, and in the UK ETS from 2021, so there is a full set of fuel data for 2008-2021, 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, UK and 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 UK and EU ETS data indicates that there are several 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 UK and EU ETS. This re-allocation increases the overall reporting of petroleum coke as an emissive energy use, deviating from DUKES;
- Analysis of UK and 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 UK / 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_2023.xlsx” lists all emission factors used in the energy sector, including a full list of references*[49]

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, considering 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 2020) 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 CH_4 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

Emissions from the combustion of biogas have been disaggregated from category 1A2gviii to the individual industry categories. This has not led to an overall change to the inventory, but a reallocation between the categories is evident. This utilises the data available within DUKES and is consistent with the methodology described here.

An improved estimate has been generated for NRMM, which is described in MS6. This has impacted the allocation of gas oil between categories. The reallocation approach is reported in Annex 4.

There are also minor revisions to DUKES which lead to small changes to the categories included in this Method Statement, for the latest 2-3 years.

Improvements (completed and planned)

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 UK and 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*[50].

The UK ETS data, is subject to its own QA process, defined and managed by the competent authority.

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 within DUKES for recent years only, through meetings with the key data providers. The use of carbon EFs derived from the UK and 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 CO_2 emissions accurately. Non-CO_2 emissions are dependent on a greater number of parameters and are largely based on defaults. As such, the uncertainties are higher, but since the emissions are smaller, this does not have a significant impact on the overall uncertainty of total GHG emissions.

MS 4 Iron and steel, and coke manufacture

Relevant Categories, source names

1A1ci: Coke production

1A2a: Iron, and steel - combustion plant coke oven coke only

1B1b: Coke production

Iron and steel - flaring

2C1a: Basic oxygen furnaces

2C1b: Iron and steel – flaring

2C1b: Blast furnaces,

Iron and steel - combustion plant (coke oven gas and blast furnace gas only)

2C1d: Sinter production

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

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

Background

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

Most UK coke is produced at coke ovens associated with the UK's three integrated steelworks, although one independent coke manufacturer also 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	21
1993-1995	9	4	21
1996	9	4	20
1997-1998	9	4	18
1999-2001	9	4	17
2002	9	3	17
2003	7	3	14
2004-2005	6	3	12
2006-2007	6	3	11
2008	6	3	8
2009-2010	6	3	7
2011	6	2	7
2012-2014	6	3	6
2015	3	2	6
2016-2021	2	2	6

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 now reported under CRF category 2C1b, in line with reviewer recommendations. 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 also reported under CRF category 2C1.
7. Pig iron has a high carbon content derived from the coke used in the blast furnace. A substantial proportion of this must be removed to make steel and this is done in the basic oxygen furnace. Molten pig iron is charged to the furnace and oxygen is blown through the metal to oxidise carbon and other contaminants. As a result, carbon monoxide and carbon dioxide are emitted from the furnace and are collected for use as a fuel. As with blast furnace gases, some losses occur and these losses are reported with blast furnace gas losses under CRF category 2C1. In DUKES, basic oxygen furnace gas is combined with blast furnace gas and so separate figures for production and use of the two gases are not given.
8. The fuels derived in coke ovens and integrated steelworks are used in boilers and in heat treatment or melting furnaces and CO_2 emissions from these energy uses are calculated using emission factors derived using the carbon balance.

Key Data sources

Activity Data:	Main sources of activity data (fuel use, production data) are DUKES (BEIS, 2022a), ISSB annual statistics (ISSB, 2022), installation-specific activity data from EU ETS (EA, NRW, both 2022), operator information for integrated steelworks (Tata Steel and British Steel, both 2022)
Emission Factors:	Input parameters for the carbon balance method are derived from EU ETS data or operators of integrated steelworks (reference as for AD). Other UK CS CEFs are derived from the 2004 Carbon Factors Review (Baggott et al., 2004). EFs for non-CO_2 gases are predominantly IPCC defaults (IPCC 2006), Baggott et al., 2004.

An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]*.* ***Table 1.5*** *gives additional information for common activity data sources.*

Method approach

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

Carbon Flow Description

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

coke + limestone + iron ore → sinter + carbon emission

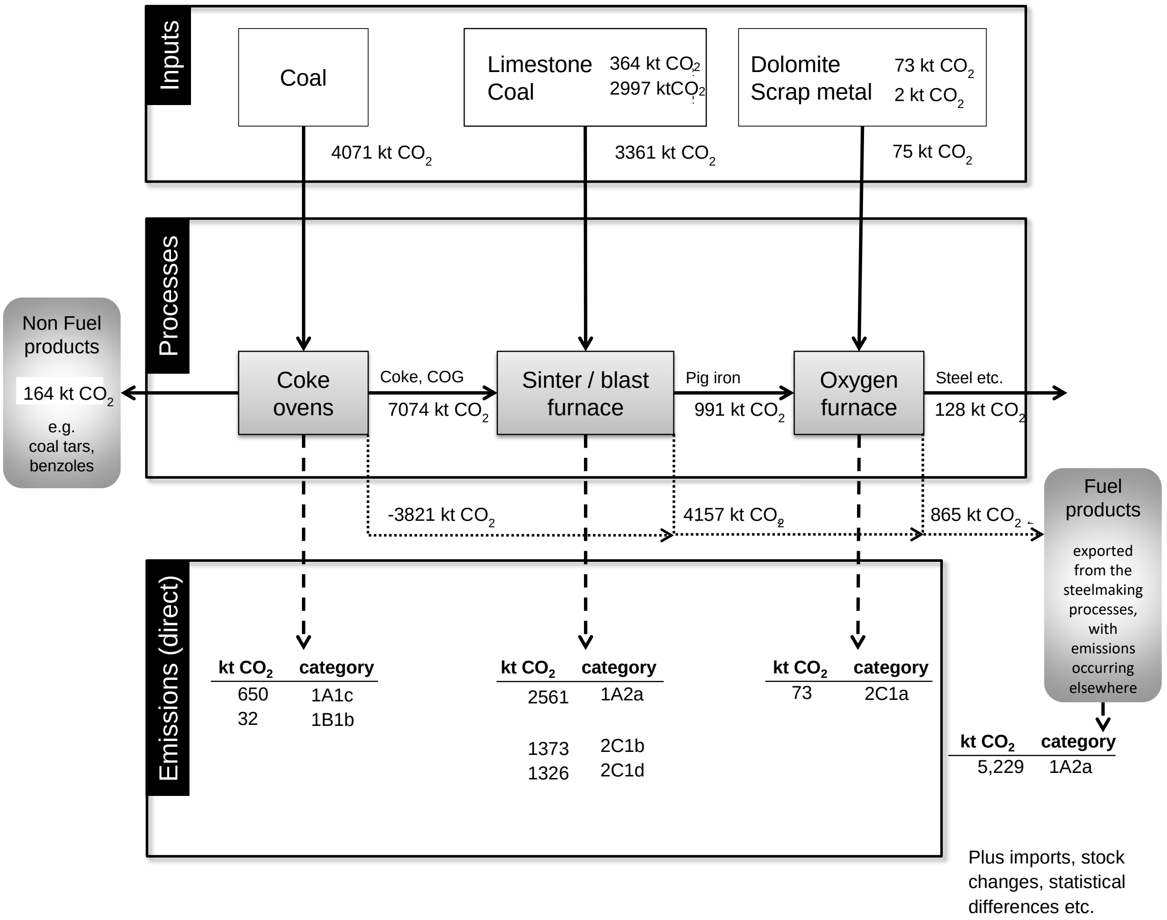
sinter + coke + other reducing agents → pig iron + blast furnace gas

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

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

The carbon balance model used is shown in a simplified form in **Figure 3.1**, with inputs and outputs of carbon (expressed as CO_2) given for the year 2020 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 2021[a]



[a] Other adjustments includes statistical differences (+6 kt CO_2), imports (-3414 kt CO_2), exports (0 kt CO_2), stock changes (-620 kt CO_2), fugitive emissions from coke ovens reported as methane (15 kt CO_2), adjustments for natural gas added to coke oven gas (-53 kt CO_2), carbon stored in dusts (+23 kt CO_2).

Emission estimates for limestone and dolomite added to sinter plants, blast furnaces, and oxygen furnaces are based on industry consumption data (Iron & Steel Statistics Bureau, 2022) and carbon contents from the operators (Tata Steel, SSI Steel, both 2015), and based on their UK and EU ETS reporting (EA, NRW, both 2022).

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

Assumptions & observations

A detailed description of the carbon balance methodology has been given in Ricardo-AEA, GHG Inventory Research: Use of EU ETS Data - Iron & Steel Sector, Chemical Industry Feedstock Use, April 2014 (available for download on the NAEI website[55]) 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 CO_2 is therefore

[55] 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 2003-2020 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

The main recalculation is the reallocation of emissions from blast furnace gas and coke oven gas from 1A2a to 2C1b, this has no impact on the national total.

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 UK 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*[50]. 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 some recent years (2005-2014 in the case of coking coal, 2007-2014 for other fuels) so the same values must be assumed to be appropriate in earlier years. Data are not available for 2015 onwards, 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 2015-2020 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.

Note that the implied emission factor for 1B1b is very sensitive to the weighting of emissions between coke manufacture and other solid fuel transformation; this is discussed further in **MS 20**.

Uncertainties

Uncertainties for both activity and emission factors are based on expert judgement. The uncertainty analysis set out in **Annex 2** provides details of these uncertainty values. Uncertainties in fuel use statistics are typically low. The carbon emission factors are based on UK specific data. Since there is a direct link between the carbon emitted and the carbon content of the fuel, it is possible to estimate CO_2 emissions accurately.

MS 5 Other stationary combustion

Relevant Categories, source names

1A4ai : Miscellaneous industrial/commercial combustion

Public sector combustion

Railways - stationary combustion

1A4bi : Domestic combustion

1A4ci : Agriculture - stationary combustion

Miscellaneous industrial/commercial combustion

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

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

Background

This method statement covers emissions from fuel combustion by non-industrial sectors including commercial, agricultural, public and residential sectors. 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, 2022a)

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

An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]*.* ***Table 1.5*** *gives additional information for common activity data sources.*

Method approach

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

Assumptions & observations

The source representing public sector combustion includes emissions from stationary combustion at military installations, which should ideally be reported under 1A5a Stationary. However, we do not currently 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 estimates provided by industry experts (CPL, 2015).

Recalculations

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

- Any revisions to DUKES and other input data have been incorporated into the inventory, including revisions to natural gas in 2020
- Data for biogas and biomass combustion have been disaggregated across all relevant reporting categories, based on DUKES (formerly all reported in 1A2gviii), affecting categories 1A4ai and 1A4ci, but with no impact on the national total.

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

Improvements (completed and planned)

Improvements made to this category include the disaggregation of biomass and biogas data, which has led to recalculations in this category but not to the national total. The model for domestic combustion has been upgraded to contain more detail on the technology types and ages used for fuel combustion, as well as to split out dry, wet and seasoned wood. These changes have been made to improve the inventory for air quality pollutants, and as there is no differentiation in the emission factors for greenhouse gases, this has not had any impact on the emissions reported here.

No further 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 1.3.3**. 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*[50].

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 CO_2 emissions accurately. Non-CO_2 emissions are dependent on a greater number of parameters, and are largely based on defaults. As such, the uncertainties are higher, but since the emissions are smaller, this does not have a significant impact on the overall uncertainty of total GHG emissions.

MS 6 Off-road machinery

Relevant Categories, source names

1A2gvii : Industrial off-road mobile machinery

1A3eii : Aircraft - support vehicles

1A4aii : Commercial off-road mobile machinery

1A4bii : House and garden machinery

1A4cii : Agriculture/Forestry/Fishing - mobile machinery

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

DERV, Gas oil, Petrol, LPG

Background

Defra commissioned Ricardo Energy & Environment to conduct a detailed Government-supported machinery population and usage survey with industry stakeholders, including evaluating the findings for their use in the inventory. Following review, agreed implementation of the data into an updated version of the off-road machinery model has been conducted, containing revised activity and population data. As such, there are now two models, the previous approach covering house and garden, and the new model for all other off-road machinery.

Emissions are estimated for 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 and aircraft support equipment. In the inventory they are grouped into four main categories:

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

Key Data sources

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

An accompanying spreadsheet “Energy_background_data_uk_2023.xlsx” lists all emission factors used in the energy sector, including a full list of references[49]*.* ***Table 1.5*** *gives additional information for common activity data sources.*

Method approach

In the previous 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 affect methane emissions. Activity data are based on bottom-up estimates of machinery 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 and petrol 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. The population and usage surveys and assessments were only able to provide estimates on activity of off-road machinery for 2004. These are one-off studies requiring intensive resources and are not updated on an annual basis. **Table 3.9** below details the drivers used for domestic house and garden machinery

Table 3.9 Activity drivers used for off-road machinery

Category	Driver source	Machinery types
Domestic house and garden	Office for National Statistics - Labour Force Survey (LFS) Table 5: number of households by size	All types of garden equipment, e.g. lawn mowers, garden tractors, leaf blowers, chain saws, trimmers

A simple turnover model is used to characterise the population of house and garden 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 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

Estimation of Off-Road Machinery (Industrial, Airports, Agriculture (1A2gvii, 1A4cii, 1A3eii)

Databases and information for the new model were provided by industry trade associations and stakeholder groups including the Off Highway Engine and Equipment Group (OHEEG) the Agricultural Engineers Association (AEA), Department for Transport (DfT) and the Construction and Agriculture Equipment Security and Registration (CESAR) database, and though these data were not designed for use in inventories, they provided valuable information.

Machinery or engine-specific fuel consumption and emission factors (g/kWh) in the new model are based on stakeholder consultation and the 2019 EMEP/EEA Guidebook. The AEA were able to provide fuel consumption rates for different agricultural machinery types in litres per hour based on telemetry data. Exception were agricultural telehandlers which were adjusted to align with fuel consumption rate implied by Guidebook factors.

The new model was designed in ‘R’, an open-source software to accommodate the new activity data and used to calculate an estimate of emissions. Using activity data collated from OHEEG, AEA, DfT licensing statistics supplemented by various assumptions from expert judgement from discussions with AEA where data are missing, the model was constructed and used to calculate trends in fuel consumption and emissions, initially from agricultural machinery and then extended to other off-road machinery (excluding house and garden).

Inventories for these machinery were grouped into portable generators, construction machinery, forklifts, machinery used in mining & quarrying, waste services, airport support and seaport support machinery and Transport Refrigeration Units (TRUs). Nearly all types of machinery use gas oil, but for some machinery types, a further breakdown in consumption and emissions is provided for machines running on petrol and LPG, where relevant.

In the case of portable generators, cement mixers, cranes and various lifting equipment used in construction and industry, data from Eurostat PRODCOM[1] statistics on sales/production of these equipment were used. ONS[2] construction statistics and BEIS energy statistics for other types of construction and industry machinery continue to be used.

Confidential data provided by the British Industrial Truck Association (BITA) have been adopted for trends in sales of forklifts.

For airport machinery, statistics on number of terminal passengers at UK airports[3] continue to be used.

DfT port freight statistics[4] have been used as proxies for trends in activities for machinery used in sea ports.

Trends in TRU activities were based on DfT statistics[5] on licensed “insulated vans” vehicle category.

In the new model, emissions from off-road agricultural machinery are calculated using the Tier 3 method in the EMEP/EEA Emissions Inventory Guidebook 2019. The equation to calculate the emissions is given below:

$$E = N\ x\ HRS\ x\ P\ x\ LF\ x\ (1 + DFA)\ x\ LFA\ x\ EFBase$$

where:

E = mass of emissions of pollutant during inventory period (g),

N = number of engines (units),

HRS = annual hours of use,

P = engine size (kW),

LF = load factor,

DFA = deterioration factor adjustment,

LFA = load factor adjustment,

EFBase = Base emission factor (g/kWh).

The emission factors are taken from the 2019 Guidebook, as provided for different legislative stages and engine power ratings. The exception to this was for the smallest and largest machinery in the power bands <19 kW or greater than 560 kW for the other machinery types. For these machines, OHEEG noted that although off-road in these power classes were unregulated in Europe prior to Stage V (which was incorporated into the new model), nevertheless it was common for machines in these size classes to be fitted with engines suitable for the US market, with the exception of >560 kW gensets. Thus, a significant proportion will have lower emissions than might be assumed for 'unregulated' engines as provided in the Guidebook. Thus, emission factors were changed to reflect US Tier 2 or Tier 4 regulations prior to Stage V. Tier 2 machines were phased into the market from 2006 for machinery for >560kW. Tier 4 is phased in from 2008 for those machines <19kW.

In contrast to the previous approach, in the new off-road model, machinery can be grouped into more than one of eight sector types (excluding house & garden which remains in the previous approach), based on stakeholder feedback. Each machinery type can be placed into eight power bands from P < 8 to P > 560, where P is power in kW. Table 3.10 summarises the machinery types and sectors in the new off-road model.

Table 3.10 Machinery types and sectors in new off-road model

	Sector							
Machinery Type	**Construction**	**Waste**	**Mining Quarrying**	**Airport**	**Port**	**Other**	**Refrigeration**	**Agriculture**
Trencher / mini excavator	√							
Excavator	√							
Forklifts	√	√	√		√	√		
Telehandlers	√	√	√		√			
Rough terrain forklifts	√		√					
Dumpers / tenders	√		√			√		
Rollers	√							
Cement & mortar mixers	√							
Cranes	√				√			
Rubber tyred gantry cranes					√			
Pumps	√							
Air compressors	√							

	Sector							
Machinery Type	**Construction**	**Waste**	**Mining Quarrying**	**Airport**	**Port**	**Other**	**Refrigeration**	**Agriculture**
Gas compressors						√		
Bore / drill rigs	√		√					
Plate compactors	√							
Landfill compactors		√						
Loaders	√	√	√					
Bulldozers	√	√	√					
Asphalt / concrete pavers	√							
Generators	√					√		
Scrapers	√							
Graders	√							
Crushing / processing equipment	√		√					
Aerial Lifts	√		√			√		
Sweepers / scrubbers	√	√						
Welding equip	√		√			√		
Concrete / industrial saws	√							
Pressure washers	√					√		
Tampers / rammers	√							

	Sector							
Machinery Type	**Construction**	**Waste**	**Mining Quarrying**	**Airport**	**Port**	**Other**	**Refrigeration**	**Agriculture**
Aircraft support equip				√				
Terminal tractors				√				
Reachstackers					√			
Shuttle carrier / Straddle carrier					√			
Terminal tractors - port					√			
Industrial tractors, burden and personnel carriers						√		
Other material handling equip						√		
Bitumen Applicator						√		
Aggregate Applicator						√		
TRUs							√	
Other general industrial equip						√		
Paving equip	√							
Surfacing equip	√							
Concrete pumps	√							

	Sector							
Machinery Type	**Construction**	**Waste**	**Mining Quarrying**	**Airport**	**Port**	**Other**	**Refrigeration**	**Agriculture**
Agricultural machine								√
Agricultural tractor								√
Agricultural telescopic handler								√
Combine harvester								√
Forage harvester								√
Root crop harvester								√
Sprayer								√
Windrower								√

[1] https://www.ons.gov.uk/businessindustryandtrade/manufacturingandproductionindustry/bulletins/ukmanufacturerssalesbyproductprodcom/2021results

[2] https://www.ons.gov.uk/businessindustryandtrade/constructionindustry/datasets/outputintheconstructionindustry

[3] https://www.caa.co.uk/Documents/Download/9115/8cce8a5d-a76b-4652-8fab-41ae2288f104/4644

[4] https://www.gov.uk/government/collections/maritime-and-shipping-statistics

[5] Private communication

Assumptions & observations

The assumptions made to estimate emissions from this source are described in the methods and approach section above. . The drivers chosen are considered by expert judgement to be most appropriate among all the statistical data that are available. A fuel reconciliation procedure is followed for gas oil which takes account of consumption from all sources, as described in **Annex 4**.

Recalculations

Petrol

The IEFs for CH_4 are significantly lower in naei21 compared to naei20. This is due to the application of 2019 Guidebook emission factors for naei21. For 2-stroke and 4-stroke petrol-fuelled engines, the base emission factors used in in naei21 are the Tier 3 emission factors from Table 3-7 and Table 3-8 respectively of the 2019 EMEP/EEA Guidebook. Base emission factors for the engine size class “100 <=S <225 cc” (or referred to as size code “SN3” in the Guidebook) have been used, as this is the most conservative assumption.

For naei20, these were based on emission factors developed as part of a large-scale off-road improvement programme over 10 years ago. For petrol-fuelled NRMM in 2020, for example, in naei20, the vast majority of emissions came from generators with an emission factor of 2 g/kWh. For naei21, the emission factor from the 2019 Guidebook applied is 0.43 g/kWh; around 4-5 times lower.

Gas oil

The IEFs for CH_4 are significantly lower in naei21 compared to naei20. This is due to the application of 2019 Guidebook emission factors for naei21. The base emission factors used in in naei21 are the Tier 3 emission factors from Table 3-6 of the 2019 EMEP/EEA Guidebook.

For naei20, these were based on emission factors developed as part of a large-scale off-road improvement programme over 10 years ago. For gas oil-fuelled NRMM in 2020, for example, in naei20, the vast majority of emissions came from “generator sets 5-100 kW” with an emission factor of 0.05 g/kWh for all stages. For naei21, the emission factor from the 2019 Guidebook applied is typically lower than this, but significantly, also varies by regulation stage. Therefore, the IEFs in naei21 decrease relative to the naei20 EFs moving towards the later time-series.

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 for years 2017 and 2018 which is as a driver for the agricultural machinery sector.
- Revision to ONS construction output data from 1997.

Improvements (completed and planned)

Defra have commissioned Ricardo Energy & Environment to conduct a detailed Government-supported machinery population and usage survey with industry stakeholders and evaluating the findings for their use in the inventory.

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 nor 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. 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 with multiple use applications, e.g. portable generators. Uncertainties in the trends for the other off-road sources (domestic house and garden, airport machinery and agricultural machinery) are considered to be smaller and less biased by the choice of proxy data.

MS 7 Aviation

Relevant Categories, source names

1A3a: Aviation

International bunkers - Aviation

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

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

Background

In accordance with the agreed guidelines, the UK inventory contains estimates for both domestic and international civil aviation. Emissions from international aviation are recorded as a memo item, and are not included in national totals. Emissions from both the Landing and Take-Off (LTO) phase and the Cruise phase (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 (2022a); CAA (2022b); BEIS (2022a); DfT (2022)

Emission Factors: Baggott et al. (2004); EMEP/EEA (2019); IPCC (1997); IPCC (2006)

An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]*. 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 1.5** 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, 2022a). 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 3.11 Aircraft Movement Data: LTOs and Cruise distances for Domestic and International Flights from UK Airports, 1990-2018

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	1395.1	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
2018	910.8	340.4	1803.6	130.8
2019	911.2	326.9	1818.1	126.5
2020	367.0	135.8	731.6	48.7

Year	International LTOs (000s)	Domestic LTOs (000s)	International Aircraft, Gm flown	Domestic Aircraft, Gm flown
2021	319.7	140.6	665.9	54.9

Gm Giga metres, or 10^9 metres

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

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

Emission factors used

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

An accompanying spreadsheet "Energy_background_data_uk_2023.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 or reverse thrust at either at idle or 30%, the remainder of the time is at idle thrust setting. Other modes (Taxi and Hold) are at idle thrust.

Idle thrust is nominally 7%, however an adjustment is made to the idle fuel flow to account 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, 2019) 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 3.1.2** 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 CO_2 were derived from estimates of fuel consumed in the cruise (see equation above) and the carbon contents of the aviation fuels. Methane emissions are believed to be negligible at cruise altitudes (IPCC, 2006).

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

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

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

Assumptions & observations

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

- Flights between the UK and overseas territories are reclassified from international to domestic;
- International flights with an intermediate stop at a domestic airport are considered international in the CAA aircraft movement data. These are reclassified as having a domestic leg and an international leg in response to a recommendation from the UNFCCC centralised review in 2013; and
- The CAA data have been supplemented with data from overseas territories, supplied by DfT.

Recalculations

There were minor recalculations from 2017 to 2020 due to revised activity data from Heathrow. These led to minor redistributions of activity amongst sources mostly resulting in changes of less that 3%.

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 2022 inventory submission included improvements resulting from the adoption of cruise factors from the 2019 EMEP/EEA Guidebook and the assignment of aircraft to the new EMEP/EEA cruise categories. There have also been improvements to helicopter emissions resulting from the adoption FOCA data.

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

QA/QC

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

Time series consistency

Consistent data sets and methods are used across the full time series to ensure time series consistency. There was a dramatic reduction in aviation activity in 2020 and 2021 as a result of the COVID-19 pandemic.

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 CO_2 emissions accurately. Non-CO_2 emissions are dependent on a greater number of parameters, and are largely based on defaults. As such, the uncertainties are higher, but since the emissions are smaller, this does not have a significant impact on the overall uncertainty of total GHG emissions.

MS 8 Road Transport

Relevant Categories, source names

1A3bi : Road transport - cars - cold start

Road transport - cars - motorway driving

Road transport - cars - rural driving

Road transport - cars - urban driving

1A3bii : Road transport - LGVs - cold start

Road transport - LGVs - motorway driving

Road transport - LGVs - rural driving

Road transport - LGVs - urban driving

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

Road transport - buses and coaches - rural driving

Road transport - buses and coaches - urban driving

Road transport - HGV articulated - motorway driving

Road transport - HGV articulated - rural driving

Road transport - HGV articulated - urban driving

Road transport - HGV rigid - motorway driving

Road transport - HGV rigid - rural driving

Road transport - HGV rigid - urban driving

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

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

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

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

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

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

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

1A3bv: Road transport - all vehicles LPG use

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Petrol (gasoline), Diesel (DERV), LPG

Background

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

Key Data sources

Activity data:	DfT (traffic data, vehicle licensing statistics, ANPR data, MOT 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 fuel consumed by the Crown Dependencies included in DUKES.
Emission factors:	COPERT 5.4, EMEP/EEA 2019 Emission Inventory Guidebook.

An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]*. **Table 1.5** 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 the 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 2006 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 derived from DUKES, detailing the consumption of this fuel in road transport. The CO_2 emissions from LPG consumption cannot be broken down by vehicle type because there are no reliable figures available on the total number of vehicles or types of vehicles running on this fuel. It is believed that many vehicles running on LPG are cars and vans converted by their owners and that these conversions are not necessarily reported to vehicle licensing agencies. Figures from DUKES suggest that the consumption of LPG is only a small percentage (0.19%) of the total amount of fuels 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. 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 CH_4 and N_2O, as well as the indirect GHGs and air pollutants, NMVOCs, NO_x, CO and SO_2, 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 5.4 (Emisia, 2020) and EMEP/EEA (2019) Emissions Inventory Guidebook, 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 CH_4 and N_2O 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, higher speed motorways/dual carriageways and 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 motorways, trunk, principal and minor roads in urban and rural areas (DfT, 2022a). DfT provides a consistent time series of vehicle km data by vehicle and road types going back to 1993 for the 2021 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 (e.g. Automatic Number Plate Recognition data) (DfT, 2022b) 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 timeseries of vehicle km data from 2008 to 2014. To create a timeseries of vehicle km data for 1990 to 2007, the vehicle km data from DRDNI (2013) was used. The data were 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 2015-2021 were not available 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 2021 in Great Britain. Motorcycle vehicle km data were not available for Northern Ireland 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 (2022d).

The Northern Ireland data has 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 2021. **Table 3.12** shows the time-series of total UK vehicle kilometres by vehicle and road type for selected years from 1990 to 2021.

Table 3.12 UK Vehicle km by Type of Road Vehicle, 1990-2021

Billion vkm		1990[56]	2000	2005	2010	2015	2019	2020	2021
Petrol cars	urban	142.2	134.8	118.1	97.8	89.2	88.0	70.3	78.5
	rural	140.9	134.1	127.6	110.5	95.5	101.1	76.5	86.0
	m-way	49.3	53.0	48.9	41.7	34.3	36.3	26.6	32.8
Diesel cars	urban	5.8	26.1	40.3	53.1	65.1	68.6	52.7	56.6
	rural	6.1	28.3	47.8	66.6	90.2	98.0	72.1	78.7
	m-way	2.8	14.7	25.2	33.6	45.9	46.8	29.5	31.3
Petrol LGVs	urban	11.2	4.5	2.1	1.2	1.0	0.9	0.8	0.8
	rural	11.6	5.4	2.6	1.7	1.3	1.4	1.2	1.3
	m-way	4.0	2.1	1.1	0.6	0.6	0.6	0.5	0.6

[56] Prior to 1993, a different definition was used for urban and rural areas; areas were defined as 'built-up'/'non-built-up'. 'Non-built-up' roads were those with a speed limit of more than 40mph, and 'built-up' roads were those with a speed limit of 40mph or less.

Billion vkm		1990[56]	2000	2005	2010	2015	2019	2020	2021
Diesel LGVs	urban	5.7	15.2	20.7	22.3	25.4	26.4	24.2	26.1
	rural	5.9	18.4	25.9	30.1	35.2	40.9	36.6	41.2
	m-way	2.0	7.2	10.3	11.4	14.7	17.0	15.7	18.3
Electric cars	urban	0.0	0.0	0.0	0.0	0.2	1.2	1.6	3.2
	rural	0.0	0.0	0.0	0.0	0.3	1.5	1.9	3.9
	m-way	0.0	0.0	0.0	0.0	0.1	0.6	0.7	1.5
Electric LGVs	urban	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2
	rural	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3
	m-way	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Rigid HGVs	urban	4.5	3.9	4.0	3.2	3.0	2.5	2.4	2.5
	rural	7.1	7.2	7.5	6.7	6.4	6.1	5.5	5.9
	m-way	3.7	4.2	4.2	4.1	3.9	4.0	3.6	3.9
Artic HGVs	urban	1.1	1.1	1.1	0.8	0.9	1.0	0.9	1.0
	rural	4.4	5.2	5.4	5.1	5.3	5.9	5.6	6.1
	m-way	4.7	7.4	7.9	7.5	8.4	9.0	8.9	9.5
Buses	urban	2.4	3.0	3.1	3.0	2.7	2.3	1.6	1.8
	rural	1.7	1.7	1.5	1.6	1.4	1.2	0.9	1.0
	m-way	0.6	0.5	0.5	0.5	0.4	0.4	0.1	0.1
M/cycle	urban	3.3	2.3	2.9	2.5	2.2	2.2	1.9	2.3
	rural	2.0	2.0	2.2	1.8	1.9	1.8	1.5	1.6
	m-way	0.3	0.4	0.4	0.4	0.4	0.4	0.2	0.2
Total		**423.3**	**482.7**	**511.3**	**507.8**	**535.9**	**566.4**	**444.4**	**497.3**

In the current inventory, a new road classification and traffic speed assignments is developed to improve the representation of total road transport emissions and their spatial distribution. Speed limit classification data has been assigned to OS Openroads geometry based on the length weighted median speed limit for each road link. The underlying speed limit dataset has been provided by Basemaps for Great Britain (Speed Limit Data Basemap, 2021). The vehicle speeds assigned to each category were derived from an analysis of GPS vehicle speed observations (Teletrac Navman, 2021) for England provided by DfT. The observed average speeds for England were applied across the UK. The vehicle speeds 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 does 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 (2022b) 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 3.12.** 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, engine size, vehicle weight and road types.

In the current inventory, a new fleet turnover model is developed that calculates the composition of the UK vehicle fleet and road transport emissions over a time-series from 1990 to 2021. The new model is based on a new, more comprehensive and up-to-date set of vehicle licensing (DfT, 2022d) and annual mileage data from MOT (Ministry of Transport) records provided by DfT (2022e), covering years between 2007 and 2021 (licensing data back to 1994 and MOT data also available for 2021). These have been supplemented with additional DfT data from the Continuing Survey of Road Goods Transport (CSRGT) and National Travel Survey and used to develop revised vehicle survival rate and mileage with age profiles that vary by year and have been used to update the NAEI's fleet turnover model. The model is used to calculate a consistent time-series in the composition of the fleet in terms of the proportion of vehicle kilometres travelled by vehicles of different Euro emission standards from 2005 to 2021.

Vehicle licensing statistics and mileage data are 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.

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 CH_4 and N_2O, technologies designed to control the regulated pollutants such as hydrocarbons and NO_x affect these GHG emissions.

Detailed information on the fleet composition in London is regularly provided by Transport for London (TfL, 2022) 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 and Ultra Low Emission Zone both introduced in stages.

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 5.4 and the EMEP/EEA Emissions Inventory Guidebook (2019). This includes a method for passenger cars which applies a year-dependent 'real-world' correction to the average type-approval CO_2 factor weighted by new car sales in the UK from 2005 to 2021. The new car average type-approval CO_2 factors for cars in different engine size bands were provided by the Society of Motor Manufacturers and Traders (SMMT, 2022). 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 3.13** for a selection of years between 1990 and 2021.

Table 3.13 UK Fleet-averaged fuel consumption factors for road vehicles (in g fuel/km)

Source	1990	2000	2005	2010	2015	2019	2020	2021
Petrol cars	55.7	55.0	55.1	55.2	53.6	50.6	50.3	49.7
Diesel cars	53.8	53.2	54.0	54.9	53.2	52.7	52.7	52.6
LGVs	74.5	69.6	66.9	66.2	66.1	66.0	66.0	65.8
HGVs	221.6	208.0	220.8	223.4	226.4	231.6	233.6	233.7
Buses and coaches	294.5	270.4	267.3	262.0	255.6	249.4	252.2	250.7
Mopeds and motorcycles	35.6	36.9	35.8	38.8	39.8	38.4	37.4	37.4

Carbon Factors

CO_2 can be calculated from the carbon content of the fuel and the fuel used (calculated as above). Carbon emission factors for petrol, diesel and LPG are set out in *"Energy_background_data_uk_2023.xlsx"*.

CH_4 and N_2O Emission Factors for Vehicle Types

The emission factors for N_2O and CH_4 for all vehicle types in g/km are based on the recommendation of the Emissions Inventory Guidebook (EMEP, 2019) derived from COPERT 5.4. 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 N_2O 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 N_2O 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 the 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 CH_4, 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 CH_4 emissions with the introduction of successive Euro standards.

Table 3.14 summarises the N_2O and CH_4 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 3.14 N_2O and CH_4 Implied Emission Factors for Road Transport (in mg/km). Includes cold start emissions

Gas	Source	1990	2000	2005	2010	2015	2019	2020	2021
CH_4	Petrol cars	125.4	64.4	36.8	19.3	13.9	11.7	12.0	11.7

Gas	Source	1990	2000	2005	2010	2015	2019	2020	2021
	DERV cars	20.1	8.7	3.1	1.1	0.4	0.2	0.2	0.1
	LGVs	89.9	28.8	8.8	2.9	1.0	0.5	0.4	0.4
	HGVs	88.1	73.2	69.2	39.2	14.6	7.9	7.1	6.6
	Buses and coaches	152.3	121.7	98.9	57.8	29.0	13.1	11.2	9.5
	Mopeds and motorcycles	233.0	206.3	158.7	105.5	82.6	68.1	65.9	65.9
N_2O	Petrol cars	9.3	12.5	8.7	3.1	1.8	1.3	1.4	1.3
	DERV cars	-	4.1	6.1	6.7	6.5	6.3	6.4	6.4
	LGVs	6.1	5.6	6.6	6.6	6.4	6.0	6.1	6.0
	HGVs	35.9	17.7	10.5	18.9	38.2	44.1	45.7	46.1
	Buses and coaches	35.9	19.1	10.8	14.3	24.4	32.2	34.3	35.0
	Mopeds and motorcycles	2.2	2.1	2.1	2.0	1.9	1.9	2.0	2.0

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

Fuel reconciliation with national statistics and normalisation

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

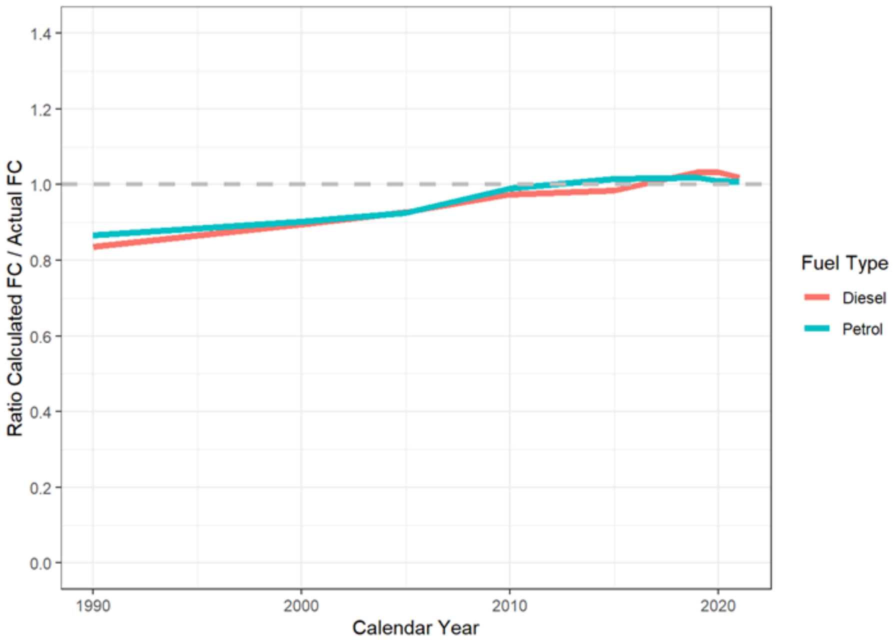
This comparison shows a small difference between the bottom-up estimated fuel consumption and DUKES-based figures. In order to be consistent with the IPCC methodologies and ensure that the fuel consumption data matches national statistics, it is necessary to adjust the calculated estimates for individual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

Figure 3.2 shows the ratio of model calculated fuel consumption (corrected for biofuel consumption) to the figures in DUKES based on total fuel sales of petrol and diesel in the UK, allowing for off-road consumption. In the earlier part of the time-series, there was a greater deviation from the DUKES figures with the maximum deviation being at 16% (for DERV, in 1994). When the ratio tends to be towards 1, it indicates a better agreement with fuel sales data. The bottom-up method for petrol consumption in 2021 was 100.9% and for diesel was 101.8% of the value from DUKES.

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

The fuel consumption, normalised to DUKES in the manner described above, is used to calculate CO_2 emissions for each vehicle type. For CH_4 and N_2O, the 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-CO_2 emissions cover all the fuel consumed by the road vehicles, including the biofuel, and not just the fossil-fuel amounts included in DUKES.

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 CH_4 and N_2O emissions from LPG consumption

Carbon emissions from LPG consumption are calculated from the total LPG consumption given in DUKES and fuel-based factors set out in *"Energy_background_data_uk_2023.xlsx"*.

Consumption of LPG is relatively small in the UK (0.19% of all road fuels in 2021) and there are no reliable data on the number or types of vehicles running on LPG. Vehicle licencing statistics suggests that 0.10% of all light duty vehicles ran on LPG in 2021.

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 CH_4 and N_2O 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 (2019) 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 (2019). These consumption estimates were used to calculate CO_2 emissions from lubricant combustion in road vehicle engines and are reported in IPCC sector 2D1 (**Section 4.22**) except for lubricants use by 2-

stroke mopeds, which is deemed to be intentional fuel use and hence reported in IPCC sector 1A3biv.

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

Overseas Territories and Crown Dependencies

Fuel consumption data for 1A3b were obtained from national statistics for all Overseas Territories and Crown Dependencies. Fleet composition data were available for all territories 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 CO_2, the assumptions have little effect on total road transport emissions as this is based on fuel sales figures in DUKES, but the assumptions used during the normalisation process affect the distribution of emissions between vehicle types. In particular, the procedure used to normalise the diesel consumption calculated for each vehicle type with the total DUKES figure is important as all vehicle types have a similar share of diesel consumption.

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

A sensitive parameter in the emission calculations of CH_4 and N_2O for petrol cars is the assumption made about the proportion of the fleet with catalyst systems that have failed, for example due to mechanical damage or failure of the lambda sensor. Following discussions with DfT, it is assumed that the failure rate is 5% per annum for all Euro standards and that up to 2008 only 20% of failed catalysts were rectified properly, but those that were rectified were done so within a year of failing. 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 CH_4 and N_2O emissions include:

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

Recalculations

Time-series emissions revisions are mainly a result of the decrease in vehicle kilometres following a revision to the DfT estimates of vehicle kilometres travelled on minor roads[57].

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. DfT statistics are accompanied by a Statement on Quality Strategy Principles and Processes[58].

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.

Uncertainties

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

There are greater uncertainties in the emission factors for CH_4 and N_2O because of limited emission factor measurements, in particular for more recent vehicle technologies and emission standards entering service. The main sources of uncertainties in the activity data affecting the CH_4 and N_2O inventories are in the division of diesel fuel consumption between vehicle types and the uncertainty in the fuel consumption factors that determine how much CH_4 and N_2O emissions are scaled to be consistent with national fuel consumption. There are also uncertainties affecting the emission estimates for CH_4 and N_2O 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

[57] https://www.gov.uk/government/statistics/road-traffic-estimates-in-great-britain-2021/minor-road-traffic-estimates-review-frequently-asked-questions#how-have-these-revisions-affected-total-road-traffic-in-great-britain

[58] Statement on Quality Strategy Principles and Processes, Department for Transport, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/10957/statement-on-quality.pdf

Railways: freight – gas oil

Railways: intercity – gas oil

Railways: regional – gas oil

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Gas oil, coal

Background

This MS includes emissions from gas oil used to power trains and from the consumption of coal used to power steam trains. The methodology for gas oil is based around three categories of railway locomotive: freight, intercity and regional. Stationary combustion in the rail sector is included in **0**. 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 and Network Rail Open Data Platform
Emission factors:	EMEP/EEA 2019, DfT's Rail Emissions Model (DfT 2012b), AP-42 (USEPA), Rail Safety and Standards Board (RSSB; 2020a)

*An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]. **Table 1.5** 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 2005-2021 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.

Apart from the relevant activity data updates for 2021 all main aspects of the inventory remain consistent with 2020 inventory. In the 2019 inventory, emission estimates were improved based on recent work for the UK's Rail Safety Standards Board (RSSB) to develop new emission factors that better reflect actual operation of the diesel engine) and account for the non-linear relationships between engine power output and emissions of pollutants (RSSB 2019).

For Great Britain, vehicle kilometre data for intercity and regional trains has been obtained from REM for 2009 to 2011, 2014 and 2018 and then estimated for other years from ORR's National Rail Trends Yearbook (NRTY) and data portal (ORR, 2022). Adjustments to the diesel vehicle kilometres for 2019, 2020, and 2021 were made to account for the introduction of new bi-mode passenger trains. Train kilometre data for diesel freight train movements in 2019 is available and this has been scaled forward to 2021 and back to 2005 using the trend in net tonne km from ORR's NRTY and data portal. Train kilometre data for freight trains is also available for 2004 and, similarly, data is scaled back to the start of the time series using information on the trend in net tonne km of freight moved.

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 2011-2021. No data is available for the years 1970-2004 and 2010. 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 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). The N_2O emission factor was updated in the 2020 inventory to utilise- the new value provided in the 2019 EMEP / EEA Guidebook for the rail sector.

Emissions of other pollutants are based on the vehicle / train kilometre estimates, and emission factors for different train classes.

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 diesel passenger train kilometres have steadily increased from 220 million km in 2000 to approximately 255 million km in 2018; however, in 2019 this metric declined to approximately 248 million km as new bi-mode trains were introduced and declined further to 186 million km in 2020, primarily as a result of reduced services due to the Covid 19 pandemic. Diesel passenger train kilometres then increased slightly in 2021 to 205 million km, but remained much lower than previous years due to the ongoing effects of the pandemic. 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 and then due to the Covid 19 pandemic. The amount of freight moved in 2020 was around 68% of the amount estimated for 2013 but increased to around 75% of the 2013 value in 2021.

Recalculations

The use of all available historic freight moved data from the Office of Road and Rail data has resulted in small recalculations of freight emissions for some years in the period 1982-2003.

Improvements (completed and planned)

Various emissions-related projects are currently being undertaken by the rail industry in the UK which may lead to further improvements in the NAEI rail emission estimates in future years.

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 and in 2010 and 2019. 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

CO_2, CH_4, N_2O

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 (2022c), MMO Fishing statistics (MMO, 2022), DUKES (BEIS 2022a), Scarbrough et al. (2017).
Emission factors:	IMO (2015).

An accompanying spreadsheet “Energy_background_data_uk_2023.xlsx” lists all emission factors used in the energy sector, including a full list of references[49]*.* ***Table 1.5*** *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 2019 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 2021 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.

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.

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 2021). 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 3.15. The main DfT statistics used are (DfT, 2022c):

- PORT0201 Domestic UK major port freight traffic by cargo type and direction, annually: 2000 – 2021
- SPAS0101 UK international sea passenger movements, by port and port area: from 1950
- SPAS0201 UK domestic sea passenger movements by type of route: from 2003

Table 3.15 Summary of activity indices

Vessel category	Activity index used	Separate domestic index?
Bulk carrier	2000-2021: Table PORT0201 – ‘All dry bulk traffic’ [Note 1]	✓
Chemical tanker	2000-2021: Table PORT0201 – ‘Other liquid bulk products’ [Note 1]	✓
Container	2000-2021: Table PORT0201 – ‘All container traffic’ [Note 1]	✓

Vessel category	**Activity index used**	**Separate domestic index?**
General cargo	2000-2021: Table PORT0201 – 'All other general cargo traffic' [Note 1]	✓
Liquefied gas tanker	2000-2021: Table PORT0201 – 'liquefied gas' [Note 1]	✓
Oil tanker	2000-2021: Table PORT0201 – 'total of Crude Oil and Oil Products' [Note 1]	✓
Ferry-pax only	2003-2021: UK domestic sea passenger movements by type of route – Table SPAS0201. *Pre-2003 trend uses the approach described in Entec (2010).*	✓
Cruise	*Same approach as used for the Ferry-pax only vessel category*	✓
Refrigerated bulk	2000-2021: Table PORT0201 – 'Other dry bulk' [Note 1]	✓
Ro-Ro	2000-2021: Table PORT0201 – 'Roll-on/roll-off traffic' [Note 1]	✓
Service - tug	2000-2021: Table PORT0201 – 'total domestic traffic' [Note 1]	✓
Miscellaneous - fishing	2010-2021: MMO UK Sea Fisheries Annual Statistics – Chapter 3 Landings. *Pre-2010 trend uses the approach described in Entec (2010).*	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	2000-2021: Table PORT0201 – 'total domestic traffic' [Note 1]	✓
Miscellaneous - other	2000-2021: Table PORT0201 – 'total domestic traffic' [Note 1]	✓

Note 1 – pre-2000 trend uses the approach described in Entec (2010).

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 back casted 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.

Emission factors

The source of the raw emission factors used for CO_2, CH_4 and N_2O 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 CO_2 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 CO_2/tonne fuel
- MDO: 3,206 kg CO_2/ 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 CH_4 emissions are approximately 2% the magnitude of NMVOCs. Therefore, the CH_4 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 N_2O emission factors are taken from IMO (2015). N_2O 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 SO_2 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

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 2021.

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

Minor changes due to revisions in the driver data used. No change at the source and activity level is greater than 0.6%.

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. An update to this work is expected to be introduced into the inventory in 2024 or 2025, using a more recent base year based on newer AIS data.

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-CO_2 gases are higher.

MS 11 Shipping between UK and OTs

Relevant Categories, source names

1A3d : Shipping between UK and Gibraltar

Shipping between UK and OTs (excl. Gibraltar)

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Fuel oil

Background

This MS includes estimates of emissions from shipping movements between the UK and the Overseas Territories. These were not included in the 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_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]. **Table 1.5** gives additional information for common activity data sources.*

Method approach

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, 2021d) 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 2021.

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 2012[59]. 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

[59] http://www.gibraltarport.com/cruise/schedules

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.

This information was combined to show the total number of cruise ship movements between the UK and OTs from 1999 to 2017. Data was unavailable upon request from DfT for calendar years 2018 and 2019. To estimate the fuel consumption for passenger vessels for 2018 and 2019, the mean fuel consumption of the previous five years (2013 – 2017) by OT was used. For 2020 and 2021, the estimated fuel consumption values were based on the trend of "UK All Cruise Passengers" from the SPAS0101 DfT data set, relative to the index value of 1 in 2019.

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 activity in 2020 as it is now assumed there is non-zero activity in 2020. There has also been a minor upwards increase in the weighted emission factors in 2020 due to revised vessel type splits as a result of updated DfT port activity data.

Improvements (completed and planned)

This emission source was introduced in response to the UNFCCC ERT in 2012. Improvements may be considered in the scope of wider improvements to shipping planned for 2024 or 2025.

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

CO_2, CH_4, N_2O

Relevant fuels, activities

DERV, Gas oil, Petrol

Background

The category 1A3dii Waterborne Navigation includes emissions from fuel used for 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 2009, IMO 2015

*An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]. **Table 1.5** 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 Guidebook (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"[60]; No data were available for this dataset after 2009, therefore a second dataset was used to estimate the activity from 2010: OECD.Stat data: - 'Final consumption expenditure of household, UK, P31CP090: Recreation and culture)[61];
- Commercial passenger/tourist craft – Visit Britain, Visitor Attraction Trends in England 2021, Full Report: "Total England Attractions"[62].
- Freight – DfT - Waterborne transport in the UK: goods lifted and moved by traffic type, Table PORT0701 (Goods lifted - UK inland waters traffic - Non-seagoing traffic – Internal[63])..

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 CH_4 were taken from the EMEP/EEA 2009. Emission factors for carbon are from Baggott et al, 2004. For N_2O, the emission factor for fuel oil is taken from EMEP/EEA 2009. For N_2O 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 at 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 (Scarbrough 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 Scarbrough 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

Revised ONS data has led to revisions from 2010, with the revision being a 4.2% decrease in private leisure craft in 2020. Updated data for visitor trends has led to an increase of 4.8% in activity for commercial passenger/tourist craft in 2019. Revised data has led to a very minor increase in freight vessels activity in 2019 and 2020 too.

[60] http://www.ons.gov.uk/ons/rel/social-trends-rd/social-trends/social-trends-41/social-trends-41---expenditure.pdf

[61] http://stats.oecd.org/Index.aspx?DataSetCode=SNA_TABLE5

[62] https://www.visitbritain.org/annual-survey-visits-visitor-attractions-latest-results

[63] https://www.gov.uk/government/statistical-data-sets/port-and-domestic-waterborne-freight-statistics-port

Improvements (completed and planned)

Emission factors and activity data are kept under review. Improvements may be considered in the scope of wider improvements to shipping planned for 2024 or 2025

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

CO_2, CH_4, N_2O

Relevant fuels, activities

Gas oil, fuel oil

Background

This method statement covers estimates of international marine bunkers which are reported as a Memo item and not included in the UK totals.

Key Data sources

Activity: DUKES (BEIS, 2022);

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

*An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]. **Table 1.5** 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 only minor changes in activity (<3%) due to revised activity data.

Table 3.16 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 for selected years since 1990. Fuel consumed in the OTs and for voyages from the OTs to the UK are not included in this table.

Table 3.16 Fuel consumption (Mtonnes) for UK marine derived from inventory method

Year	Domestic coastal and military Gas oil	Fishing Gas oil	Inland waterway Gas oil	International bunkers Gas oil	Domestic coastal and military Fuel oil	Fishing Fuel oil	Voyages from UK to OTs Fuel oil	International bunkers Fuel oil
1990	1.89	0.23	0.03	1.14	0.82	0.82	0.008	1.39
2000	1.96	0.18	0.03	1.14	0.80	0.80	0.011	0.93
2005	1.64	0.19	0.04	0.89	0.78	0.78	0.009	1.16
2010	1.41	0.17	0.04	0.96	0.57	0.57	0.011	1.83
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	1.35	0.17	0.05	1.67	0.17	0.17	0.011	0.77
2018	1.37	0.16	0.05	1.63	0.16	0.16	0.009	0.81
2019	1.37	0.15	0.05	1.59	0.16	0.16	0.009	0.68
2020	1.18	0.14	0.02	1.33	0.15	0.15	0.006	0.54
2021	1.22	0.14	0.02	1.33	0.16	0.16	0.006	0.59

Improvements (completed and planned)

Improvements may be considered in scope as part of wider improvements planned for shipping in 2024 or 2025.

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

CO_2, CH_4, N_2O

Relevant fuels, activities

Gas oil

Background

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

Key Data sources

Activity:	MoD, 2022
Emission factors:	Scarbrough et al. (2017) and based on IMO (2015)

An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]*.* ***Table 1.5*** *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, 2022). 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

Revised MoD data has led to a 16% and 7.5% decrease in activity in 2019 and 2020 respectively. There are only minor (<0.4%) recalculations to emission factors due to updated DfT port statistics used to derive the time-series.

Improvements (completed and planned)

Emission factors and activity data are kept under review. Improvements may be considered in scope as part of wider improvements planned for shipping in 2024 or 2025.

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 CH_4 and N_2O 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

CO_2, CH_4, N_2O

Relevant fuels, activities

Aviation spirit, aviation turbine fuel

Background

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

Key Data sources

Activity: MoD, 2015, 2022

Emission factors: Baggott et al., 2004, IPCC, 1997.

*An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]. **Table 1.5** 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, 2022) and IPCC (1997). 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, 2022) 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.

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-CO_2 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 Gases

CH_4

Relevant fuels, activities

Coal produced

Background

In 2021 there were only seven small deep-mining collieries licensed to operate 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 an over 99% reduction in UK deep-mined coal production since 2015, according to UK energy statistics (BEIS, 2022). None of the remaining 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 3 open-cast coal mines were also operating in the UK in 2021. This is compared with 188 deep mining collieries and 126 open-cast mines operating in 1990[64].

Key Data sources

Activity Data: All activity data on coal production at open cast and deep mines is from DUKES (BEIS, 2022), 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

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

are used to derive CS EFs (UK Coal, 2015; Coal Authority, 2015), in conjunction with UK energy statistics from DUKES (BEIS, 2022). However, due to the closure of all UK large deep mines there are no operator-reported emissions data for all years from 2015. 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 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, 2015) *excluding any mitigation of methane in gas engines*, applied to the 2016 to 2021 UK activity data on coal production in deep mines (BEIS, 2022). 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_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]*.* ***Table 1.5*** *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, 2022). 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, 2022).

From 1990-1995, a small number of privately-owned mines classified as "deep mines" operating in the UK were shallower and smaller than Government-owned deep mines. These mines were licensed by the UK Government and in all years produced less than 3% of total UK deep-mined coal, whilst the majority of deep mines were Government-owned and operated. The Watt Committee Report #28 (Williams, 1993) indicates that these smaller licensed mines emitted less methane than the nationalised deeper mines, and therefore the aggregate emission factor for the early part of the time-series is slightly lower. Activity data for production at licensed mines is taken from Barty (1995), with the activity data for non-licensed mines calculated by difference from the UK deep-mine coal production total in UK energy statistics.

Emission factors for methane from **deep-mined coal** production are taken from:

1990-1992 Bennett et al (1995) was a study on deep mines which produced estimates of emissions for the period 1990-93. This was a period over which significant numbers of mines were being closed, hence the range in emission factors from 10 to 13.1 kg CH_4 per tonne coal extracted.

1990-1995 The methane emission factor of 1.36 kg CH_4/tonne coal produced at licensed, shallow mines is from Williams (1993).

1993-1997 No time-series of emissions data or industry research for deep-mined mines are available for 1993-97, and therefore the 1998 factor from operator reporting at deep mines (see below) is used. The combination of this 1998 factor for deep-mined coal and the lower factor for licensed, shallow mines operating to 1995 leads to a variable aggregate factor during 1993-1995.

1998-2014 The emission factors for UK mines in 1998-2014 are based on operator measurements of the methane extracted by the mine ventilation systems for all collieries operated by UK Coal (UK Coal, 2015) and for collieries owned by other operators that report methane utilisation and venting data (Coal Authority, 2015). Not all UK collieries provide data on methane utilisation and venting. The emission factor derived from the sites that provide data is applied across all UK production at deep-mined sites. The proportion of UK production that is covered by the reporting collieries ranges from 77% in 1998 to 96% in 2004 and 2007, and was around 90% from 2008 to 2012, 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.

From 2016 onwards, as all of the UK's major deep mines had already closed, 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 from 2016 onwards.

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 with no methane utilisation, the EF is derived from the sites that do report (from the vented and drained methane). Annual data (methane generation, methane utilisation, coal production) are obtained from mine operators. In 2005 there were 7 mines that reported methane emissions, then 6 in 2006, 5 in 2007 to 2010, 4 in 2011-12 and only three in 2013 and 2014. For these mines the aggregate emissions of methane (before any utilisation in gas engines) has been used together with the annual production data to derive an “unabated” methane IEF that is regarded as the most representative factor to apply to the production data from the smaller non-reporting (of emissions) UK deep coal mines.

Therefore, total methane emission estimates for deep-mined coal in the UK from 1998 onwards are calculated as follows:

UK Emissions = D + (E*F)

Where:

D = the sum of methane emissions reported (after any utilisation in gas engines) by the (typically larger) UK deep coal mines that can provide annual methane emission estimates;

E = UK total deep-mined coal production from DUKES – Annual coal production at all sites included in D; and

F = IEF for unabated methane emissions, based on reported methane emissions data from sites included in D (i.e. methane elution before any utilisation) / production at the sites included in D.

The decline in methane emissions in recent years in the UK reflects both the decline in UK deep-mined coal production and the increase in uptake of technology to utilise coal mine methane to generate electricity.

The emission factor for methane from coal storage and transport factor of 1.16 kg CH_4 per tonne of coal produced is only applied to deep mined coal production and is taken from industry research, Bennett et al (1995).

The emission factor for methane emissions from open-cast coal production of 0.34 kg CH_4 per tonne of coal production is taken from industry research, Williams (1993). The total production of saleable coal is derived from the DUKES statistics. Where coal is upgraded to saleable form, some coal is rejected in the form of coarse discards containing high mineral matter and also in the form of unrecoverable fines. Typically, around 20% of the weight of the raw coal feed is lost through these preparation processes, as per the 2006 IPCC guidelines. Raw coal production is therefore estimated by increasing the amount of 'saleable coal' by the fraction lost through washing. The total emissions from open-cast mining are based on measurements of the total methane content of freshly sampled coal cores from open-cast sites from the three main producing regions in the UK. These data are used to generate the total emission factor for all open-cast coal production, regardless of the stage at which this emission takes place.

Assumptions & observations

- **Open cast coal emission factor:** As noted in the method section, the CS EF for CH_4 emissions from open cast coal production are based on analysis of the total methane content of freshly sampled coal cores and these EFs reflect the total methane emissions for all open-cast coal produced, regardless of the stage at which this emission takes place. i.e. it is assumed in the UK GHGI 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 since 2014) 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 96% reduction in emissions reported in 1B1a1i since 2015, is fully consistent with the almost complete closure of UK deep-mined coal production. Between 2018 and 2019, deep mined coal production increased from 24kt to 99kt as the Aberpergwm Colliery started up production again towards the end of 2018.

Recalculations

There have been no recalculations to data for 1B1a1i.

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, the latest years of reporting (since 2015) 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 to 2021. Therefore the overall uncertainty of deep-mined coal methane emissions is higher for these years, but it this is set against the context that deep mined coal emissions only account for less than 0.06% of total methane emissions in the UK in 2021, whilst open-cast coal mining only accounts for 0.02% of total UK methane emissions.

MS 17 Closed coal mines

Relevant Categories, source names

1B1a1iii: Closed Coal Mines

Relevant Gases

CH_4

Relevant fuels, activities

Modelled emissions of releases of residual methane within coal seams from abandoned coal mines, including from the flooding of mine seams following closure.

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 major UK deep coal mines were closed by the end of 2015, leaving a very small number of operating small mines. The abandoned mines model was updated to reflect this for the 2017 submission, and there has been no further update to the model in the 2023 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_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]. **Table 1.5** 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 2021 emission estimates in the 2023 UK GHGI submission were 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 has 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 0.8% of total UK methane emissions in 2021.

The emissions from all abandoned mines are included within the 1B1a1iii source category.

All large deep mines in the UK have now closed, and therefore this source category will decline in significance in future years.

Recalculations

There were no recalculations or method changes to the closed coal mines source category in this submission. 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 updates to the model have been made for subsequent submissions, as the modelled future profile of emissions across the sector is unchanged. 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 2021 only accounts for 0.8% 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 ±17% to ±41% over the period 1990-2050. This level of uncertainty is in line with IPCC guidance on Tier 2 and Tier 3 methodologies. This considered the uncertainty in the future mine closure dates, gas reserve estimates, the annual methane emissions rate as % of gas reserve, the open cast mine methane emissions factor and the methane utilisation factor.

MS 18 1B2 excluding: Oil refining, storage and distribution (1B2aiv to v) and natural gas distribution (1B2biii to v)

Relevant Categories, source names

1B2a1: Onshore, offshore oil well exploration; Oil production: offshore well testing

1B2a2: Upstream oil production: fugitives, direct processes; Onshore oil production (conventional); Oil terminal: other fugitives, direct processes

1B2a3: Upstream oil production: onshore, offshore oil loading; Oil transport fugitives: pipelines, road/rail tankers

1B2a4: Oil terminal storage

1B2a6: Abandoned oil wells: onshore, offshore

1B2b1: Unconventional gas well exploration; Onshore, offshore gas well exploration; Gas production: offshore well testing

1B2b2: Onshore natural gas production (conventional); Onshore natural gas gathering

1B2b3: Upstream gas production: fugitives, direct processes; Gas terminal: other fugitives, direct processes

1B2b4: Gas terminal storage

1B2b6: Abandoned gas wells: onshore, offshore

1B2c1i: Upstream oil production: venting; Oil terminal: venting

1B2c1ii: Upstream gas production: venting; Gas terminal: venting

1B2c1iii: *(Reported as IE)*

1B2c2i: Upstream oil production: flaring; Oil terminal: flaring

1B2c2ii: Upstream gas production: flaring; Gas terminal: flaring

1B2c2iii: *(Reported as IE)*

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

All fugitive releases from oil and gas production, excluding leakage from gas transmission and distribution. Distribution of oil products is not described since there are no direct GHG emissions.

The activity data for well exploration and also for wells abandoned are the number of wells (drilled or abandoned, accordingly) per year.

The activity data for well testing is the mass of flared gas arising from the well tests, whilst the activity data for all other gas flaring is also the mass of gas flared.

The activity for the oil transport source categories is the annual mass of crude oil transported per source per year.

The activity data for source categories in 1B2b2 is the annual volume of natural gas produced/gathered.

For other source categories the methods are based on the sum of reported emissions and there are no associated activity data.

Background

These source categories across 1B2 cover fugitive emissions arising from the exploration, production, transportation, processing and storage of liquid and gaseous fuels. It excludes fuel combustion emissions associated with upstream oil and gas exploration and production which are reported within 1A1cii Oil and Gas Extraction, the method for which is presented in **MS2.**

The UK has been producing oil and gas, predominantly offshore in the North Sea, for decades, and there are several hundred oil and gas platforms that have been operating across the time series. Oil and gas exploration activities (well drilling, completions, well testing) lead to fugitive and flaring emissions; similarly at the end of the production life of each well there may be emissions from abandoned wells, whether they are plugged or not, and from purging of infrastructure during decommissioning. Process treatments (e.g. acid gas treatment) and fugitive releases give rise to GHG emissions during the production phase at offshore facilities and in subsequent material processing at onshore terminals to prepare oil and gas products for onward distribution.

[Emissions from leakage during gas transmission and distribution, and the point of use are included in ***MS 19****.]*

Offshore oil and gas is transported to onshore terminals via pipelines and marine tankers; emissions of CH_4 and NMVOC occur during loading of oil into the ship's tanks and the subsequent the unloading. This includes when onshore storage tanks. Emissions of CH_4 and NMVOC also occur from storage tanks at oil terminals.

There are also a small number of onshore oil and gas wells in the UK. This is a very small component of the upstream sector. Fugitive emissions do arise from well drilling, the production of oil and gas, flaring of waste gases, from well abandonment and from the transfers of oil product to rail and road tankers for deliver to oil terminals and refineries.

Shale gas reserves have been identified and some preliminary testing to explore the prospects for shale gas production has occurred during the inventory time series, but there is no active exploration or production of shale gas currently in the UK.

Key Data sources

Activity data:	EEMS (BEIS OPRED, 2022), DUKES (BEIS, 2022a), IED/PRTR-reported data (EA, NRW and SEPA, 2022) UK ETS data (BEIS, 2022b), UKOOA (2005), UKPIA (2022), PPRS data (BEIS, 2022c), DTI Brown Book (DTI, 2004), WONS data (NSTA, 2022).
Emission factors:	EEMS (BEIS OPRED, 2022), UK ETS (BEIS, 2022b), UKOOA (2005), IPCC 2006 Guidelines (IPCC, 2006), 2019 Refinement to the 2006 GLs (IPCC, 2019)

An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[65]*.* ***Table 1.5*** *gives additional information for common activity data sources.*

Method approach

The Inventory Agency has researched and analysed all available activity and emissions data for the UK upstream oil and gas sector across the time series during a recent inventory improvement project (Thistlethwaite et al, 2022). The inventory methods for sources across 1B2 draw upon the best available data from the sector, through a range of reporting mechanisms that have been developed by UK regulatory agencies across the time series.

A more detailed summary of the oil and gas sector improvement project is presented in ***Annex 3.1.6****. The methods developed impact both fuel combustion emissions reported in 1A1cii (see* ***MS 2****) and all upstream oil and gas fugitive emission sources reported in 1B2.*

[65] This can be found as one of the additional documents to the NIR https://naei.beis.gov.uk/reports/reports?report_id=1108. Note that there can be a delay between the NIR being published on the NAEI website after official submission.

An overview of the data sources and methods used to derive estimates for the categories included in this MS is below, with further details presented in **Annex 3.1.6**.

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 (of which, there is no current production). These different regulatory systems dictate data availability 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 the exception that there are no data available currently to estimate emissions from oil and gas well blowouts other than for the 2012 blow-out at the Elgin platform, as outlined below.

Table 3.17 Overview of UK GHGI methods per source category

IPCC	Source Category	Method Description
1B2a1	Oil Exploration	**Onshore wells, all years**: IPCC Tier 1 (2019 Refinement) method. Emission = #wells drilled x IPCC default EF (per conventional oil well) **Offshore well testing, 1990-1997**: UKOOA 2005 (Tier 2). Assumptions to derive time series using well drilling time series. **Offshore well testing, 1998 – Latest year**: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022), which includes well testing emissions per facility, per year. Tier 2/3 as EFs are from EEMS operator guidance (CS).
1B2a2	Oil Production	**Onshore oil production**: Hybrid Tier 2 method. ∑ Large + small sites. Larger sites, Emissions = ∑operator emissions per wellsite (EA, 2022) Smaller sites, Emissions = Production AD (PPRS) x EF derived from larger sites, IEF from (PI emissions / PPRS production data) **Offshore oil production, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on crude oil production trends; residual category for CH_4. **Offshore oil production, 1998- Latest year**: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022). Tier 3 as emissions for process emissions are derived from operator reporting; fugitives derived from EEMS guidance EFs. **Oil terminals, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on crude oil production trends; residual category for CH_4. **Oil terminals, 1998- Latest year**: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022) and PI, SPRI (EA, SEPA, 2022). Tier 3 as process emissions are based on operator reporting; fugitives derived from EEMS guidance EFs. 2011- only RI data, so estimates modelled on previous years share of RI total; source is also used to report residual CH_4.
1B2a3	Oil Transport	**Offshore oil loading, all years**: IPCC Tier 1 (2019 Refinement).

IPCC	Source Category	Method Description
		Emission = OTL production (PPRS/BB) x IPCC default EF (*assumes no VRU*) **Onshore oil loading, 1990-1997**: UKOOA 2005 (Tier 2). Time series based on crude oil production trends. **Onshore oil loading, 1998-latest year**: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022) and PI/SPRI (EA, SEPA, 2022). Tier 2/3 as emissions for oil loading are derived from operator reporting and use of EEMS guidance EFs (CS). 2011- only RI data, so estimates modelled on previous years share of RI total; Seal Sands data from operator consultation. **Onshore oil transport (pipelines), all years**: IPCC Tier 1 (2019 Refinement). Emission = Wytch Farm production (PPRS/BB) x IPCC default EF **Onshore oil transport (road/rail), all years**: IPCC Tier 1 (2019 Refinement). Emission = Onshore production *less Wytch Farm* (PPRS/BB) x IPCC default EF
1B2a4	Oil Refining / Storage	**Oil terminal storage, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on crude oil production trends. **Oil terminal storage, 1998 – latest year**: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022) and PI/SPRI (EA, SEPA, 2022). Tier 2/3 as emissions for oil storage are derived from operator reporting and use of EEMS guidance EFs (CS). 2011- only RI data, so estimates modelled on previous years share of RI total.
1B2a6	Oil - Other	**Oil wells abandoned, all years**: IPCC Tier 1 (2019 Refinement) method. Emission = #wells abandoned per year (cumulative) x IPCC default EF (*per well abandoned where it is unknown if plugged or not*) The AD are taken from the NSTA wellbore database search facility. The AD comprise all historic oil and gas wells, so the estimates include abandoned gas wells. IPCC Refinement states that leaks from abandoned offshore wells are assumed to be 2% of those onshore, as 98% of the gases are dissolved in the water column. This assumption is applied in the method for offshore wells abandoned.
1B2b1	Natural Gas Exploration	**Onshore conventional gas wells, all years**: IE, reported within 1B2a1, as there are no AD specific to gas wells drilled, only oil and gas combined. **Onshore unconventional gas well drilling**: Activity only evident in 2011, 2012, 2014, 2018 and 2019. ∑operator emissions per facility, based on operator and regulator information. **Offshore well testing, 1990-1997**: UKOOA 2005 (Tier 2). Time series based on #wells drilled per year, from NSTA. **Offshore well testing, 1998 – Latest year**: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022), which includes well testing emissions per facility, per year. Tier 2/3 as EFs are from EEMS operator guidance (CS).

IPCC	Source Category	Method Description
1B2b2	Natural Gas Production	**Onshore gas production, all years**: IPCC Tier 1 (2019 Refinement) method. Emission = natural gas produced (Mm^3) x IPCC default EF (for onshore activities with higher-emitting technologies and practices) **Onshore gas gathering, all years**: IPCC Tier 1 (2019 Refinement) method. Emission = natural gas produced (Mm^3) x IPCC default EF (for onshore activities with higher-emitting technologies and practices)
1B2b3	Natural Gas Processing	**Offshore gas production, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on natural gas production trends; installation-level direct process emissions from key sites (i.e. Elgin, Rough) based on their gas production trends. Residual category for CH_4 and NMVOC. **Offshore gas production, 1998- Latest year**: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022). Tier 3 as process emissions are based on operator reporting; fugitives derived from EEMS guidance EFs. Also includes one-off estimate of emissions from Elgin blow-out, 2012, based on *Lee et al* publication from aircraft monitoring of methane, NMVOC plume. **Gas terminals, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on natural gas production trends; installation-level estimates of process emissions from key sites (i.e. SAGE, CATS) based on gas throughput. Residual category for CH_4. **Gas terminals, 1998- Latest year**: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022) and PI/SPRI (EA, SEPA, 2022). Tier 3 as process emissions are based on operator reporting; fugitives derived from EEMS guidance EFs. 2011- only RI data, so estimates modelled on previous years share of RI total.
1B2b4	Natural Gas Transmission & Storage	**Gas terminal storage, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on natural gas production trends. **Gas terminal storage, 1998 – latest year**: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022) and PI/SPRI (EA, SEPA, 2022). Tier 2/3 as emissions for gas storage are derived from operator monitoring and use of EEMS guidance EFs (CS). 2011- only RI data, so estimates modelled on previous years share of RI total.
1B2b6	Natural Gas - Other	**Gas wells abandoned, all years**: Included Elsewhere. Reported within 1B2a6, as there are no AD specific to gas wells abandoned, only oil and gas wells combined.
1B2c1i	Venting & Flaring: Oil venting	**Offshore oil venting, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on crude oil production trends. **Offshore oil venting, 1998- Latest year**: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022). Tier 3: venting emissions are based on operator monitoring. **Oil terminals venting, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on crude oil production trends.

IPCC	Source Category	Method Description
		Oil terminals venting, 1998- Latest year: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022) and PI/SPRI (EA, SEPA, 2022). Tier 3: venting emissions are based on operator monitoring. 2011-only RI data, so estimates modelled on previous years share of RI total.
1B2c1ii	Venting & Flaring: Gas venting	**Offshore gas venting, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on natural gas production trends. **Offshore gas venting, 1998- Latest year**: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022). Tier 3: venting emissions are based on operator monitoring. **Gas terminals venting, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on natural gas production trends. **Gas terminals venting, 1998- Latest year**: ∑operator emissions per facility, based on EEMS (BEIS OPRED, 2022) and PI/SPRI (EA, SEPA, 2022). Tier 3: venting emissions are based on operator monitoring. 2011-only RI data, so estimates modelled on previous years share of RI total.
1B2c2i	Venting & Flaring: Oil flaring	**Offshore oil flaring, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on crude oil production trends. **Offshore oil flaring, 1998- Latest year**: ∑operator emissions per facility, based on UK ETS (BEIS, 2022b), EEMS (BEIS OPRED, 2022). Tier 3: flaring emissions are based on operator reporting. CEFs from flare gas sampling, analysis, 98% oxidation factor. **Oil terminals flaring, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on crude oil production trends. **Oil terminals flaring, 1998- Latest year**: ∑operator emissions per facility, based on UK ETS (BEIS, 2022b), EEMS (BEIS OPRED, 2022). Tier 3: flaring emissions are based on operator reporting. CEFs from flare gas sampling, analysis, 98% oxidation factor.
1B2c2ii	Venting & Flaring: Gas flaring	**Offshore gas flaring, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on natural gas production trends. **Offshore gas flaring, 1998- Latest year**: ∑operator emissions per facility, based on UK ETS (BEIS, 2022b), EEMS (BEIS OPRED, 2022). Tier 3: flaring emissions are based on operator reporting. CEFs from flare gas sampling, analysis, 98% oxidation factor. **Gas terminals flaring, 1990-1997:** UKOOA 2005 (Tier 2). Time series based on natural gas production trends. **Gas terminals flaring, 1998- Latest year**: ∑operator emissions per facility, based on UK ETS (BEIS, 2022b), EEMS (BEIS OPRED, 2022). Tier 3: flaring emissions are based on operator reporting. CEFs from flare gas sampling, analysis, 98% oxidation factor.

[Where BB = DTI Brown Book "*Development of the Oil and Gas Resources of the UK*"]

Key data sources for the 1B2 inventory methods include:

- Oil and gas operators submit annual source-specific emission estimates to the **Environmental and Emissions Reporting System (EEMS)**, regulated by BEIS Offshore Petroleum Regulator for Environment and Decommissioning (BEIS OPRED).

- Industry survey data from 1990 onwards were used to derive a time-series of sector estimates from 1990 to 2003, reported to UK Government studies by the trade association **(UKOOA, 2005).** Whilst the data resolution per source is limited in this dataset, it is the best available information to inform estimates prior to the EEMS system, i.e. during 1990-1997
- **Well testing** emissions estimates on an installation-specific basis are also included within the EEMS datasets from 1998 onwards at all sites of offshore exploration activities within UK's territorial waters, including data on both activity and emission factors of excess gas that is flared or released to the atmosphere. Emissions released at the seabed are not included in estimates; it is assumed that any such releases will dissolve in the water column without subsequent release to the atmosphere.
- **Onshore well drilling** for oil and gas exploration leads to fugitive emissions. These are estimated using a Tier 1 method from the 2019 IPCC Refinement, with the number of wells drilled per year obtained from the North Sea Transition Authority's Well Operations Notification System (WONS). **Abandoned wells** also release fugitive methane and NMVOC, and again a 2019 IPCC Refinement Tier 1 method is applied, using NSTA wellbore database information on the number of wells abandoned.
- 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 CO_2, CH_4 and N_2O. Whilst there is a high level of complete reporting from onshore oil and gas terminals, operators only report to these Regulatory Inventories (RIs) where the annual pollutant emission is above a reporting threshold; hence there is very little RI data reported by operators of onshore well sites in the UK, where emissions are low.
- 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 GHG and air quality pollutants. Since 2010 onshore terminals report voluntarily to EEMS, but the reporting is incomplete across UK terminals; reporting to EEMS was deemed a duplication of the reporting requirements under IED/PRTR and hence was no longer a mandatory duty on terminal operators. Hence from 2010 onwards the EEMS dataset is not a comprehensive record of emissions from onshore terminals. The UK GHGI estimates are based on the IED/PRTR data in conjunction with UK ETS data, which provides emissions of CO_2 from combustion and flaring sources.
- Under the Energy Act and Petroleum Act, upstream oil and gas operators are mandated to report on their economic activities to the North Sea Transition Authority (NSTA). Whilst these data are not specific to environmental reporting, they do provide a full time series of useful activity data such as UK oil production and gas production; detailed data per oil and gas field are now reported via the **Petroleum Producers Reporting System** (PPRS), which began in 2000. Prior to PPRS, the same data were published in annual statistical releases such as the historic DTI publication "*The Development of the Oil and Gas Resources of the UK*", known as the **Brown Book**, which ceased to be published in 2004. Together these resources provide a full, time-series consistent dataset on activity for the sector, as well as a wealth of installation-level detail. They are used in inventory method development primarily to support the use of IPCC good practice gap-filling techniques, as they provide a useful proxy dataset of activity to help address reporting gaps per source, per installation and/or at the sector level.

- The Inventory Agency continues to investigate ways in which methane and NMVOC emissions from **oil and gas well blow outs** can be estimated, although there is no IPCC methodology for such events, and only limited data are available in the UK with which to estimate emissions. The Inventory Agency has researched the UK Health and Safety Executive (HSE) hydrocarbon release database, and there is only one major blow-out event recorded by upstream operators and reported to the HSE across the time series, which was the Elgin blow-out of 25th March to 16th May 2012. In this case, the Inventory Agency has estimated the total methane and NMVOC released by the blowout and added it to the fugitive emission estimates for the year 2012. The UK emission estimate is based on reported daily methane flow-rate observations taken on 5 days during the blow-out period (30th March, 3rd April, 17th April, 24th April and 4th May 2012). These estimated flow rates of methane are derived from air sampling and analysis by research aircraft flights, as reported by **Lee *et al*. (2018)**[66].The Inventory Agency will continue to research data from UK academic and industry researchers, regulators and operators, in order to develop emission estimates for any similar historic events.
- All UK onshore 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 has sought to estimate **methane emissions from onshore shale gas exploration** activities, though to date there has been no production of natural gas from unconventional shale gas resources in the UK. Since 2010 there have been twelve shale gas wells spudded in the UK. None of these sites are actively producing gas and 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 available 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. Therefore the Inventory Agency has consulted with the regulatory agencies (NSTA, EA) and obtained one-off reports, where available, from each unconventional gas well site.
    - The EA has confirmed that 12 wells were spudded during the period of August 2010 to January 2019 in England and that no extraction of products has occurred. It has been confirmed with the Regulator that all shale wells are now abandoned, and permits surrendered or suspended, with no foreseeable exploration and production activity[67].
    - One report to the EA provides methane emission estimates during a nitrogen gas lift operation at one of the larger shale gas well sites; review of the other sites identified that several wells did not strike any hydrocarbon deposits.
    - Based on the limited data available, a conservative estimate of emissions for methane from the well exploration activities has been made and added to the UK GHGI; methane emissions are estimated to peak at 60t CH_4 in 2010 and 2011, with well drilling emissions in 2014 of 20t CH_4, and 25t CH_4 in 2019.
    - Further information can be made available to an ERT, to access the NAEI research report which contains commercial in confidence details on a site-by-site basis (Thistlethwaite, Gorji and Passant, 2021).

[66] Atmos. Meas. Tech., 11, 1725-1739, 2018.

[67] Personal communication with the Environment Agency, March 2021

Assumptions & observations

The source resolution in the UKOOA 2005 data reference is limited across the 1990-1997 period, and a series of proxy datasets have been used to derive time-series estimates per source back to 1990. These are described in more detail in **Annex 3.1.6**.

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.

The 2019 Refinement method has been applied as the better resolution of fugitive EFs in the 2019 Refinement enables the UK to address the emissions from the onshore gas production and gathering sector. UK production is a very small part of the upstream industry and predominantly takes place at small gas well sites that do not typically report emissions (e.g. of hydrocarbons) to UK regulatory mechanisms (e.g. to the Pollution Inventory of the Environment Agency). Therefore applying the 2019 Refinement method to the total UK onshore gas production AD ensures that the inventory is complete. Implementing mitigation practices / technologies is unlikely to be cost-effective at small gas well sites and so the Inventory Agency has applied the 2019 Refinement EFs for "activities occurring with higher-emitting technologies and practices". Noting that the 2019 Refinement is based on latest scientific research, this is considered to be the most representative approach to estimating UK inventory emissions.

We note that the emissions reported in 1B2b3 (natural gas processing) do not include any pollutant emissions that are also reported in 1B2b2, i.e. there is no double-counting of emissions. The 1B2b2 emissions are all associated with onshore production at well sites and the associated gathering systems. The 1B2b3 emissions are based on separate data streams of production and treatment at (i) offshore dry gas and associated gas platforms/FPSOs, and (ii) UK onshore gas terminals that process the gas from offshore sources and inject the gas to the National Transmission System.

Recalculations

There have been minor recalculations to estimates in recent years with more significant recalculations due to the method improvement for the early part of the time series, as a result of the oil and gas improvement project.

The most notable recalculations for CO_2 and CH_4 are:

- **1B2a1 Upstream Oil Production: Exploration**

Improvements (completed and planned)

The oil and gas sector improvement project (Thistlethwaite *et al*, 2022) has assessed all available UK data to improve the quality of the UK GHGI submission across 1A1cii and 1B2, and is described in more detail in **Annex 3.1.6**.

Emission factors and activity data remain 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, Offshore Energies UK (OEUK). 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 UK ETS dataset quality system is managed by the regulatory agency (BEIS OPRED). The reporting standards of the ETS currently operating in the UK are consistent with the EU ETS, 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, UK ETS and IED/PRTR data to derive the oil and gas sector estimates, then conducts time series consistency checks using other sector activity data from PPRS and the Brown Book to identify and address any potential data reporting gaps or outliers. Where the UK ETS or IED/PRTR data are inconsistent with the EEMS data, the Inventory Agency works with BEIS OPRED and facility operators to help 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 regulators and operators, as required.

Time-series consistency

The emission estimates for the offshore industry are based predominantly on the EEMS dataset for 1998 onwards, whilst emission estimates for 1990-1997 are based on sector data submitted to UK Government (UKOOA, 2005).

The method is compromised by the lack of source-specific data for the 1990-1997 period, where only aggregate emissions data across all sources in 1A1cii and 1B2 are available from the industry submissions to UK Government; this coincides with a period where consultation with the BEIS energy statistics team has confirmed that that the UK energy statistics were not gathering complete data for all oil and gas terminals. Wherever possible the Inventory Agency has filled data gaps with operator-reported estimates and applied IPCC good practice gap-filling methods to ensure that the time series consistency is as good as practicable given the available data; this is possible as there are a defined number of installations that are active in this sector and their activities (and emissions) are generally well documented with gaps in data being relatively minor.

Further, the Inventory Agency has conducted time series consistency checks between the aggregated emissions reported in the 1990-2003 data submission (UKOOA 2005) and the installation-level EEMS and NAPs data (BEIS OPRED, 2022), across the overlap years of 1998 to 2003. This analysis shows close consistency, indicating that the scope of reporting in the UKOOA 2005 dataset is consistent with the later installation-level EEMS data. *Further details are presented in* ***Annex 3.1.6****.*

We further note that whilst the emission estimates specific to fuel combustion in 1990-1997 are uncertain, that the total emissions across all upstream oil and gas sources (∑1A1cii, 1B2) in the UK GHGI are aligned with the industry submission to UK Government (UKOOA, 2005) and hence are regarded as the most accurate data available.

The EEMS dataset (BEIS OPRED, 2022) 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. For this reason, the Inventory Agency has moved away from using EEMS data for the estimates of oil loading, and instead uses the PPRS activity data on oil production at OTLs, in conjunction with industry EFs, as this method delivers a more complete and time series consistent estimate.

The Inventory Agency continues to work with the regulatory agency, BEIS, in the continued development of emission estimates from this sector.

Uncertainties

Uncertainties for both activity and emission factors are based on expert judgement, informed by the understanding of the available data, the level of uncertainty that is accepted within the reporting systems (e.g. UK ETS) and the likelihood of error compensation across the UK installations.

The uncertainty analysis set out in **Annex 2** provides details of these uncertainty values.

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. As noted above, while the uncertainty per source may be high due to the limited source resolution in the UKOOA 2005 dataset, the overall uncertainty in the sum of emissions across 1A1cii and 1B2 is much lower and is based on the best available data for that period.

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

CO_2, CH_4

Relevant fuels, activities

Leakage from gas transmission and distribution, leakage at the point of use

Background

The UK GHG inventory includes estimates of methane and carbon dioxide emissions from natural gas leakage from the downstream gas supply network, including releases from: high pressure transmission network; distribution network; gas leaks at point of use. Annual activity data and gas compositional analysis are provided by National Grid, four companies (formed in 2005) that operate the low-pressure gas distribution networks within Great Britain, and three gas suppliers 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 Phoenix Gas and Firmus Energy. AD for gas use in domestic and commercial sectors from DUKES (BEIS, 2022a) 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 GB 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_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49].

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, Phoenix Gas, Firmus Energy); (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; Phoenix Gas, SGN and Firmus Energy together supply gas within the Northern Ireland network. 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, (ii) NG records of intentional venting actions on the network, (iii) estimation of fugitive emissions from AGIs using Marcogaz model and (iv) estimation of emissions as the result of incomplete combustion using compressor station turbine specification and site running hours. 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 2011-2021, 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; CO_2 compositional data from 2004 onwards are derived from annual compositional analysis by gas network operators, whilst the 1990-2003 data have been extrapolated back from the 2004 figure.

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 Great Britain (GB) 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. No gas composition data have been provided by any operator in Northern Ireland, and in the absence of data, the average composition of the gas available in GB’s network is assumed to be applicable in Northern Ireland. The estimates of gas consumption within each LDZ are based, from 2007 onwards, on LDZ throughput data presented within Long Term Development Statements by each of the gas network operators; prior to 2007 these data are unavailable, and the best available data to inform the UK weighted average composition are sub-national gas use statistics at local authority level (then aggregated to LDZs) which are published by BEIS annually and processed for UK Local Authority CO_2 emission estimates via the CLARE database.

Northern Ireland Gas Network

The gas infrastructure in Northern Ireland is much newer than in the rest of the UK, as the gas pipeline (from Scotland) was only commissioned in 1999. Since then, the gas network has continued to develop across Northern Ireland. Annual estimates of gas leakage from 2005 onwards have been provided by the main gas operator (Phoenix Gas, 2022; SGN, 2022; Firmus Energy, 2022), 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, 2022).

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, 2022) 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, 2022) which provides a time series of gas use for catering and other uses in the commercial sector to 2021. 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

There are minor recalculations throughout the timeseries, reflecting revisions to the natural gas net calorific values, updates to NTS leakage data due to the application of Marcogaz model, and some minor updates to the leakage data from the distributors.

Improvements (completed and planned)

An improvement project is currently planned to evaluate the evidence and consider potential improvements of methods for obtaining emissions as the result of leakage from the downstream low-pressure gas distribution networks.

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.

As recommended during the September 2014 centralised review of the UK inventory, the UK Inventory Agency has also conducted verification checks on the UK GHGI estimates, by deriving separate emission estimates for methane using the Tier 1 default methods outlined in both the 1996 GLs and the 2006 GLs. The method in the 1996 GLs uses max and min default factors based on the pipeline length of the transmission and distribution network, whilst the 2006 GLs Tier 1 method uses max and min default factors based on the total volume of delivered natural gas. The results are summarised below for 1990 and 2013 data:

1990 UK GHGI total (transmission plus distribution) = 378.8 kt CH_4

Using IPCC 1996 GLs Tier 1 method, the range for emissions is derived as 155 to 215 kt CH_4

Using IPCC 2006 GLs Tier 1 method, the range for emissions is derived as 67 to 105 kt CH_4

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

2013 UK GHGI total (transmission plus distribution) = 168.5 kt CH_4

Using IPCC 1996 GLs Tier 1 method, the range for emissions is derived as 155 to 215 kt CH_4

Using IPCC 2006 GLs Tier 1 method, the range for emissions is derived as 95 to 148 kt CH_4

Therefore, compared to the Tier 1 methods, the 2013 UK GHGI estimate is within the range of values for the 1996 GLs method and higher than the range of values for the 2006 GLs method.

The comparison against the IPCC Tier 1 methods indicates that the UK GHGI estimates are of a similar order of magnitude as the Tier 1 defaults. The 1990 UK GHGI value appears to be high, as it is above the range of values derived from the IPCC Tier 1 methods, whilst the 2013 UK GHGI value is also higher than the range for the 2006 GLs Tier 1 method. However, the UK estimates are derived from a country-specific method and we note that the uncertainty estimates provided in the 2006 GLs for the default EFs provided for gas network distribution (which is by far the greatest contributor to overall methane leakage) are cited as -20 % to +500% for factors for developed countries. Therefore, given the large uncertainty range, the UK data are consistent with the IPCC Tier 1 estimates.

Time series consistency

As far as possible, consistent source data and methods are used across the time series. However, we note the following limitations of the current methods:

- The available data on methane leakage from the high pressure gas transmission system is limited. Data are not available for all years of the time series and therefore gap-filling techniques (extrapolation and interpolation) are used;
- The calibration of the UK gas leakage model used by all natural gas network operators in based on two in-depth studies of the leakage rates from different constituent elements of the UK gas network – one in 1992, another in 2002. These studies have been used to establish estimated leakage rates in the UK model that are then applied to activity data gathered annually through surveys and from gas network renewal projects; and
- The derivation of the UK average natural gas composition uses the best available data for every year of the time series, as the factors are critical for the UK GHGI estimates as a whole (not just for the leakage estimates, but also for natural gas combustion estimates). Since 2007 the weighted average has been calculated using actual data available on gas throughout for each LDZ; prior to 2007 these data are not available and the LDZ gas throughput estimates used in the calculation of the UK average gas composition use Local Authority level gas use estimates, aggregated up to LDZs. These earlier data at Local Authority level were regarded as “experimental statistics” by DECC until the 2005 dataset were published as national statistics, and as such are regarded as more uncertain than the more recent data.

Uncertainties

Uncertainties are presented in **Annex 2**. Uncertainties in the emission estimates from leakage from the gas transmission and distribution network stem predominantly from the assumptions within the industry model that derives mass leakage estimates based on input data such as network pipe replacement (plastic replacing old metal pipelines) and activities/incidents at Above Ground Installations; for these sources the methane content of the gas released is known to a high degree of accuracy, but the mass emitted is based on industry calculations.

As noted in the section above, the uncertainties for the estimates of gas leakage at point of use are high due to the lack of source data, an IPCC method and the need to use a series of assumptions and expert judgement to estimate the leakage from different gas appliance types. The Inventory Agency considers that the assumptions provide a conservative estimate of gas leakage at point of use across the time series.

MS 20 Other solid fuel transformation

Relevant Categories, source names

1A1ci: Solid smokeless fuel production

1B1b: Solid smokeless fuel production

Charcoal production

Relevant Gases

CO_2, CH_4, N_2O

Relevant fuels, activities

Coke oven coke, petroleum coke, solid smokeless fuel production, charcoal production

Background

Solid smokeless fuels (SSF) are products which are designed to be suitable for use in smoke control areas. These are manufactured by combining products (often with low volatile content, such as anthracite or coke) using binding agents such as waxes and reforming them into brickettes. Charcoal production and some SSF production involves processes similar to those of coke oven coke production.

Key Data sources

Activity: DUKES (BEIS, 2022), FAOSTAT Forestry Production and Trade Statistics (FAO, 2022)

Emission factors: Inventory Agency mass balance calculations, EIPPCB, 2000, IPCC, 1997.

An accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" lists all emission factors used in the energy sector, including a full list of references[49]*.* ***Table 1.5*** *gives additional information for common activity data sources.*

Method approach

Emissions of carbon from SSF production are based on a carbon balance approach. For other pollutants, estimates are either made based on a mass balance approach (for sulphur dioxide) or on SSF production data and emission factors as provided in Table A 3.2.9.

There are a number of SSF production processes used in the UK ranging from processes similar to coking which convert coal into smokeless fuels, to briquetting of anthracite dust and other naturally smokeless fuels. Given the range of processes in use, emission estimates will be very uncertain. It is possible that some emissions from SSF manufacture could arise from the combustion of off-gases produced during SSF manufacturing processes e.g., gases evolved from retorts used to manufacture some fuels, similar to the use of coke oven gas as a fuel in the coke manufacturing process. However, combustion of this type is not identified in the energy statistics and so emissions from SSF manufacture are treated as fugitive and reported under 1B1b.

In addition to coal, the manufacture of SSF involves the consumption of small quantities of coke oven coke in some years. This coke oven coke is treated as a fuel rather than a feedstock and the carbon within the coke is assumed emitted and reported under 1A1c.

Activity data for coal use in SSF manufacture are taken from UK energy statistics, DUKES (BEIS, 2022), combining the sum of fuel used in SSF manufacture. The emission factor is derived from the carbon balance approach which calculates total carbon lost (i.e., emitted) during the SSF manufacturing process, by subtracting the carbon retained in the SSF product from the sum of carbon inputs.

The methane emission factor of 0.0802 kt per Mt coke produced is taken from the EIPPCB, Best Available Techniques Reference Document on the Production of Iron & Steel, March 2000 (EIPPCB, 2000) and applied to the SSF production.

Emissions from charcoal production are based on UK activity data on charcoal production from FAOSTAT Forestry Production and Trade Statistics (FAO, 2022). These data were available for the UK and the Falkland Islands but not for and other overseas territories or crown dependencies. The methane emission factor is derived from the default emission factors in table 1.14 of the IPCC 1996 Guidelines. Note that we did not identify suitable factors in the 2006 IPCC guidelines.

Assumptions & observations

Note that any fugitive emissions of CO_2 from charcoal production would be considered biogenic, and therefore does not contribute to the GHGI national total.

Recalculations

There have been no major changes to estimates for these sources in the 2023 submission.

Improvements (completed and planned)

The UK is considering reviewing the mass balance methodology for SSF, in particular to better capture the wide range of SSF products with varied feedstocks, and an increasing range of biomass being used for SSF production.

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 UK believes that the estimates are time-series consistent, although the data reported under sector 1B1b (including coke oven coke manufacture described in **MS 4**) are a diverse group of sources with highly variable implied emission factors, particularly when aggregated. For example, solid smokeless fuel production sources dominate emissions for 2015–2019 and are mainly responsible for some large inter-annual variation in the CO_2 IEF during this period. The IEF variation is driven by fluctuations in the ratio of coal to petroleum coke inputs and by the ratio of inputs to solid smokeless fuel outputs. The activity data and emission factors for these sources can be found in the accompanying spreadsheet "Energy_background_data_uk_2023.xlsx" help explain the underlying data for these fluctuations.

Uncertainties

Due to the nature of the mass balance approach used for SSF manufacture, uncertainty in both the estimated carbon content of input products and the carbon content of SSF delivered to market both contribute to a substantial uncertainty in the difference (i.e., the carbon assumed to be emitted during manufacture). This uncertainty is further increased by the range of SSF products, including SSF products which include biomass inputs, introducing an uncertainty on the proportion of the carbon which might be biogenic.

Non-CO_2 emissions for this category only contribute a small proportion of the total emissions, and therefore do not make a major contribution to overall uncertainty

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 1990-2021 and 2020-2021. 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

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Key Categories	Uncertainty	Latest year total (Mt CO_2e)	BY-Latest year trend	Last 2 yr trend	Recalculation-: 2021	Recalculation-: BY	Gases included	Methodology reference (NIR Section)	Method	EF	Notes
Total industrial processes			32.33	-61%	-5%	0%	3%					
A. Mineral industry			6.08	-41%	10%	-2%	1%					
1. Cement production	CO_2 (L1)	3%	4.22	-42%	8%	0%	0%	CO_2	4.2	T2	CS	
2. Lime production		5%	1.09	-18%	9%	0%	0%	CO_2	4.3	T1 (1990-1993) T3 (1994 – latest year)	D	
3. Glass production		5%	0.34	-17%	5%	0%	0%	CO_2	4.4	T2	CS	
4. Other process uses of carbonates		4%	0.43	-65%	34%	-27%	9%	CO_2, CH_4	4.5	CS	CS (bricks), D (FGD)	CH_4 from this source reported under

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Key Categories	Uncertainty	Latest year total (Mt CO_2e)	BY-Latest year trend	Last 2 yr trend	Recalculation-: 2021	Recalculation-: BY	Gases included	Methodology reference (NIR Section)	Method	EF	Notes
												2H3i in the CRF tables.
B. Chemical industry	CO_2, N_2O, HFCs (L2, T2)		3.19	-93%	-32%	0%	7%					
1. Ammonia production		2%	1.21	-43%	-29%	0%	0%	CO_2, CH_4, N_2O	4.6	T3 (CO_2), T1 (CH_4, N_2O)	CS (CO_2), D (CH_4, N_2O)	
2. Nitric acid production	N_2O (T1)	10%	0.03	-99%	-36%	0%	0%	N_2O	4.7	T2	CS	
3. Adipic acid production	N_2O (L1, T1)	N/A	0.00	-100%	N/A	N/A	0%	N_2O	4.8	T2	CS	
4. Caprolactam, glyoxal and glyoxylic acid production		N/A	0.00	N/A	N/A	N/A	N/A	N/A	4.9	N/A	N/A	
5. Carbide production		N/A	0.00	N/A	N/A	N/A	N/A	N/A	4.10	N/A	N/A	
6. Titanium dioxide production		10%	0.16	48%	15%	0%	0%	CO_2	4.11	CS	CS	
7. Soda ash production		6%	0.13	-41%	-7%	0%	0%	CO_2	4.12	CS	CS	
8. Petrochemical and carbon black production	CO_2 (L1)	30%	1.54	-68%	-41%	0%	0%	CO_2, CH_4, N_2O	4.13	CS, T1	CS, D	N_2O from this source reported under 2B10 in the CRF tables
9. Fluorochemical production	HFCs, PFCs, SF_6 and NF_3 (L1, T1)	10%	0.12	-99%	61%	0%	0%	HFCs, PFCs	4.14	T2	PS	
10. Other *(as specified in table 2(I).A-H)*		26%	0.03	-86%	-51%	0%	0%	CH_4	4.15	CS	CS	
C. Metal industry		8%	10.73	-59%	-1%	1%	-4%					

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Key Categories	Uncertainty	Latest year total (Mt CO_2e)	BY-Latest year trend	Last 2 yr trend	Recalculation-: 2021	Recalculation-: BY	Gases included	Methodology reference (NIR Section)	Method	EF	Notes
1. Iron and steel production	CO_2 (L1)		10.62	-55%	-1%	1%	0%	CO_2, CH_4, N_2O	4.16	T2 (CO_2), T1, T3 (CH_4)	CS (CO_2), CR, CD, D (CH_4)	N_2O from this source reported under 2C7 in the CRF tables.
2. Ferroalloys production			0.00	N/A	N/A	N/A	N/A	N/A	4.17	N/A	N/A	
3. Aluminium production			0.06	-92%	6%	0%	12%	CO_2, PFCs	4.18	T1 (CO_2), T2 (PFCs)	CS (CO_2), PS (PFCs)	
4. Magnesium production			0.04	-90%	37%	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	N_2O from iron and steel production reported here in the CRF tables
D. Non-energy products from fuels and solvent use		52%	0.40	-27%	8%	-2%	0%					
1. Lubricant use			0.32	-39%	9%	-3%	0%	CO_2	4.22	T1	CS	
2. Paraffin wax use			0.02	-30%	-5%	0%	0%	CO_2	4.23	T1	D	

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Key Categories	Uncertainty	Latest year total (Mt CO_2e)	BY-Latest year trend	Last 2 yr trend	Recalculation-: 2021	Recalculation-: BY	Gases included	Methodology reference (NIR Section)	Method	EF	Notes
3. Other			0.06	N/A	10%	4%	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		46%	0.02	75%	-7%	0%	0%					
1. Integrated circuit or semiconductor			0.02	75%	-7%	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)	10%	10.80	1247%	-6%	0%	-2%					
1. Refrigeration and air conditioning	HFCs, PFCs, SF_6 and NF_3 (L1, T1)		9.16	4449%	-5%	0%	0%	HFCs	4.29	T2	CS	
2. Foam blowing agents			0.35	111%	-7%	0%	0%	HFCs	4.30, 4.31	T2	CS	
3. Fire protection			0.29	19873%	-9%	0%	0%	HFCs, PFCs	4.32	T2	CS	
4. Aerosols	HFCs, PFCs, SF_6 and NF_3 (T1)		0.94	131%	-13%	-2%	0%	HFCs	4.33	T2	CS	
5. Solvents			0.02	N/A	-1%	0%	N/A	HFCs	4.34	T1a	OTH	
6. Other applications			0.03	28%	-6%	-15%	-34%	HFCs	4.35	CS	CS	

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Key Categories	Uncertainty	Latest year total (Mt CO_2e)	BY-Latest year trend	Last 2 yr trend	Recalculation-: 2021	Recalculation-: BY	Gases included	Methodology reference (NIR Section)	Method	EF	Notes
G. Other product manufacture and use	N_2O (L2, T2)	59%	1.12	-28%	-1%	0%	1%					
1. Electrical equipment			0.33	-60%	-3%	0%	1%	SF_6	4.36	T3	CS	
2. SF_6 and PFCs from other product use			0.12	-37%	-2%	0%	0%	PFCs, SF_6	4.37, 4.38, 4.39	T2 (Accelerators), T2, T3 (Electronics and shoes), OTH (Tracer gas), T1 (military)	D (Accelerators), CS, D, (Electronics and shoes), CS (Tracer gas), D (military)	
3. N_2O from product uses			0.59	N/A	N/A	0%	0%	N_2O	4.40, 4.41	OTH (Medical), CS (propellants)	CS (Medical), OTH (Propellants)	
4. Other			0.07	N/A	N/A	0%	10%	N_2O,	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	CH_4 from 2A4 reported here in CRF tables

* CH_4 emissions from fletton brick production are reported under 2H in the CRF tables, as not possible to report in 2A4 alongside CO_2 emissions from this source.

** N_2O emissions from 2B8 are reported under 2B10 in the CRF tables

***N_2O emissions from 2C1 are reported under 2C7 in the CRF tables

The industrial processes and other product use sector (IPCC Sector 2) contributes 7.6% 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 60% decline in emissions, mostly due to changes in the emissions from the chemical production and halocarbon and SF_6 production industries. The step-change in emissions between 1998 and 1999 evident in **Figure 4.2** is due predominantly to the fitting of nitrous oxide abatement equipment at the UK's only adipic acid production plant (this plant has since closed).

The figures in **Figure 2.14** - **Figure 2.16** 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 for the latest inventory year

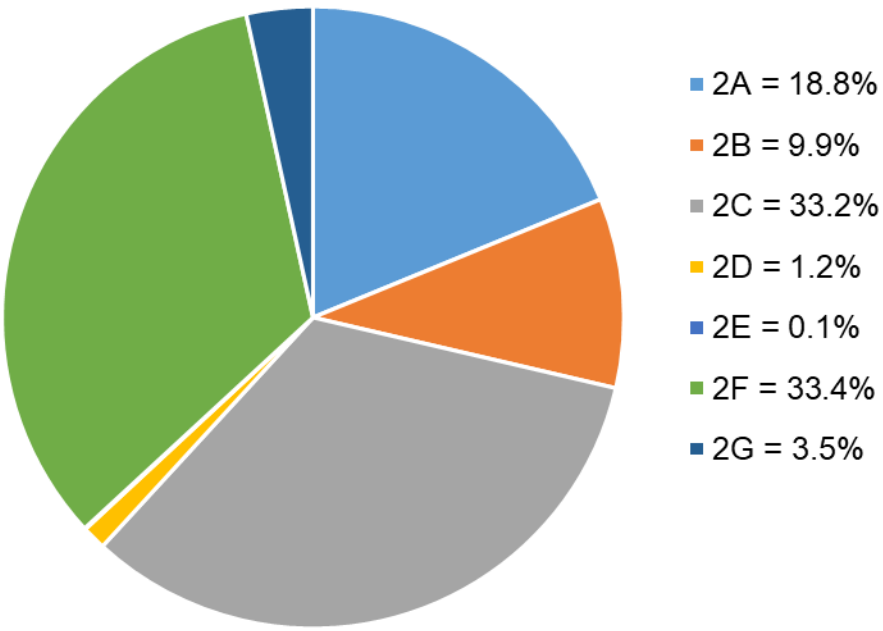
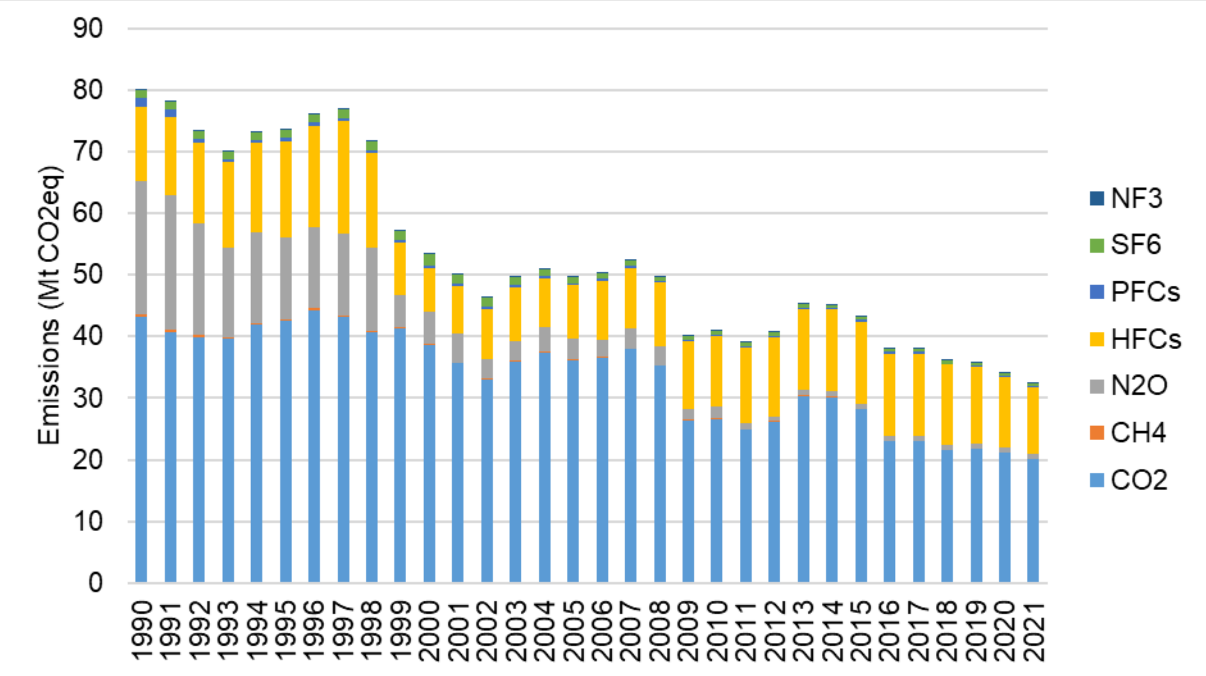


Figure 4.2 Trend in total GHG emissions in Industrial Processes sector



4.2 SOURCE CATEGORY 2A1 – CEMENT PRODUCTION

4.2.1 Source Category Description

Emissions of CO_2 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 onwards are available from the annual UK production of clinker and emission factors provided by the Mineral Products Association (MPA, 2022), formerly the British Cement Association (BCA). These AD and EFs are based on site-specific data generated by UK cement clinker producers for the purposes of reporting to the EU Emission Trading Scheme, and therefore the methodology is effectively Tier 3. Data from the MPA are cross-checked against the EU/UK 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 0.08%. 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 & 2019, and EU ETS for 2008-2009, 2011-2014, 2018 and 2020. The EU ETS and MPA/BCA data include emissions associated with cement kiln dust.

EU ETS and MPA data are available for 2005 onwards 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, several kilns closed during the economic down-turn of the late 2000s, meaning that emission factors for 2007 onwards are less representative of the period before 2005.

The methodology used for estimating CO_2 from calcination is summarised in **Table 4-2**.

Table 4-2 Methods used to estimate cement production emissions of CO_2

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, 2019	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, 2018, 2020		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.

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 and uneven increase in clinker production since 2009, and production in Great Britain in 2016 was at the highest level since 2008, before falling back slightly in subsequent years.

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 CO_2 emissions data in the table are for the whole of the UK. The CO_2 emission factors are therefore a mixture of those based entirely on UK data (for 1990-2000) and those that mix UK emissions and GB activity data (2001 onwards), but are shown to give an indication of the trend in the factor over time.

Table 4-3 Activity data and carbon EF for cement production, 1990 - 2021

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	*10,074*	5,941	0.590
2006	*10,069*	5,893	0.585
2007	*10,227*	6,117	0.598
2008	*8,700*	5,205	0.598
2009	*6,421*	3,721	0.580
2010	*6,598*	3,792	0.575
2011	*7,096*	4,097	0.577
2012	*6,555*	3,724	0.568
2013	*6,712*	4,029	0.600
2014	*7,197*	4,215	0.586
2015	*7,804*	4,393	0.563
2016	*8,056*	4,553	0.565
2017	*7,824*	4,410	0.564
2018	*7,734*	4,364	0.564
2019	*7,830*	4,448	0.568
2020	*6,941*	3,900	0.562
2021	*7,419*	4,215	0.568

[a] Figures in italics exclude production in Northern Ireland

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 onwards 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 CO_2 are therefore higher. The emission factors in the period 2001 onwards do vary from year to year, from a minimum value of 0.562 t CO_2 / t in 2020 and a maximum value of 0.600 t CO_2 / t in 2013. The reason for the large increase in the IEF in 2013 compared with the previous year is not known, although the inconsistency between the activity data (excluding Northern Ireland) and emissions (including Northern Ireland) may be at least partially responsible.

4.2.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the 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/UK ETS to ensure complete coverage of all emissions.

4.2.5 Source Specific Recalculations

No recalculations have been made to emissions from this category.

4.2.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.3 SOURCE CATEGORY 2A2 – LIME PRODUCTION

4.3.1 Source Category Description

Lime (CaO) is manufactured by the calcination of limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) in kilns fired mainly by coal, coke or gas, though some wastes and other fossil fuels are also used. 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 and UK 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 UK ETS data consist of CO_2 emission estimates (including emissions associated with lime kiln dust) and activity data. The activity data takes various forms e.g. feedstock or product, depending upon site, and so it is not possible to generate UK activity data simply by summing the activity data in UK ETS. Therefore, 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. UK ETS returns do provide some indication of site-specific activity data although this is a mixture of data on carbonate inputs and lime outputs. Nevertheless, it would be possible to generate an approximate time-series of lime production for merchant lime producers from UK ETS returns for the period from 2008 onwards and while these cannot be published due to the confidential nature of the data, the figures could be provided on request to a UNFCCC Expert Review Team. There are no suitable data in UK ETS for captive lime processes so we are unable to provide any similar lime production estimates for those sites.

Prior to 2005 there are no EU/UK ETS data at all, and data are incomplete for 2005-2007 because of UK exemptions from the EU ETS for some sites in those years. Therefore, between 1994 and 2004, CO_2 emission estimates for lime production are based on emissions data published for each site in the Pollution Inventory (PI), and these data are also used for those sites that were exempt from EU ETS before 2008. The PI data are mostly for total CO_2 i.e. include emissions from both decarbonisation and fuel combustion on a site, but estimates of the CO_2 from decarbonisation only are made using EU ETS data and PI data for 2006-2008, both of which give fuel combustion emissions separately from decarbonisation. For the period 1994-1997, there is less reporting of CO_2 in the PI and so site-specific CO_2 emissions are estimated based on other site-specific data such as emissions data for particulate matter from those sites in the relevant years. The PI data are assumed to cover the same scope as the later EU ETS data i.e. to include emissions from lime kiln dust as well as lime product. 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, t 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
2005-2007	(back-calculated)	121.5	EU ETS & PI CO_2
2008-2020	(back-calculated)	121.5	EU ETS
2021	(back-calculated)	121.5	UK 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 UK 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

CO_2 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 back to calcium carbonate at the end of the process, meaning no net emission in CO_2. However, the UNFCCC centralised review of the 2013 submission of the UK GHG Inventory recommended that CO_2 emission estimates were needed and that it should be assumed that some unreacted lime was present in waste sludges at the end of the carbonatation process. Emission estimates are therefore included using a default percentage (24%) 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 and UK ETS provide 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 CO_2 emissions data are available, and emissions have therefore to be based on the BGS data that are known to be inaccurate for later years. An adjustment is made to the BGS data to try to deal with the expected underestimating of activity by BGS, but a comparison of BGS and other data for later years indicates that the BGS underestimates are not consistent and so the scale of any underestimation in 1990-1993 is difficult to predict with any confidence.

The estimates for lime kilns used in sugar production are highly uncertain since EU ETS data for those sites suggest no CO_2 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 CO_2 emissions released from the limestone that is used". The UK producer has also indicated that they consider the conversion of lime back to calcium carbonate as being complete (Personal Communication: British Sugar, 2013).

4.3.4 Source-specific QA/QC and Verification

This source category is covered by the general QA/QC of the 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

No recalculations have been made to emissions from 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/UK 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. As discussed in **Section 4.3.2**, it would be possible to provide an ERT with an approximate timeseries of lime production estimates for 2008 onwards for merchant lime sites only, which could then be used to generate an approximate IEF for those sites only.

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 Na_2O respectively in soda-lime and other glasses. Emissions from fuels used in glass furnaces are reported in 1A2g.

The UK had 23 large sites making glass at the end of 2021, 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 2021. 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/UK 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/UK 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 N_2O 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 N_2O from these sites (including N_2O 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/UK Emissions Trading System (EU/UK 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/UK ETS data are for CO_2 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 2008-2021 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 two data sources can be used to derive estimates of carbonate use / CO_2 emissions for each sub-sector of the glass industry as follows:

2008-2021: 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/UK ETS for 2008-2021, 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, 2022), 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 CO_2 emissions from carbonate use

Glass Sector	1990 production, kt	2021 production, kt	Emission estimates included for use of Limestone	Emission estimates included for use of Dolomite	Emission estimates included for use of 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	63	Yes	Yes	Yes
Glass wool	104	302	Yes	Yes	Yes
Stone wool	85	69	No	Yes	Yes
Ceramic fibres	14	14	No	No	No
Frits	13	0	No	No	No
Ballotini	20	35	No	No	No

a – confidential

The EU/UK ETS data also includes extremely small CO_2 emissions (<1 tonne) occurring due to use of barium or potassium carbonate by the glass sector, and somewhat larger though still relatively trivial emissions from other process sources. The largest of these is emissions that occur when waste wool at one site is recycled through the process, and it is assumed that the carbon results from oxidation of organic coatings that were applied to the wool as part of the finishing process. Waste generated during cutting of the wool following the coating process is recycled to the glass kilns. A time-series of emission estimates has been added for this version of the UK inventory.

4.4.3 Uncertainties and Time Series Consistency

For the years 2008-2021, the methodology is based on the use of highly accurate emissions data reported under the EU and UK 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 and UK ETS data of 2008-2021 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 recalculations.

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, 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 CO_2 from the carbonaceous material in the clay. Limestone, dolomite and barium carbonate can also be used in brickmaking, leading to further releases of CO_2 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 Emissions Trading Scheme (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. Also included are emission estimates for the use of clays to produce ceramics other than bricks.

The 2006 GLs draws attention to other sources of CO_2 emissions from use of soda ash and other carbonates. These other uses include Flue Gas Desulphurisation (FGD), magnesia production, and use of soda ash in soaps & detergents, and other applications.

The UK inventory includes CO_2 emissions that occur during the manufacture of soda ash and from the use of soda ash by the glass sector and detailed descriptions of those source categories are provided in **Sections 4.12** & **4.4** respectively. The inventory also includes emission estimates for the use of soda ash in applications other than glass production, and these emissions are reported in 2A4b. These estimates are based on a review (Passant *et al*, 2019) which found that soda ash is used in the UK for a wide range of applications but that most is used for one of three purposes – manufacture of glass, manufacture of chemicals (including sodium bicarbonate) and manufacture of detergents and soaps. Not all uses of soda ash are likely to result in CO_2 emissions and so this review also considered the potential for emissions. Emissions also occur from the subsequent use of sodium bicarbonate and these emissions are reported in 2A4d.

Limestone is used in FGD systems for abatement of SO_2 emissions at most remaining UK coal-fired power stations and emissions are reported under 2A4. The power stations at Drax and Ratcliffe were the first to get FGD (in 1994), 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, Eggborough closed in September 2018, and Cottam in September 2019. Various small, predominantly waste and/or biomass-fired stations also report CO_2 emissions from limestone scrubbing in the ETS. In all of these processes, limestone reacts with the SO_2 present in flue gases, being converted to gypsum, with CO_2 being evolved. Uskmouth B has a dry lime-injection system, so there is no potential for CO_2 emissions at this site. Seawater scrubbing systems are used at Aberthaw and Kilroot and was also used at the now-closed Longannet power station but CO_2 emission estimates are not included in the GHGI for this type of FGD system: there is no estimation method for this process. Some MSW incinerators are believed to use the dry lime injection process to remove SO_2 emissions: as with Uskmouth B, there will be no CO_2 emissions from this type of FGD technology.

Magnesia production in the UK is thought to be limited to a single plant that closed in 2005. This site produced magnesia from seawater, with magnesium salts in the seawater precipitated as magnesium hydroxide, followed by conversion to magnesia in kilns. No process emissions of CO_2 occurred at this site.

4.5.2 Methodological Issues

CO_2 emissions from production of bricks and tiles are based on data reported in the UK and EU ETS. ETS provides site by site emissions, with data in most cases broken down by source (e.g., from clays, fuels, colourants etc.). The ETS data from the producers of bricks and tiles are representative of the sector from 2008 onwards, when all significant manufacturing sites were included in ETS. The ETS dataset is documented and reported at a level of resolution such that the Inventory Agency can readily apportion the emissions data between fuel combustion and non-fuel sources (i.e., process emissions). However, 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 CO_2 is presented as aggregated data and not resolved per specific material input to the process. The information presented by UK operators confirms that the emissions from the colourant (coke oven or petroleum coke) are included within the aggregated process emissions, but it is not practicable to obtain a precise figure for the colourant alone.

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 (British Ceramic Confederation, 2014). These 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. A high proportion of the carbon in the colourant is known not to be oxidised during firing and remains in the brick: for ETS reporting purposes, all UK brick makers use a figure of 50% oxidation (British Ceramic Confederation, 2013).

Consultation with the brick industry indicates that the ETS data for 2008-2012 covered 93% of sector production. A single further site joined ETS in 2013, bringing coverage to 95%. The remaining 5% of production is at small sites that are outside the scope of ETS. The ETS emissions data for 2008 onwards 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 since 2008 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 2022, 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. 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 2021, it is estimated that 5% of UK bricks produced were of the fletton type.

A figure of 152 grams CO_2 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 ETS for 2008 onwards. Total CO_2 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 only coal 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	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.

Years	Number of sites and fuels	Availability of data
	England, now burn natural gas only. Approximately 100 non-fletton brickworks in early 2000s.	Estimates for non-fletton bricks have to be generated using emission factors from later 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. 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 ETS data.
2009 onwards	Saxon works closed in 2011, leaving only the Kings Dyke fletton brickworks in operation. Many closures of non-fletton brickworks, with 49 reporting in ETS by 2011. In 2013, final large site joins ETS, with total of 46 non-fletton sites then reporting.	Annual emission of CO_2 and methane available in the Pollution Inventory for the Saxon/Kings Dyke works. 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 ETS data.

Other types of ceramics are manufactured in the UK, including wall and floor tiles, refractories, sanitary ware, household ceramics etc. No suitable national data on the levels of production for these types of ceramic goods have been found. However, the UK Minerals Yearbook (BGS, 2022) gives production, imports, and exports for 4 types of clay (ball clay, china clay, fireclay, other clays & shales), and these data can be used to estimate total UK demand for each type of clay. These figures can then be compared with ETS data for clays used in brick production, and then the difference can be assumed to be clay usage for non-brick manufacture. ETS data only extend back to 2005 but clay usage for bricks in 1990-2004 can be estimated by extrapolating back from 2005 using the brick production data. Significant quantities of clays and shales are used in the manufacture of cement clinker, and emissions from this usage will already be reported in 2A1. BGS reports separate figures for this usage, so clay usage in other ceramics can then be calculated using the following equation:

$$Clay_{Other\ ceramics} = Clay_{Total}\text{ (from BGS)} - Clay_{Bricks}\text{ (from ETS)} - Clay_{Cement}\text{ (from BGS)}$$

There are likely to be other, possibly non-emissive uses of clay, for instance some china clay may be used in paper production. But we assume these other uses are either trivial or emissive. The calculations suggest that, on average over the 1990-2020 period, about two thirds of UK clay consumption is used for bricks, and the remaining third is used for the manufacture of other ceramics, cement clinker or other uses. The trends in the total clay and brick clay estimates are fairly similar in the 1990-2014 period, so that this pattern of approximately two thirds bricks to one third other uses is broadly true for all years within that period. But this pattern has changed since 2015, and the total clay figures for 2015, 2018 & 2019 are only slightly higher than the estimates for brick clay, suggesting that hardly any clay was used in those years for other uses. BGS data for clays used for cement confirm that consumption by this sector reduced by about 90% after 2014. It is therefore assumed likely that UK production of other ceramics has declined significantly in the last five years. BGS data are never available for the latest year in each inventory submission, and therefore we have to assume the same total clay consumption in the latest year as the year prior. The figures for the latest year will be revised in the next submission once BGS data for the year become available.

No emission factors are available specifically for clays used in other ceramics, therefore we apply the emission factors used by brickworks to estimate their emissions in the ETS dataset. Separate factors are available for ball clay and fire clay, whereas emissions from china clay and ‘other clays and shales’ are estimated using the generic ‘other clay’ factor also used for ETS reporting by brick producers. A few non-brick ceramic processes do report in ETS and so the emissions data for these sites are used directly.

For non-glass use of soda ash, consultation with the only UK producer of soda ash identified the main uses of soda ash, as shown in **Table 4-7**. This table also notes whether each application has been assumed to be emissive i.e., leading to emissions of CO_2.

The UK emission estimates are based on UK demand estimates supplied by the sole UK producer for soda ash, who estimated consumption in 1990 and 2019 (Tata Chemicals Europe, 2019). Consumption in 1991-2018 was then estimated by the Inventory Agency, with one of three methods being used to estimate consumption in each sector:

- For most sectors, the overall demand for soda ash/sodium bicarbonate was similar in 1990 and 2019, so intervening years were estimated on the basis of a linear change.
- For the chemical sector, a linear change would not be realistic since consumption would have been dominated by a small number of sites, many of which are now closed. Therefore, the processes operating each year were identified, and annual consumption then estimated based on the likely consumption at each site. The overall consumption figures then reflected the closure of key sites and the commissioning of new processes:
    - Closure of the tripolyphosphate works in 1999
    - Closure of the Ultramarine Blue works in 2008
    - Closure of the sodium chromate works in 2009
    - Commissioning of the sodium percarbonate works in 2000 and closure in 2014
- A breakdown of the sodium bicarbonate market is only available for 2019 (for 1990 we have only the total market). Therefore, we have estimated the market split for sodium bicarbonate by extrapolation back from the 2019 figures. However, one of the key markets is flue gas treatment and we consider it unlikely that this market existed until fairly recently. This type of flue gas treatment is likely being used in recently commissioned Energy from Waste (EfW) plants, and since many have been built since 2010, we assume that consumption for flue gas treatment was zero up until 2009.

Figures for 2019 were extrapolated to 2020 onwards assuming no change in demand. We expect that some uses such as detergents might have been affected by the pandemic and demand in sectors could have also increased or decreased for other reasons. However, we believe that any year-on-year changes will be relatively small because of the nature of these uses. Future submissions may be able to incorporate new data if soda ash suppliers can provide this.

Table 4-7 - Non-glass uses of soda ash and sodium bicarbonate

Sector	Uses	% Emissive
Soda ash: chemicals	Used in production of various chemicals or chemical processes: • Sodium tripolyphosphate • Sodium chromate • Ultramarine Blue • Sodium silicates • Sodium percarbonate	 100% 100% 100% 100% 0%

Sector	Uses	% Emissive
	• Metal carbonates • Brine purification • Sodium bicarbonate	0% 0% 0%[a]
Soda ash: detergents	Used as a builder to emulsify oil; to reduce the deposit of dirt during cleaning; to provide alkalinity, and to soften laundry water.	0%
Soda ash: other	Fertilizers, production of bentonites, organic and inorganic colourings, enamelling, petroleum industry, fats, glue and gelatin.	50%
Sodium bicarbonate: animal feed	Used in poultry & cattle feeds	0%
Sodium bicarbonate: detergents	Sodium bicarbonate used where a milder detergent is required. Used in hard surface cleaners where its limited water-solubility is advantageous.	0%
Sodium bicarbonate: flue gas treatment	Used for treatment of acidic flue gases.	100%
Sodium bicarbonate: food	Used as a raising agent for a wide range of bakery and confectionery products.	100%
Sodium bicarbonate: miscellaneous	Sodium bicarbonate can be used in foam blowing, soda blasting, explosion suppressants and fire extinguishing.	50%
Sodium bicarbonate: distributors	Sold to distributors (so end use is unknown)	75%

[a] Rather than being emissive, conversion of soda ash to sodium bicarbonate requires CO_2 so the process consumes some of the CO_2 generated in the production of soda ash. This consumption of CO_2 to convert from soda ash to sodium bicarbonate is taken into account in the emissions reported in 2B7.

Emissions were then estimated assuming that uses were emissive or non-emissive as shown in **Table 4-7**. The assumptions regarding the level of emissiveness were suggested by UK industry, except those for named chemical processes, where the assumption was based on the chemical reactions taking place. For emissive processes, it is assumed that all of the carbon in the soda ash was converted to CO_2 which was then emitted. So, an emission factor of 0.4151 ktonne CO_2 / ktonne soda ash consumed was used for emissive applications. In the case of sodium bicarbonate use, the activity data used in the UK inventory are expressed as soda ash converted to bicarbonate. The conversion from soda ash requires reaction with CO_2:

$$Na_2CO_3 + CO_2 \rightarrow 2\ NaHCO_3$$

So, it follows that for any emissive uses of sodium bicarbonate, an emission factor of 0.8302 kt CO_2 / kt soda ash is appropriate i.e., double that of soda ash used for other applications. Further detailed discussion of the methodology is included in the report by Passant et al (2019).

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 ETS, and so a composite series of emissions data is used with BGS activity data, and the emission factor used for 1994-2004, and ETS emissions data for 2005-2019. Four small biomass-fired power stations were no longer in ETS after 2012, and so we have obtained CO_2 emissions data for the scrubbing systems at these sites from the operator. Emissions at these non-ETS sites have averaged about 2% of the total emission in recent years.

Table 4-8 summarises the activity data for different soda ash and sodium bicarbonate applications in the inventory for 1990-2021. The provided activity data correspond to the sectors provided in Table 4-7 and Table 4-9.

Table 4-8 Activity data for different soda ash and sodium bicarbonate applications (ktonnes).

Year	Non Energy Use: chemical feedstock, soda ash	Bread baking, sodium bicarbonate	Flue gas treatment, sodium bicarbonate	Other emissive applications of soda ash	Unknown applications of sodium bicarbonate	Other emissive applications of sodium bicarbonate
1990	170.4	10.8	0.0	59.2	5.7	3.8
1995	179.1	11.2	0.0	59.0	5.9	3.9
2000	146.5	11.6	0.0	58.8	6.1	4.1
2005	146.5	12.0	0.0	58.6	6.3	4.2
2008	146.5	12.2	0.0	58.5	6.5	4.3
2009	109.6	12.3	0.0	58.5	6.5	4.3
2010	78.0	12.4	2.8	58.4	6.6	4.4
2015	67.9	12.8	17.1	58.3	6.8	4.5
2020	67.9	13.1	28.5	58.1	6.9	4.6
2021	67.9	13.1	28.5	58.1	6.9	4.6

Table 4-9 Source of activity data for soda ash and sodium bicarbonate in the inventory per sector.

Inventory source	Sector
Non Energy Use: chemical feedstock, soda ash	Soda ash: chemicals
Bread baking, sodium bicarbonate	Sodium bicarbonate: food
Flue gas treatment, sodium bicarbonate	Sodium bicarbonate: flue gas treatment
Other emissive applications of soda ash	Soda ash: other
Unknown applications, sodium bicarbonate	Sodium bicarbonate: distributors
Other emissive applications, sodium bicarbonate	Sodium bicarbonate: miscellaneous

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 2015-2019 and so no comparison can be made with the EU ETS based figures.

Emission estimates for soda ash are relatively uncertain, for a number of reasons:

- The time-series of estimates rely on estimates for UK demand in 1990 and 2019 only and a linear interpolation is generally used to estimate demand in the years in-between. The UK manufacturer was unable to provide further data, so alternative sources would probably need to be identified in order to refine the time-series.
- No data could be obtained for 2020 onwards, so we assumed the same consumption as in 2019. In reality some uses such as detergents might have been affected by the Covid pandemic and demand in sectors could have also increased or decreased for other reasons. However, we believe that any year-on-year changes will be relatively small because of the nature of many of the sectors that use soda ash and sodium bicarbonate, and so assuming no change in usage is unlikely to introduce large errors providing this is only done over a very short period. Future submissions will be able to incorporate new data if soda ash suppliers can provide this, alternatively it will be necessary to obtain alternative data to allow a better long-period timeseries (for example, estimates of consumption of bread and other baked products could be considered as a means to extrapolate forward the estimates for bicarbonate usage by the food industry.
- Estimates are also sensitive to assumptions regarding the operation of certain chemical processes. However, since these plant closed in the years from 1999 to 2014, this uncertainty does not affect the estimates for recent years.
- While it is certain that some uses of soda ash are emissive (e.g., glass and certain chemical processes), for other uses it is less so. Soda ash seems to be used for a wide range of minor applications, including both emissive and non-emissive ones. In the absence of any detailed breakdown of individual uses, we assume 50% emissive.

Estimates for bricks are considered to be highly reliable for the period 2008 onwards where 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.

Emission estimates for other ceramics are derived using the difference between total UK consumption of clays, and consumption of clays by the brick and cement sectors. Emission factors specifically for other ceramic processes do not exist, therefore we use factors developed by the UK brick industry for the purpose of reporting to ETS. Emission estimates for other ceramics are more uncertain than those for bricks because of this. The figures for 1990-2004 are also more uncertain than later figures, because the estimates for clay usage for brickmaking are more uncertain.

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

The methodology for extrapolating bricks activity data for 1990-97 has been refined to use an average of several years' reported data instead of only 1998 data.

4.5.6 Source Specific Planned Improvements

Emission factors and activity data for bricks, ceramics, soda ash use and FGD will be kept under review. We will continue to seek updated data on soda ash consumption from the manufacturers and suppliers.

We are aware that one sodium bicarbonate site has recently started using captured CO_2 from combustion as a feedstock for the process, and it is on the improvement programme to consider how best to estimate and report this process.

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:

$$CH_4 + H_2O \Leftrightarrow CO + 3H_2$$

$$CO + H_2O \Leftrightarrow CO_2 + H_2$$

The hydrogen is then reacted with nitrogen to form ammonia.

$$N_2 + 3H_2 \Leftrightarrow 2NH_3$$

If the by-products CO and CO_2 are not captured and used, then these are emitted to atmosphere. Ammonia plants can be integrated with methanol manufacture for greater efficiency, since the carbon oxides can be used to manufacture methanol:

$$CO + 2H_2 \Leftrightarrow CH_3OH$$

$$CO_2 + 3H_2 \Leftrightarrow CH_3OH + H_2O$$

Over the time period covered by the UK greenhouse gas inventory, ammonia has been manufactured at four locations in the UK. CO_2 emissions are reported from three of those sites: at the remaining site (Hull), the ammonia is produced with hydrogen supplied as a by-product from another chemical process operated on a neighbouring site. At one of the remaining three sites where CO_2 is reported, some carbon from the steam reformer was, until 2001, exported for use in the manufacture of methanol.

At least one ammonia plant sells CO_2 to the food industry and nuclear industry. Because this CO_2 is still ultimately emitted to atmosphere, it is included in the emissions reported here. This is considered more reliable than trying to identify carbon emissions at the point of final use since CO_2 will also be emitted from other processes within those sectors, for example from fermentation. Potential applications for exported CO_2 might include (but are not limited to):

- use in carbonating drinks (emitted on consumption of the drinks, which is not reported elsewhere in the inventory);
- use as a cover gas for the brewing industry (emitted during brewing or consumption of drinks, not reported elsewhere in the inventory);
- use as a refrigerant (emitted from leakage during the manufacture, use and disposal of the product, not reported elsewhere in the inventory, although it is modelled as part of wider refrigerant modelling);

- use as a feedstock for other chemical industries (emitted on oxidation of those chemicals, this is accounted for in the case of methanol; we don't currently hold data on the extent to which other chemical processes might use this feedstock); or
- by slaughterhouses to render animals unconscious (emitted during use, and not reported elsewhere in the inventory).

It is also worth noting there is cross-border activity for some CO_2-containing products, such as soft drinks. So, it is expected that some of the CO_2 is emitted outside the UK, and some CO_2 will be emitted in the UK which ultimately derives from by-product CO_2 generated outside the UK. For simplicity, we assume that by-product CO_2 generated in the UK is emitted in UK and that net imports of CO_2 in products is zero.

Methane emissions from the steam reforming processes and the associated ammonia production facilities are reported partly under 2B1 and partly under 2B10, with the latter including methane emissions from other chemical manufacturing sites as well. Nitrous oxide emissions from natural gas combustion are also estimated. UK ammonia manufacturers do not report any emissions of this pollutant and so any additional process emissions are assumed to be negligible or not occurring.

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 CO_2 from both fuel and feedstock use of natural gas are calculated by combining reported data on CO_2 produced, emitted and sold by the various ammonia processes. Where data are not available, they have been calculated from other data such as plant capacity or total natural gas consumption. The ammonia plant utilising hydrogen by-product from chemical manufacture does not need to be included as there are no process emissions of CO_2.

Table 4-10 summarises the details of the UK ammonia plants and **Table 4-11** gives details of production and emissions etc. by the sector.

Table 4-10 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

Plant	Feedstock	Carbon emissions	Notes
Ince	Natural gas	Yes	
Hull	Hydrogen	No	

Table 4-11 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
2018	876	1339	1.53
2019	960	1548	1.61
2020	1038	1645	1.58
2021	771	1179	1.53

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

CRF table 2(I).A-Gs1 presents the ammonia production data for all UK sites (including Hull where there are no CO_2 emissions).

Due to the limited market for ammonia production in the UK, to present detailed technology-specific data on production and emissions would be disclosive. Full details of the installation-specific production, fuel use and emissions will be provided upon request to a UNFCCC Expert Review Team. The data in the table above summarises the estimated overall UK production of ammonia (which is partly based on operator data and partly on Inventory Agency estimates based on plant capacity), total estimated 2B1 CO_2 emissions and ammonia IEF on a production basis, as presented in the CRF.

The operator of the Ince and Billingham UK ammonia plants has provided information on reasons underlying the year on year variation in emission factors. Firstly, plants are typically shut down for routine maintenance every two years, and start-up and shut-down procedures increase the emission factors overall. Secondly, plant production rates are varied by the operator during times of high gas prices or low demand, which reduce efficiency and increase emission factors. In addition to these operational variables, each plant will have a different intrinsic efficiency, which will in part reflect the age of the plant and the technology used.

The IPCC 2006 Guidelines suggests a Tier 1 default emission factor of 1.694 tonnes CO_2 / tonne NH_3 for a 'modern' European plant, but a higher Tier 1 default of 2.104 tonnes CO_2 / tonne NH_3 for a 'typical' plant i.e. based on a mix of modern and old plant. The overall UK IEF presented in the table above are below the IPCC default, but this is due to the production at the UK plant where there are no CO_2 emissions; Aggregate UK factors for the three sites with CO_2 emissions show an average of 1.51 tonnes CO_2 / tonne NH_3 for production across the whole 1990-2021 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 CO_2 / tonne NH_3, and 2002 when the emission factor was slightly higher than 2.1 tonnes CO_2 / tonne NH_3. *[Note that 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.

Methane and nitrous oxide emissions from natural gas burnt at ammonia plant to produce heat are estimated by applying IPCC default factors for industrial combustion of natural gas (1 kg methane / TJ & and 0.1 kg N_2O / TJ), and these emissions are reported in 2B1. It is assumed that there are additional emissions of methane from the ammonia process itself, for example from fugitive leaks. Therefore in the UK inventory, methane emissions from ammonia production also include estimates provided from plant operator reports to the UK regulators; these emissions are reported, together with process emissions from other chemical sites, in 2B10a. These operator-reported emissions may include estimates of methane from fuel combustion and hence there is potential for a small double-count in emissions reported across 2B1 and 2B10a. Because it is not at all certain that the methane reported by the operator would include methane from fuel combustion, we have retained the estimates in both 2B1 and 2B10a on the basis that a potential double-count is preferable to a potential gap, particularly since we believe that the latter is more likely were we to remove one of the estimates.

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.

4.6.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.7 SOURCE CATEGORY 2B2 – NITRIC ACID PRODUCTION

4.7.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	2B2: Nitric Acid Production	T3, T2	CS
Gases Reported	N_2O, NO_x		
Key Categories	2B2: Nitric acid production - N_2O (T1)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Not occurring		
Completeness	No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**.		
Major improvements since last submission	No major improvements 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:

$$4NH_3 + 5O_2 \Rightarrow 4NO + 6H_2O$$

$$2NO + O_2 \Leftrightarrow 2NO_2$$

$$3NO_2 + H_2O \Leftrightarrow 2HNO_3 + NO$$

Nitrous oxide is also formed by oxidation of ammonia:

$$4NH_3 + 3O_2 \Rightarrow 2N_2O + 6H_2O$$

Nitrous oxide is emitted from the process, as well as a small percentage of the NO_x that cannot be recovered for conversion into nitric acid. At the end of 2021, nitric acid was being manufactured at 2 UK sites with a total of 4 production plants. At one site, the nitric acid production plant has had NO_x/N_2O abatement fitted to all units since commissioning (pre-1990), whilst at the other UK production site, all three production lines have had nitrous oxide abatement retrospectively fitted during 2011 Quarter 1. This has led to a notable reduction in the UK IEF for nitrous oxide emissions from nitric acid production in the UK between 2010 and 2011 (see **Table 4-13** below).

4.7.2 Methodological Issues

Across the 1990-2021 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 N_2O are derived for each nitric acid site using one of the following:

a) Emissions data provided by the process operators directly or via the Pollution Inventory (1998 onwards for plant in England, 2001 onwards for plant in N Ireland);
b) Site-specific emission factors derived from reported emissions data for the same site for another year (1990-1997 for some plant in England, 1994-1997 for other plant in England, 1990-2000 for plant in N Ireland); and
c) A default emission factor of 7 kt N_2O /Mt 100% acid produced in cases where no emissions data are available for the site (some sites in England, Scotland, 1990-1993). This default factor is the default factor provided in the 2006 IPCC Guidelines (IPCC, 2006) for medium pressure plant.

Table 4-12 gives a summary of the approaches used across the time series to estimate production and N_2O 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 UK 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 N_2O monitoring systems at these sites comply with the requirements of UK 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.

Table 4-12 Methods used to estimate emissions from this category (figures are numbers of sites)

Period	Estimated production data	Operator reported production data	Reported by operator Based on emission factors	Reported by operator Based on monitoring	Inventory Agency Estimate using Site-specific EF	Inventory Agency Estimate using 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	
2001		5	3	1	1	
2002-2004		4	3	1		
2005		4	2	2		
2006-2007		4	1	3		
2008		4	2[a]	2		
2009-2021		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 4-13 Summary of Nitric Acid Production in the UK, 1990-2021

Year	Number of sites	Production (Mt 100% Nitric Acid)	Aggregate EF (kt N_2O / 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	0.108
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
2018	2	1.08	0.077
2019	2	1.19	0.108
2020	2	1.14	0.145
2021	2	0.90	0.117

The larger of the two remaining UK plants fitted control equipment to reduce N_2O 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 N_2O emissions between 1998 and 1999 resulted from a change in the NO_X abatement system at one plant from NSCR to SCR. NSCR reduces emissions of N_2O as well as NO_X, whereas SCR only abates NO_X and can actually increase N_2O emissions.

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 N_2O destruction in a catalyst bed using ammonia gas and hydrocarbon inputs to mitigate the NO_X and N_2O. The technology is described in a reference document (Groves and Sasonow, 2010)[68]. The UK installations apply the technology in process variant 2 design, which achieves N_2O 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 N_2O 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 nitic 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 N_2O for this sector does vary through the time-series depending upon the availability of data. The calculated N_2O

[68] 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 N_2O abatement performance of the technology.

EF for UK nitric acid production facilities varies quite significantly across the time series, which is a reflection of nitric acid production patterns across UK sites that utilise different process conditions. Successive closures have changed the average N_2O EF, as plants with generally above-average emission rates cease production. Abatement of N_2O 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 (2009-2021) 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

There have been no significant recalculations to this category.

4.7.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.8 SOURCE CATEGORY 2B3 – ADIPIC ACID PRODUCTION

4.8.1 Source Category Description

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 N_2O abatement system was fitted to the plant. The abatement system was a thermal oxidation unit and was reported by the operators to be 99.99% efficient at N_2O destruction. The abatement unit was not available 100% of the time, and typically achieved 90-95% availability during adipic acid production.

A small nitric acid plant was associated with the adipic acid plant, and both the adipic and nitric acid plants emitted NO_x. From 1994 until the plant's closure in 2009, the NO_x 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. Therefore, the N_2O emissions from nitric acid production and adipic acid production were reported together for 1990 – 1994 under category 2B3 (adipic acid production). This discrepancy in reporting will cause a variation in the reported effective emission factor for these years for 2B2 and 2B3 but overall emission estimates are not affected.

4.8.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

Emissions data for N_2O from adipic acid production are provided by the process operator, but can be cross-checked against emissions reported in the Pollution Inventory. The level of uncertainty associated with reported emissions 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 N_2O EF from this plant are apparent since the installation of the abatement plant. Following direct consultation with the plant operators, it has been determined that the variability of emissions is due to the varying level of availability of the abatement plant. A small change in the availability of the abatement system can have a very significant impact upon overall plant emissions and hence upon the annual IEF calculated.

4.8.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the 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 CO_2 and chemical CO_2 separately, so the latter could be assumed to cover emissions from coke use only;
- From the 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 CO_2 emissions), and 2013-2021 (from the detailed ETS data). The fuel/process split in emissions for these years can be calculated, and the PI provides total CO_2 emissions at each site back to 1998. Prior to 1998, there is no data on either emissions or production, and therefore it is assumed that emissions in 1990-1997 are at the same level as in later years (the production capacity at all UK sites producing TiO_2 by the chloride route is the same for all years).

In order to avoid a potential double-count in emissions in the UK GHGI, it is necessary to ensure that the reductant used in the processes is not included as a fuel and emissions reported in 1.A. The method adopted by the inventory team addresses this issue by back-calculating the coke oven coke/petroleum coke 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 UK 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

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 CO_2 gas, both of which are used in the process. Coke oven coke is used to fire the lime kilns and CO_2 from the coke is included in the gases used in the soda ash plant. In theory, if limestone and brine are converted completely to soda ash and calcium chloride, then that part of the soda ash process is carbon-neutral and the CO_2 emitted should be equal just to those emissions occurring from the coke. In practice, the process is not 100% efficient so emissions of CO_2 are actually higher than would just be due to the coke use. Soda ash production at one of the two UK sites (Winnington) ceased in February 2014, although the site is still being used to make sodium bicarbonate from sodium carbonate solution & CO_2, which we assume is sourced from the neighbouring Lostock plant. The sodium bicarbonate process will consume CO_2 some of which is subsequently emitted since some uses of sodium bicarbonate are emissive. However, these emissions from sodium bicarbonate usage are reported elsewhere. EU/UK ETS data suggest that the sodium bicarbonate process does emit some CO_2 – presumably unreacted CO_2 that passes through the process and, since this CO_2 probably originates with the soda ash process at Lostock, it is included in the emission estimates for 2B7.

Emissions from soda ash (sodium carbonate, Na_2CO_3) used in the manufacture of soda-lime glasses is reported under source category 2A3 and emissions from other uses of soda ash and sodium bicarbonate are reported in 1B2d and 2A4d.

4.12.2 Methodological Issues

The 2006 GLs suggest that emissions should be based "on an overall balance of CO_2 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 2013-2021 EU and UK ETS data therefore meets the requirements for the method suggested in the GLs.

Prior to 2013, no data for the UK plant were reported in EU ETS, but CO_2 emissions have been reported in the PI from 1998 onwards. Comparison of the PI and EU ETS data for 2013-2020 shows that EU ETS data were 34% higher than emissions in the PI in 2013 and, on average, 60% higher in the years from 2014-2020. 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 CO_2 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 1.34 to give estimates of emissions in those years. The difference in 2014-2020 was consistently higher and so a more conservative approach would be to use a factor based on data for all years after 2013 (1.65). 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 and UK ETS data for 2013-2021 should ensure that the emission estimates for those years are quite certain. The poor agreement between the PI and EU ETS data in 2013-2020 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 2014-2020 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 1.34 (based on both plants 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

No recalculations have been made to emissions from 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 Other. The UK has a large petrochemical industry, with manufacture of all the chemicals explicitly mentioned in the 2006 IPCC Guidelines for at least part of the period 1990-2021, 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 2021. The UK ethylene crackers use either naphtha or natural gas liquids as feedstocks, and off-gases from the ethylene crackers are used as fuels on-site. Ethylene dichloride (EDC) has been produced at 4 sites over the period covered by the GHGI, although only 1 is still in operation, and only 2 of those processes used the oxychlorination route that causes process emissions of CO_2. Ethylene oxide (EO) was produced at a single UK plant between 1990 and closure in January 2010. There is also a single site producing acrylonitrile (ACN): this has operated since 1990 and is still in operation. Two sites produced carbon black, until their closure at the very start, and in the middle of 2009 respectively. Most of the production was of furnace black.

A number of other chemical sites also emit CO_2 due to the use of off-gases as fuels. Emissions of CO_2 at these sites are very small relative to the emissions from ethylene production. All emissions of CO_2 from use of off-gases as fuels is reported under 2B8g, including the emissions from ethylene production.

Many chemical processes emit small quantities of methane, either as a result of fugitive releases from equipment, or as a component of tail gases released from vents. The inventory includes separate emissions data for production of ethylene, methanol, ACN, EO, and carbon black. Emissions of methane from other chemical processes are reported under 2B10.

4.13.2 Methodological Issues

Details of the methodologies used for petrochemical and related processes are shown in **Table 4-14**.

Table 4-14 Methodologies for petrochemical and related processes

Chemical product	CO_2 reported in	CH_4 reported in	Methodology
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].

Chemical product	CO_2 reported in	CH_4 reported in	Methodology
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 2008-2021 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.
Other petrochemicals	2B8g	2B10	Emissions data for other petrochemical processes are 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 CO_2, and additional CO_2 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 CO_2 / t methanol) to give the emission reported in 2B8b. The production estimates are also used to calculate the CO_2 stored, and finally, both emitted CO_2 and stored CO_2 are also converted into estimates of natural gas consumed so that we can ensure there is no double-counting of that natural gas either in 2B1 or in 1A2c. **Table 4-15** summarises the data for methanol production.

Table 4-15 Estimates for methanol production (all kt)

Year	Estimated methanol production	CO_2 emitted	CO_2 stored
1990	488	498	671
1995	488	498	671
1996	488	498	671
1997	488	498	671
1998	232	237	319
1999	215	219	295
2000	257	262	353
2001	130	133	179
2002 onwards	0	0	0

The methodology for CO_2 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 included in the UK GHGI (Personal communication, Chemical Industries Association, 2014). These are dominated by the four ethylene production sites and a handful of other sites producing organic chemicals, typically co-located with refineries.

Emission estimates for other sources are mostly based on a mixture of PI and/or EU ETS data with estimates for earlier years then based on the assumption that emissions are as in later years. Tier 1 IPCC default emission factors are used for the minor sources 2B8c (for CO_2), 2B8d and 2B8f (both CH_4, part of time-series only). No UK-wide activity data (production data) are available with which to generate a better time series for any of the sub-sectors within 2B8, so the earlier part of the time-series for all of the chemical industry sectors is particularly uncertain. EU ETS-based emissions are considered the most reliable basis for estimates in the GHGI and the uncertainty is estimated to be +- 5%. PI data are more uncertain, because it is not clear what methods are used and the emission sources (combustion, process, other) are not transparent. Uncertainty for GHGI estimates based on the PI data is estimated to be +- 15%. Emissions data for methane are likely to be more uncertain than those for CO_2 since the former are often fugitive in nature, or minor components in stack emissions (thus requiring stack monitoring to quantify).

4.13.4 Source Specific QA/QC and Verification

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

4.13.5 Source Specific Recalculations

No recalculations have been made to emissions from this category.

4.13.6 Source Specific Planned Improvements

It is noted that this sector has been identified as a key category, and that not all of the estimates within this sector use a tier 2 or higher approach. The UK has recently reviewed this sector and included some additional sources using what is believed to be the best currently available data. The UK will review this position should further information come to light.

4.14 SOURCE CATEGORY 2B9 – FLUOROCHEMICAL PRODUCTION

4.14.1 Source Category Description

Emissions 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 SF_6.

4.14.2 Methodological Issues

A full description of the emission model and associated methodology used for this sector is contained in AEA (2008). Within the model, manufacturing emissions from UK production of HFCs, PFCs and HFC-23 (by-product of HCFC-22 manufacture) are estimated from reported data from the respective manufacturers. Manufacturers have reported both production and emissions data, but only for certain years, and for a different range of years for different manufacturers. Therefore, the emissions model is based on implied emission factors, and production estimates are used to calculate emissions in those years for which reported data are not available. Two of the three manufacturers were members of the UK greenhouse gas Emissions Trading Scheme. As a requirement of participation in the scheme, their reported emissions were verified annually via external and independent auditors. For PFC production, emissions are now reported to the Environment Agency's Pollution Inventory, and these emissions are directly used within the GHG inventory. The operator of the HFC and (now closed) HCFC-22 plant provides speciated emissions data directly to the Inventory Agency, based on vent analysis and flowmeter readings, or on weighbridge differences. The other

HCFC-22 plant, which closed in 2008, also reported to the Pollution Inventory and these emissions were used within the GHG inventory.

4.14.3 Uncertainties and Time-Series Consistency

The uncertainty analysis in **Annex 2**, provides estimates of uncertainty according to IPCC source category and fuel type. The uncertainty estimate for emissions from HFC manufacture has been revised for this submission, based on information from the plant operator.

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

There have been no significant recalculations in this category.

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, 2022) and Welsh Emission Inventory (NRW, 2022) 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, 2022).

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 (2022).

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

There are recalculations for the years 2010 to 2021 due to revisions to the ONS index of production figures in the most recent publication.

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 2C1. Gases emitted from the top of the blast furnace are collected and emissions occur when this BFG is subsequently used as fuel.

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 CO_2 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 CO_2 released would be emitted from the blast furnace stage of steelmaking rather than the sintering stage. However, this distinction is not important for GHG reporting and the practice is ignored for the GHGI with all additions and, therefore, emissions being reported as from sintering. Dolomite is also an important addition as a fluxing agent in basic oxygen furnaces and CO_2 evolved from the dolomite is reported as a separate category under 2C1.

Electric arc furnaces produce steel from ferrous scrap using electricity to 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 2021, 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 electric arc steelworks once operated in Sheerness, and Newport.

4.16.2 Methodological Issues

The methodology for estimating CO_2 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 (2021). 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 2007-2021. These data show close consistency across the time series and therefore the 2007 value has been extrapolated back to 1990.

The carbon emissions from electric arc furnaces cover electrode emissions, as well as CO_2 emissions from the addition of scrap metal, alloys, carbonate minerals and other additives. The methodology also takes account of carbon stored in by-products, such as steel, slag, scales etc., produced during the steelmaking process.

Electric arc furnace operators including Liberty Steel and Outokumpu have provided additional information regarding the fuels used, process inputs (e.g. other carbon sources, reductants, electrodes, wastes, slags, carbonates) that underpin the carbon emissions data for their electric arc furnaces as reported via the EU ETS.

[A UK GHG Inventory research paper was drafted in 2021 to summarise research in the sector and describe the development of the inventory methodology; that report (Passant and Gorji, 2021) is commercial in confidence but can be shared with an Expert Review Team on request.]

The comparison between the operators and EU ETS data allows for calculation of a more detailed timeseries of emission factors for those individual sites. Further analysis was then required for the purpose of gap-filling for the periods where no or limited data were available due to the changes in the reporting procedures in different EU ETS phases.

There are a number of electric arc furnace plants that have been closed over the years, and therefore further gap-filling exercise was required to estimate emissions from such plants. Based on the revision of the operations of such plants, the emission factors obtained from the first phase of the currently operational plants were deemed suitable for estimating their emissions. This method therefore allowed to account for emissions from the plants that have stopped production over the timeseries.

The Inventory Agency has developed a time series consistent method by applying IPCC good practice methods to address data gaps, as follows:

- Identification of (22) EAF sites operating in the UK across the time series; this includes several EAFs that operated only prior to the start of the EUETS in 2005 and for which there are very scarce data on activity and emissions;
- Analysis of the ISSB production statistics on EAF steel production since 1990, including annual UK-wide statistics and also regional production data;
- Analysis of the Regulator Inventory data, to identify all available emissions data, including for smaller EAF sites that are evidently omitted from the ISSB statistics;
- Use of EU ETS emissions data and ISSB regional production data to derive a time series of IEFs for production for the larger (8) EAF sites that report within EU ETS;
- Development of a hybrid approach to apply operator emissions data per installation where available and to gap-fill for the remaining UK production using the IEF across the sector from the EU ETS reporting, with the 2005 data back-cast to earlier years.

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 4-16** summarises the methods used for emissions reported under 2C1.

Table 4-16 Summary of Emission Estimation Methods for Source Categories in CRF Category 2C1

Source Category	Method	Activity Data	Emission Factors
Sintering – coke breeze	AD x EF	BEIS energy statistics	Carbon: UK-specific factor from carbon balance CH_4: UK-specific based on reported emissions N_2O: Fynes & Sage (1994)
Sintering – carbonates	AD x EF	ISSB	Carbon: UK-specific from EU ETS
Iron & steel - flaring	AD x EF	BEIS energy statistics	Carbon: UK-specific factor from carbon balance CH_4, N_2O: IPCC (2006)
Electric arc furnaces	AD x EF	ISSB	Carbon: UK-specific factor CH_4, N_2O: EMEP/EEA
Ladle arc furnaces	AD x EF	ISSB	Carbon: UK-specific factors

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

Due to a methodology update to further utilise the EU ETS data, a more complete timeseries of operator data has been developed. The result of this is an increase in total emissions across the timeseries, specifically an increase of 18kt in 1990 and an increase of 8kt in 2019. For further information on 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 CO_2 emissions include:

- Use of reductants such as coke oven coke;
- Consumption of carbon electrodes in furnaces used for melting raw materials;
- Decarbonisation of limestone or dolomite used as a fluxing agents;
- Decarbonisation of any carbonate ores used.

The UK has been a minor producer of ferroalloys. The previous version of the BREF note (Best Available Techniques Reference document) for the non-ferrous metals industry, produced by the European IPPC Bureau[69] 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

[69] downloadable from http://eippcb.jrc.ec.europa.eu/reference/

from use of reductants), and 10,000 tonnes of other ferroalloys in electric furnaces. The ferroalloy producers identified as in operation in recent years either carry out exothermic processes only (for ferro-molybdenum alloys) or use electric induction furnaces for melting. None of the processes report any CO_2 emissions in the Pollution Inventory, or are included in the EU/UK 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 CO_2. 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 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 CO_2. The PFC species tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6) are formed if the alumina content of the electrolyte falls too low. Computerised control of alumina addition to the cells is a feature of modern plant and has helped to reduce PFC emissions from aluminium production. Emissions of methane are not estimated as there is no methodology available and emissions are considered to be negligible.

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 (CF_4 and C_2F_6) 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 (British Geological Survey, 2022) 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 5 years between 2013 and 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 for 2005 and for 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 4-17**.

Table 4-17 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 (British Geological Survey, 2022); Σ operator production data (latest from Alvance British Aluminium, 2022)	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 4-18** below. Note that the PFC EFs presented here are essentially back-calculated IEFs for the UK industry, derived from the reported production data and sum of operator-reported emissions.

Table 4-18 Activity Data and Emission Factors: UK Aluminium Production 1990-2021

Year	Activity Data (Mt Aluminium Produced)	Carbon Emission Factor (kt/Mt)	CF_4 Emission Factor (kt/Mt)	C_2F_6 Emission Factor (kt/Mt)
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

Year	Activity Data (Mt Aluminium Produced)	Carbon Emission Factor (kt/Mt)	CF_4 Emission Factor (kt/Mt)	C_2F_6 Emission Factor (kt/Mt)
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
2018	0.044	420.0	0.027	0.003
2019	0.039	420.0	0.018	0.002
2020	0.036	420.0	0.014	0.002
2021	0.038	420.0	0.014	0.002

4.18.2.1 Aluminium alloy production

No emissions of SF_6 are reported by any of the aluminium foundries in the Pollution Inventory or SPRI. Emissions from the use of SF_6 in the UK aluminium sector are therefore reported as Not Occurring.

4.18.3 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 (BGS) 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, has occurred 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, SF_6 and an HFC act as cover gases to prevent molten magnesium from burning during the production of magnesium.

4.19.2 Methodological Issues

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. SF_6 is non-flammable and non-toxic and is therefore a safe gas to use. In the UK, SF_6 has been used as an alternative cover gas to SO_2 in magnesium alloy production and sand and die-casting since the early 1990s. Since 2006, EU magnesium producers have looked for alternatives to SF_6 in response to bans in the EU F-Gas regulation. Some die casters have gone back to using SO_2. Others have used HFC-134a and a fluoro-ketone (FK 5-1-12) with the trade name Novec 612.

The UK magnesium casting industry is very small. There are three significant manufacturers (one alloy producer, one die-caster and one sand-caster) plus two very small operations (both sand-casters). Alloy production involves the use of primary magnesium ingots, recycled scrap material and second-generation magnesium materials (i.e. material already made into alloys) for the production of different alloys. Both die and sand casters use these magnesium alloys to produce specific components for a wide range of industries. For the casting industry, SF_6 is used for casting specific magnesium alloys where other cover gases, such as HFC-134a, are currently considered not suitable.

The 2014 EU F-Gas Regulation prohibits the use of SF_6 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 SF_6 and HFCs that are emitted from the consumption of these F-gases were reviewed through discussion with industry experts and in some cases amended. It is estimated that 95% of SF_6 consumption is emitted but that only 20% of HFC-134a consumption is emitted (as a much greater proportion reacts with the magnesium). These figures are based on expert estimates by Gluckman (2013).

For magnesium alloy production, SF_6 emissions from 1998 onwards are estimated based on the data reported to the Pollution Inventory (Environment Agency, 2021), whilst emissions prior to 1998 are estimated based on consultations with the plant operators.

From 2004, one of the main industry users of SF_6 as a cover gas has implemented a cover gas system using HFC-134a for some of its production capacity. There has not been a complete switch to HFC-134a, although the operator is considering this on an ongoing basis depending on suitability for the different alloys produced. In addition to having a significantly lower GWP than SF_6 (and thus reducing emissions on a CO_2 equivalent basis), use of

HFC-134a is further advantageous in that a significant fraction of it is destroyed by the high process temperatures (80%) thus reducing the fraction of gas emitted as a fugitive emission.

From 2008, emissions of HFCs have been reported in the Pollution Inventory (Environment Agency, 2021), 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 SF_6 and HFC-134a (that represent 99% of UK emissions from magnesium) are now contacted annually for their activity data (consumption of SF_6 and HFC-134a).

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 CO_2. It is estimated that the decomposition of 1 tonne of FK 5-1-12 during use as a cover gas generates ~400 tonnes CO_2e 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 CO_2 eq.". Therefore, the UK considers this a low priority to formally estimate and report emissions for. This source is included in the Assessment of completeness in **Section 1.8**.

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 SF_6 from casting based on discussions with the sector Trade Association for the period prior to 1998. Data from the main magnesium alloy producer is also uncertain for this period.

For the period 1998-2017, 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.

SF_6 emissions from UK magnesium producers peaked in 2000 at approximately 1,000 kt CO_2 equivalent. The use has fallen steadily, particularly from 2006 onwards, being 80 kt CO_2 equivalent in 2020. HFC-134a emissions were zero until 2008 and are 2 kt CO_2 equivalent in 2020.

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

We have recalculated HFC estimates for 2019 and SF_6 estimates for 2016-2019 to reflect the more up to date operator data received.

4.20 SOURCE CATEGORY 2C5 – LEAD PRODUCTION

Lead production in the UK consists of one primary lead production site (now closed) and a small number of secondary lead sites. The primary lead site produced zinc, lead and other metals from imported ore concentrates and closed in 2003. This site produced more zinc than lead, and because it is not possible to split emissions between 2C5 and 2C6 (other than on an arbitrary basis), emissions for this site are reported under 2C6. Further details on this process are given in the following section. The UK also has a number of secondary lead processes, all of which involve the recovery of lead either from automotive batteries or from clean scrap. Emissions of CO_2 could, in theory, occur from the use of reductants such as coal, coke oven coke, or natural gas during secondary lead processes, however none of these secondary lead processes are known to involve the use of reductants, and therefore we do not believe that there are any process emissions of CO_2 from any of the UK's secondary lead processes. If any use of reductant did occur, it would be included in UK fuel statistics as an energy use, and thus emissions of CO_2 would in any case be included in the UK inventory, but 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 CO_2 from processes. These were:

- the Capper Pass Tin Smelter at Melton, Humberside (closed in 1991)
- IMI Refiners' secondary copper smelter at Walsall (closed in 1997)

There is very little data specific to these installations available to the Inventory Agency as their closure pre-dates most of the routine annual emissions reporting regulations in the UK. Both processes used coke oven coke as a reductant that would have led to process emissions of CO_2, and since we only have data on the total use of coke oven coke in non-ferrous metal production in UK energy statistics (BEIS, 2022a), we report all emissions from use of this coke oven coke in 2C6. Therefore, the emissions reported in 2C6 will also include emissions from these two sites, as well as emissions related to the production of lead at the Britannia Zinc site.

4.21.2 Methodological Issues

Britannia Zinc reported CO_2 emissions in the Pollution Inventory (Environment Agency, 2018) from 1998 until 2002, at which point the site ceased operation. Emissions of CO_2 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 CO_2 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, 2022a), '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 no sites, 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

No major recalculations have been made to this sector.

For further information on recalculations, see **Section 10**.

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 Agricultural engines – lubricants Marine engines – lubricants Road vehicle engines – lubricants	T1 T1 T1 T1	D, CS D, CS D, CS D, CS

Emissions of CO_2, CH_4 and N_2O 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. Where the term lubricants is referred to, this correlates to the DUKES definition of lubricating oils (and grease), i.e. “Refined heavy distillates obtained from the vacuum distillation of petroleum residues. Includes liquid and solid hydrocarbons sold by the lubricating oil trade, either alone or blended with fixed oils, metallic soaps and other organic and/or inorganic bodies.”

4.22.2 Methodological Issues

Emissions reported in 2D1 cover all lubricants used by all sectors, with the sole exception of lubricants used in mopeds engines. This is deemed to be intentional fuel use and hence is reported in IPCC sector 1A3biv. 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, 2022a) 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 (2019).

Lubricant use in the remaining sectors uses activity data from DUKES, but the total lubricant use estimated by the inventory diverges from DUKES due to the use of the above method for road engines. While in general we would consider the totals from UK energy statistics to have a higher confidence than bottom-up estimates of demand, in this case we have taken a more conservative approach, reflecting that trends in activities that would demand lubricants do not correlate with the strong decreasing trend presented in DUKES.

The consumption estimates are used to calculate CO_2 emissions which are reported in IPCC sector 1A3biv for mopeds and 2D1 for all other sectors,. 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 is oxidized during use. In all cases we apply a UK-specific carbon emission factor for lubricants, based on analysis of UK waste oil samples.

Emissions of CH_4 and N_2O also arise from lubricant combustion in road vehicle engines. However, the exhaust emission factors for these gases will include the contribution of, and hence the emissions of, CH_4 and N_2O (and other air pollutants estimated on a vkm-travelled basis) from lubricants are included implicitly in the hot exhaust emissions (IPCC Sector 1A3b) calculated for each vehicle and fuel type. Treating emissions of these pollutants separately would lead to a double count.

4.22.3 Uncertainties and Time Series Consistency

The use of a Tier 1 methodology means that estimates are quite uncertain.

Additionally, the divergence in trend in total lubricant consumption presented by energy statistics, and bottom-up estimates of demand reflects uncertainty in activity data for this source.

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

Improvements to the road transport model have allowed lubricant use in road vehicle engines to be calculated at a more granular level. The size of the impact of this recalculation is a 0-3% reduction in emissions from 2006 onwards.

For further information on recalculations, see **Section 10**.

4.22.6 Source Specific Planned Improvements

We are continuing to engage the UK energy statistics team to understand the trends in UK energy statistics for total lubricant demand, and the inventory estimates will be revisited if any major improvements are made to energy statistics.

4.23 SOURCE CATEGORY 2D2 – PARAFFIN WAX USE

4.23.1 Source Category Description

This category includes CO_2 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: BEIS, 2022c) on the same basis as the earlier data, as they comprise part of other long-term energy data reporting outputs, e.g. to EUROSTAT.

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

No major recalculations have been made to this sector.

For further information on recalculations, see **Section 10**.

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 CO_2 are estimated from consumption of urea by road vehicles with relevant types of catalytic converters for control of pollutant emissions and are reported under 2D3. Urea has the chemical formula $(NH_2)_2CO$ and is injected into the exhaust stream of certain types of diesel vehicles (currently Euro IV, 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 CO_2 from the urea in the tailpipe.

Petroleum coke is known to be used by various sectors either as a fuel (e.g. at power stations and in cement kilns), or in various processes (e.g. in brickmaking, titanium dioxide manufacture, aluminium smelting, or electric arc steelmaking). The consumption of petroleum coke for each sector is either available directly from DUKES or estimated, based on 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 32) between 1990 and 2021, 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 CO_2 emissions from urea consumption. This is either from statistics on total urea sales or by estimating urea consumption as a proportion of the amount of fuel consumed. There are no statistics on urea sales in the UK, so the approach based on fuel consumption is used. Not all diesel vehicles use urea, so it is necessary to know the amount of fuel consumed specifically from those vehicles with the relevant exhaust after treatment technology that require urea injection.

Urea is used by HGVs and buses in the UK manufactured to Euro IV, V 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 kgCO_2/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 CO_2 emission factor from urea consumption are very low because the carbon content of urea is known with high accuracy.

The end uses of the petroleum coke reported in 2D3 are unknown and could actually include some use of coke as a fuel and/or some non-energy uses that result in storage of carbon, as well as emissive non-energy uses. The approach taken is conservative since we assume all of the carbon is emitted, but emissions may be wrongly allocated if some of the petroleum coke is actually used as a fuel. The uncertainty in emissions for this source is very high. Because of the use of this source as a balance against energy statistics, the time series is very erratic. There are many 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

Petroleum coke estimates for this sector have been revised due to a removal of a double count of petroleum coke estimated for residential combustion and some revisions to gap filling for lime sector use of petroleum coke. As the data reported here is a residual of unknown use of petroleum coke, these changes to other sectors have a significant impact on the residual reported in 2D3.

For further information on recalculations, see **Section 10**.

4.24.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

4.25 SOURCE CATEGORY 2E1 – INTEGRATED CIRCUIT OR SEMICONDUCTOR

Emissions of SF_6 and PFCs from semiconductor manufacturing are combined with emissions from training shoes and electrical insulation in source category 2G2e for reasons of commercial confidentiality. Emissions of NF_3 and HFCs from semiconductor manufacture are reported in sector 2E1. This source category (both for pollutants reported in 2E1 and 2G2e) 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 given[70] 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. This source is included in the Assessment of completeness in **Section 1.8**.

4.26.2 Source Specific Planned Improvements

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

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 given[71] for the UK in 2003. When using this activity data and the default methodology the resulting

[70] Table 6.7 of Volume 3 of the IPCC 2006 Guidelines

[71] Table 6.8 of Volume 3 of the IPCC 2006 Guidelines

emission was well below the threshold to be considered significant, so is reported by the UK as 'NE' for years before 2014. This source is included in the Assessment of completeness in **Section 1.8**.

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 (C_6H_{14}), including one company that manufactures this PFC in the UK. These discussions indicated that there is a small use of PFCs for HTF applications in some EU countries and in non-EU export markets. However, very small quantities (<2 kt CO_2e) of PFCs are sold in the UK market for this application, but it is believed that these are sold exclusively for hermetically sealed applications and products that are sold on to be used outside the UK. This source is included in the Assessment of completeness in **Section 1.8**.

4.28.3 Source Specific Planned Improvements

Any emergence of volume manufacturing capacity of heat transfer applications using F-gases is kept under review.

4.29 SOURCE CATEGORY 2F1 – REFRIGERATION AND AIR CONDITIONING EQUIPMENT

4.29.1 Source Category Description

HFCs and HFC blends have been widely used as replacement refrigerants for ozone depleting substances across virtually all refrigeration and air-conditioning 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;
- During on-site installation of equipment
- 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 model based on 7 main market sectors.

Table 4-19 Model End-Uses and Definitions

End-Use		Description
Residential	Domestic Refrigeration	Refrigerated appliances including refrigerators, chest freezers, upright freezers, and fridge freezers.
Commercial refrigeration	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.
	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.
	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.
Industrial refrigeration	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.
Comfort cooling and heating, direct	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-to-air heat pump.
	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.
Comfort cooling and heating, indirect	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. Some are reversible and can operate as air-to-water or water-to-water heat pumps
	Hydronic Heat Pumps	Residential and small commercial heating only heat pumps providing heat in the form of hot water, including air-source heat pumps (ASHP) (air-to-water systems) and ground-source heat pumps (GSHP).

End-Use		Description
Transport refrigeration	Land Transport Refrigeration	Refrigerated road vehicles (i.e., light commercial vehicles, trucks, trailers) and intermodal containers.
	Marine Transport Refrigeration	Refrigerated general cargo ships, container ships and fishing vessels (1,000 GT and above).
Mobile air-conditioning	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).
	Other Mobile Air Conditioning	Air-conditioning systems for buses/coaches and railcars.

4.29.2 Methodological Issues

The UK estimates activity and emissions in his sector using a comprehensive modelling platform developed by Gluckman Consulting called *HFC Outlook* which uses a Tier 2a methodological 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 Refrigeration, Air Conditioning and Heat Pumps (RACHP) sector with top-down data for the sales of HFCs in the UK and with predicted emissions made by Bristol University and the UK Met Office based on atmospheric measurements of F-Gas concentrations. The model takes full account of the impact of the EU F-Gas Regulation (517/2014), including bans of some higher HFCs for some applications and a general phase down of HFC consumption. The model is reviewed on a regular basis.

For each of the 36 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.

A key input assumption is the split of different refrigerants used in new and existing equipment in each of the 36 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).

A summary table of the 2020 input assumptions is provided below in **Table 4-20**.

Table 4-20 Summary of 2021 Input Assumptions by End-Use

CRF Sector	UK Category	Total Stock (units)	Lifetime (years)	Charge (kg)	Most common refrigerant in new equipment, 2021[72]	Manufacturing / Installation Loss Rate	Operational Loss Rate	Disposal Loss Rate
Domestic Refrigeration	Domestic Refrigeration	47,181,000	15	0.03 to 0.1	HC-600a	1%	0.1%	58%
Commercial Refrigeration	Small Hermetic Stand-Alone Refrigeration Units	1,892,000	15	0.2 to 1	HC-290, HFC-134a	1%	2%	66%
	Condensing Units	519,000	15	1.5 to 15	X1500, X600, R-744	3%	9%	45%
	Centralised Supermarket Refrigeration Systems	27,800	15	40 to 400	R-744	3%	9%	25%
Transport Refrigeration	Land Transport Refrigeration	62,800	9 to 15	1 to 10	R-452A	2%	22%	60%
	Marine Transport Refrigeration	400	25	50 to 1,500	R-744, HFC-134a, R-717	2%	20%	55%
Industrial Refrigeration	Industrial Systems	42,100	18 to 30	30 to 3,000	X1500, HFC-134a, R-717	2%	8%	50%
Stationary Air-Conditioning	Small Stationary Air Conditioning	2,910,000	12	0.5 to 8	HFC-32	3%	4%	80%
	Medium Stationary Air Conditioning	288,000	15	2010 to 100	R-410A	2%	4%	55%
	Large Stationary Air Conditioning (Chillers)	56,000	15 to 21	30 to 1,500	HFC-134a, HFO-1234ze	2%	5%	50%
	Heat Pumps	199,000	18	3 to 150	R-410A, R-134a, R-407C	2%	3%	60%
Mobile Air-Conditioning	Light Duty Mobile Air Conditioning	31,888,000	16	0.4 to 0.8	HFO-1234yf	1%	5%	65%
	Other Mobile Air Conditioning	136,800	15	4 to 25	HFC-134a, R-410A	2%	13%	65%

[72] X600 = R-450A or R-513A; X1500 = R-448A or R-449A

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 for the Falkland Islands and the Crown Dependencies
- The proportion of households with air conditioners for stationary air conditioning in Bermuda and the Cayman Islands
- 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.

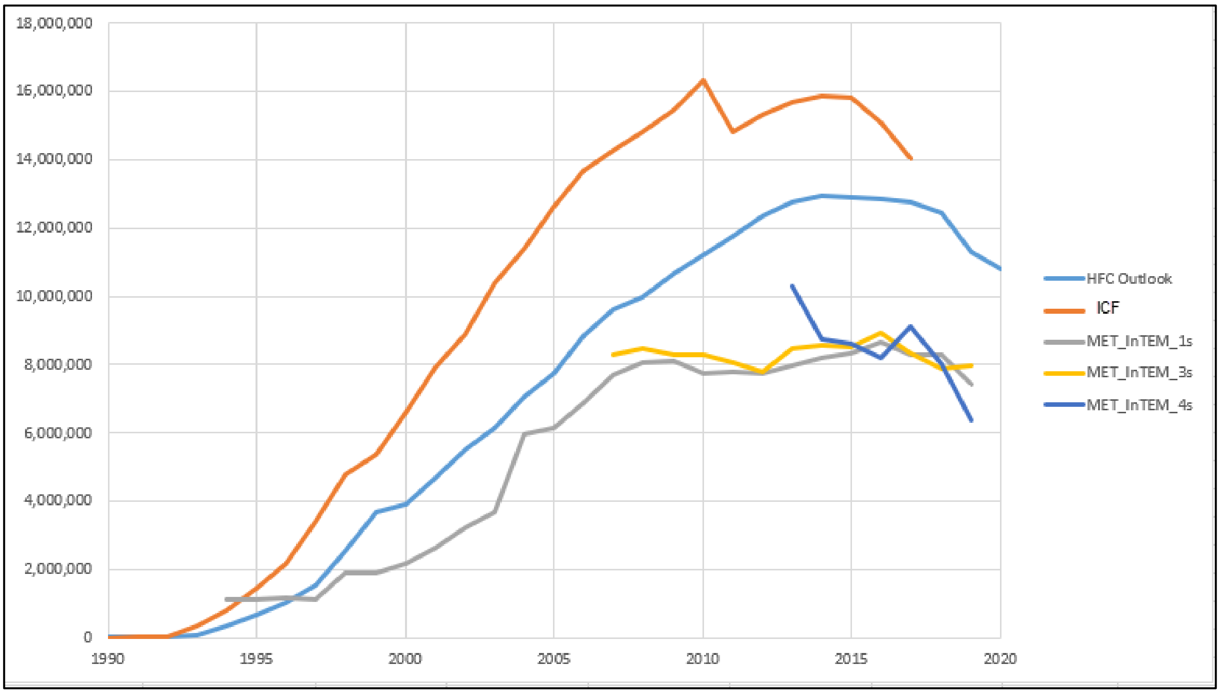
4.29.4 Source Specific QA/QC and Verification

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). Further detail about this comparison is not presented due to the BRA data being confidential data.

Experts from the University of Bristol and the UK Met Office carry out measurement of atmospheric concentration data for all HFCs. These data are combined with meteorological data through a process called "Inversion Technique for Emission Modelling" (InTEM) to create an estimate of UK HFC emissions. See **Section 1.6.3** for a description of InTEM. **Figure 4.3** shows a comparison of data from InTEM with the ICF model[73] estimates and the current *HFC Outlook* model. Both the ICF and HFC Outlook emissions estimates are higher than those created by InTEM and are likely to be conservative over-estimates of HFC emissions. This chart also shows that the estimates from the HFC Outlook model are much closer to the InTEM measurements than the ICF model.

[73] The ICF HFC Model was used in the NAEI prior to the development of the HFC Outlook model.

Figure 4.3 Comparison of RACHP Emissions Model Estimates with InTEM, tonnes CO_2e



In the UNFCCC review of the 2019 submission, it was highlighted that the UK trends in emissions presented a steep decline in emissions in recent years, which is a much stronger trend that other EU Member States subject to the same F-gas regulations. While the model has been updated since this date, and the decline is not modelled to be a few years later and less steep, the overall trend remains. This is in part due to the use of conservative emission factors, which means that the UK's bank model will deplete historically used refrigerants (with typically higher GWPs) more quickly, and therefore the impact of legislation to improve the choice of refrigerants might be reflected earlier in the model than in practice. This is potentially verified by the atmospheric measurements and verification of UK emissions estimates provided in **Annex 6**; which, for recent years, shows a similar declining trend in emissions of some key HFCs used as refrigerants. There are also some UK-specific factors that mean we might expect emissions to be falling faster than other countries in Europe:

1. The UK supermarket sector is believed to have had historically high emissions (mainly of HFC-blend R-404A, which has a very high GWP). Since 2014, UK supermarkets have taken significant steps to rectify this situation through improved maintenance of existing systems. These improvements are taken into account in the emissions model.
2. Despite the date of the new equipment ban on refrigerants with a GWP>2500 being in 2020, the UK industry took early action and stopped using R-404A in new equipment several years earlier. For large systems (e.g. in supermarkets and industrial systems) there was little R-404A used in new equipment from around 2016. A key driver was the recognition of the "service ban" which also started in January 2020 and bans the use of virgin refrigerants with a GWP>2500 for the servicing of existing systems.
3. An important difference between the UK and most of the rest of the EU is the widespread retrofitting of R-404A systems, especially in supermarkets. R-404A (with a high GWP) can be retrofitted with several "near drop-in" alternatives. These include HFC blends R-407A and R-407F (which both have GWPs roughly half of R-404A) that were used in the period 2012 to 2016 and the more recent HFC / HFO blends R-448A and R-449A (both with lower GWPs again). By carrying out a retrofit, any subsequent leakage emissions will have a much lower global warming impact, because of the considerably reduced GWP. One UK supermarket chain had completely retrofitted their

R-404A equipment by 2014 and others did retrofit trials at that time. The old UK model assumes significant further retrofits in the period 2015 to 2019, to ensure that all large R-404A users would be compliant with the 2020 service ban. It is interesting to note that supermarkets in most other EU countries did not adopt retrofits until around 2018. The new UK model recognises that many previously planned UK retrofits were delayed for economic reasons – with few being carried out in 2015 and 2016. Most of the large UK supermarket chains started major retrofit programmes in 2017 (driven by the massive price rise that occurred before the 2018 phase-down step, which drove up the price of R-404A by around 1000%). They have combined the retrofits with a careful R-404A recovery and reclaim programme, which allows the retrofits to take place more slowly than originally modelled, during the period 2017 to 2023. The reclaimed R-404A can continue to be used for maintenance of the remaining R-404A equipment. This slower rate of retrofits does mean that 2015 to 2017 drop in emissions may be lower than predicted by the old model. This will be confirmed during 2022.

4.29.5 Source Specific Recalculations

No major recalculations have been made to this source for the 2023 submission.

For information on the magnitude of recalculations, see **Section 10**.

4.29.6 Source Specific Planned Improvements

The bottom-up RACHP modelling is currently under review to take into account:

a) Market changes related to the rapid roll-out of heat pumps.

b) Market changes related to the on-going review of the F-Gas Regulation in both the UK and EU.

c) Improved data from InTEM that can be used to better calibrate the modelled estimates of HFC emissions.

Work is on-going to update the HFC Outlook model in response to these issues. Results from this work are expected to feed into the RACHP modelling in the next inventory.

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 cycle[74].

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.

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

[74] 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.

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 4-21 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 4-22** *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 4-23**.

Table 4-22 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.

Application	EF Source	Product Lifetime (years)	Manufacturing Factor	Product Lifetime Factor	Notes
	UK GHGI Model	30	15%	0.75%	
XPS Board	IPCC 2006 GLs		25%	0.75%	Annual cell losses greater but decreases with greater thickness
	UK GHGI Model		12-25%	2.5%	

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

Table 4-23 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

HFC-245fa and HFC-365mfc are only used in foam blowing applications. The University of Bristol / UK Met Office HFC atmospheric measurements include emissions estimates for both these HFCs. Work is on-going to cross-check the emissions based on the bottom-up modelling methodology with the InTEM estimates based on these atmospheric measurements. Results from this work are expected to feed into the foams modelling in the next inventory.

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 CO_2 equivalent per annum (3100 tonnes of HFC-134a); and
- 2000: 1,700 kt CO_2 equivalent per annum (1200 tonnes of HFC-134a; 1000 tonnes of HFC-152a)

Emissions in tonnes of CO_2 equivalent have reduced between 1996 and 2000 due to the use of HFCs with lower GWP values, and the manufacture of cans containing less HFC. In 2000, 23 million OCF cans that contained HFCs were sold in Germany while 7 million 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. This is used as an alternative to Halon 1301 in fixed systems.

The UK makes no use of HFCs as an alternative to Halon 1211 in hand-held fire extinguishers. There is no suitable HFC used in the UK and the fire industry has switched to a range of not-in-kind technologies including water, water mist, foam spray, CO_2 and powder extinguishers. The Fire Safety Advice Centre[75] confirm that: "It is not the policy of the fire industry to select fluorinated gases for use in this sector except in special circumstances and none are generally available in the market at present."

[75] https://www.firesafe.org.uk/phase-out-of-halon-in-portable-extinguishers/

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 (2019) 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, is it 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 C_4F_{10} 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 4-24 Key assumptions used to estimate HFC emissions from fire extinguishers

Parameter	1990-2000	2001-2004	2005 onwards
Equipment lifetime (yrs)	20		
% released through fire (lifetime)	1.5		
% released through servicing	3.4	1.5-2.9[76]	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

[76] Interpolated between 2000 and 2005

‘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 exempted from the 2014 EU F-gas regulation phase down of HFC consumption.

4.33.2 Methodological Issues

4.33.2.1 Aerosols

The methodology used to estimate emissions corresponds to an IPCC Tier 2a 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. A 2006 IPCC default approach is used, of assuming that 50% of emissions occur in the year that aerosols are placed on the market, and 50% the following year.

4.33.2.2 Metered Dose Inhalers (MDIs)

The methodology used to estimate emissions corresponds to an IPCC Tier 2a method. The current approach is essentially a “UK consumption model”. The number of MDIs prescribed each year in the UK is derived from the UK National Health Service (NHS) prescription data, and a 2006 IPCC default approach applied, i.e. of assuming that 50% of emissions occur in the year of prescription and 50% the following year. 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 2018. 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 (8%) have been formulated using HFC-227ea. The table shows the estimated number of MDIs consumed each year in the UK and the estimated charge size.

Table 4-25 Key assumptions used to estimate HFC emissions from MDIs

Year	MDI Number (thousands)	Average Propellant (g per MDI)
2006	40,146	14
2007	41,874	13
2008	45,353	12
2009	48,413	12

Year	MDI Number (thousands)	Average Propellant (g per MDI)
2010	50,190	12
2011	50,644	12
2012	52,009	12
2013	51,518	12
2014	53,317	12
2015	53,612	12
2016	54,174	12
2017	53,452	12
2018	53,155	12
2019	52,338	12
2020	54,038	12
2021	50,633	12

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

HFC-152a had previously been expected to see an increase in use to replace HFC-134a in non-medical aerosols. In consultation with the British Aerosol Manufacturers' Association, we found that this has not been the case for the following reasons:

- 152a is more flammable than 134a
- 152a isn't as cheap as using hydrocarbon replacements

The BAMA contact expected that the reality has been that ~75% of 134a applications went to hydrocarbons. The remaining ~25% of applications are expected to have changed to HFO-1234ze, which has low flammability but is more expensive than hydrocarbons.

In future, it's anticipated that the aerosols sector will go towards using compressed air/nitrogen/CO_2 for applications that need to be non-flammable rather than towards another F-gas.

It is now assumed that use of HFC-152a only continues at the level that it was used before the ban on 134a use.

For information on the magnitude of recalculations, see **Section 10.**

4.33.6 Source Specific Planned Improvements

The MDI sector is currently under review. The NHS has identified that MDI-related HFC emissions are a significant part of its carbon footprint and are putting policies in place to reduce these emissions. This sector will be closely monitored to measure the impact of NHS policies. Several pharmaceutical companies are developing low GWP alternatives to the current HFC-134a and HFC-227ea propellants. The first of these are expected to enter the market by 2025 and a significant transition away from current MDIs is expected by around 2030.

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:

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

Where:

$Emissions_t$ = emissions in year t, tonnes

S_t = quantity of solvents sold in year t, tonnes

S_{t-1} = quantity of solvents sold in year t-1, tonnes

EF = emission factor (= fraction of chemical emitted from solvents in the year of initial use), fraction

D_{t-1} = quantity of solvents destroyed in year t-1, tonnes

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 (2019) 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 (2019) were scaled down using a time-dependent UK to EU GDP ratio from Eurostat (2019). 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%[77] was applied in this analysis using the IPCC (2006) equation above. Recovery and recycling are not considered in emission estimates, per the 2006 IPCC Guidelines.

4.34.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

4.34.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. Details of verification of emissions are given in **Annex 6**.

4.34.5 Source Specific Recalculations

There have been no major recalculations to emissions from this sector.

For information on the magnitude of recalculations, see **Section 10.**

4.34.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

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

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 split of cylinder sizes for each application type was estimated through discussions with packer-fillers as summarised in the table below.

Table 4-26 Estimated split of UK refrigerant sales by cylinder size

	Bulk (1 tonne / 15 tonne)	Large cylinder (60 kg)	Small cylinder (13 kg)	Disposable cans[1] (0.34 kg)
Mobile A/C	15%	5%	70%	10%
Stationary refrigeration	5%	25%	70%	
Stationary air conditioning	5%	5%	90%	

[1] these were banned in 2008, so after this date it is assumed that small cylinders are used instead

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:

a) They "de-heel" each cylinder by transferring any remaining refrigerant into a large storage drum. When this drum is full it is tested for quality and then added to the main refrigerant bulk tank for use in filling new cylinders
b) They "top-fill" a cylinder with the appropriate refrigerant, filling to the required total weight.

Packer-fillers indicate negligible losses from these processes (e.g. for top fill there is no emission other than that for cylinder filling). Conservatively the model uses 10 grams per de-heeling operation in the period 1990 to 2000, tapering to 2 grams after 2008.

4.35.2.4.3 Non-returnable cylinders

Any heel left in a non-returnable cylinder will be emitted e.g. from a landfill site or a waste metal reprocessing site. There is no data on the average heel size for non-returnable cylinders or small cans. Only a small proportion of UK refrigerant was sold in non-returnable packages in the period 1990 to 2008 and none after that date (due to the ban in the 2006 EU F-Gas Regulation). The model assumes a 2% heel in small cylinders (approx. 0.25 kg) and a 10% heel in small cans (approx. 30 grams).

4.35.2.4.4 Cylinder use in the field

There are losses each time a cylinder is connected / disconnected to RACHP equipment during field installation or maintenance. The loss will depend on the care taken by the technician carrying out the filling operation. Refrigerant is lost from the connection hoses when a cylinder is disconnected. Technicians are trained how to use cylinders correctly (it is part of the mandatory F-Gas handling training specified in the 2006 EU F-Gas Regulation and part of the training specified by the EU Ozone Regulation). With best practice the losses are estimated to be in the range of 0.5 to 3 grams of refrigerant per filling event, assuming only refrigerant vapour is emitted. However, with poor practice some liquid refrigerant could be emitted – this could result in an emission of 50 to 100 grams per event. Discussion with experts has established that an average loss of 10 grams per event is reasonable for properly trained technicians (allowing for one in ten filling events to be poor practice). Prior to the introduction of mandatory training loss rates were higher – the model assumes 40 grams per filling event prior to 2001, tapering to 10 grams in 2008.

Some cylinders are used multiple times in the field e.g. a 15 kg cylinder could be used to add, say 5 kg to plant A, 1 kg to plant B etc. There is no detailed data available on average cylinder use patterns. Based on discussion with experts the model assumes 5 filling events per cylinder.

A high proportion of the emissions are from cylinder use in the field. There is a drop of field emissions in the period 2000 to 2008 due to the introduction of better training. There is a drop in filling / disposal emissions in 2008 due to the ban on non-returnable cylinders and cans.

4.35.2.5 Refrigerant handling by other organisations

In addition to the Fillers & Packers, Koura Global (formerly known as 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

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**.

4.35.5 Source Specific Recalculations

The input data for quantities of HFC used in new systems has been updated to align with the HFC Outlook model now used for RACHP emissions estimates. In general, this results in lower emissions estimates, reflecting that HFC Outlook's estimates were lower than the prior ICF model in the historic time-series.

For information on the magnitude of recalculations, see **Section 10.**

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 highly 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.

Recently, alternatives such as fluoronitrile-based blends are being commercially deployed as much lower GWP alternatives to SF_6 for many types of electrical insulation, including retro filling of SF_6-based systems in some cases. As far as the UK inventory team are aware, these alternatives are yet to be proven for the highest voltage applications, but progress continues to be made towards those. In December 2021 National Grid announced a pilot project to deploy an alternative product at a substation[78], and if successful this might play a significant role in the operator's target to reduce SF_6 emissions by 50% by 2030.

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 SF_6 for switchgear from the environmental regulators' inventories (EA, NRW, SEPA and NIEA; all 2021). Since the introduction of the EU F-Gas Regulation in 2006, the UK electricity industry has made significant efforts to monitor and reduce consumption of SF_6.

The operator-reported annual data are used to estimate the size of the SF_6 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**.

[78] https://www.nationalgrid.com/national-grid-and-hitachi-energy-announce-world-first-collaboration-replace-sf6-existing-high

4.36.5 Source Specific Recalculations

Data for 2019 and 2020 have been revised due to data that was not available in time for the last submission now being available. There are some smaller changes to earlier years relating improved estimates for one operator.

For information on the magnitude of recalculations, see **Section 10.**

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 SF_6 is used as an insulating gas in the radar system.

4.37.2 Methodological Issues

Estimates for this source are based on data supplied by the MoD Defence Equipment & Support Secretariat (MoD, 2021). Data supplied includes:

- Measurements of SF_6 emitted from AWACS systems for 2016-2020
- Estimates of SF_6 emitted from AWACS systems based on logistic throughput for 2014 and 2015
- The number of AWACS active in the UK fleet for 1990-2021

The estimates for 2014-2020 have been used directly in the NAEI for those years. For years where measurements data are not available, an implied emission factor for SF_6 emissions per active AWACS has been determined using the data based on measurements and applied to the time-series of active AWACS.

4.37.3 Uncertainties and Time Series Consistency

Uncertainties for this source for recent years are low given the data received from the MoD on actual SF_6 data. Time-series consistency for earlier years is achieved by using MoD data on the number of active AWACS for each year since 1990 as a proxy for emissions in years where actual SF_6 data are available.

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 major recalculations to emissions from this sector.

For information on the magnitude of recalculations, see **Section 10.**

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 particle accelerators.

4.38.2 Methodological Issues

The emissions from industrial particle accelerators are a result of leakage during operation and repair. Research and industrial high voltage systems usually need to be opened more frequently than industrial low voltage accelerators. Hence the emission factor of low voltage industrial accelerators is comparably lower. In the case of radiotherapy applications, industrially pre-set particle accelerators with hollow conductors filled with SF_6 are used. The emissions of SF_6 are planned releases. Radiotherapy accelerators are typically opened two times a year when being serviced and the SF_6 contained is not captured but completely released. (Schwartz, 2005).

SF_6 emissions from research and university accelerators are estimated using an IPCC Tier 2 method – an accelerator-level emission-factor approach. This required information on the individual charge of the various research and university accelerators operating in the UK. This information is used in the following equation along with default emission factors (IPCC 2006):

> *Total emissions = University and research particle accelerator Emission Factor x Σ Individual Accelerator Charges*

Where:

> *SF_6 university and research particle accelerator Emission Factor* = 0.07 kg SF_6 per kg SF_6 charge, the average annual university and research particle accelerator emission rate as a fraction of the total charge.
>
> *Individual Accelerator Charges* = SF_6 contained within each university and research accelerator.

The SF_6 emissions from medical and industrial accelerators are estimated using a Tier 1 method – country-level method. Given the scale of the number of medical and industrial particle accelerators, it was not feasible to collect individual charge information of each accelerator. The Tier 1 estimation method consists of the following equation, which relies on default emission factors (IPCC 2006):

> *Emissions = (number of particle accelerators that use SF_6 by process description in the country) x (SF_6 charge factor, kg) x (SF_6 applicable particle emission factor)*

Where:

> *Number of particle accelerators by type in the* country = the total number of particle accelerators by type (industrial high voltage, industrial low voltage and radiotherapy)
>
> *SF_6 charge factor* = the average SF_6 charge in a particle accelerator by process description.

SF_6 particle accelerator Emission Factor = the average annual SF_6 particle accelerator emission rate as a fraction of the total charge by process description. These factors are presented in **Table 4-27** below.

Table 4-27 IPCC default Tier 1 particle accelerator emission factors

Process Description	**SF_6 Charge Factor, kg**	**Emission Factor, kg/kgSF_6 charge**
Industrial Particle Accelerators – high voltage (0.3-23 MV)	1300	0.07
Industrial Particle Accelerators – low voltage (<0.3 MV)	115	0.013
Medical (Radiotherapy)	0.5	2.0

For the Particle Accelerators sector, ICF (ICF 2014) contacted the Science and Technology Facilities Council (STFC) and the Cockcroft Institute to gather activity data for the Tier 1 and Tier 2 methods. STFC and the Cockcroft Institute were able to provide ICF with the charge information, years of operation and status of usage of SF_6 in the research and university particle accelerators in the UK. It is assumed that the charges of the accelerators are constant for all the years. For one facility whose charge was unavailable, a default charge in Tier 1 was assumed.

The Cockcroft Institute also provided an approximate estimate of the number of low voltage industrial accelerators in the UK for 2012—approximately 100 (Cockcroft Institute 2013). The total number of medical accelerators for 2012 was estimated from a list of accelerators compiled by a member of STFC, estimated at 50 (STFC, 2013). Due to the large number of medical and industrial accelerators, collecting accelerator-specific charge data was not feasible. Therefore, a Tier 1 approach was used to estimate emissions. To confirm the number of accelerators, ICF also solicited information from the National Physical Laboratory and the Institute of Engineering and Technology, but without success. In the absence of specific information on the number or percent of medical particle accelerators that use SF_6, ICF conservatively assumed that 100% of UK medical particle accelerators use and emit SF_6. To estimate SF_6 emissions for years 1990-2011 and 2013 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 SF_6 charge. After its closure in 1992 (assumed to be at the end of 1992), the emissions of research and university particle accelerators and medical and industrial accelerators are comparable. In 2004, the only operational particle accelerator ceased usage of SF_6 and, hence, the emissions are considered to be zero. Three other particle accelerators began operation in 2010, 2011, and 2012, respectively, leading to non-zero but small SF_6 emissions due to their small charges.

For the medical and industrial particle accelerators, the emissions rise as they were estimated based on GDP as proxy.

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

4.38.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. Details of verification of emissions are given in **Annex 6**.

4.38.5 Source Specific Recalculations

There have been no major recalculations to emissions from this sector.

For information on the magnitude of recalculations, see **Section 10.**

4.38.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

4.39 SOURCE CATEGORY 2G2E – SF_6 AND PFCS FROM OTHER PRODUCT USE

4.39.1 Source Category Description

Emissions of PFCs and SF_6 from the production of semiconductors, and PFCs and SF_6 from sporting goods (training shoes) have been combined in order to preserve the confidentiality of estimates of emissions of SF_6 and PFCs used in training shoes. Emissions from the use of SF_6 as a tracer gas are also reported under 2G2e, and the methodology described in this section of the NIR.

The semiconductors industry uses PFCs for:

- Cleaning of chambers used for chemical vapour deposition (CVD) processes;
- Dry plasma etching;
- Vapour phase soldering and vapour phase blanketing;
- Leak testing of hermetically sealed components; and
- Cooling liquids, e.g. in supercomputers or radar systems.

In addition, SF_6 is used in etching processes for polysilicon and nitrite surfaces, and there is some usage of CHF_3 (also referred to as HFC-23), NF_3 and some other fluorine compounds.

In the semiconductor manufacturing process, the fluorinated gases (PFCs, SF_6, HFCs and NF_3) are mainly used as a source of highly reactive fluorine ions that are used in plasma etching and plasma cleaning. The stable fluorinated molecules are converted into a plasma (via high voltage electrical breakdown) and the majority of fluorine ions react with other materials to create stable molecules that are not GHGs. Hence emissions of the F-Gases are only a small proportion of consumption.

The UK uses of SF_6 as a tracer in scientific research.

A sports goods manufacturer selling shoes in the UK used SF_6 as a cushioning material in a range of training shoes from 1990 to 2003. Prior to 1990, the manufacturer used perfluoroethane (a PFC) for cushioning. SF_6 is well suited to this application because it is chemically and biologically inert and its high molecular weight means it cannot easily diffuse across membranes. This means the gas is not released until the training shoe is destroyed at the end of its useful life.

The manufacturer committed itself to eliminating SF_6 from its training shoes by 30 June 2003 – a goal which was achieved. It had originally planned to replace all SF_6 applications with nitrogen-filled cushioning, but technical difficulties mean it had to switch temporarily to perfluoropropane (a PFC) in some high-performance applications. The use of F gases in footwear was banned in 2006 by the F-gas Regulation and discussions with the manufacturer have confirmed that they are no longer using PFCs or SF_6.

Cushioning units typically outlast the lifetime of the training shoe because the rate of diffusion of SF_6 is so slow. In the UK, training shoes are generally sent to landfill at the end of their useful lives, where any SF_6 or PFC will eventually leak to the atmosphere.

4.39.2 Methodological Issues

4.39.2.1 Semiconductor manufacture:

For the semiconductor manufacture sector, the methodology adopted follows the T2a approach described in Volume 3 chapter 6 of the 2019 refinement to the 2006 IPCC guidelines (IPCC 2019).

The 2019 refinement Tier 2a method is represented by equations 6.5-6.9 as follows:

$$E_i = C_i * (1 - U_i) * (1 - D_i)$$

$$BPE_k = \sum_i C_i * B_{k,i} * (1 - D_k)$$

$$EAB_{CF4,i} = C_i * (1 - U_i) * (1 - \eta) * AB_{CF4,i}$$

$$D_i = a_i * d_i * UT$$

Where: i = Input gas;

E_i = emissions of gas i (kg);

C_i = consumption of input gas i (kg);

U_i = use rate of gas i (fraction destroyed or transformed in process) (fraction);

D_i or D_k = Overall reduction of mass of gas i or k emissions;

k = By-product gas;

BPE_k = Emissions of by-product k generated from the conversion of all input gases (kg);

$B_{k,i}$ = Emission factor for by-product k generated from input gas i (kg of by-product gas k created per kg of gas i consumed);

$EAB_{CF4,i}$ = Emissions of CF_4 from hydrocarbon-fuel-based combustion emissions control systems when direct reaction with hydrocarbon fuel and fluorinated species i is not certified not to occur by the emissions control OEM or electronics manufacturer (only for i = NF_3 used in remote clean process or F_2) (kg);

η = Ratio of emissions control systems certified not to form CF_4 within emissions control systems to the total number of emissions control systems in the facility (site-specific fraction);

$AB_{CF4,i}$ = Mass fraction of i in process exhaust gas that is converted into CF_4 by direct reaction with hydrocarbon fuel and F2 gas in a combustion emissions control system;

a_i = Estimate of the fraction of gas i emitted from process tools equipped with suitable emissions control technologies (site-specific fraction);

d_i = Destruction Removal Efficiency (DRE) for gas i (fraction); and,

UT = Average uptime factor of all emissions control systems (site-specific fraction).

The 2019 refinement also sets out equations for determining a_i, and UT, but as the UK does not hold data that would be required to make these calculations but does have input from stakeholders on suitable assumptions for the equivalent to $(a_i * UT)$, these equations are not required for the UK approach.

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, including trends in total semiconductor industry trends, the relative use of different PFCs, and the installation of abatement technology (AEAT, 2004).

Specific trends which stakeholders have indicated include:

- A 3% growth rate in input gas per unit production required between 1990 and 1996;
- A -8% growth rate in CF_4 and C_2F_6 demand per unit production between 2005 and 2010 as part of a global semiconductor industry drive to reduce PFC emissions;
- The output of the sector has grown 15% per year between 1990 and 2000;
- The output of the sector contracted by 39% in 2001[79]; and,
- Mixed assessments of how the sector will grow after 2003.

In addition to the 2004 study, more recent engagement with the UK trade association TechWorks, who represent all UK semiconductor manufacturers, has indicated that it is likely that the sector has contracted in recent years. In the absence of data on the degree of this contraction, we have conservatively assumed that the sector has remained constant in size since 2001.

On our understanding that the primary use of PFCs in this sector is to generate a fluorine plasma, we have assumed that there is an increase in other input gases in 2005-10 to offset the reduction in CF_4 and C_2F_6 and maintain a constant level of total fluorine in input gases used per unit production. The resulting % growth in the substitutes are presented in **Table 4-28**.

The NF_3 consumption has been divided into NF_3 remote clean and all other NF_3 consumption (i.e., for in-situ chamber clean and etch processes). NF_3 remote clean refers to a cleaning method for chemical vapour deposition chambers in which the film cleaning-agents formed from NF_3 (F-atoms) are produced in a plasma upstream (remote) from the chamber being cleaned. In situ chamber cleans are chemical vapour deposition chamber cleaning processes, which may use NF_3 or other F-gases to generate F-atoms in the chambers whose walls are being cleaned. NF_3 may also be used to etch patterns (i.e., circuits) on semiconductors. The use of NF_3 remote clean is assumed to start in 2003 and growing increasingly over time. As no data on the UK's use of NF_3 remote clean processes was made available from NMI, the US semiconductor market was used as a proxy to estimate the use of NF_3 in remote clean processes relative to all other processes.

Specifically, the share of NF_3 remote clean versus other uses was estimated based on industry reported NF_3 usage data from US semiconductor manufacturers for the years 2009 and 2010 (US EPA, 2011). This US data was readily available and is believed to be a good proxy for the UK given that semiconductor processes do not typically vary by world region. The ratio of NF_3 remote to other uses was interpolated for years between 2003 and 2010, assuming zero before 2003.

[79] This reflects our understanding of the semiconductor industry over this period where there was a closure of several operators in the UK, particularly those linked to 'silicon Glen'. 'Silicon Glen' was the name given to a region in Scotland where the UK semiconductor industry was focussed, and after strong growth throughout the 90s, but many of these businesses closed in quick succession in the early 2000s in part triggered by the bursting of the dotcom bubble.

The final activity data assumptions used are summarised in **Table 4-28**.

Table 4-28 Summary of UK assumptions of activity data for semiconductor manufacture

Year	Output growth rate	Input gas per unit production growth rate	CF_4 and C_2F_6 per unit production growth rate	Substitutes (for CF_4 and C_2F_6) per unit production growth rate
1990-1996	15%	3%	0%	0%
1997-2000	15%	0%	0%	0%
2001	-39%	0%	0%	0%
2002-2004	0%	0%	0%	0%
2005	0%	0%	-8%	24%
2006	0%	0%	-8%	18%
2007	0%	0%	-8%	14%
2008	0%	0%	-8%	11%
2009	0%	0%	-8%	9%
2010	0%	0%	-8%	8%
2011 onwards	0%	0%	0%	0%

4.39.2.1.2 Emission factors and other default factors

A summary of the model parameters used from the 2019 refinement to the 2006 IPCC guidelines Tier 2a method is provided in the table below. Values are taken from tables 6.7, 6.17 and page 21 of Volume 3, chapter 6.

Table 4-29 Summary of 2019 refinement Tier 2a model parameters for the semiconductor manufacture sector (kg per kg input gas)

Model Parameter[80] (column headings are the input gas, i)	CF_4	C_2F_6	C_3F_8	c-C_4F_8	CHF_3	NF_3 Remote	NF_3	SF_6
$(1-U_i)$	0.73	0.55	0.4	0.13	0.47	0.02	0.18	0.55
$B_{CF4,i}$	NA	0.19	0.2	0.099	0.082	0.034	0.067	0.12
$B_{C2F6,i}$	0.043	NA	0.000018	0.02	0.045	NA	0.014	0.095
$B_{C3F8,i}$	NA	NA	NA	NA	NA	NA	NA	NA
$B_{CHF3,i}$	0.04	0.002	0.000012	0.022	NA	NA	0.0068	0.0014
$AB_{CF4,i}$	NA	NA	NA	NA	NA	0.093	NA	NA
d_i	0.89	0.95	0.99	0.98	0.98	0.95	0.95	0.95

NA = Not Applicable.

The degree of abatement utilisation (equivalent to $a_i * UT$ as defined at the beginning of **Section 4.39.2.1**) has been estimated using information from stakeholders collected during the 2003 study (AEAT, 2003), specifically:

- Abatement was not used in UK operations until 2003;
- It is expected that all fabrication plants opened after 2003 will have abatement installed; and,
- Semiconductor fabrication plants have a lifetime of 25 years.

[80] As defined at the beginning of **Section 4.39.2.1**

This allows us to model the turnover of semiconductor fabrication plants, and therefore the rate at which modern plants with higher degrees of abatement substitute legacy unabated plants. We are continuing to engage the UK semiconductors industry to understand how successful the sector were in having abatement installed in post-2003 plants, and in the meantime have made the conservative assumption that abatement is only applied to half of production at new fabrication plants. This means that we estimate that in 2002 $a_i * UT$ = 0, and this increases over almost[81] 25 years to $a_i * UT$ = 0.5

Due to the toxicity of NF_3, it is assumed that all use of NF_3 is abated, i.e. $a_{NF3} * UT$ = 1.

4.39.2.1.3 Justification for using a 2019 refinement to the 2006 IPCC guidelines methodology

The conclusions and recommendations from the 18th meeting of greenhouse gas inventory lead reviews[82] states in paragraph 12a that:

> "…The LRs also noted that for categories and subcategories covered by the 2006 IPCC Guidelines, the ERT should review whether (1) the methodologies, emission factors (EFs) and/or assumptions taken from the 2019 Refinement or a country-specific approach based on or consistent with the 2019 Refinement are well documented, (2) the Party demonstrated that they better represent the national circumstances and justified their use in its NIR, and (3) emission and removal estimates are accurate and time-series consistency has been maintained in accordance with the 2006 IPCC Guidelines…"

The UK believes that these are addressed in this case, as:

(1) The methodology adopted is documented in the preceding sections
(2) The 2019 refinement utilises more recent studies and understanding of emissions from this source and the methodology presented accounts for more features; we argue that means that the methodology should be better representative of UK emissions. The UK trade association TechWorks, who represent all UK semiconductor manufacturers, were engaged during the development of the UK implementation of the 2019 refinement approach, and there were not any more UK-specific parameters identified.
(3) The methodology has been applied to the entirety of the time-series estimated, and activity data have been reviewed with stakeholder support to ensure that they are consistent and representative of UK trends.

4.39.2.2 Use of SF_6 as a tracer gas in scientific research:

SF_6 is used in a number of applications in the UK

- Tracer gas to certify fume hoods; and
- UK studies of greenhouse gas emissions

ICF investigated the use of tracer gas to certify fume hoods.

The use of SF_6 as a tracer gas to certify fume hoods is a practice established by ASHRAE in the test procedure ASHRAE-110, "Method of Testing Performance of Laboratory Fume Hoods" (ASHRAE, 1995). SF_6 is emitted in the fume hood and the concentration of the gas is measured after some time has passed. This is to ensure that the gases created under the fumes, toxic or otherwise, are properly ventilated. The amount of gas used per test is dependent on the tester. All of the SF_6 used in tracer tests is lost in the atmosphere and so the emissions are treated as prompt emissions—i.e., each test results in direct emissions of SF_6 (IPCC 2006). SF_6 is also

[81] Because we model the sector to have contracted in 2001, we assume that there were not any new plants installed between then and 2003, meaning that it took less time for the oldest legacy plants to be replaced than might otherwise be expected.

[82] https://unfccc.int/sites/default/files/resource/Conclusions%20GHG_LRs_2021.pdf

used for tracer testing of nuclear power plant control room emergency ventilation systems (CARB, 2009).

Due to data limitations, SF_6 emissions were estimated using a slightly modified Equation 8.23 of Volume 3 of the 2006 GLs. The SF_6 emission is calculated on a per-use basis as opposed to the amount purchased/sold as provided in the equation. This modified method relies on the number of tracer tests conducted annually as the activity data, which when multiplied by the emissions per test as the emission factor, gives the total SF_6 emissions from this sector. This method is represented in the following equation:

Total emissions = emissions per test x number of tests

Additional emissions may also occur from bottling, leakage, and piping; however, such emissions cannot be estimated without activity data and are believed to be de minimis.

In order to apply the method above, ICF had to gather information on the number of tracer tests conducted annually (activity data) and the emissions per test (emission factor). ICF first identified various companies that performed fume hood tracer testing. ICF contacted the three largest companies that perform tracer tests in the UK (Crowthorne, Dale Flow, and Invent-UK) and obtained the company-specific emissions per test and the total number of tests performed in 2012 (Crowthorne 2013, Dale Flow 2013, Invent-UK 2013). For the prior years, the total numbers of tests have been estimated by scaling the number of tests performed in 2012 to the UK's historical GDP growth rate. The amount of emissions per test for prior years was held constant unless a company specified that the volume had increased after a certain period. The value of the emissions per test differed among companies and ranged from 0.033 to 0.046 kg SF_6 per test.

ICF also verified when these companies came into existence. Other, smaller companies were identified but were not contacted as—according to qualitative information from Dale Flow (2013)—the bulk of the market is covered by the three major companies, and any additional research was not expected to result in significant changes to the emission estimates, which only account for a very small share of total F-gas emissions.

ICF also contacted Sellafield Ltd, a nuclear decommissioning company, which uses SF_6 to conduct tracer tests, and included their company specific emission factor and total number of emissions (Sellafield, 2013).

Finally, ICF contacted the UK Nuclear Regulation Agency to confirm if there is any use of SF_6 in the tracer testing of nuclear power plant control room emergency ventilation systems in the UK. ICF was unable to obtain information because the inquiry did not fall within the remit of the Office of Nuclear Regulation/Health and Safety Executive. However, ICF experts believe that such use was replaced many years ago.

SF_6 is used as a tracer gas in UK studies of greenhouse gas emissions from ruminant livestock. It is currently the only viable way to measure emissions of methane from ruminant livestock individuals at pasture (Defra, *per. comm.*).

A small charge of SF_6 is stored in a permeation tube, which is then introduced to the rumen of the animal. The gas emissions are vacuum sampled from eructation via a tube near the animal's muzzle connected to an evacuated flask. The total CH_4 emissions are inferred from the differential concentrations of SF_6 and CH_4 between the flask and atmosphere.

The total amounts of SF_6 used are given in the table below:

Table 4-30 Quantities of SF_6 used in scientific research

Year	kg SF_6
2011	1.224

Year	kg SF_6
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).

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

There have been no major recalculations to emissions from this sector.

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. We note that the ERT has specifically requested that the UK improves estimates for semiconductor manufacture, and there is an in progress study investigating this topic.

4.40 SOURCE CATEGORY 2G3A – MEDICAL APPLICATIONS

4.40.1 Source Category Description

This category includes emissions from N_2O 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 N_2O emissions based on the number of bed-days in NHS England 2011 – 2012, multiplied by the EU GHG inventory derived emission factor of 10.3 kg

N_2O/bed/year[83]. This provides an estimated total N_2O emission of 1,641,147 kg per annum, arising from the use of anaesthetic at NHS England facilities. This is not the recommended methodology given in the 2006 IPCC guidelines, but as we have been unable to obtain the data required to follow the default methodology (sales of N_2O for anaesthetic use) this was considered the best approach to a country specific estimate for this source. Suppliers of N_2O 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 N_2O emission of 0.031 kg per annum has been derived from the total N_2O figure provided in the Carbon Footprint report. This has then been applied to the total population for the England, Wales, Scotland and Northern Ireland to provide a 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 N_2O should be considered to have a high degree of uncertainty. The methodology doesn't take into account N_2O used in non-NHS hospital environments (for example dental and veterinary practices or private hospitals), however total emissions from these sources are estimated to be much smaller than the uncertainty in the conservative NHS estimate.

The time series estimate does not consider trends in the uptake of alternative anaesthetics or alternative approaches to applying N_2O as an anaesthetic, as some methods can reduce the consumption of N_2O. Though using population as an indicator of trend should well reflect demand for anaesthetics, it would not take into account changing practices. We also make the assumption that the rest of the UK consumes anaesthetic in the same way as England.

4.40.4 Source Specific QA/QC and Verification

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

In the case of Gibraltar, we have actual data on N_2O 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**.

4.40.6 Source Specific Planned Improvements

The inventory team will continue to search for data relating to the sales of N_2O for anaesthetic use, and will make improvements to the methodology when this information is available.

[83] http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2013

4.41 SOURCE CATEGORY 2G3B – OTHER PRODUCT USES OF N_2O

4.41.1 Source Category Description

Very little UK data are available on the use of N_2O in cream products, therefore the approach adopted has been based on the method used in the Danish GHG Inventory (Hjelgaard, 2015). The method therefore assumes:

- 1% of cream consumption is in the form of whipped cream sprays;
- N_2O consumption in those sprays is equal to 5% of the mass of the cream; and
- All N_2O is emitted.

UK cream consumption data are available from Government (DEFRA) statistics (Defra, 2022).

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, which is now maintained by ONS (Office of National Statistics, 2021b), whilst frequency of use is available only for financial year 2017/8. It is therefore assumed that:

- The average frequency of use for 2017/18 is appropriate for other years of the time-series;
- Each recorded use of new psychoactive substances is only a single canister;
- An N_2O cartridge has a volume of 10ml and is compressed to 60 bar; and,
- All N_2O 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 N_2O relative to cream content is expected to be reasonable – there is no reason to think that the products sold in Denmark and the UK will differ significantly in design. UK cream consumption data are available for the full time-series from 1990 onwards.

The UK method for recreational use of N_2O 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 some gaps. In these cases, 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 therefore are recorded as “Not Estimated”.

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

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

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 N_2O emissions from the chemical industry that are not captured elsewhere. All chemical sites reporting significant N_2O emissions are included where that emission is believed to be from a chemical process, rather than combustion. Other sites do report N_2O emissions, but those are small, and there is no evidence that they are from chemical processes. As such, the estimates reported in 2G4 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 N_2O (as well as other pollutants). From 1998, when reporting was first required, until 2001 there was no threshold for reporting N_2O, but since 2002, reporting is required only when emissions exceed 10 tonnes. Across the time-series, N_2O emissions have been reported in at least one year for about 30 permitted processes which could include chemical manufacturing. For most of those sites, N_2O is reported for only one or two years out of the time-series and we think it is likely that the reported N_2O is an error (operators do occasionally confuse N_2O and NO_X on their reporting submissions) and in a few other cases it is likely that the N_2O occurs from the substantial combustion processes that constitute part of the reporting installation. In four cases however N_2O is reported in multiple years, from processes which are either known to emit the gas, or thought to be the most likely source:

- A process to manufacture nitrous oxide, and to transfer it into gas cylinders for sale. This process was commissioned in 2004;
- A process manufacturing industrial gases, which probably also supplied nitrous oxide in cylinders and which closed in 2008;
- A process manufacturing pharmaceutical products. This process has been in operation since at least the early 90s; and,
- A catalyst manufacturing process which involves dissolving metals in nitric acid, leading to emissions of oxides of nitrogen (including both NO_X and N_2O). This process has been in operation since the 1940s.

Emission estimates are based on the data reported by the process operators to the Environment Agency for inclusion in the Pollution Inventory (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 N_2O back to 2002, but reports NO_x in 2002 as well, and also in 1997-2001. Emissions of N_2O in the years 1997-2001 are therefore assumed to follow the same trend as for NO_x back to 1997 and to be at 1997 levels prior to that. Emissions for the third site for 1990-2005 are assumed to be the same as 2006, i.e. the earliest year where nitrous oxide emissions are reported, and for 2013 onwards, emissions have been below the reporting threshold, so we have conservatively assumed that emissions were at the reporting threshold. Emissions for the fourth site for the years 1990-1997 i.e. before reporting of N_2O was required, are assumed to follow the same trend as emissions of NO_x, which is reported back to 1995, and to be the same as in 1995 before that. Using this approach suggests that emissions from this plant were about 2 times higher in 1990 than in 1998, when data are first reported.

4.42.3 Uncertainties and Time Series Consistency

Gaps in the PI data for the three sites is the most significant source of uncertainty in the estimates. It is possible that other sites that report N_2O emit the gas from chemical manufacturing processes but if this were the case, these emissions would be 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

There are recalculations in the year 1990 to 1998 for this source due to correcting a discrepancy in the calculations. The size of this change is an increase of 10-16%.

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
Gases Reported	CO_2, CH_4, N_2O, NO_x, CO, NMVOC, SO_2
Key Categories ('T' or 'L' indicates whether it's been identified in the trend or level assessment respectively and the number indicates which KCA approach it was identified in)	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 - N_2O (L1) 3D: Agricultural soils - N_2O (L1, T1, L2, T2)
Key Categories (Qualitative)	None identified
Overseas Territories and Crown Dependencies Reporting	See **Section 5.10**.
Completeness	A general assessment of completeness for the inventory is included in **Section 1.8**
Major improvements since last submission	Revision to fertiliser N estimates applied to cropland in GB, based on re-analysis of British Survey of Fertiliser Practice (BSFP) data and access to import-export fertiliser data; improvement to analysis to derive timing of fertiliser application by type, improving disaggregation of fertiliser use across different months, better-reflecting climatic conditions and emissions arising; revision of mitigation uptake for fertiliser placement to cropping, now derived from BSFP data per fertiliser type, and for uptake of urease inhibitors since first-reported in 2009; revision to estimates of the use of ammonium sulphate and diammonium phosphate. Method improvement to better-reflect available data resolution for crop yield estimates across crop sub-categories, including for malting / non-malting barley, spring and winter-sown oats and oil seed rape, impacting emissions from crop residues. Updates to dairy cow concentrate use in GB; revisions to poultry N excretion rates using higher precision values from source references. Updates to manure storage and application practices, using new 2021 NI Nutrient Management Survey data; revisions to proportion of cattle managed on slurry vs FYM systems for

	Wales and Scotland, to estimates of manure stored under different storage types and estimates of land application activity data all based on reviews of available AD; revised data on proportion of dairy cow collecting yards that are washed down as a mitigation method, previously assumed to be zero but now based on analysis of farm management survey data; update to use latest AD on manure processed via Anaerobic Digestion including an increase in poultry litter in NI diverted to AD since 2016. Updates to nitrous oxide EFs for histosols used as cropland and improved grassland from Tier 1 to Tier 2 using values developed by the James Hutton Institute. Minor changes to the assumed area of histosols based on re-analysis of the organic soil base maps. The agriculture inventory uncertainty analysis has now been fully updated to properly reflect the method developments across all source categories, including all cattle methods.

In the agriculture sector, the United Kingdom reports emissions from the following categories:

i. enteric fermentation, methane (CH_4) (Table 3A);
ii. manure management, methane and nitrous oxide (CH_4, N_2O) (Table 3B);
iii. agricultural soils direct and indirect, nitrous oxide (N_2O), including synthetic fertiliser, manures and digestates applied to soils, urine and dung deposition during grazing, sewage sludge, mineralisation, crop residues, histosols (only direct) (Table 3D);
iv. liming (CO_2) (Table 3G);
v. urea application (CO_2) (Table 3H);
vi. emissions of other pollutants, including NMVOCs, NO_x and PM (Tables 3B and 3D).

Emissions from fuel use on UK farms are reported in the Energy sector. 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.

5.1.1.1 Agriculture Emissions in the UK Inventory: Trends and drivers

The UK total emissions from agriculture have decreased since 1990 (**Figure 5.1**) with a decrease of 18.0% between 1990 and 2021.

Emissions of CH_4 were the largest contributor to the total emissions in 2021 (65.1%) followed by N_2O (31.6%) and CO_2 (3.3%) (**Figure 5.2**).

Key events and other drivers of UK agriculture emission trends include the following:

- Long term trends are primarily impacted upon by the key underlying activity data such as livestock numbers and crop production across the UK;
- 2001 UK foot and mouth crisis. Large numbers of livestock culled to mitigate the spread of foot and mouth disease, leading to a large one-off decline in livestock numbers;
- Other livestock diseases have also contributed to this trend;
- Annual fertiliser application rates and associated emissions are strongly affected in the UK across the time series by periods of poor weather, most commonly when the UK experiences very wet autumn/winter weather, inhibiting the sowing of winter crops and lowering the fertiliser application overall. This explains the lower agricultural soil emission of nitrous oxide from inorganic fertiliser application in years including: 2020, 2013, 2001 and 1993. In all cases the fertiliser rates declined and then recovered the following year;
- Changes in organic fertilisers and manure management over time.

Figure 5.1 Time series of CH_4, N_2O and CO_2 emissions from the Agriculture sector in the UK inventory

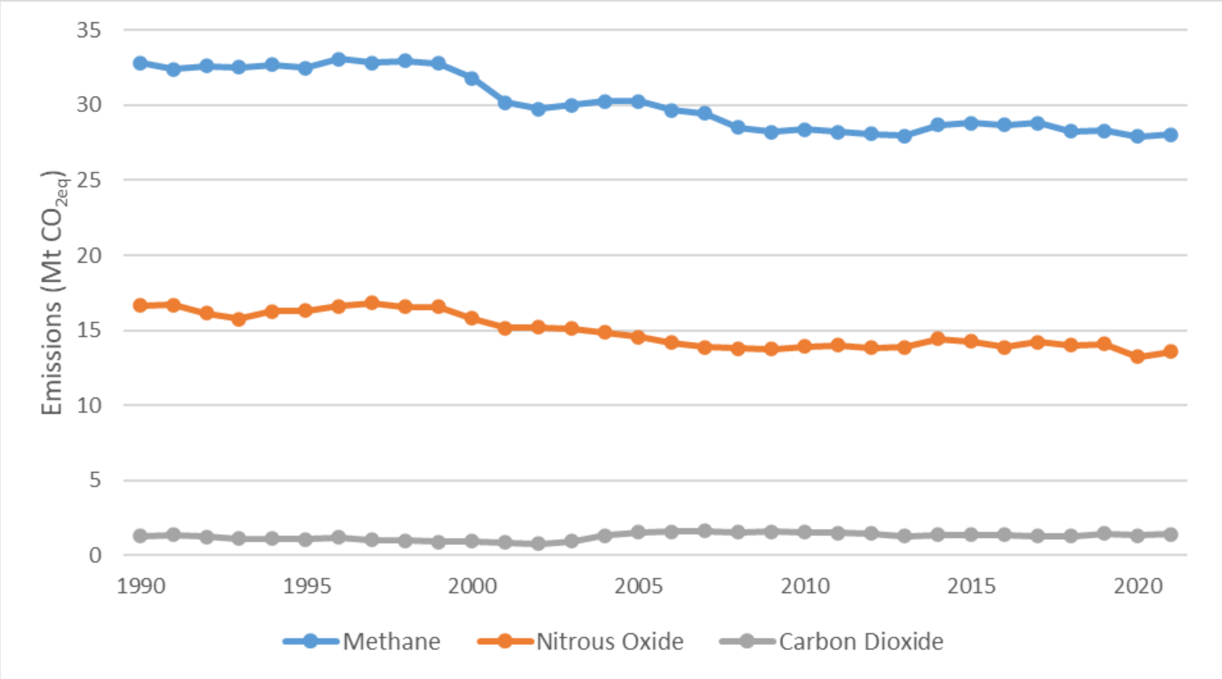
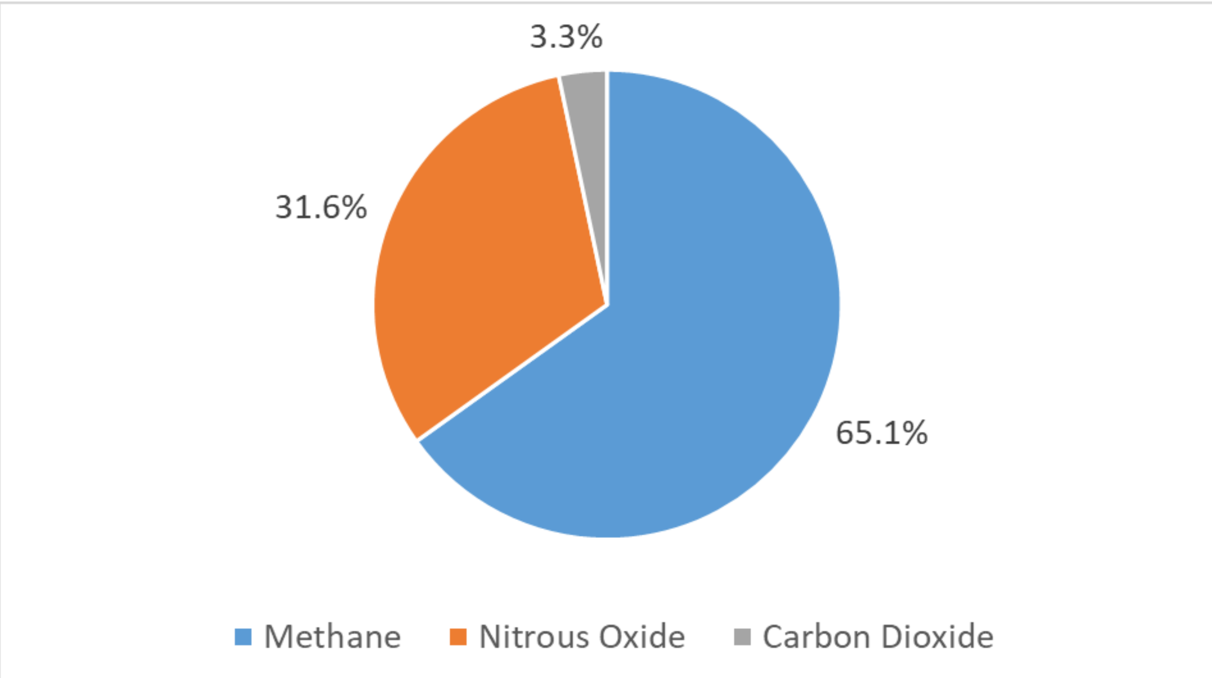


Figure 5.2 Contribution (%) to the UK agricultural GHG inventory from CH_4, N_2O and CO_2 emissions in 2021



5.1.1.2 Agriculture Inventory: National System, Stakeholders and Management of Improvements

The UK agriculture inventory of GHGs and ammonia (NH_3) is managed by the UK Department of Environment, Food and Rural Affairs (Defra), which is the UK Government department with policy responsibility for farming, food standards and air quality emissions. The inventory is used as a reporting mechanism for UK and sub-national emissions as well as to underpin emission projections and policy scenario analysis; as such it is developed and managed via a network of stakeholders in order to identify new / emerging data, to keep pace with UK regulation, farm practices, mitigation actions, scientific and policy research.

Defra funds the compilation and reporting of the agriculture GHG and ammonia (NH_3) inventory via a multi-year contract, currently held by a consortium led by Rothamsted Research (to August 2023). The outputs are incorporated into the wider UK GHG inventory via the National Atmospheric Emissions Inventory database, which is managed by the UK Department of Energy Security and Net Zero (DESNZ); DESNZ is the UK's Single National Entity for GHG submissions to the UNFCCC. The Rothamsted Research consortium sector experts are the inventory compilers for the Agriculture sector, whilst the DESNZ-contracted Ricardo consortium is the UK Inventory Agency and compiles the GHGI for other sectors.

The process for inventory review, identification of new data and method improvements, prioritisation and implementation, compilation and reporting involves a range of stakeholders and can be summarised as follows:

- **January - March:** Post submission review by the Inventory Agency team; inputs from latest UN and other reviews; engagement with research and industry contacts (e.g. academic researchers, Agricultural Industries Confederation (AIC), Defra and Devolved Administration (DA) science and policy leads). Identification of new data and/or methodological improvement options, prioritising key source categories, sources of high uncertainty and sources where mitigation actions are planned or implemented and not currently represented in the inventory;
- **April – May**: Consult with the National Inventory Steering Committee (NISC), advisory and executive stakeholders, i.e. across industry and Government; distil down to highest priority improvement actions for implementation in the next inventory cycle. Specify data requirements.
- **June – October**: Access data, consult stakeholders (e.g. AIC, Defra, devolved Governments of Scotland, Wales and N Ireland) develop new methodologies, where necessary consult with peer reviewers (UK, international) to test and refine the new methods; consider cross-sectoral impacts (where appropriate) and communicate to other inventory teams (e.g. waste, bioenergy, LULUCF). Where there are impacts also on air quality pollutant emissions, e.g. ammonia, consult with the Defra-led Air Quality Inventory Steering Group which comprises AQ modellers, air quality researchers. Engage with the UNFCCC review process as required.
- **November-December**: Prepare documents to share with the NISC (Advisory panel) in late November as part of the pre-submission review process for the UK inventory; present the new data / methods and impacts on level and trend of emissions; outline uncertainties, next steps. The NISC Executive then meets to consider the improvement and sign it off or indicate that further work is needed prior to acceptance within the UK submission.
- **January – March (n+2)**: Finalise the UK agriculture inventory submission, i.e. update the UK inventory central estimates and uncertainty analysis and then start again with the post-submission review.

In the 2023 submission cycle, the Rothamsted team has considered an inventory method improvement to disaggregate the activity and emissions across the livestock manure management systems (MMS), aiming to develop a method that will more accurately represent the emissions and the fate of materials across different manure management stages: in storage, in housing and at the point of spreading, for slurry and manure materials. UK sector experts prepared a draft paper for submission to international peer reviewers from Ireland, Denmark and France. Peer reviewer feedback on the proposed method indicated that the rationale and objective of the proposed improvement is sound and should be explored further, noting that further work is needed to address data and evidence gaps before the UK can move to implementation. We will seek to progress this item during the 2024 submission cycle, subject to resource availability and identification of relevant evidence to populate the proposed new method.

The UK has developed a new model to estimate the emissions from cropland which has been approved and used in the 2023 submission. Whilst the implemented calculation method has not been revised, the inventory team recognised that the previous MS Excel models were reaching the end of their useful life. In some cases, methodologies to fill data gaps across the time series, for example where fertiliser survey data were very limited for specific country-crop-fertiliser combinations, were not considered statistically reliable. The team has made several improvements:

- Rebuilt the methodology in a coded model in R and taken the opportunity to work back through the full time series of electronic versions and hard copies of the British Survey of Fertiliser Practice, implementing a systematic tiered approach to gap-filling where survey data were insufficient for a specific country/crop/fertiliser type.
- The level of disaggregation of per crop type has been revised to reflect the limited data for some specific crop types.
- Fertiliser activity data available from the UK surveys has now been supplemented by information from import statistics, in particular to deliver more accurate estimates of fertiliser types that are not manufactured in the UK and hence must be imported; this approach has enabled the team to over-write previous assumptions regarding the share of the UK market for these fertilisers and use the import data as more accurate totals for the UK farming sector.
- More strict checks in cross-sector activity data, including LULUCF, Waste sectors.

5.1.1.3 Uncertainty Analysis in the Agriculture Sector

The identification of inventory improvement priorities, as then managed via the stakeholders and mechanisms described above, is informed by the assessment of inventory uncertainty. In the 2023 submission, the UK agriculture uncertainty analysis has been extensively revised and updated.

The agriculture inventory uncertainties have been calculated using an Approach 2 method as described by the IPCC, i.e. a Monte Carlo simulation based on probability distribution functions for all key model input parameters (IPCC, 2006). Model runs of the UK agriculture inventory are computationally intensive and so a preliminary analysis was undertaken to determine the number of samples needed. This analysis showed that 2500 samples were sufficient to estimate the 95% confidence interval with 95% confidence. Once samples were computed, suitable distributions were fitted to the outputs and fed forward to the wider inventory calculations. As an assurance check, the central tendencies from the uncertainty analysis were compared with those produced from the deterministic inventory runs and these were found to accord.

In the 2023 submission, all of the uncertainty parameters per source category have been fully updated to reflect the higher tier UK methods. Where this has led to substantial revisions in the uncertainty ranges *per source category – pollutant* compared to the 2022 submission, this is noted in the relevant NIR source category sections. In some cases (e.g. dairy cattle – enteric methane) the uncertainty in the underlying parameters has been updated but remains under review and will be updated as appropriate in the next inventory cycle.

5.1.2 The UK Greenhouse Gas Inventory Model for the Agriculture sector

This section provides an overview of the UK GHGI model for agriculture; for more details on the model, please see **Annex 3 Section A3.3.7.**

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 and air quality pollutant emissions for the agriculture sector, focusing on methane (CH_4), nitrous oxide (N_2O) and ammonia (NH_3). 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. The UK inventory undergoes continuous improvement to reflect developments in source data and scientific understanding, for example when inventory guidance is updated to improve methods, new EFs or to add new emission sources. The inventory improvements are documented in the relevant source category sections below.

5.1.2.1 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 sources of the agriculture sector with a separate module for each source, drawing on source-specific input tables and generating source-specific output tables, including for:

- enteric CH_4,
- manure management CH_4 and N_2O emissions from Dairy, Beef, Sheep, Swine, Poultry Goats, Horses and Deer;
- direct and indirect N_2O emissions from synthetic N fertiliser, organic N (e.g., animal manure, sewage sludge and digestate) applied to grassland and arable crops, and crop residues;
- N_2O emissions from urine and dung N deposited on pasture from Dairy, Beef, Sheep, Swine, Poultry, Goats, Horses and Deer.

N_2O emissions from mineralisation and histosols and CO_2 emissions from liming and application of urea to soils and NMVOC emissions from rough grazing are estimated using simpler MS 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 aggregated 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.

5.1.2.2 Activity data handling

When there are data gaps for one year in livestock numbers or crop areas, holding level data for the previous year are used. Scaling factors are applied where necessary to ensure that the sum of all holding level data equates with the official statistics for national totals, for a given category. For example, if the sum of all holding level data (of a given category) is 100, and the official statistic reported national total is 101, a scaling factor of 1.01 would be applied to all holding values (to ensure the holding level data matches national totals).

5.1.3 General sector characteristics

Activity data that apply to more than one source category are: (i) farm types (**Section 5.1.3.2**); (ii) livestock types and numbers (**Section 5.1.3.3**); (iii) crop types and crop areas (**Section 5.1.3.4**); (iv) fertiliser types and application rates (**Section 5.1.3.6**). These are described in this section and are referred to in the relevant sections throughout this chapter. The data relevant to calculation of emissions from crop residues are described in **Section 5.1.3.5**. The emission factors used to estimate N_2O emissions from synthetic fertiliser applications to soils are determined via an empirical model that relies on environmental factors and is described in **Section 5.1.3.8.**

Year-specific activity data and EFs are provided in supplementary tables.

5.1.3.1 Soils 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 topsoil 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 from the Met Office. Met Office UKCP09 baseline average datasets are for the period 1981 to 2010 (Jenkins et al., 2008). The UKCP09 data are available at 5 by 5 km resolution and summarised to the reference 10 by 10 km grid cells used in the agriculture inventory model. Daily time-series of measured rainfall derived from the UK synoptic network for the MORECS model (Hough and Jones, 1997) were obtained from the Met Office across the 1981 to 2010 time series at 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 cells.

5.1.3.2 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 book (EC typology handbook). 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.

5.1.3.3 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 (Defra, 2022a) provide a number of sub-categories within the major livestock categories (dairy and beef cattle, sheep, swine, poultry), which are used as the basis for subsequent emission calculations. Since 2005, Cattle Tracing Scheme (CTS) data from the British Cattle Movement Service (BCMS, 2022) are used to provide further detail of all cattle across England, Wales and Scotland, based on analysis of cattle movement records.

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, in accordance with the approaches set out in the Defra AC0114 GHG platform project for GHGI data management (Defra, *in prep.*). 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). Note that for animals which are present for less than 1 year (e.g. broilers, finishing pigs) 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.

5.1.3.3.1 Dairy Cattle

For the purposes of inventory calculations, 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 not in calf, dairy replacement in calf, dairy cow). Data are derived from the CTS (BCMS, 2022) 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 ensures complete reporting of total emissions from UK agriculture, with all bulls 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 one of the inventory categories of large, medium or small.

For years prior to the introduction of the CTS in England, Scotland and Wales (1990-2004), and for Northern Ireland for the entire timeseries, annual data were 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, i.e. 1990 to 2004. Breakdown of dairy cow breed types for 1990 was derived from Dairy Facts and Figures, 1992 (Milk Marketing Board), with the breeds being associated with the inventory production system categories. Data for 1991 to 2005 were interpolated between Dairy Facts and Figures for 1990 and CTS data for 2006 onwards. Straw use is a fixed quantity per head based on survey data.

5.1.3.3.2 Beef cattle

Beef cattle are disaggregated into 15 age bands, four breed types (Continental, lowland native, upland native and all 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 (BCMS, 2022) 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. Straw use is a fixed quantity per head based on survey data.

5.1.3.3.3 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 June Agricultural Survey (Defra, 2022a), the December Agricultural Survey (1993 to 2010), a specific survey on the disposal of lambs and their slaughter age from the United Kingdom sheep flock by Wheeler et al. (2012) and the occasional surveys of the Breeding Structure of the British Sheep Industry (Pollott, 1998; Pollott and Stone, 2006; Pollott, 2012; and Pollott and Boon, 2021).

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 proportions of replacement ewes that are first mated as ewe-lambs is based on an analysis of an extended time-series from the December Agricultural Census (1993 to 2010), that was verified against the latest Breeding Structure of the British Sheep Industry survey (Pollott and Boon, 2021).

The June Agricultural 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 survey takes place (Pollott and Stone, 2006; Wheeler et al., 2012; Pollott and Boon, 2021).

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 (LFA) weighted by survey data from Wheeler et al. (2012), and verified against historical records of payments made under the Hill Livestock Compensatory Scheme (Agricultural Notebook, 2003). For each system, the proportions of lambs finished at grass, finished as stores, or used for breeding replacements, are derived from analyses of the survey data collected by Wheeler et al. (2012), and verified against the occasional surveys of the Breeding Structure of the British Sheep Industry (Pollott, 1998; Pollot and Stone, 2006; Pollot, 2012; and Pollot and Boon, 2021).

Bedding straw use in housing is calculated from how much urine an individual sheep produces, and the quantity of straw that is required to absorb the urine, based on absorbance measurements reported by Misselbrook and Powell (2005) and Olsen (1940).

5.1.3.3.4 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 (including barren sows for fattening); (5) fattening swine 20-80 kg; (6) fattening swine <20 kg. Data are obtained from the JAS (Defra, 2022a) for England, Wales, Scotland and Northern Ireland, and where JAS categories do not match the inventory categories, consistent data translation rules are applied from the Defra AC0114 project (Defra, *in prep*).

5.1.3.3.5 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 (Defra, 2022a) for England, Wales, Scotland and Northern Ireland, and where JAS categories do not match the inventory categories, consistent data translation rules are applied from the Defra AC0114 project (Defra, *in prep.*). 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.

5.1.3.3.6 Goats, deer, and horses

The number of goats, deer and horses are derived from JAS holding level data (Defra, 2022a), and for horses not kept on agricultural holdings, from the British Equestrian Trade Association national survey (BETA, 2019). Missing data for some years were gap-filled by extrapolation, using data from adjacent years.

5.1.3.4 Crop types and crop areas

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

Forty-eight annual and perennial crops (and composite crop groups) are categorised in the UK inventory. Cereals comprise oats, wheat, barley and other minor cereals (with disaggregation for spring and winter types and end uses (e.g. milling *vs* feed wheat) where possible); other crops include field beans and peas; potatoes, sugar beet, oilseed rape, maize (for silage), root crops, leafy forage and other fodder crops; vegetables and other horticultural crops, soft and top fruit, miscanthus coppice, willow, vine grapes, linseed and flax. Full details of crops are in the supplementary material.

Grassland is classed as either: (i) improved temporary (sown within the last 5 years), (ii) improved permanent (not sown with the last 5 years), and (iii) unimproved (Unimproved Sole Right Rough Grazing and Unimproved Common Grazing). Areas are estimated using a new categorisation of holding level records from the JAS (Defra, 2022a). 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, 2022). As part of the quality control (QC) process, the grassland areas are verified using 2 different data sources (**Figure 5.3**), modelled DM offtake and N offtake are compared to field data (**Figure 5.4** and **Figure 5.5**) providing reassurance of the accuracy of the values used.

Figure 5.3 Comparison of two datasets for the annual grassland renewal rate

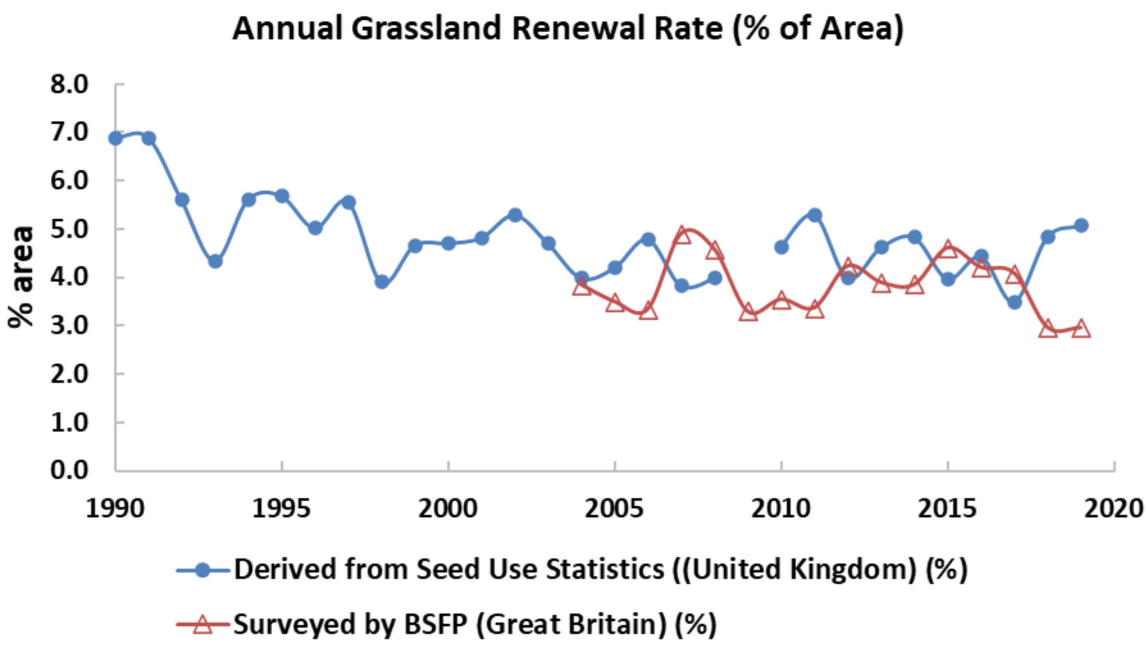


Figure 5.4 Dry matter off-take from measurements and the model

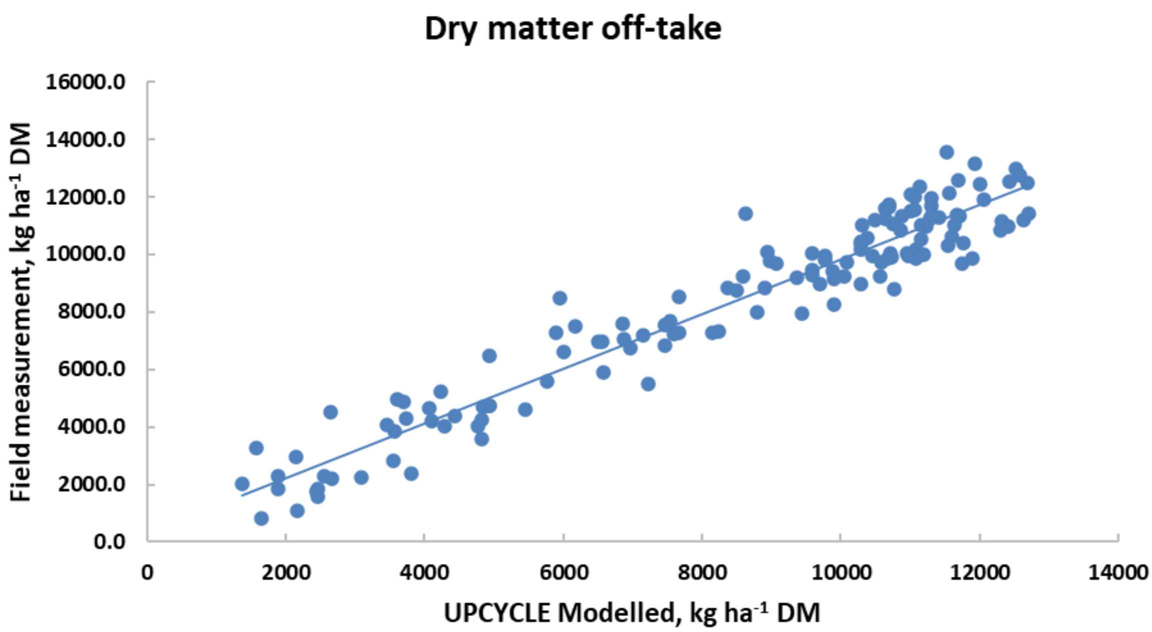
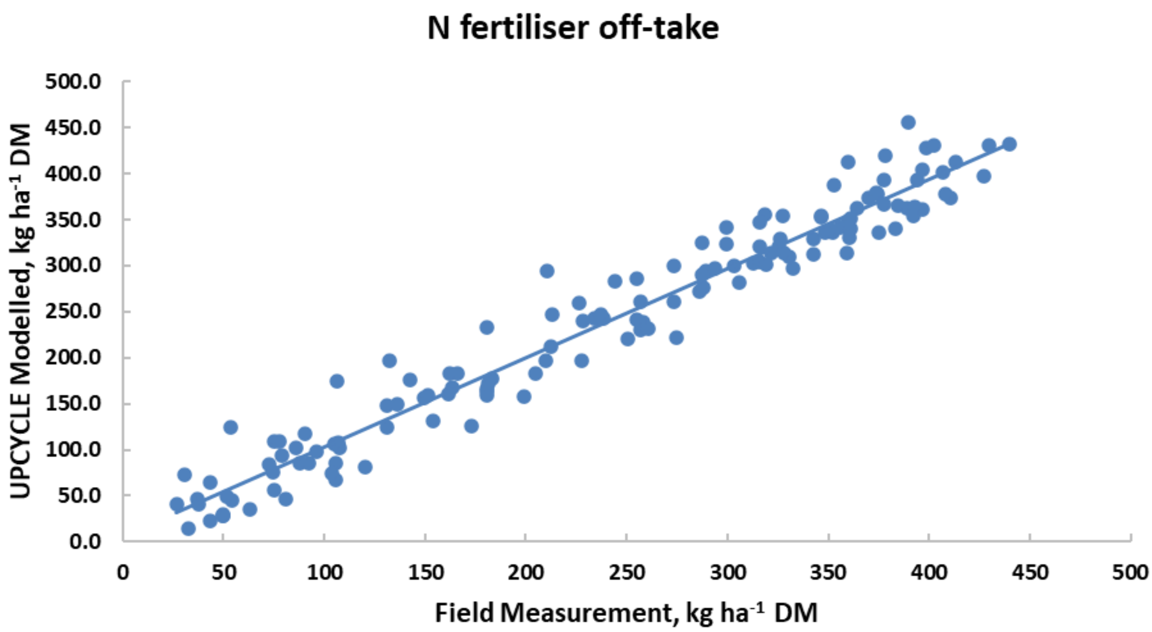


Figure 5.5 N fertiliser off-take from measurements and the model



For the estimate of emissions from mineralisation, the land use change areas have been significantly updated (see the LULUCF chapter for further details). Previously they were based on decadal matrices derived from the Countryside Survey data. In the 2022 submission these historic estimates were updated to use annual matrices derived from a land use tracking data assimilation process bringing together earth observation / remote sensing and national datasets. Areas of bioenergy crops in England (miscanthus and short rotation coppice) have been included in the cropland management calculations for the first time.

5.1.3.5 Crop residues

Calculations of N inputs from the biomass in crop residues include UK-specific data on above ground biomass, management methods 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, 2022) enables limited disaggregation by country, crop and farm type.

Residues from grassland are calculated using a UK-specific semi-empirical nitrogen mass-balance model which captures the effect of level of nitrogen fertilisation, soil water stress and cutting frequency on dry matter production, nitrogen off-take and nitrogen leaching. The structure of the model is informed by existing grassland N-balance (Scholefield et al, 1991; and Ritjema, ICW, 1980) and nitrate leaching models (SLIM: Addiscott and Whitmore, 1991; and SLIMMER: Anthony et al., 1996), and calibrated against national field trials.

Areas of crop residues that were harvested or burned came initially from national level surveys from 1990 to 1993 (when straw burning was made illegal in the UK) and then from the BSFP field level data from 2004 to the latest year (BSFP, 2022). Primary crop yields are taken from national statistics, except for some minor crops that that are taken from the main farm management guides (Nix, 2020; Mowbray, 2020). Regional yields of major cereals in England became available from 1999 and these are used in preference to the national values for England (Defra, 2022a; Defra, 2022d). Farm practice data in Northern Ireland (NI) is supplied by the lead NI government agricultural statistician (DAERA, 2022).

Details of values used for this year's inventory are in the **Annex** section **A3.3**.

5.1.3.6 Inorganic fertiliser types and application rates

Six N fertiliser types are considered in the UK greenhouse gas inventory: 1) ammonium nitrate, 2) urea, 3) urea ammonium nitrate, 4) ammonium sulphate/diammonium sulphate (considered together), 5) calcium ammonium nitrate, and 6) all other N fertilisers. The inventory uses data from the BSFP for England, Wales and Scotland (BSFP, 2022) and the Farm Business Survey (FBS) for Northern Ireland (DAERA, 2022) on application rates to crop type and the relative use of different fertiliser types. The data from before 2004 is sourced from paper reports of the BSFP (1990 to 2003). From 2004, field level data are available from BSFP enabling N applications for most crops (or crop groups) to be disaggregated to the levels of country, region and Farm Type. Less data exists for minor crops which are disaggregated at the country level.

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. As part of the quality control process, data are verified for nitrogen application rates to crops and grass (**Figure 5.6**, **Figure 5.7**, respectively), proportion applied as urea and ammonium nitrate (**Figure 5.8**, **Figure 5.9**, respectively). The proportion used as urea is slightly less in the inventory compared to IFA data (<6%), the other data have good agreement with our estimates.

Figure 5.6 Comparison of the BSFP data and values used in the inventory for the overall N application rate to crops

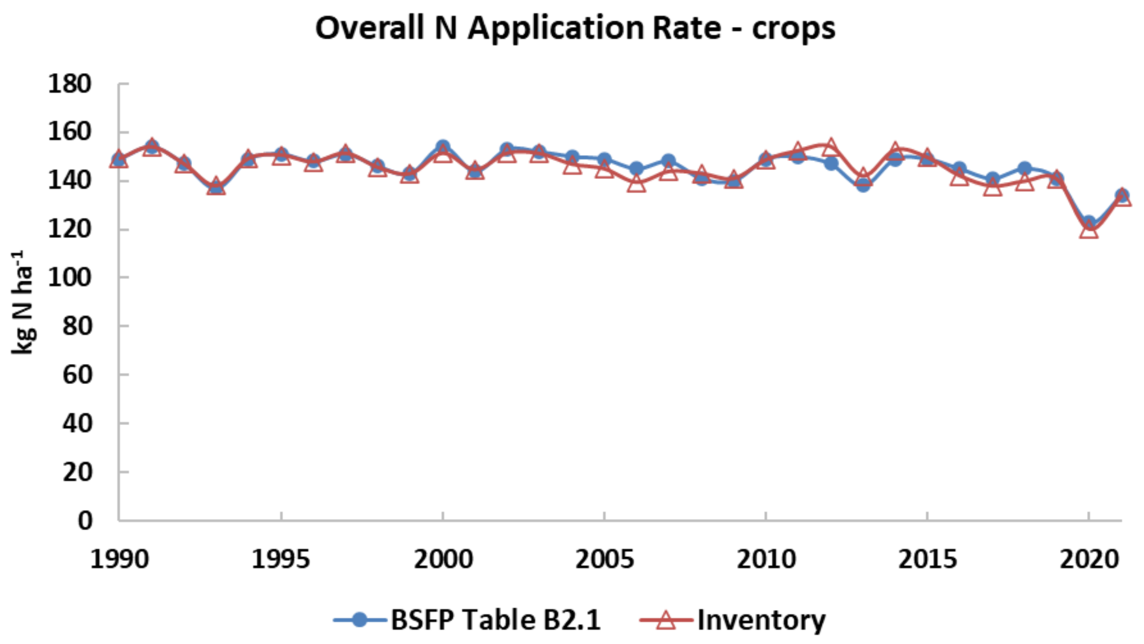


Figure 5.7 Comparison of BSFP data and values used in the inventory for the overall N application rate to grass

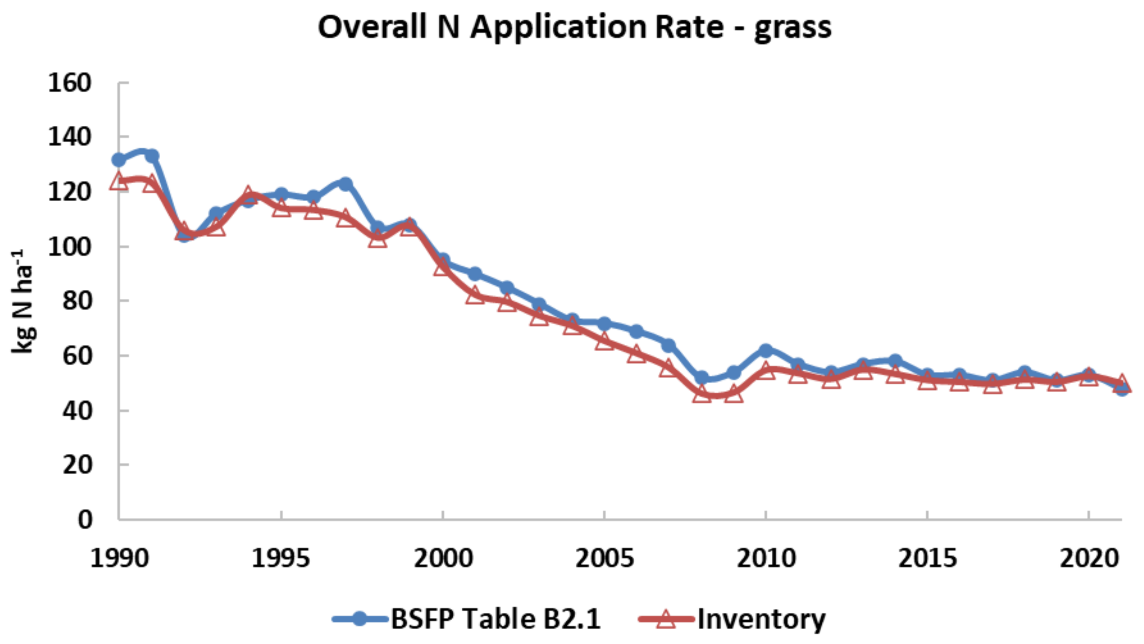


Figure 5.8 **Comparison of IFA data and values used in the inventory for urea contribution to total fertiliser use**

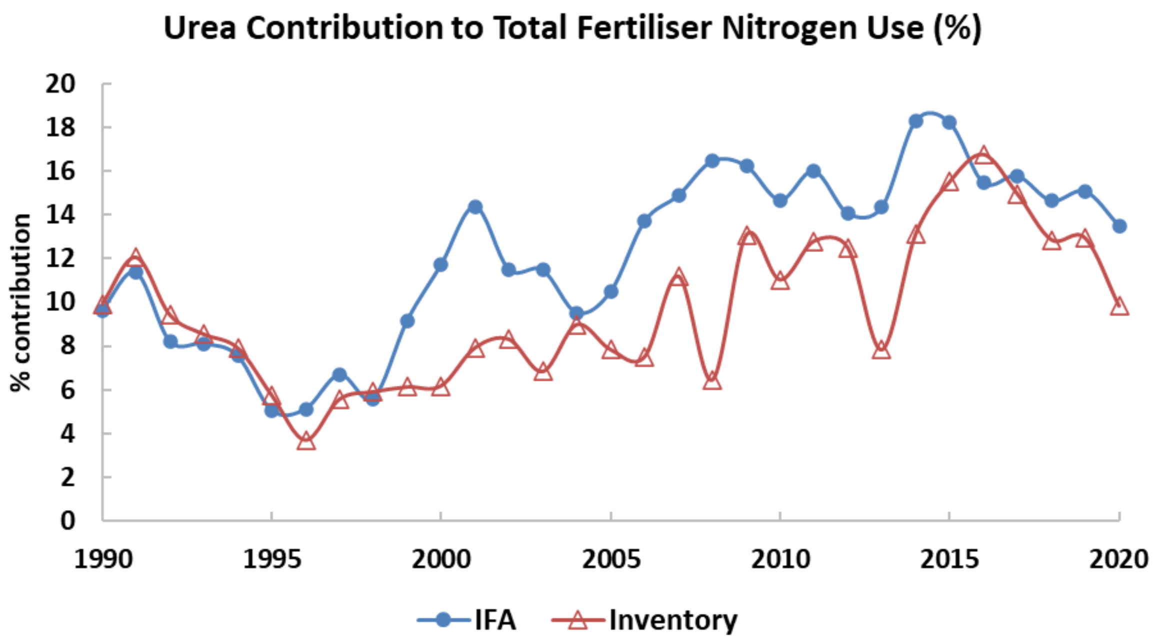
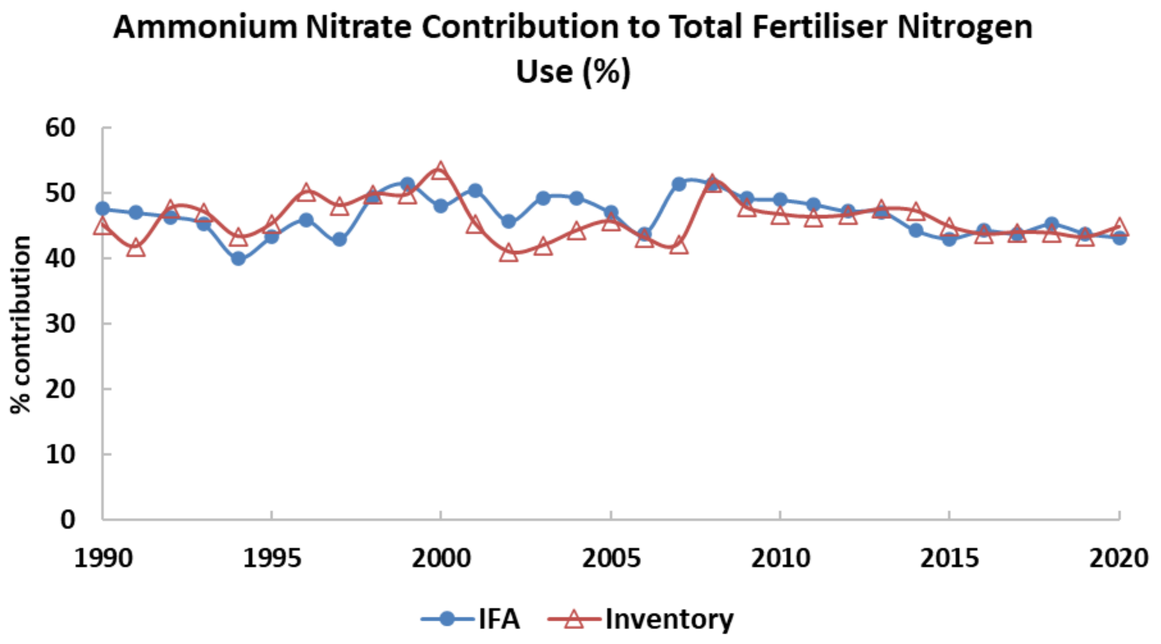


Figure 5.9 **Comparison of IFA data and values used in the inventory for ammonium nitrate contribution to total fertiliser use**



5.1.3.7 Organic fertilisers

The data sources, application and deposition of animal manures are described in **Chapters 5.3** and **5.4**. In addition, other organic sources are also applied in the UK:

a) Sewage sludge (liquid or as sludge cake)
b) Digestate from the anaerobic digestion of livestock manure

c) Digestates from the anaerobic digestion of energy crops, food waste and other organic residues
d) Composted green waste applied to land (emissions from which are currently NE as no activity data are available)

Emissions are estimated based on the quantities of the different organic materials being applied to land, the characteristics of those materials (e.g. N content, total ammoniacal nitrogen (TAN) content), the land use to which they are being applied (arable or grassland), the appropriate emission factor for each greenhouse gas or air quality pollutant (see Chapters 5.4 and 5.5) and a reduction factor for the proportion to which specific mitigation measures are implemented.

Emissions of N_2O are calculated from:

$$E_{N2O} = Q \times TN \times EF_{N2O}$$

Where Q is the quantity of organic material applied (m^3), TN is the total nitrogen content of the material (kg m^{-3}); EF_{N2O} is the emission factor applied (as % of the TN applied). Month of application (to account for seasonal differences in practices and emission factors if such data become available) and robust farm type (to reflect differences in practices if such data become available) are considered. Indirect N_2O emissions from volatilised and leached N are calculated according to IPCC 2006 Guidelines, using default IPCC N_2O emission factors EF_4 and EF_5 and applying UK-specific values for $FRAC_{leach.}$

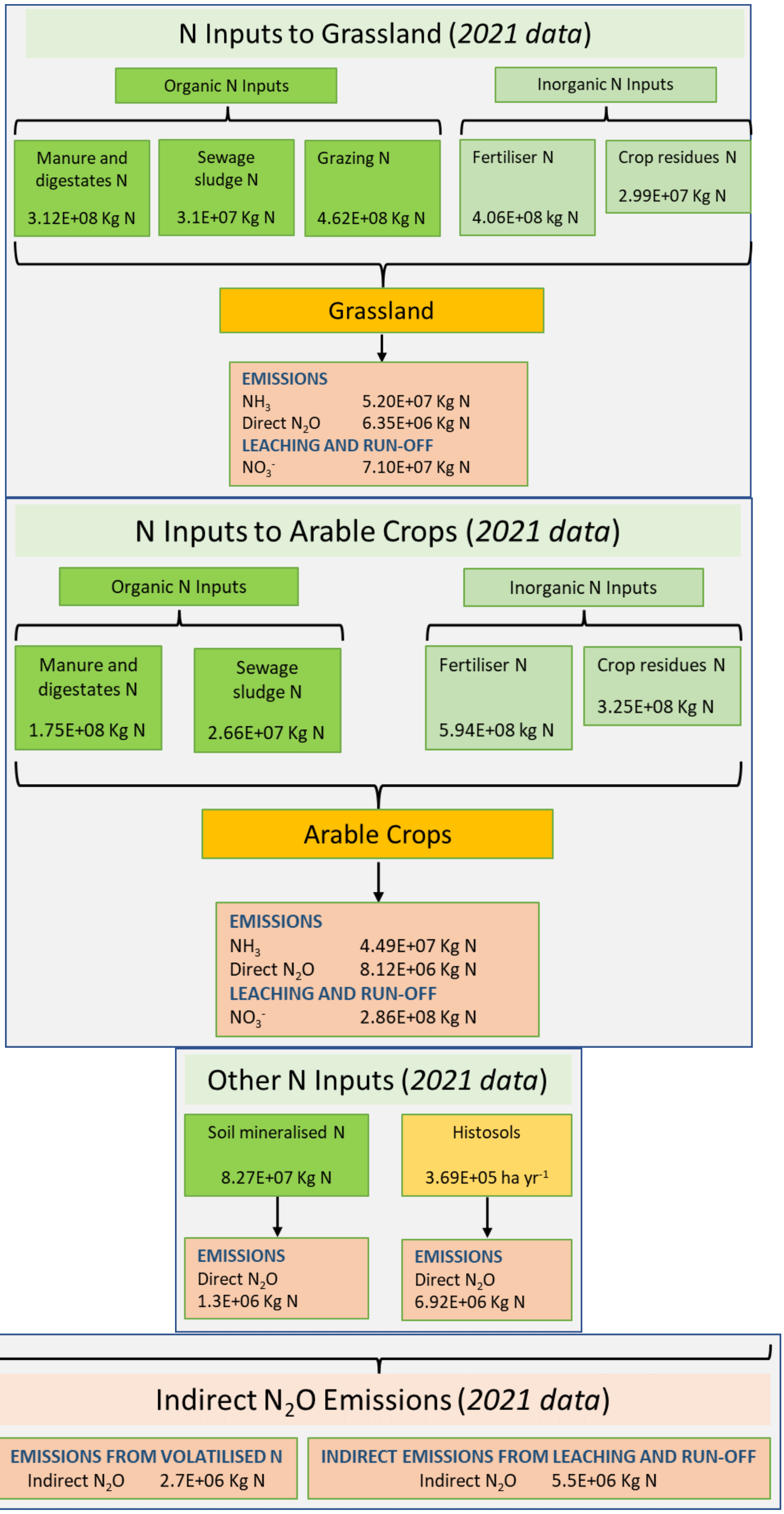
5.1.3.8 Animal waste manure systems

The split of manures into different management systems is based on data from several reference sources: Smith, 2012; Smith and Williams, 2016; Parsons and Williams, 2015; DAERA personal communication, 2019 (see details in Annex 3).

5.1.3.9 N flow approach

The UK has implemented a detailed N-flow model for synthetic fertiliser application and livestock excretion through the manure management chain (based on Webb and Misselbrook, 2004), at each manure management stage, followed by the application to soil accounting for all N losses (via NH_3, N_2O, NO, N_2 and N leaching) and transformations (immobilisation, mineralisation). A flow diagram illustrating for the latest year the N inputs and main outputs is shown below. In response to ERT review comments the UK has also provided a supplementary file to accompany the NIR with further details of the N flows through the livestock MMS.

Figure 5.10 N-flows from manure management, fertiliser and other N inputs to grassland, arable, other soils, to emissions and losses



5.2 EMISSION FACTORS

The UK has now appended the Emission Factors used for the 1990-2021 inventory in a supplementary file in excel format.

5.3 SOURCE CATEGORY 3A – ENTERIC FERMENTATION

5.3.1 Source category description

	Source included	Method	Emission Factors
Emissions sources	3A1: Dairy Cows Enteric	T3	CS
	Non-dairy 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, T1) 3A2: Enteric fermentation from Sheep - CH_4 (L1, T1)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	See **Section 5.10**.		
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		

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 some non-ruminant animals (e.g. swine and horses) produce methane, although ruminants are the largest source per unit of feed intake.

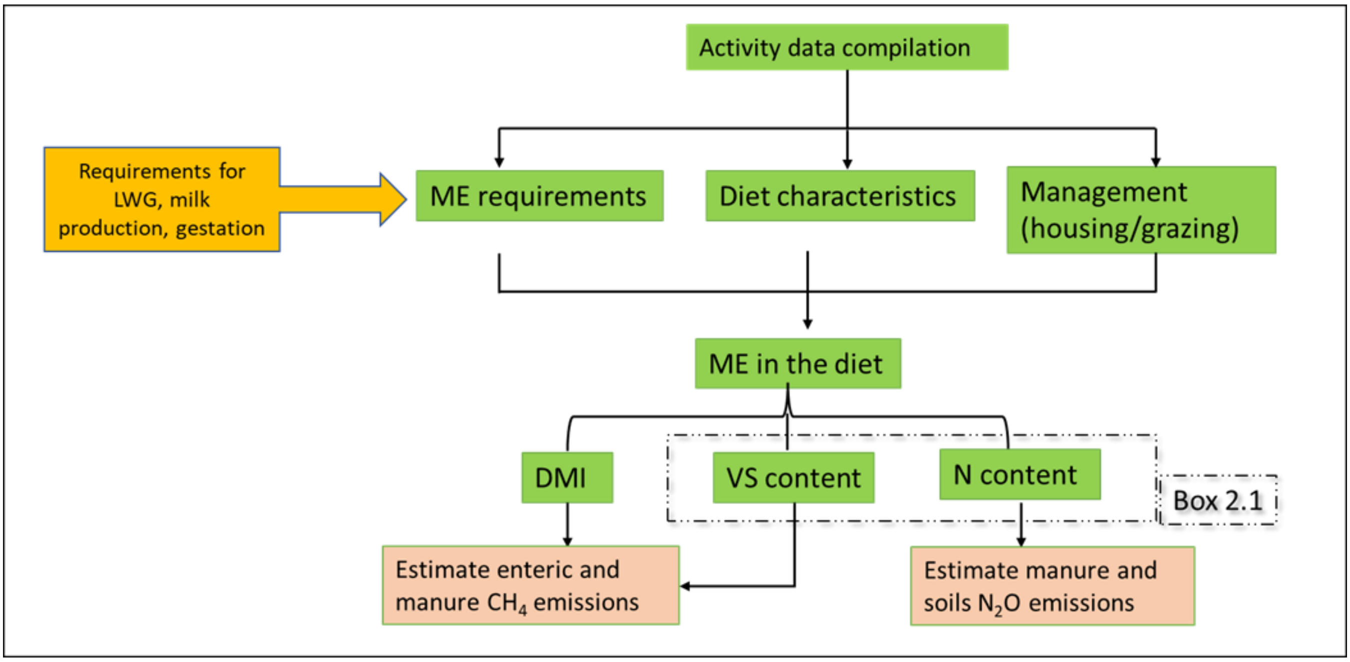
5.3.1.1 Source category emissions: significance, trends and drivers

Between 1990 and 2021, total emissions of enteric methane decreased by 15%. Total enteric methane emissions in 2021 were 841 kt CH_4.

5.3.2 Methodological issues

Enteric methane emissions are estimated from the intake and diet characteristics for ruminants. The steps are summarised in the figure below.

Figure 5.11 Enteric methane: methodology flow diagram



The flow diagram illustrates the highest Tier method used for estimating dry matter intake and N content in the diet from ruminant livestock. For non-ruminants, calculations for N_2O and manure CH_4 start from Box 2.1 using Country Specific N contents and default VS; enteric CH_4 is estimated using IPCC default methodology.

5.3.2.1 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, 2014a) and AC0114 (Defra, *in prep*.):

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

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**.

5.3.2.1.1 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[84] regarding yields for specific breeds (www.nbdc.uk). Breed-specific data are available back to 1999 and extrapolated back to 1990 based on the trend from 1999-2014. All are then normalised against the national Devolved Administration (DA), and finally UK statistics on average milk yield.

5.3.2.1.2 Live weight (LW)

A standard growth curve is defined for dairy cattle, based on that given by Coffey et al., (2006), and 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. Calf birth weight is related to mature cow weight (AFRC, 1993). Average age at conception for first calving is defined as 19, 20 and 18 months for large, medium and small breed proxies for GB and 20, 23 and 25 months for NI, respectively, giving respective age at first calving of 28, 29 and 27 months for GB and 29,32 and 34 for NI, 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.

5.3.2.1.3 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 (Redman, 2022) for GB cattle, and Ferris (2021) for NI cattle, with 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. Increasing use of forage maize, with associated higher energy and lower crude protein content, is reflected in the time series.

5.3.2.1.4 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) for GB cattle and Ferris (2021) for NI cattle and industry expert judgement on trends since 1990, assuming no year-round housing.

5.3.2.2 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 (presented above in 5.3.2.1) is used. For all non-lactating cattle, the relationship as developed under Defra-funded projects AC0115 (Defra, 2014a) and AC0114 (Defra, *in prep.*) 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**).

[84] See: www.nbdc.uk

5.3.2.2.1 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 FBS module (Parsons and Williams, 2015) is used to derive diets, characterised by 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]).

5.3.2.2.2 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 level (Defra, 2022b), 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, as summarised in 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.

5.3.2.2.3 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). Diet data for dairy replacements and calves follows the same approach as for dairy cows with data derived from the same sources.

5.3.2.2.4 Housing and grazing period

Data from a FBS module (Parsons, Williams, 2015) and other farm practices surveys (Defra, 2022c) were used to derive the grazing season lengths across the UK at DA level and with England split into three parts. These applied to cattle roles and ages, although age bands were more highly 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 (NH_3) and nitrous oxide (N_2O).

5.3.2.3 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.

5.3.2.3.1 Feed intake

Is calculated using a modified version of the ARFC (1993) energy 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.

5.3.2.3.2 Sheep live weights (LW)

The inventory uses country- and system-specific values for the live weights 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 42 and 45% respectively, derived from national slaughterhouse statistics[85]. 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.

5.3.2.3.3 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 N 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.

5.3.2.3.4 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.

5.3.2.4 Other livestock

Enteric emissions for swine, 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. The EF for goats of 9 kg/head/y, is according to the IPCC 2019 refinement to the 2006 guidelines for high production systems, as this is regarded as the most representative of UK farming practices in the expert judgement of the UK Inventory Agency. Whilst the UK GHG Platform research has not led to the derivation of a UK-specific EF, we note that the UK evidence was used to derive a value consistent with the value presented in the 2019

[85] Rural and Environment Science and Analytical Services (Annual), Economic Report on Scottish Agriculture, Scottish Government Directorate for Environment and Forestry (https://www.gov.scot/collections/economic-report-on-scottish-agriculture/), Department of Agriculture, Environment and Rural Affairs (Annual) Output Value of Farm Products (https://www.daera-ni.gov.uk/publications/output-value-farm-products), Hybu Cig Cymru (Meat Promotion Wales) Welsh Monthly Slaughterings (https://meatpromotion.wales/en/markets/livestock-market-trends/uk-monthly-average-carcase-weights), Defra Latest Cattle, Sheep and Pig Slaughter Statistics (https://www.gov.uk/government/statistics/cattle-sheep-and-pig-slaughter)

Refinement, and hence in our expert judgement to use the 2019 Refinement EF is the most representative EF option available to best reflect UK circumstances; we consider that applying that EF minimises the uncertainty in the UK Inventory for this source.

5.3.2.5 Overseas Territories and Crown Dependencies

Emission estimates were compiled 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.

5.3.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty per 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.

Enteric emissions from cattle and sheep are derived using Tier 3 methods in the UK inventory. In the 2023 submission uncertainty analysis the Inventory Agency has reviewed and updated all of the uncertainty parameters for these source categories. The uncertainty parameters for the ME requirement and enteric methane VS DMI relationship have been revised to be more representative of UK circumstances and the Tier 3 method, applying parameters that reflect the statistical relationships evident from UK field experiment results.

However, the resultant uncertainties related to dairy cattle enteric fermentation methane emissions are noted to be somewhat lower than those derived for other country Tier 3 approaches. Our sector expert view is that whilst the updated uncertainty estimates are an improvement on the previous approach, for the next submission we must review the component of uncertainty that is related to the derivation of the DMI estimates. We are confident that the analysis of the relationship between DMI and methane emissions is well characterised and accurately reflected in the updated uncertainty calculations.

Compared to previous inventory uncertainty analysis, the results reflect where methods have been improved. The beef sector method is unchanged, and the uncertainties are not significantly revised. Where changes have been made to methods, data and assumptions and hence to uncertainty parameters, there are increases in the uncertainty ranges evident for: sheep, pigs, dairy.

Emissions are calculated from animal population data and appropriate emission factors. The animal population data are collected in the June Agricultural Census (JAC), 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 Bovine Spongiform Encephalopathy (BSE, also known as "mad cow disease") outbreak in the UK introduced an inconsistency in the slaughter weight statistics and the derived dairy cow live weights for the years 1997 to 2005. To correct for the artefacts introduced by these control measures in the data time-series, data for this period were interpolated using the linear trend of increasing lives weight with time for the years immediately prior to and following this period.

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 5.11**.

Details of the data flows and QAQC across the agriculture inventory model and methods are described within **Annex A3.3**. Some of the data validation checks are also presented within the supplementary MS Excel file that accompanies the NIR and within the NIR (sections 3.1.3.4 and 3.1.3.5). Specific to the Enteric Fermentation source category, the UK sector experts conduct the following QC activities on the cattle data:

In Cattle Tracing Scheme (CTS) data processing, QC is conducted to identify cattle that are mixed breeds (dairy/beef) and to review the holding level information across the time series to ascertain the type of farm and likely cattle type; in additional QC identifies any new breeds and flags those to sector experts to assign them to dairy or beef sector.

Completeness and time series consistency checks against other herd statistics (e.g. from Defra JAS/C data) are conducted at the DA / livestock type level.

5.3.5 Implied emission factors

The implied emission factors for dairy, other cattle and sheep (124, 55 and 5 kg/head/year, respectively) were different to IPCC 2006 default values (109, 57, 8 kg/head/year).

5.3.6 Source-specific planned improvements

Revise the parameters for the energy balance equations for non-lactating cattle based on recent and ongoing research (AFBI). Explore Northern Ireland CTS data access, to bring the cattle method for NI into line with other parts of the UK. Revise housing assumptions. Simplify the allocation of ewes to hill-upland-lowland sectors.

5.3.7 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 emissions since previous submission (kt)

IPCC Category	Source Name	2022 submission 1990	2022 submission 2020	2023 submission 1990	2023 submission 2020	Units	Comment/Justification
3.A.1	Enteric fermentation – Dairy cattle	278.37	229.36	279.44	229.05	kt	Very small correction to coded model dairy DMI vs CH_4 relationship (affects all years); Replaced slaughter weight timeseries (affects 2008 to 2020); Updated 2019 and 2020 milk yield to match UK/NI stats and replaced unweighted Scotland milk yield data with weighted milk yield data from 2013-2020 which also has a very small effect on other DAs due to weighting/correction factors applied against UK milk yield; Concentrate use updated for 2020 for E,W,S which has slight effect on emissions from 2011 due to values being interpolated
3.A.1	Enteric fermentation – Non-Dairy cattle	476.30	415.85	476.49	416.09	kt	Very small correction to coded model dairy DMI vs CH_4 relationship (affects all years); Replaced slaughter weight timeseries

Table 5.2 3A Recalculations to Emission Factors since the previous inventory (kg/hd/year)

IPCC Category	Source Name	2022 submission 1990	2022 submission 2020	2023 submission 1990	2023 submission 2020	Units	Comment/Justification
3.A.1	Enteric fermentation – Dairy Cattle	97.73	123.81	98.11	123.64	kg/hd/year	Reason for change as above
3.A.1	Enteric fermentation – Non-Dairy Cattle	51.34	54.89	51.36	54.92	kg/hd/year	Reason for change as above

5.4 SOURCE CATEGORY 3B – MANURE MANAGEMENT

5.4.1 Source category description

	Source included	Method	Emission Factors
Emissions sources	3B11: Dairy Cattle Wastes Non-Dairy Wastes 3B12: Sheep Wastes 3B13: Swine Wastes 3B14: Goats Wastes 3B14: Horses Wastes 3B14: Broilers Wastes Laying Hens Wastes Other Poultry Wastes 3B14: Deer Wastes 3B21: Dairy Cattle Wastes Other Cattle Wastes 3B22: Sheep Wastes 3B23: Swine Wastes 3B24: Goats Wastes 3B24: Horses Wastes 3B24: Poultry Wastes	T2 T2 T2 T2 T1 T1 T2 T2 T2 T1 T2 T2 T2 T2 T2 T2 T2	CS, D CS, D CS, D D D D D D D D CS, D CS, D CS, D CS, D D D CS, D
Gases Reported	CH_4, N_2O		
Key Categories	3B1: Manure management from Cattle - CH_4 (L1, T1) 3B2: Manure Management - N_2O (L1)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	See **Section 5.10**.		
Completeness	There are no UK activity data for the practice of composting of manure within MMS and hence no methane nor nitrous oxide emissions for this source are currently reported in the GHGI. A general assessment of completeness for the inventory is included in **Section 1.8.**		
Major improvements since last submission	Updates to manure storage and application practices Aside from method improvements, the UK has also included a detailed livestock MMS nitrogen flow dataset for the latest inventory year. This is in response to ERT findings from the Centralised Review of the 2022 UK GHGI submission and can be found in the supplementary MS Excel file that accompanies the NIR.		

Methane is produced from the decomposition of manure under anaerobic conditions.

5.4.1.1 Source category emissions: significance, trends and drivers

Total methane emissions from manure management in 2021 were 153.2 kt CH_4. Emissions in 2021 were 7.7% lower than in 1990.

For nitrous oxide, total emissions from manure management in 2021 were 9.4 kt N_2O. Emissions in 2021 were 17.2% lower than in 1990.

5.4.2 Methodological issues

5.4.2.1 Methane emissions from animal manures and manure-based digestates

The emission factors for manure management are calculated following IPCC Tier 2 methodology for cattle, sheep, swine 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 5.1**) 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:

$$VS_{ex} = \left(GE_i \times \left(1 - \left(Me_{req}/GE_i\right)\right)\right) \times ((1 - ASH)/(GE_i/DMI))$$

Where: VS_{ex} is the volatile solids excretion, kg d^{-1}; GEi 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}. In the case of sheep, VS excretion also accounts for varying energy content of urine, varying with feed protein level.

UK-specific data on the methane producing potential (Bo) of cattle excreta were not significantly different from IPCC (2006) default values (Defra 2014a), so the default values are retained. For swine and poultry, IPCC (2006) default values for VS and Bo are used.

Default IPCC (2006) Methane Conversion Factor (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 recent literature evidence (e.g. Petersen et al., 2013). Country-specific MCF values are used for the anaerobic digestion of livestock manures based on the values used in the German inventory. 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 MCFs assumed for the different systems.

There are no UK activity data for the practice of composting of manure within MMS and hence no methane nor nitrous oxide emissions for this source are currently reported in the GHGI. The composting of manures is a very minor activity in the UK and as noted in recent UNFCCC reviews the omission of this activity is not expected to lead to an under-report in UK emissions. The separate reporting of manure being composted would be expected to lead to lower overall emissions from manure management; methane emissions would be lower, as MCFs for composting are lower than for most other manure management systems (in particular lower than for solid storage and liquid systems). In the view of recent ERTs, the actual difference in nitrous oxide emissions would depend on the management system that is diverting manure to composting, but any underestimation would likely be small and the impact on overall emissions negligible. The UK will retain this completeness issue on our inventory improvement log, seeking activity data to address this omission.

For goats, deer and horses, IPCC (2006) Tier 1 default emission factors were used (IPCC Tables 10.15). For broilers the VS excretion value of 0.02 kg/hd/d, is according to the IPCC 2019 refinement to the 2006 guidelines, as this is regarded as the most representative of UK farming practices in the expert judgement of the UK Inventory Agency. Whilst the UK GHG

Platform research has not led to the derivation of a UK-specific EF, we note that the UK evidence was used to derive a value consistent with the value presented in the 2019 Refinement, and hence in our expert judgement to use the 2019 Refinement EF is the most representative EF option available to best reflect UK circumstances; we consider that applying that EF minimises the uncertainty in the UK Inventory for this source.

5.4.2.2 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):

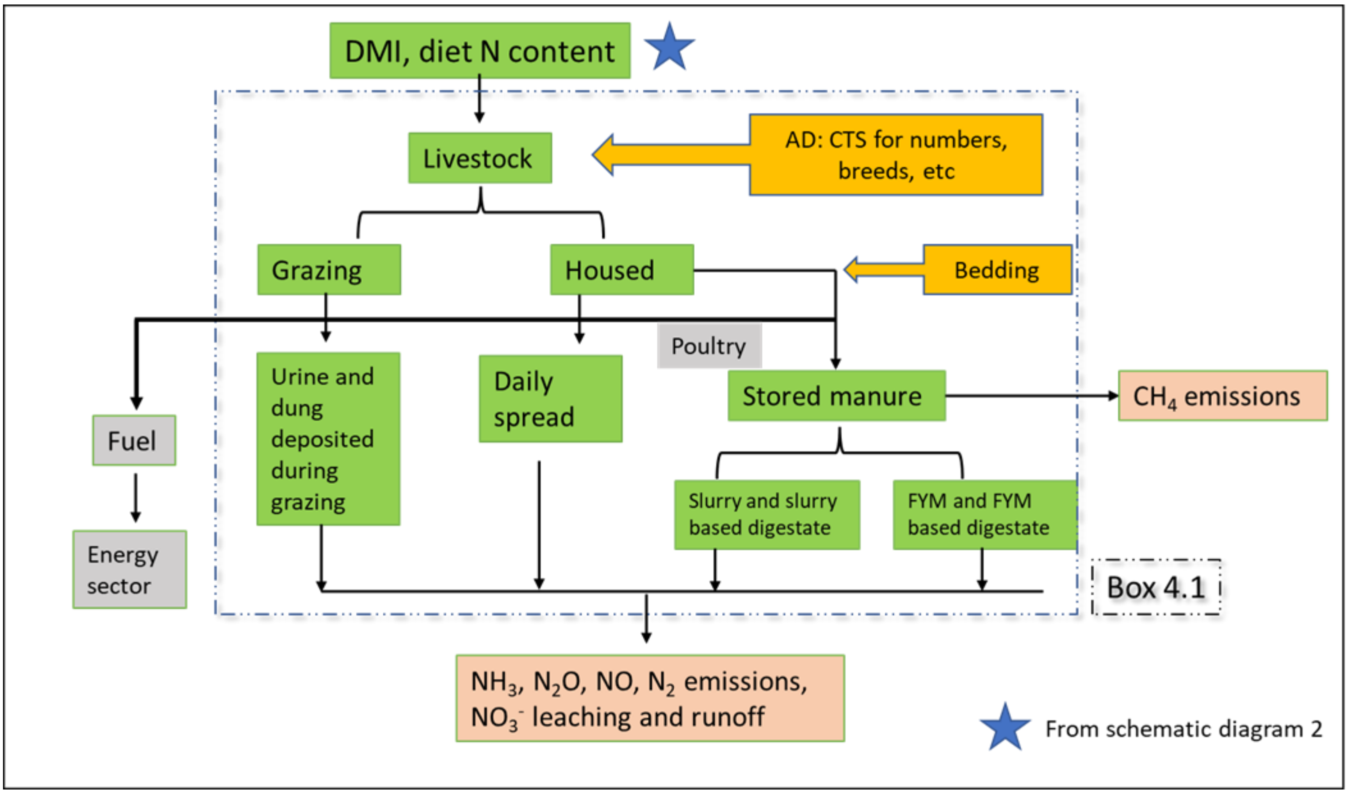
- Liquid/slurry;
- Solid storage/deep litter/poultry manure;
- Anaerobic digestion

Following IPCC methodology IPCC (2006), the following AWMS are reported in the Agricultural Soils category:

- All animal manures, slurries and digestates applied to soils; and
- Pasture range and paddock

The methodology is summarised in the flow diagram below. *Note that the DMI, diet N content at the start here (blue star) is derived in the process depicted in Figure 5.11.*

Figure 5.12 Overview of manure management systems in the UK inventory



Emissions trends and methodologies

Total nitrous oxide emissions from manure management in 2021 were 9.44 kt N_2O. Emissions in 2021 were 18.1% lower than in 1990.

5.4.2.2.1 Livestock N excretion

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 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 5.1**), 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, based upon a national survey by Roderick (2001) of 2,649 flocks managed by members of the National Sheep Association, the inventory calculations assume that 75% of ewes associated with lowland systems, 60% with upland systems, and 40% with hill systems are housed in the last weeks of pregnancy. Also, that housed breeding ewes are housed for 42 days prior to lambing, and that neither the ewe nor new-born lamb are housed post lambing. The effect of excluding new-born lamb from the housing calculations is a negligible (< 1%) reduction in the quantity of managed manure. Data from 2 other surveys by Lima et al. (2018) (England and Wales) and Bohan (2017) (Ireland) were used to assume that no lambs are housed during the finishing period. Other assumptions regarding handling sheep for short period in housing or yards are based on smaller surveys (Defra 2004; Dauven and Crabb, 1998; Webb et al., 2001) and communications from sheep experts (*Pers. comm.*: Kate Phillips).

For sheep, the partition of excreta N between urine and dung is dynamic and from these 85% of urine N is TAN, and 15% of dung N is TAN, estimated from separate regression equations for excreta and urine N on the dietary protein content taken from the meta-analysis published by Decandia et al. (2011).

The N excretion values for lambs appear low in comparison to published values for other countries, as these are often presented on the assumption that a lamb is present for a complete year (365 days) before slaughter. Statistical analyses of United Kingdom surveyed slaughter ages (after Wheeler et al., 2012) have proven that lamb are present on average for only 237 days. The N excretion value of around 4 kg N per lamb is therefore for a 237-day period, and not for a complete year (365 days). In the case of sheep weighted average N excretion rate from all sheep categories is 7.5 kg N yr^{-1} (2019). We report N excretion values of around 4 kg N per lamb produced (see important note on N excretion above); around 11 kg N yr^{-1} per ram; and around 9 kg N yr^{-1} per ewe.

Average N excretion values for neighbouring countries reported in their NIR are for all sheep 7.8 kg N yr^{-1} (Germany) and 6.6 kg N yr^{-1} (Denmark); and for ewes they range from 6.5 kg N yr^{-1} for upland ewes (Ireland) to 12.9 kg N yr^{-1} for lactating ewes (France).

Decandia et al. (2011) reported published N excretion rates data from sheep. The total N excretion rate averaged 13.9 g N day^{-1} for growing sheep (n 52); 16.7 g N day^{-1} for rams (n 20); 15.5 g N day^{-1} for dry ewe (n 21); and 40.4 g N day^{-1} for lactating ewe (n 26). The values for the dry and lactating ewe can be weighted by the UK surveyed average number of days from birth of lamb until weaning (around 120 days) to give an average yearly value of 23.7 g N day^{-1} per ewe. These average literature values are either the same or lower than the UK inventory values of 17.3 g N day^{-1} for all lamb, both finished and replacements; 30.9 g N day^{-1} for ram; and 23.8 g N day^{-1} for all ewes. These reported data support the UK CS values.

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), and Defra WT1568 (2016b), presented in **Table A 3.3.4** in **Annex 3**. For swine 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%. In the case of swine and poultry, in this submission the N excretion values were revised using data from Defra WT1568 (2016b) to interpolate for years from Defra WT0715NVZ (2004). For poultry also included a revision to proportional uplift in N excretion for outdoor laying hens. Values were also updated for goats (from 20.6 to 8.4 kg/y) and deer (from 13 to 29.3 kg/y) according to IPCC 2019 refinement to the 2006 guidelines.

5.4.2.2.2 Direct nitrous oxide emissions from MMS

The conversion of excreted N into nitrous oxide 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, as derived from UK measurements (Misselbrook, 2017) (**Table A 3.3.6c** in **Annex 3**).

UK data relating to direct N_2O emissions from manure management were reviewed as part of Defra project AC0114. There were a limited number of studies, the mean EF for which are summarised in **Table A3.3.6d**, and no data were available for some emission sources. The UK CS values for cattle and pig FYM are greater than the default values given in the 2006 IPCC Guidelines (but much closer to the IPCC 2000 Good Practice Guidance value of 2%), and this higher value is also supported by other UK studies not included in the literature review (Moral et al., 2012; Defra project AC0112 – unpublished). The values are not significantly different, so a value of 2% is applied to both cattle and pig FYM. The mean measured EF for broiler litter is also greater than the default 2006 IPCC Guidelines value and therefore a CS value of 0.5% is applied to poultry manure management. UK measurements of emissions from pig slurry storage were very low (apparently negative) and support the zero emission default given by the 2006 IPCC Guidelines which is therefore applied in the UK inventory.

A review of the literature on livestock housing and manure management practices (K. Smith, ADAS, Defra project AC0114), updated with survey data on manure spreading practices from the BSFP (BSFP, 2022), and data from DAERA statistics for Northern Ireland (DAERA, 2022) was used as the basis for developing the 1990 to 2021 timeseries of livestock housing and manure management practices for each country (England, Wales, Scotland and Northern Ireland) from which a weighted average was derived for the UK. Underlying data sources include routine and ad-hoc surveys such as the Defra Farm Practices Surveys (Defra, 2022c) and published manure management surveys (Smith et al., 2000, 2001a, 2001b).

The proportions of cattle manure management practices were based on a UK data synthesis by Smith and Williams (2016). The housing period for beef animals was derived from Parsons and Williams (2015).

Within the sheep sector, all (100%) manure from the ewe housing period is assumed to be managed as solid farmyard manure with additions of straw bedding. All (100%) manure from the housing period is assumed to be stored for a period of several months as a field heap on grass before spreading to land. It is assumed that 75% of ewes associated with lowland systems, 60% with upland systems, and 40% with hill systems are housed in the last weeks of pregnancy and that these breeding ewes are housed for 42 days prior to lambing, and that neither the ewe nor new-born lamb are housed post-lambing (Roderick, 2001). Management for other activities (e.g. shearing) were obtained from various sources (Defra, 2004; Webb et al., 2001).

For swine and other minor livestock, the inventory code was updated to include bedding N at housing before estimating emissions (it had been included after the emissions calculation).

Poultry manure subsequently going to incineration in power stations is associated with N_2O emissions during the housing/storage phase using the proportions as per **Table A 3.3.6a** and EF as per **Table A 3.3.6c**. The amount of poultry litter incinerated in each year are obtained directly from MRE UK[86]; the amounts exported from Northern Ireland to be incinerated in Scotland and England are provided by DAERA (**Table A 3.3.6b** showing transfers between DAs). The quantities going for incineration are deducted prior to calculations of emissions from land spreading. Manure types going to incineration are assumed to be broiler and turkey litter and the reported quantities incinerated are converted to a proportion of the total manure for these poultry categories based on estimated manure outputs per bird.

5.4.2.2.3 Indirect nitrous oxide emissions from MMS

For estimation of indirect N_2O emissions from manure management, country-specific values for $Frac_{GASM}$ and $Frac_{LEACH}$ are used. $Frac_{GASM}$ is derived directly as output from the UK N-flow model for each livestock x AWMS combination, as the sum of the NH_3-N and NO-N emissions (further details can be found in the UK Informative Inventory Report). A country-specific value of 2.4% of manure N for $Frac_{LEACH}$ is used, based on Nicholson et al. (2017) 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 the IPCC 2019 refinement to the 2006 Guidelines default value ('wet climate') for EF_4 (1.4%) and the IPCC 2006 Guidelines default value for EF_5 (0.75%), as these are regarded as the most representative for UK conditions.

5.4.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty per IPCC source category.

The estimates of uncertainties in emissions were calculated using Approach 2 (Monte Carlo simulation) described by the IPCC, applying uncertainty parameters that reflect the Tier 3 models used to derive the UK greenhouse gas inventory emission estimates. The uncertainties in the estimates of livestock data were provided by the devolved administrations, as they are the data providers.

The UK sector experts have reviewed the uncertainty parameters for the UK method for methane and nitrous oxide emissions from manure management during the 2023 submission. Models and associated uncertainties are now incorporated for minor livestock. The main change in the models since the last uncertainty run is moving the calculation of methane emissions from the housing phase to the storage phase in order to fully represent emissions from anaerobic digestion. There are also changes to the activity data, for example the percentages of livestock on different housing systems / storage as well as the addition of some new housing types for poultry. This includes improvements in how the animal waste management systems (AWMS) breakdown is parameterised.

[86] https://www.mreuk.com/

In previous inventories the uncertainty was assumed to be ±20 % for the AWMS breakdown but now estimates are based on analysis of the underlying data. Overall changes in uncertainty for this source category are as follows:

- For methane, uncertainties have reduced:
    - England ±13.3% to ±8.5%;
    - Wales ±17.2% to ±9.0%;
    - Scotland ±18.9% to ±11.6%; and
    - Northern Ireland ±15.9% to ±11.4%
- For nitrous oxide, uncertainties have increased:
    - England ±23.1% to ±28.8%;
    - Wales ±25.1% to ±38.3%;
    - Scotland ±27.3% to ±42.5%; and
    - Northern Ireland ±24.9% to ±30.9%.

The uncertainty parameters will be kept under review for future submissions.

Emissions are calculated from livestock population data and appropriate emission factors. The livestock population data are collected in the JAC, 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.

5.4.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.11.**

5.4.5 Source-specific recalculations

Details of and justifications for recalculations to activity data and to emission factors are given in the tables below.

Table 5.3 3B Source specific recalculations to emissions since previous submission (kt)

IPCC Category	Source Name	2022 submission		2023 submission		Units	Comment/Justification
		1990	2020	1990	2020		
3.B.1.1	Manure management: Methane emissions – Dairy Cattle	63.03	71.19	63.89	70.70	kt	As ‘Enteric fermentation – Dairy cattle’ plus updated proportion of animals kept on slurry/FYM systems with fewer dairy cows on slurry systems in Wales from 2010 (interpolated from 1990-2010 so affects all years bar 1990) and more dairy cows kept on slurry for all years in Scotland; Updated slurry storage proportions for NI resulting in less slurry being stored in below ground tanks and lagoons and more being stored in above ground tanks (affects all years); Updated FYM storage proportions for all DAs resulting in more FYM being spread direct (stored in house) for S and NI with adjustments for all DAs in the amount of FYM stored in field heaps or steading (affects all years); Updated amount of manure destined for anaerobic digestion (affects all years)
3.B.1.1	Manure management: Methane emissions – Non-Dairy Cattle	60.20	52.78	59.09	52.53	kt	Very small correction to coded model dairy DMI vs CH_4 relationship (affects all years); Replaced slaughter weight timeseries
3.B.1.3	Manure management: Methane emissions – Swine	35.16	20.59	35.00	20.36	kt	Updated FYM storage proportions for all DAs resulting in more FYM being spread direct (stored in house) for S and NI which is associated with a lower MCF (virtually no FYM in NI so little effect), alongside adjustments for all DAs in the amount of FYM stored in field heaps or steading (affects all years); Updated amount of manure destined for anaerobic digestion (from 2008)
3.B.1.4	Manure management: Methane emissions – Poultry	2.48	3.24	2.48	3.57	kt	Updated quantities of litter going to anaerobic digestion (from 1991); Updated FYM storage proportions for all DAs (all years)
3.B.2.1	Manure management: Nitrous Oxide emissions – Dairy Cattle	1.1741	0.9917	1.1744	0.9881	kt	Very small correction to coded model dairy DMI vs CH_4 relationship (affects all years); Small changes in N excretion associated with changes to milk yield (from 2013) and slaughter weight updates (from 2008); Concentrate use updated for 2020 for E,W,S which has small effect on emissions from 2011 due to values being interpolated; Updated proportion of animals kept on slurry/FYM systems with fewer

IPCC Category	Source Name	2022 submission 1990	2020	2023 submission 1990	2020	Units	Comment/Justification
							dairy cows on slurry systems in Wales from 2010 (interpolated from 1990-2010 so affects all years bar 1990) and more dairy cows kept on slurry for all years in Scotland; Updated slurry storage proportions for NI and FYM storage proportions for all DAs which only affects indirect emissions because N_2O emissions are calculated at the housing phase; Introduced 73% uptake of washing down of dairy cow collecting yards for E,W,S and 100% for NI (whole timeseries)
3.B.2.1	Manure management: Nitrous Oxide emissions – Non-Dairy Cattle	5.17	4.39	5.16	4.30	kt	Very small correction to coded model dairy DMI vs CH_4 relationship (affects all years); Small changes in N excretion associated with changes to milk yield (from 2013) and slaughter weight updates (from 2008); Concentrate use updated for 2020 for E,W,S which affects emissions from 2011 due to values being interpolated; Updated proportion of dairy followers/beef kept on slurry systems with fewer animals on slurry systems in Wales from 2010 (interpolated from 1990-2010 so affects all years bar 1990) and more dairy follower/beef kept on slurry for all years in Scotland; Updated slurry storage proportions for NI and FYM storage proportions for all DAs which only affects indirect emissions because N_2O emissions are calculated at the housing phase; Introduced 3% mitigation uptake of rigid covers on above ground tanks in NI from 2010
3.B.2.4	Manure management: Nitrous Oxide emissions – Poultry	0.93	0.75	0.93	0.76	kt	N excretion values have been revised for 2016 (affects 2005 onwards as values are used in extrapolating for previous years and taking forward for future years); Updated FYM storage proportions for all DAs which only affects indirect emissions because N_2O emissions are calculated at the housing phase
3.B.2.5	Manure Management: Indirect N_2O Emissions	2.28	1.80	2.24	1.78	kt	As direct manure management above

Table 5.4 3B Recalculations to Emission Factors since the previous inventory (kg/hd/year)

IPCC Category	Source Name	2022 submission		2023 submission		Units	Comment/Justification
		1990	2020	1990	2020		
3.B.1.1	Manure management: Methane emissions – Dairy Cattle	22.13	38.43	22.43	38.16	kg/hd/year	Reason for change as above
3.B.1.1	Manure management: Methane emissions – Non-Dairy Cattle	6.49	6.97	6.37	6.93	kg/hd/year	Reason for change as above
3.B.1.3	Manure management: Methane emissions – Swine	4.66	4.06	4.64	4.02	kg/hd/year	Reason for change as above
3.B.1.4	Manure management: Methane emissions – Poultry	0.018	0.018	0.018	0.020	kg/hd/year	Reason for change as above
3.B.2.1	Manure management: Nitrous Oxide emissions – Dairy Cattle	0.4122	0.5353	0.4123	0.5334	kg/hd/year	Reason for change as above
3.B.2.1	Manure management: Nitrous Oxide emissions – Non-Dairy Cattle	0.558	0.579	0.556	0.567	kg/hd/year	Reason for change as above
3.B.2.4	Manure management: Nitrous Oxide emissions – Poultry	0.0067	0.0041	0.0067	0.0042	kg/hd/year	Reason for change as above

5.4.6 Implied emission factors

The methane implied emission factors from manure management for major categories such as dairy and other cattle in the UK inventory (38, 6.9 5 kg/head/year, respectively) are higher than the IPCC default values (21, 6 kg/head/year, respectively). Values for sheep and swine (0.13 and 4.0 kg/head/year, respectively) are lower than IPCC (0.19 and 6 kg/head/year, respectively).

5.4.7 Source-specific planned improvements

Development of partial EF for nitrous oxide and methane emissions for the different manure management stages, i.e. separate EF for housing and storage, that also enable accounting of the impacts of duration and conditions of manure storage.

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 3D – AGRICULTURAL SOILS

5.5.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3D1: Direct N_2O Emissions from Managed Soils 3D2: Indirect N_2O Emissions from Managed Soils	T2, T1 T1	D, CS D
Gases Reported	N_2O		
Key Categories	3D: Agricultural soils - N_2O (L1, T1, L2, T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	See **Section 5.10**.		
Completeness	A general assessment of completeness for the inventory is included in **Section** 1.8 Emissions from the composting and subsequent land application of livestock manures are currently Not Estimated due to a lack of activity data.		
Major improvements since last submission	No major improvements		

Emissions of nitrous oxide from agricultural soils are estimated using IPCC (2006) Tier 1 and 2 methodology (IPCC Equations 11.1, 11.2), implementing UK-specific EF and parameters where available.

The IPCC (2006) method involves estimating direct emissions from (see also Figure 5.13):

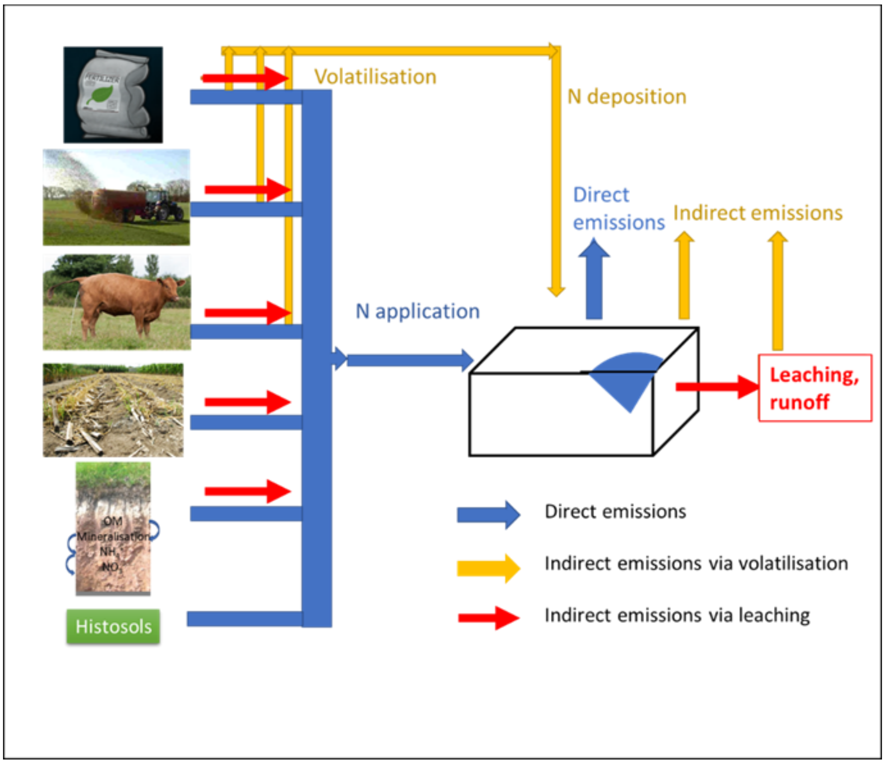
(i) The use of inorganic fertiliser
(ii) Application of livestock manures to land
(iii) Application of sewage sludge and other organic sources to land

(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 nitrous oxide emissions are estimated from 2 sources:

(viii) Atmospheric deposition of agricultural NO_x and NH_3 (from (i), (ii), (iii) and (iv))
(ix) Leaching and run-off of agricultural nitrate (from (i), (ii), (iii), (iv), (v) and (vi)).

Figure 5.13 Sources of Nitrous Oxide (N_2O) emissions from soils

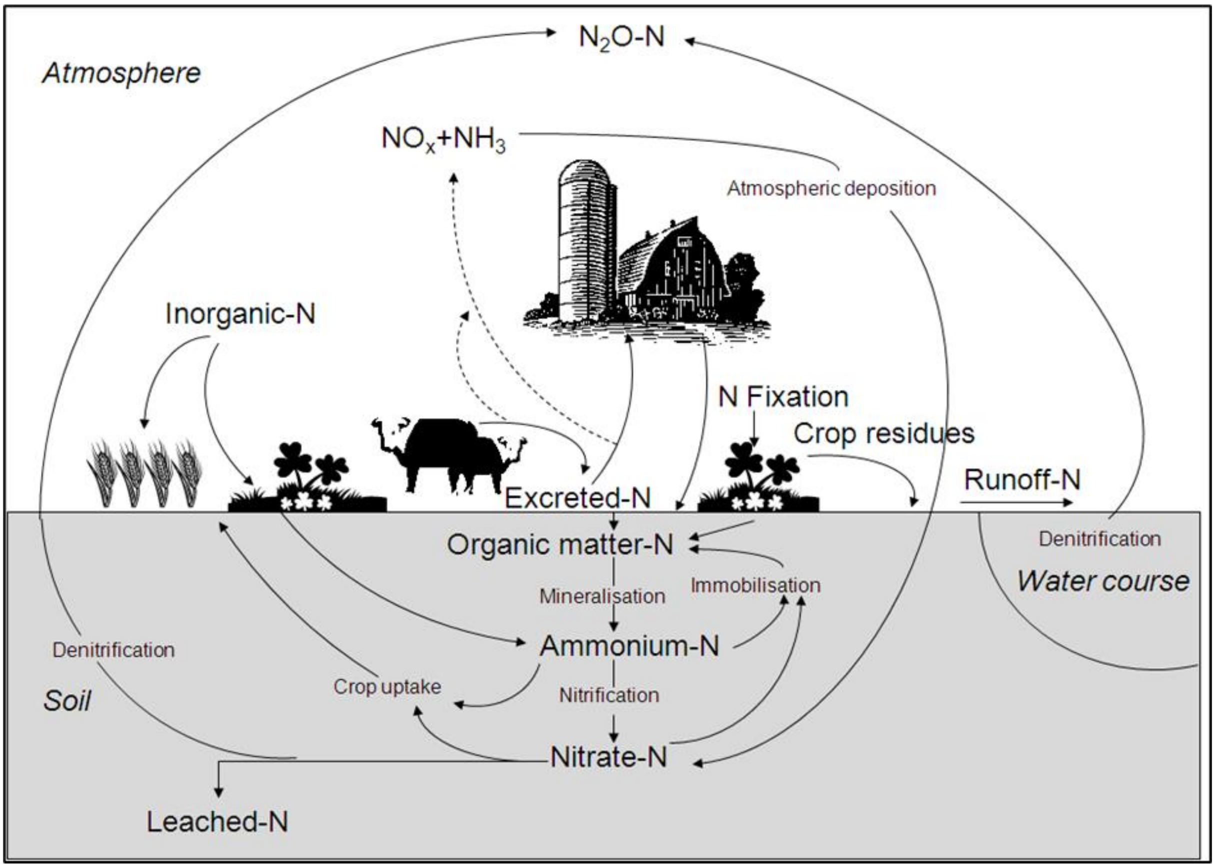


Further details on activity data and EF are given in **Annex 3.3**.

5.5.1.1 Source category emissions: significance, trends and drivers

The total emissions of N_2O in 2021 across all agriculture sources were 41.5 kt. Emissions have decreased by 18% since 1990.

Figure 5.14 Simplified nitrogen cycle highlighting the steps involved in the production of nitrous oxide (N_2O) from agriculture



5.5.2 Methodological issues

Sources leading to nitrous oxide (N_2O) emissions include slurry, farmyard manure (FYM), sewage sludge, digestates, fertiliser, and dung and urine depositions to grazed lands. 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; Sylvester-Bradley et al., 2015). Following the guidelines of the IPCC (2006) for the derivation of N_2O EFs, all the data from the experiments were collected over a 12-month period. The static chamber methodology was used for emission measurement, which is consistent with the Global Research Alliance guidelines (de Klein and Harvey, 2012; Charteris et al., 2020). Data were collated by N-source: surface-spread and broadcast slurry, farmyard 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 N application rates, data on the soil characteristics, 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 fertiliser N category 'Other N to grassland', the EFs for fertiliser application, FYM, broadcast slurry and grazing were lower than the IPCC default value of 1%.

5.5.2.1 Inorganic Fertiliser

Direct N_2O emissions from fertiliser N applications are calculated using values of EF_1 derived from UK-specific measurements (Topp et al., *in prep*). Direct N_2O 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) (see small changes in parameters compared to previous years).

$$\ln(CumN_2O + 1.63) = 0.8404(\pm 0.06846) + 0.001518(\pm 0.0001077) * NRate \quad \textbf{(eq.1)}$$

$$\text{Ln}(CumN_2O + 1.63) = 0.5700(\pm 0.1107) - 0.0001942(\pm 0.0001968) * NRate + 0.3962(\pm 0.1326) * RainYr + 0.003284(\pm 0.0002291) * NRate * RainYr \quad \textbf{(eq.2)}$$

$CumN_2O$ = cumulative annual N_2O-N emission (g ha^{-1})

NRate = rate at which fertiliser N is applied (kg ha^{-1})

RainYr = annual average rainfall (m) limited to 0 to 1.3 m.

EF are derived as shown in equation 3.

$$((CumN_2O \text{ at specified } NRate - CumN_2O \text{ at zero } NRate) \,/\, NRate \quad \textbf{(eq.3)}$$

The correction multipliers to the total N_2O losses due to the bias for the log transformation were: 1.011 and 1.02 for urea and ammonium nitrate application, respectively.

The activity data for annual fertiliser applications are primarily obtained from the British Survey of Fertiliser Practice (BSFP) which provides sampled data from a stratified survey of farm types across Great Britain; these data are analysed and upscaled to generate UK-wide fertiliser application data by fertiliser type and crop type. In addition the BSFP data provide temporal information that enables analysis of the timing of fertilisers by type across the year; this added detail enables the UK method to reflect the different climatic conditions that prevail at the time of fertiliser application, which impacts upon the emissions. For a couple of fertiliser types that are not produced in the UK, the activity data are obtained from fertiliser import data.

As a data validation step, the UK inventory team also consults with the farming industry, such as the Agricultural Industries Confederation (AIC), to compare the inventory fertiliser activity data against other statistics that are gathered from suppliers. In some instances the inventory data do deviate from the industry statistics; the Inventory Agency continues to explore the reasons for these differences with the fertiliser suppliers, to seek any potential improvement in total fertiliser application per fertiliser type.

Crop data are shown in **Annex tables A 3.3.10** to **Table A 3.3.13**.

5.5.2.2 Application of livestock manures to land

Emissions are calculated following IPCC methodology (2006, equation 11.1) using country-specific EFs. Proportions of managed manure N applied to GB cropland are derived from Smith (2012). Assumptions regarding proportions of manures spread to land for Northern Ireland were made based on data provided directly by DAERA (DAERA, 2021). The values assumed (see following paragraphs) are constant throughout the time series with the exception of poultry as described below.

The nature of manure management differs between farm 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 for those farm types than to arable crops. In general, slurries are less likely to be transported long distances than solid manures. The fate of manure is estimated 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.

In the case of dairy, the UK inventory assumes for England, Wales and Scotland that, 24% slurry and 40% of FYM is spread to cropland. For Northern Ireland, 9.5% of slurry is spread to cropland and 25.5% of FYM is spread to cropland. In the case of beef cattle, for England, Wales and Scotland it is assumed 12% is slurry and 33% FYM is spread to cropland and for Northern Ireland the values are 9.5% and 20% for slurry and FYM, respectively.

For sheep, all (100%, as FYM) of managed manure is assumed to be spread to improved grassland as a simplification of actual practice. Based on statistical analyses of a limited number of survey records from the British Survey of Fertiliser Practice (2007 to 2012) for England and Wales (no survey records were available for Scotland and Northern Ireland, but the location of managed manure spreading is likely to be more similar to Wales than England, on the basis of the similarity of relative national crop and grass areas) we estimated that 87% of all managed manure from all sheep in the United Kingdom is spread to improved grassland, and 13% to crop. These percentages are based on assumptions from regional data (BSFP 2007-2012), where 94.7 % of managed sheep manure in Wales was spread to improved grassland and the remainder to crop; and that 77.5 % of managed sheep manure in England was spread to improved grassland and the remainder to crop. No survey records were available for Scotland and Northern Ireland, but the location of managed manure spreading is likely to be more similar to Wales than England, on the basis of the similarity of relative national crop and grass areas (England 50% grass; Wales 92% grass; Scotland 70% grass; and Northern Ireland 93% grass). The model assumption of 100% applied to grassland has no actual impact on the emission estimate.

In the case of pigs, for England, Wales and Scotland, 54% slurry and 78% of FYM is spread to cropland. For Northern Ireland, 16% of slurry is spread to cropland and 78% of FYM is spread to cropland.

In the case of poultry, the percentage of layer manure and all other poultry manure spread to cropland across the time series in the UK is detailed in **Table A 3.3.7** (Smith et al., 2001b; Defra, 2022c). Manure that has been sent to incineration is excluded from these data.

The inventory model currently assumes that all (100%) of managed manure from minor livestock (horse, goat and deer) is spread to improved grassland.

Country-specific direct N_2O EF values were derived from a large number of experiments distributed across the UK (Defra, 2016a, Defra, 2014b). Derived values for the direct N_2O EF are 0.75, 0.33 and 1.01% of applied N for slurry, farmyard manure and poultry manure, respectively (Topp et al., *in prep*.)

5.5.2.3 Application of other organic sources to land

Emissions of nitrous oxide are calculated from:

$$E_{N2O} = Q \times TN \times EF_{N2O}$$

Where Q is the quantity of organic material applied (m^3), TN is the total nitrogen content of the material (kg m^{-3}); EF_{N2O} is the emission factor applied (as % of the TN applied).

For sewage sludge and non-manure based digestates the default IPCC EF_1 of 0.01 kg N_2O-N per kg total N applied is used to estimate direct N_2O emissions. For manure-based digestates the same EF as slurry is used (0.75% of N applied).

5.5.2.3.1 Sewage sludge

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 from a combination of the UK environment regulatory agencies and water companies. The N content is assumed to be 3.6% of the dry matter content. According to CEH (2017), in the UK 95% of sewage sludge is assumed to be applied as sludge cake and 5% as a liquid (ADAS, personal communication, December 2006), with no change across the time series. 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 are assumed per DA.

For the inventory model we use the average RB209 value for the total N content of biosolids (4 categories: digested cake, thermally dried, lime-stabilised and composted), assuming equal proportions of each, giving 3.7% on a DM basis. For the purposes of expressing the NH_3 emission factor as a %TAN applied, the TAN content is assumed to be 10% of the TN content (RB209) for sludge cake and 50% (assumed similar to livestock slurry) for liquid sludge. The N_2O EF from application of sewage sludge is presented in **Table A 3.3.9**.

No data have currently been collated regarding proportional split in application to grassland and arable land, so a simplistic assumption is made that it is applied approximately in proportion to the ratio of improved grassland to arable land at DA level. Based on 2010 land area values (and used across the time series for simplicity) this gives a proportional application to improved grassland of 50%, 94%, 71% and 93% for England, Wales, Scotland and Northern Ireland, respectively, with the remainder to arable. We have updated sewage sludge data for 2019 with actual data and used 2019 data for 2021. For both sewage sludge and non-manure based digestate applied to land, the N_2O EF_4 (mean and uncertainty) and EF_5 (uncertainty) were updated according to the IPCC 2019 refinement to the 2006 guidelines.

5.5.2.3.2 Manure-based digestate and other non-agricultural materials

Application 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. The N_2O EFs for these categories are in **Table A 3.3.9**.

Four categories of digestate applied to land are included depending on feedstock: livestock manure, energy crops, food-waste and other organic residues, and for the purpose of the emission calculations each is treated individually (i.e. excludes and potential interactions that may arise through co-digestion). Emissions from digestate arising from the anaerobic digestion of livestock manures are included in the relevant livestock sector calculations. Emissions from spreading of digestate arising from the anaerobic digestion of manures, food waste, energy crops and other organic residues are included in this sector.

Material inputs to anaerobic digestion facilities are derived from the National Non-Food Crops Centre (most recently NNFCC, 2021), with estimated capacity and type of feedstock. Total N content of digestates is based on literature review (Tomlinson et al., 2019) giving mean values of 5.00, 3.97 and 3.35 kg t^{-1} for food-waste, energy crop and other organic residue based digestates, respectively, and it is assumed there is no trend across the time series. The TAN content of all digestate types is assumed as 80% of the total N content (RB209). Although co-digestion of two or more feedstocks is commonly practiced, for the purpose of the emission calculations each is treated individually. As with sewage sludge, we currently have no data relating to the proportion of digestate applied to grassland or arable land, so the same assumptions are applied (i.e. application in proportion to total land area as improved grassland or arable at DA level). Thus, proportion applied to improved grassland is assumed as 50, 94, 71 and 93% for England, Wales, Scotland and Northern Ireland, respectively, with the remainder to arable, and constant across the time series.

Composted materials subsequently applied to land include green wastes, other organic materials (e.g. kitchen wastes) and mixed other materials (e.g. cardboard), with activity data for recent years sourced from government and local authority statistics and the Waste Data Interrogator returns system (Tomlinson et al., 2019). Emissions from the composting process are reported in the Waste sector. Emissions from the composting and subsequent land application of livestock manures are currently Not Estimated in the UK GHGI due to a lack of activity data; it is not a widespread practice and to date the UK farm survey data have not identified any activity data for use in the inventory.

The EFs to estimate emissions of N_2O from dairy, sheep, pig, poultry and minor livestock manure spread to land (as a % of N applied) were derived from a large number of experiments distributed across the UK also under Defra project AC0116 (Topp et al., *in prep.*). The resulting values are: slurry 0.7475, FYM and poultry manure 0.3635, for digestate is assumed to be the same as that for slurry.

5.5.2.4 Urine and dung deposited by grazing animals in the field

Emissions are calculated a slightly modified IPCC methodology (equation 11.1), as different EFs are applied for urine and dung in the case of cattle. Estimates of the times of the year when ruminant stock types were housed were made by Parsons and Williams (2015) in a module of the FBS in England. It is 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 EF_3 for urine and dung are applied accordingly (**Annex 3.3**, **Table A3.3.10**). As the UK do not have any experimental data specifically for sheep grazing, EF_3 for sheep excreta deposited to land is estimated by scaling down from cattle the ratio of EF_3 for excreta from sheep vs cattle as exactly 50% of the CS values for cattle urine and dung. For swine, poultry, goats, deer and horses where behaviour of outdoor animals is quite different to that of cattle and sheep, the default value in IPCC (2019) EF_3 is used, as this is regarded as the EF that is most representative of UK circumstances in the expert opinion of the UK Inventory Agency.

The UK applies a CS N_2O EF for cattle urine and dung, based on measurements, but there are insufficient CS data for N_2O emissions from sheep excreta during grazing. According to the 2006 IPCC Guidelines (vol. 4, chap. 11, table 11.1), the N_2O EF for sheep excreta is 50% of the value for cattle excreta. This is supported, for sheep urine, by information in the 2019 Refinement to the 2006 IPCC Guidelines (table 4A.1 on wet climates gives a revised value of 0.39% for sheep compared with 0.77% for cattle), while the EF for sheep dung contained therein is less than 50% of the value for cattle (0.04% for sheep compared with 0.13% for cattle). On the basis of this information, the UK has derived an N_2O EF for sheep urine and dung by halving the CS values for cattle urine and dung. We note that the resulting values (0.315% and 0.097% for sheep urine and dung, respectively) are closely comparable the revised values for sheep given in the 2019 Refinement to the 2006 IPCC Guidelines, and hence the UK considers that their use is justified and representative of UK circumstances.

5.5.2.5 Crop Residues returned to soils

Direct N_2O emissions from crop residues are estimated following IPCC (2006, equation 11.2) using the default value for EF_1. 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 Tables A 3.3.13** and **A 3.3.14**). 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 NHI 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).

$$HI_{DM} = Crop_T / Crop_T + AG_{DM(T)} \quad \text{(eq.4)}$$

$$HI_N = \left(Crop_T * Crop_{N(T)}\right) / \left(Crop_T * Crop_{N(T)} + AG_{DM(T)} * N_{AG(T)}\right) \quad \text{(eq.5)}$$

$Crop_{N(T)}$ = fraction of N in the DM of $crop_T$.

$$AG_{DM(T)} = Crop_T - (Crop_T * HI_{DM})HI_{DM} / HI_{DM} \quad \text{(eq.6)}$$

$$AG_{DM(T)} = (1 - HI_{DM}) * Crop_T / HI_{DM} \quad \text{(eq.7)}$$

The IPCC default values for the ratio of above to below ground biomass were used, except for crops not defined by the IPCC, e.g. sugar beet. These were evaluated by Williams and Goglio (2017).

Estimates of the N returned to soil under 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).

5.5.2.6 Mineralisation

N_2O emissions from mineralisation of soil organic matter on land converted to Cropland more than 20 years ago are included in the Agricultural inventory (emissions from more recent land use change are included in the LULUCF inventory). Details are included in the LULUCF chapter (**Section** 6.3 Category 4B Cropland and in **Annex 3**).

N_2O emissions from mineralisation of soil organic matter as a result of Cropland Management activities are estimated from the change in soil carbon stocks due to Cropland Management using a Tier 1 approach with the mineralised N calculated from:

mineral soil carbon stock losses * (1/C:N ratio)

where C/N is the IPCC default value of 15. The methodology used to assess change in soil carbon stocks due to Cropland Management is described in **Section** 6.3 and **Annex 3** and briefly consists of using a Tier 3 model described in section A 3.4.2 of the NIR annex.

5.5.2.7 Cultivation of histosols (organic soils)

Direct N_2O emissions from the cultivation of histosols are estimated following IPCC (2006, equation 11.2) using UK-specific data for the area of cultivated histosols. Areas are based on an estimate from a BEIS-funded research project (Evans et al., 2017), specified as cropland or intensive grassland (368.6 kha combined areas in 2021). IPCC Tier 2 EFs from the Peatland code report (Defra, UK - Science Search) are used for cropland and intensive grassland (see LULUCF chapter, **Section** 6.3 Category 4C Grassland). **Annex section A 3.4.6** covers emissions from organic soils and EFs are listed in a supplementary Excel file (*see Supplementary file EFs UK inventory agriculture_2023 submission.xlsx*)

Updates to the deforestation areas on organic soils feed through into changes to the total cropland and intensive grassland areas on organic soils over time.

Activity data and emissions are shown in **Annex Table A 3.3.15**.

5.5.2.8 Atmospheric deposition of NO_X and NH_3

Indirect emissions of nitrous oxide (N_2O) from the atmospheric deposition of ammonia (NH_3) and oxides of nitrogen (NO_X) are estimated according to IPCC (2006, equation 11.9) using a country-specific value for EF_4 (*Pers. comm.*: Anthony, 2021). The derived overall emission factor is similar to the recently revised IPCC (2019) default N_2O EF_4 of 1.4±0.15%, for a 'wet climate' where annual rainfall exceeds potential evapotranspiration, based on an updated global database of measurements of emissions following applications of manufactured fertiliser nitrogen and organic manures (excluding urine and dung) to agricultural land (IPCC 2019; Table 11.3). Whilst the UK GHG Platform research has not led to the derivation of a UK-specific EF, we note that the UK evidence was used to derive a value consistent with the value presented in the 2019 Refinement, and hence in our expert judgement to use the 2019 Refinement EF is the most representative EF option available to best reflect UK circumstances; we consider that applying that EF minimises the uncertainty in the UK Inventory for this source. Country-specific values were also applied for the fraction of N that is volatilised as NH_3 and NO_x from inorganic fertiliser and organic (livestock manure, sewage sludge, digestate, grazing returns) N applications to land ($Frac_{GASF}$ and $Frac_{GASM}$, 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 NH_3 EF are used for inorganic fertiliser and organic manure applications to land, as detailed in the UK Informative Inventory Report. $Frac_{GASF}$ and $Frac_{GASM}$ values range between 0.03-0.15; the NH_3 EFs are given in a supplementary excel file. NO_x emissions from fertiliser, organic manure applications, grazing returns to grassland, and for crop residues are assumed to be a factor of 0.6 of the N_2O emissions estimated for each source, whereas those from applications to arable land are assumed to be a factor of 0.4 (see detail in the UK Informative Inventory Report). The method used corrects for the N content of manures used as fuel (poultry litter incineration) which are therefore not applied to land.

5.5.2.9 Leaching and runoff

Indirect emissions of nitrous oxide (N_2O) from leaching and runoff are estimated according to IPCC (2006, equation 11.10) using the default value for EF_5. The sources of N considered are synthetic fertiliser application, animal manures, digestates 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 ($Frac_{LEACH}$) is used for both inorganic fertiliser and manure application to grassland and excretal returns from grazing livestock, based on the UPCYCLE model (*Pers. comm.*: Anthony, 2021). For fertiliser and manure application to arable land, crop residues and sewage sludge the default IPCC (2006) $Frac_{LEACH}$ 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. For other organic sources applied to land, $Frac_{LEACH}$ values of 10 and 30% of applied N are used for grassland and arable land, respectively, to estimate leached N based on Cardenas et al. (2013). In the case of NO_x, the emission multiplier was set to 0.60 and 0.40 of direct emission from N application to grassland and arable land, respectively. In the case of swine and goats, the value was set to 0.60 of direct N_2O emissions for outdoor pigs.

Activity data and emissions are shown in **Annex Table A 3.3.16** and **Table A 3.3.17**.

5.5.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty per IPCC source category.

The estimates of uncertainties in emissions were calculated using an Approach 2 method (Monte Carlo simulation) as described by the IPCC. The uncertainties in the estimates of crop areas were provided by the devolved administrations, and the uncertainties in estimates of fertiliser application rates to crops were calculated from the BSFP. Together these give estimates of fertiliser 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 UK specific emission factors and model parameters were calculated from the data used to derive the emission factors.

The UK inventory uncertainty calculations have been reviewed and updated by the UK sector experts within the 2023 submission; the analysis is now fully consistent with the methods applied in the UK inventory and uncertainty parameters will be kept under review for subsequent submissions.

We note that the UK continues to apply the indirect N_2O EF_4 (mean and uncertainty parameters), EF_5 (uncertainty bounds only) and the N_2O EF_3 (mean and uncertainty, lower mean value and narrower uncertainty bounds) for poultry, deer, horses, pigs and goats according to the IPCC 2019 Refinement to the 2006 Guidelines, as they are regarded as more representative of UK circumstances based on the expert judgement of the UK Inventory Agency.

Emissions are calculated from a range of activity data and appropriate emission factors (see **Annex 3**). Emissions of nitrous oxide 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 BSFP). 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.

5.5.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.11**.

5.5.5 Implied emission factors

All sources IEFs agree with the IPCC default value of 1% (inorganic and organic fertilisers, crop residues and mineralisation) except for pasture, range and paddock with 0.33%, histosols with 11.9 kg N ha^{-1}, higher than the IPCC default values of 2% and 1% (the latter for sheep) and 8 kg N ha^{-1}, respectively.

5.5.6 Source-specific planned improvements

Review methods and assumptions in grassland and cropland; including the estimates of fertiliser application rates from the BSFP; calculate N_2O emissions from spreading of compost.

Seek UK activity data or identify a suitable IPCC good practice gap-filling option, in order to address the minor gap in the UK GHGI estimates from the spreading of composted manures.

Improve estimates of the urea content of the ‘other nitrogen’ compound fertiliser types.

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

5.5.7 Source-specific recalculations

Details of and justifications for recalculations to activity data and to emission factors are given in the tables below.

Table 5.5 3D Source specific recalculations to emissions since previous submission (kt)

IPCC Category	Source Name	2022 submission		2023 submission		Units	Comment/Justification
		1990	2020	1990	2020		
3.D.1.1	Direct N_2O Emissions from Managed Soils: Inorganic N fertilisers	20.03	10.91	20.14	10.88	kt	Grassland: Improved methodology to estimate fertiliser application rates; Updates to the quantity of Di-Ammonium Phosphate applied to crops based on improved methodology; Update of provisional surveyed fertiliser rate for Northern Ireland in 2020; Arable: As Grassland plus revision of the uptake of ‘placed’ N fertiliser as a mitigation option and minor changes to crop areas
3.D.1.2.a	Direct N_2O Emissions from Managed Soils: Organic N Fertilisers – Animal Manure Applied to Soils	4.60	3.88	4.63	3.90	kt	Emissions from spreading affected by the changes detailed for ‘Manure management: Nitrous Oxide emissions’ plus spreading mitigation uptake for cattle and pig slurry updated; Introduced NI-specific data for proportion of cattle slurry and FYM applied to grassland and arable land
3.D.1.2.c	Direct N_2O Emissions from Managed Soils: Organic N Fertilisers - Other Organic Fertilisers Applied to Soils	0.00	1.00	0.00	1.07	kt	Updated amounts of manure and non-manure based digestate spread to land
3.D.1.3	Direct N_2O Emissions from Managed Soils: Urine and Dung Deposited by Grazing Animals]	2.948	2.374	2.952	2.379	kt	Emissions from urine and dung affected by the changes detailed for ‘Manure management: Nitrous Oxide emissions’ affecting N excretion

IPCC Category	Source Name	2022 submission		2023 submission		Units	Comment/Justification
		1990	2020	1990	2020		
3.D.1.4	Direct N_2O Emissions from Managed Soils: Crop Residues	5.19	5.47	5.34	5.10	kt	Updates to crop yield estimates and fertiliser N activity data used in crop residue calculations
3.D.1.5	Mineralisation/Immobilization Associated with Loss/Gain of Soil Organic Matter	0.61115	1.30359	0.61116	1.30387	kt	Minor changes to the area of cropland on organic soil
3.D.1.6	Direct N_2O Emissions from Managed Soils: Cultivation of Organic Soils	5.68	5.37	7.31	6.93	kt	Minor changes to organic soil areas and adjustment to peatland restoration data for intensive grassland in England; Emission factors applied to cropland and intensive grassland have been updated from T1 to T2 values
3.D.2.1	Indirect N_2O Emissions From Managed Soils – Atmospheric Deposition	3.14	2.56	3.01	2.59	kt	As 'Direct N_2O Emissions from Managed Soils' plus revisions to NO_x ratios for the poultry sector
3.D.2.2	Indirect N_2O Emissions From Managed Soils - Nitrogen Leaching and Run-off	6.34	5.32	6.38	5.19	kt	As 'Direct N_2O Emissions from Managed Soils' plus adjustment to the FracLeach value for goats, deer and horses to ensure consistency across all sectors

Table 5.6 3D Recalculations to Emission Factors since the previous inventory (kg N_2O-N/kg N)

IPCC Category	Source Name	2022 submission		2023 submission		Units	Comment/Justification
		1990	2020	1990	2020		
3.D.1.1	Direct N_2O Emissions from Managed Soils: Inorganic N fertilisers	0.00810	0.00730	0.00815	0.00731	kg N_2O-N/kg N	Reason for change as above
3.D.1.2.a	Direct N_2O Emissions from Managed Soils: Organic N Fertilisers – Animal Manure Applied to Soils	0.00609	0.00606	0.00610	0.00607	kg N_2O-N/kg N	Reason for change as above
3.D.1.2.c	Direct N_2O Emissions from Managed Soils: Organic N Fertilisers - Other Organic Fertilisers Applied to Soils	0	0.0094	0.0075	0.0093	kg N_2O-N/kg N	Reason for change as above
3.D.1.3	Direct N_2O Emissions from Managed Soils: Urine and Dung Deposited by Grazing Animals]	0.003331	0.003299	0.003332	0.003301	kg N_2O-N/kg N	Reason for change as above
3.D.1.6	Direct N_2O Emissions from Managed Soils: Cultivation of Organic Soils	9.46	9.54	11.86	11.94	kg N_2O-N/kg N	Reason for change as above

5.6 SOURCE CATEGORY 3E – PRESCRIBED BURNING OF SAVANNAS

This source is not relevant in the UK.

5.7 SOURCE CATEGORY 3F – FIELD BURNING OF AGRICULTURAL RESIDUES

5.7.1 Source category description

	Source included	Method	Emission Factors
Emissions sources	3F11: Wheat 3F12: Barley	T1 T1	D D
Gases Reported	CH_4, N_2O, NO_x, CO, NMVOC, SO_2		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	See **Section 5.10**.		
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.		

5.7.2 Methodological issues

The National Atmospheric Emissions Inventory reports emissions from field burning under the category agricultural incineration. The estimates are derived from emission factors calculated according to IPCC (1997) and from USEPA (1997).

The estimates of the masses of residue burnt of barley, oats, wheat and linseed are based on crop production data from DEFRA (England & Wales), The Scottish Government (Scotland) and DAERA (Northern Ireland), 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.

5.7.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty per IPCC source category. The UK inventory uncertainty calculations have been reviewed and updated by the

UK sector experts within the 2023 submission; the analysis is now fully consistent with the methods applied in the UK inventory and uncertainty parameters will be kept under review for subsequent submissions.

Field burning ceased in 1993, and emissions are reported as NO after this date.

5.7.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.11**.

5.7.5 Source-specific recalculations

No recalculations were carried out in this sector.

5.7.6 Source-specific planned improvements

No improvements are planned.

5.8 SOURCE CATEGORY 3G - LIMING

5.8.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3G1: Limestone $CaCO_3$ 3G2: Dolomite $CaMg(CO_3)_2$	T1 T1	D D
Gases Reported	CO_2		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	See **Section 5.10**.		
Completeness	A general assessment of completeness for the inventory is included in **Section** 1.8		
Major improvements since last submission	Adjustment to the liming areas and rates for NI and introduction of 3-year rolling average for all DAs		

5.8.1.1 Source category emissions: significance, trends and drivers

Total CO_2 emissions from liming in 2021 were 1175 kt CO_2. Emissions in 2021 were 15.6% higher compared to 1990.

5.8.2 Methodological issues

CO_2 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 sugar beet lime - LimeX) an emission factor of 120 tC/kt applied is used, and for dolomite application, 130 tC/kt.

These factors are based on the stoichiometry of the CO_2 loss from the carbonates and assume pure limestone/chalk and dolomite.

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 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, Calcifert, granules, Humistar, lime slag, screed lime (Defra, *pers. comm.*); the majority of these are $CaCO_3$ based limes and thus were included in the activity data for limestone.

Limex is assumed to have 46% $CaCO_3$ content (British Sugar, Chemical Safety Data; Median of LimeX45 (45%) and LimeX70 (52%) $CaCO_3$ content).

Activity data and emissions are shown in **Table A 3.3.18**.

5.8.3 Uncertainties and time-series consistency

Uncertainty in both the activity data and emission factor are judged to be low. The main source of uncertainty in the estimates is caused by non-publication of some activity data due to commercial restrictions although these are not judged to be very significant.

There is good time series consistency as there has been continuity in the published data sources.

5.8.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.11**.

5.8.5 Source-specific recalculations

Table 5.7 3G Source specific recalculations to emissions since previous submission (kt)

IPCC Category	Source Name	2022 submission		2023 submission		Units	Comment/Justification
		1990	2020	1990	2020		
3G	CO_2 from Liming: Limestone and Dolomite	1014.03	947.83	1016.42	1117.28	kt	Adjustment to the liming areas and rates for NI; Introduction of 3 year rolling average for all DAs; Minor changes to arable crop areas for some years

5.8.6 Source-specific planned improvements

Emission factors and activity data will continue to be reviewed when new data are available

5.9 SOURCE CATEGORY 3H - UREA APPLICATION

5.9.1 Source category description

Emissions sources	Source included	Method	Emission Factors
	3H: Urea Application	T1	D
Gases Reported	CO_2		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	See **Section 5.10**.		
Completeness	A general assessment of completeness for the inventory is included in **Section** 1.8		
Major improvements since last submission	Revisions to application rates of urea-based fertiliser as part of the improved methodology adopted in the grass and arable sectors.		

5.9.1.1 Source category emissions: significance, trends and drivers

Total CO_2 emissions from urea application in 2021 were 252 kt CO_2. Emissions in 2021 were 14% lower compared to 1990.

5.9.2 Methodological issues

The annual amount of fertiliser as urea, alone or as part of urea ammonium nitrate (UAN), used in kt N was estimated from the BSFP (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).

Activity data and emissions are shown in **Table A 3.3.19**.

5.9.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty per IPCC source category.

The UK inventory uncertainty calculations have been reviewed and updated by the UK sector experts within the 2023 submission; the analysis is now fully consistent with the methods applied in the UK inventory and uncertainty parameters will be kept under review for subsequent submissions.

The same data source is used for the entire time series to ensure consistency.

5.9.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.11**.

5.9.5 Source-specific recalculations

Details of and justifications for recalculations to activity data and to emission factors are given in the table below.

Table 5.8 3H Source specific recalculations to emissions since previous submission (kt)

IPCC Category	Source Name	2022 submission		2023 submission		Units	Comment/Justification
		1990	2020	1990	2020		
3H	CO_2 from Urea Application	326.88	233.59	292.95	233.63	kt	Revisions to application rates of urea-based fertiliser as part of the improved methodology adopted in the grass and arable sectors; Minor changes to arable crop areas for some years

5.9.6 Source-specific planned improvements

Emission factors and activity data will continue to be reviewed when new data are available.

5.10 AGRICULTURE EMISSIONS IN THE OVERSEAS TERRITORIES (OT) AND CROWN DEPENDENCIES (CD)

5.10.1 Description

Emissions sources	3A: Enteric Fermentation 3B: Manure Management 3D: Agricultural Soils 3F: Field Burning of Agricultural Residues 3G: Liming 3H: Urea application In the CRF, all UK overseas territories and crown dependencies emissions data are reported in sector 3J.
Gases Reported	CO_2, CH_4, N_2O
Methods	Tier 1
Emission Factors	Default EFs (OTs), UK implied EFs (CDs)
Key Categories	None identified
Key Categories (Qualitative)	None identified
Completeness	Emissions are not estimated from 3G Liming for Bermuda, Cayman Islands and the Falklands, from 3H Urea application for Bermuda and the Falklands, and from 3F Field Burning of Agricultural Residues for any OT.
Major improvements since last submission	No major improvements.

Livestock and crop production occur in all of the UK overseas territories (OTs) and crown dependencies (CDs), resulting in emissions from categories 3A, 3B and 3D for all OTs and CDs. Agricultural GHG emissions from OTs and CDs combined made up less than 1% of the total UK agricultural emissions in 2021.

Note that no agricultural activities occur in Gibraltar, so emissions and activity data are zero for Gibraltar for all agriculture sector sources.

5.10.2 Methodological Issues

5.10.2.1 Emissions from livestock

The CDs have similar farming systems to the mainland UK and are located nearby with a similar climate. Due to this similarity, emissions for CDs are calculated by applying implied EFs calculated from the UK GHGI to data on livestock numbers for CDs aggregated to a basic classification. The implied EFs are calculated for each year, so that the implied EF can vary across the time series. Tables of animal numbers used in calculations are presented in **Annex 3.6.**

For OTs, emissions from livestock are calculated using Tier 1 methodology from the IPCC 2006 Guidelines (2019 Refinement for deer enteric fermentation and wastes), applying default EFs for the appropriate geographic region and climate type to the number of livestock reported.

For both CDs and OTs, data on livestock numbers was provided by local contacts.

5.10.2.2 Emissions from 3D Agricultural Soils

For the CDs, estimates of emissions from agricultural soils for all sub-categories 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 emissions related to loss of soil carbon). For OTs, the Tier 1 methodology from the 2006 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 3.6**. Emission factors taken from the 2006 IPCC guidelines were applied to all activity data from OTs.

In the Falklands, according to local expert judgement no synthetic fertilisers are applied, so emissions from this source are not estimated there.

In the Falklands, despite there being a very large area of grassland histosols, N_2O 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 N_2O emissions. The UK understands managed organic soils to be present only in the Falkland Islands and the Isle of Man, and absent from all other CDs and OTs.

5.10.2.3 Emissions from other agriculture categories

For the CDs, emissions 3F Field Burning of Agricultural Residues and 3H Urea Application are estimated in the same way as emissions from 3D Agricultural soils, by applying implied EFs from the UK GHGI to the land area of cropland (for both field burning and urea application) and grassland (for urea application only). Emissions from 3G Liming are calculated using the default 2006 IPCC EF of 0.12 kg C/kg limestone, applied to data on the quantity of limestone applied.

For the OTs, no emissions were estimated for categories 3F Field Burning of Agricultural Residues due to lack of available activity data. Emissions were not estimated from 3G Liming due to local experts indicating the activities do not occur. Emissions from 3H Urea Application are estimated for Cayman Islands only from 2014. Total agricultural land area and emissions from 3F, 3G, and 3H for each territory are presented in **Table 5.9.**

Table 5.9 Total agricultural area (kha) and emissions (kt) from 3F, 3G and 3H for the UK, Isle of Man, Falkland Islands, all other crown dependencies and all other overseas territories

Territory	Category	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
UK	Cropland area (kha)	5430	5386	5297	5148	4957	4899	4818	4813	4792	4772
	Grassland area (kha)	10,281	10,160	9,808	10,065	9,980	9,880	10,072	10,193	10,042	9,965
Isle of Man	Cropland area (kha)	50.49	50.29	50.04	49.79	49.54	49.54	49.54	49.54	49.54	49.54
	Grassland area (kha)	45.15	45.31	45.06	44.80	44.57	45.45	46.09	46.15	46.08	46.18
	3F emissions (ktCO_2e)	0.222	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3G emissions (ktCO_2e)	0.592	0.565	0.571	0.574	0.570	0.531	0.531	0.531	0.531	0.531
	3H emissions (ktCO_2e)	0.0950	0.0446	0.0387	0.0594	0.0727	0.0760	0.0654	0.0630	0.0493	0.0479
Falkland Islands	Cropland area (kha)	0.566	0.566	0.566	0.566	0.793	0.793	0.793	0.793	0.793	0.793
	Grassland area (kha)	1215	1215	1215	1215	1215	1215	1215	1215	1215	1215
	3F emissions (ktCO_2e)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
	3G emissions (ktCO_2e)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3H emissions (ktCO_2e)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Jersey, Guernsey	Cropland area (kha)	6.86	7.03	6.62	5.90	6.34	5.82	5.79	5.81	5.84	5.84
	Grassland area (kha)	4.83	4.66	4.84	5.16	4.51	5.11	5.11	5.08	5.04	5.03
	3F emissions (ktC2e)	0.286	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3G emissions (ktCO_2e)	0.157	0.157	0.158	0.152	0.145	0.140	0.140	0.140	0.140	0.140
	3H emissions (ktCO_2e)	0.122	0.063	0.051	0.070	0.093	0.108	0.110	0.108	0.083	0.083
Bermuda, Cayman Islands	Cropland area (kha)	0.338	0.740	0.740	0.740	0.740	0.740	0.740	0.740	0.740	0.740
	Grassland area (kha)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3F emissions (ktCO_2e)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
	3G emissions (ktCO_2e)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3H emissions (ktCO_2e)	NE	NE	NE	NE	NE	0.000349	0.000830	0.000735	0.000730	0.000730

To provide an indication of emissions reported as NE for 3F Field Burning and 3H Urea Application, cropland area for the OTs were calculated as a percentage of UK cropland area. Cropland area in the Falkland Islands does not exceed 0.002% of UK cropland area, as is the case for Bermuda and the Cayman Islands. The magnitude of emissions currently not estimated is therefore below the threshold of significance.

Whilst grassland area in the Falklands Islands is a sizeable proportion of UK grassland area at 12.1%, local contacts indicate that liming does not occur, and that synthetic fertiliser (including urea) application is minimal.

5.10.3 Uncertainties and time-series consistency

There is incomplete activity data available for several sub-categories, including field burning activity, crop production, and application of synthetic fertiliser, liming and urea application.

- Livestock statistics are not annually collected for all livestock types in all the OTs and CDs, so in some cases extrapolation was necessary, such as for non-cattle livestock for Jersey and all livestock types for Bermuda.
- For synthetic fertiliser application, in the Cayman Islands there is no data available before 2010, so this is extrapolated backwards based on an average. In Bermuda, only a single value is available for the whole time series, which has been assumed to remain constant.
- For emissions from crop residues, no data is available for the Falkland Islands so this source is not estimated. For Bermuda, crop production data is sourced from FAO up to year 2016 but is not available for later years so 2016 values have been extrapolated.
- For the CDs, data on application of limestone was compiled until 2015 but is not now available, so 2015 values have since been extrapolated.
- Due to lack of activity data for any year, emissions are not estimated from 3G Liming for Bermuda, from 3H Urea application for Bermuda and the Falklands, and from 3F Field Burning of Agricultural Residues for any OT.

IPCC Tier 1 default factors from the 2006 Guidelines have been used to estimate emissions for the OTs, using the closest regional values matching the climate and production systems. However, this does introduce uncertainty as local geography, livestock breeds and production practices may differ. A similar uncertainty in CDs emissions arises from use of UK GHGI implied emission factors because local production practices may differ significantly from the UK average. However, there is generally a lack of available data and resource to support using higher-tier methods or developing local-specific EFs.

Due to the proportionally small contribution of OTs and CDs to the national inventory, the UK only periodically aligns the CD emission factors with UK emission factors (currently the values from the 2019 submission are used), and for simplicity the UK present all OT and CD agriculture data in the CRF against 3J.

5.10.4 Planned improvements

The UK is considering changes to the institutional arrangements to make the process of updating the UK GHGI IEFs more robust in the future, to apply to activity data in the CDs. Improvements could be made to the method to update these IEFs regularly, instead of maintaining constant IEFs across the time series.

It has been added to the improvement plan to discuss the changes to the institutional structure to make it more feasible to fully integrate emissions from the OTs and CDs and other data, into the appropriate CRF categories, rather than having emissions reported under 3J.

The Inventory Agency is consulting with stakeholders to seek more complete activity data for the OTs and CDs where this is currently lacking, including updated livestock, fertiliser and crop production data from OTs, and liming data from the CDs. Further, the Inventory Agency will review the assumptions, based on local expert judgement, that no synthetic fertiliser, limestone or urea is applied in the Falklands.

Finally, there is a longer-term research project into organic soils and emissions in the Falkland Islands, the results of which will inform future inventory improvements once completed.

5.11 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 QA/QC plan is subject to annual review.

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 DESNZ) 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. Furthermore, the UK underwent an In-Country Review in 2019 and recommendations for improving the NIR have been taken into account in this submission.

Further details of the QAQC of the UK agriculture model are provided in the model description within **Annex A3.3.**

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 (CO_2, CH_4, N_2O, 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 UNFCCC submission.

Table 6.1 LULUCF Sector Overview (GBR submission)

LULUCF Greenhouse Gas Source and Sink Categories	KCA Rank[1] (gas)	Uncertainty[2]	1990 emissions total (Mt CO_2e)	2020emissions total (Mt CO_2e)	2021emissions total (Mt CO_2e)	Recalculations 1990[3] (Mt CO_2e	Recalculations 2020[3] (Mt CO_2e)
Total LULUCF	-		11.2	1.3	1.2	-2.3	-2.9
A. Forest Land	11 (CO_2)	15%	-13.4	-17.7	-17.6	-0.2	-0.5
B. Cropland	10 (CO_2),	20%	15.2	13.4	13.4	-1.7	-1.7
C. Grassland	23 (CH_4), 31 (CO_2)	15%	2.3	0.3	0.3	-0.6	-0.7
D. Wetlands	26 (CH_4)	40%	3.0	3.0	3.0	0.2	0.1
E. Settlements	22 (CO_2)	40%	5.8	4.1	4.1	0.0	-0.2
G. Harvested Wood Products	29 (CO_2)	15%	-2.1	-2.0	-2.0	0.0	0.1
Indirect N_2O emissions	-	165%	0.3	0.2	0.2	0.0	0.0

[1]These values are the rank for each category given in the KCA Ranking in **Annex Table A 1.5.1**

[2]All values for uncertainty refer to those associated with the latest year CO_2 emissions with the exception of Indirect N_2O where the value is for latest year N_2O.

[3]The values given are the difference in 1990 or 2020 emissions/removals from the data reported in the previous UK GHGI submission using AR5 GWP values (without feedbacks).

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. This information is presented in the last cell of the tables at the start of each section providing an overview of each of the LULUCF categories (*Major improvements since last submission*).

The LULUCF sector covers emissions and removals of direct greenhouse gases under seven categories, of which Forest Land (4A) and Harvested Wood Products (4G) are net sinks, and Cropland (4B), Grasslands (4C), Wetlands (4D), and Settlements (4E) are net sources (**Figure 6.1**) as well as indirect N_2O emissions. The UK does not report any emissions or removals from the Other Land (4F) category.

The LULUCF sector is the only sector within the national greenhouse gas inventory which reports both sources and sinks. The net sink is provided by removals from carbon stock gains in above-ground and below-ground biomass, soils and harvested wood products exceeding emissions from carbon stock losses and GHG emissions (CO_2, CH_4 and N_2O) from LULUCF activities (Figure 6.2).

Figure 6.1 LULUCF emissions and removals from the UK 1990-2021 by category

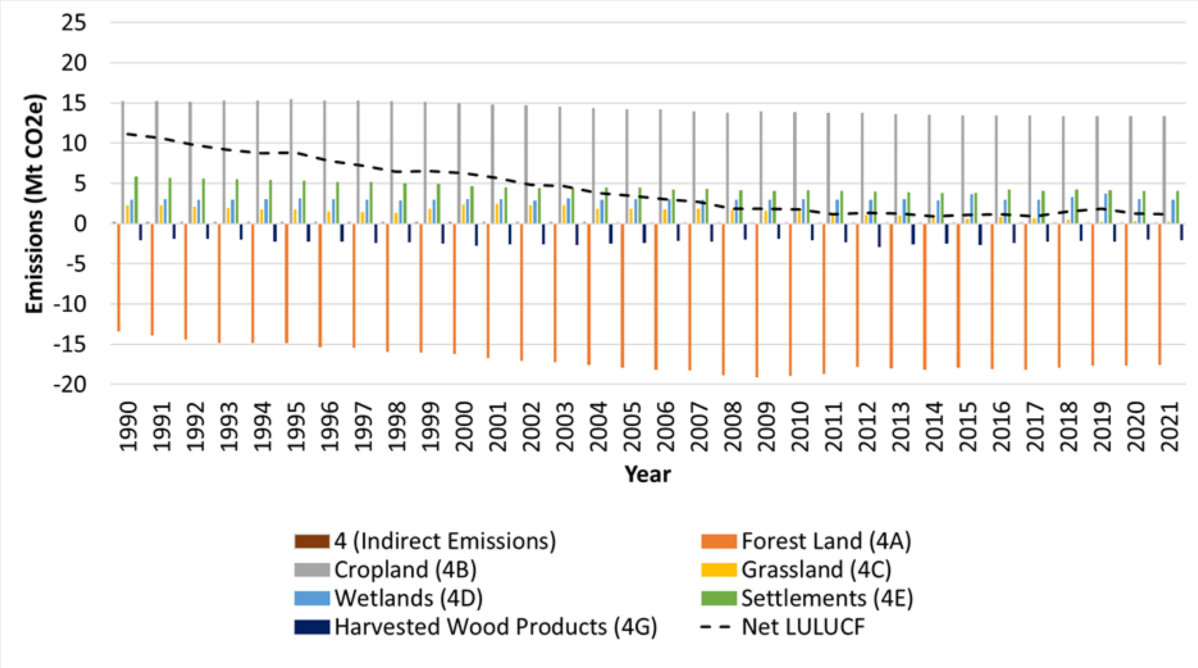
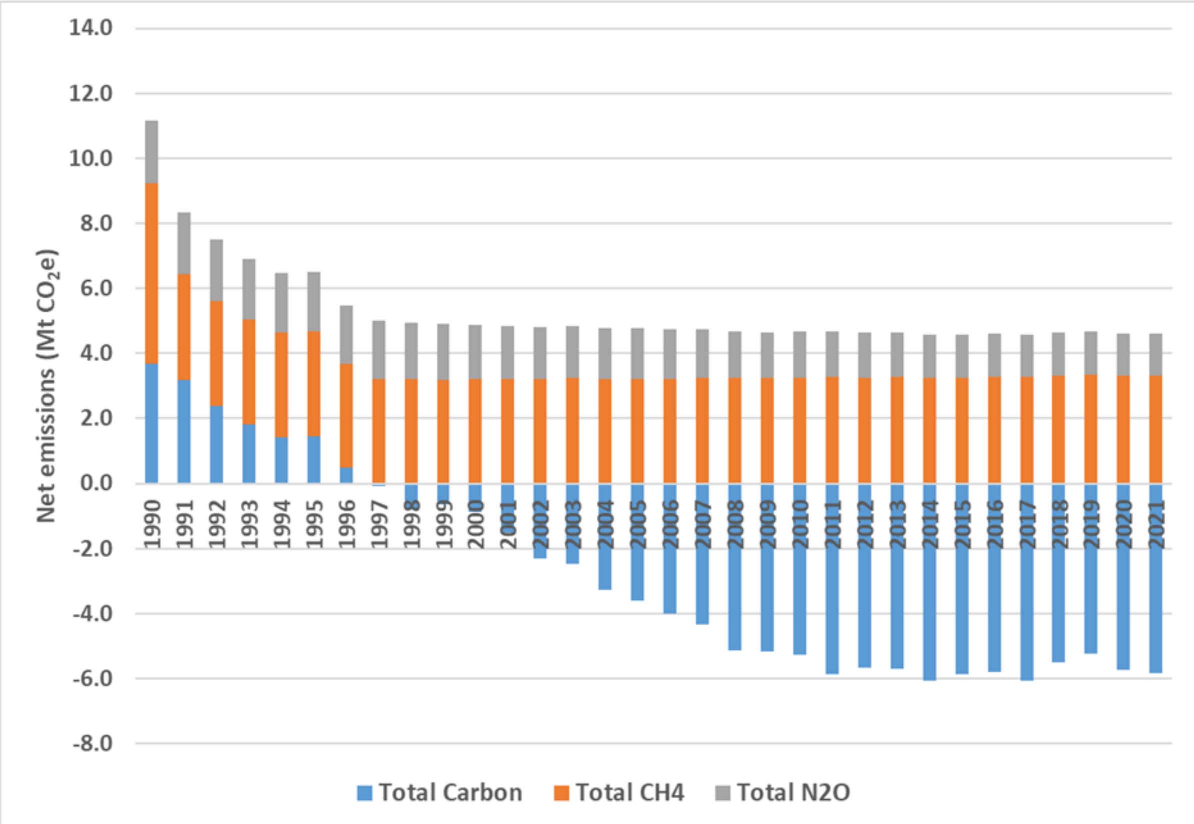


Figure 6.2 Contribution of all gases to net LULUCF emissions



6.1.1 The land use transition matrix

The areas used for the three UK CRF submissions are based on 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 2017) and the land areas reported in national statistics for the OTs and CDs:

- Gibraltar: 0.7 kha
- Isle of Man: 57.2 kha
- Guernsey: 6.3 kha
- Jersey: 12.0 kha
- Cayman Islands: 26.4 kha
- Falkland Islands: 1,217.3 kha
- Bermuda: 5.4 kha.

All areas are assigned to one of the LULUCF land use categories (Forest Land, Cropland, Grassland, Wetland, Settlements, Other). All land use is considered to be managed, apart from a small area of wetland (0.12 kha of sea) in Jersey which has been used for land reclamation since 2009.

The UK uses Approach 2 (IPCC 2006) for the representation of land use areas in the inventory. The UK estimates land use change using a Bayesian data assimilation approach (**Annex 3.4.2.1**). This constrains estimates of gross land-use change with national-scale census data, whilst retaining the detailed information available from other land-use data sources. The data sources are compiled at the individual country level (England, Scotland, Wales and Northern Ireland) and results are combined to give UK totals.

In order to 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 for the UK that:

- The total areas of land use categories from recent reports (2015 or 2021) 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 UK 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 Annual afforestation and deforestation areas 1990-2021	NFI main dataset (woods >0.5 ha) Tree cover outside woodland (0.1-0.5 ha)[1]	3,573
Cropland	UK Agricultural Census (Defra, DAERA, Scottish Government, Welsh Government)	Arable land Orchards and perennial crops Fallow and set-aside land	4,902
Grassland	ONS Standard Area Measurement land area – area of other categories[3]	NA	12,813
Wetlands	ONS Standard Area Measurement (water bodies >1km^2) UK Directory of Mines and Quarries, Google Earth imagery and Growing	Natural water bodies and reservoirs > 1km^2 Active and inactive peat extraction sites	964

LULUCF Category	Source dataset	Relevant components of dataset	Area in 2015, kha
	Media Association data (peat extraction sites) Peat condition maps (Evans *et al*. 2017), Growing Media Association and Peatland Action (2020) (peatland restoration data)	Areas of near-natural and rewetted wetlands	
Settlements	Land Cover Map 2015 (UKCEH 2015)	Urban land cover class Suburban land cover class	1,765
Other Land	Land Cover Map 2015 (UKCEH 2015)	Inland rock, supra-littoral rock, supra-littoral sediment and freshwater classes, adjusted for area of inland water included in Wetlands category	421

[1] Forestry Commission (2017) “Tree cover outside woodland in Great Britain report”

For the UK 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 **6.6** 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. Forest Land is the exception- the area in the latest inventory year is considered to be the most reliable and the initial and final areas are calculated back in time from that point.

Land cover surveys and agricultural land statistics are used to compile annual land-use change matrices for the OTs and CDs. Information on these data sources is given in **Annex 3.4.11**.

Gibraltar’s land area is all categorised as Settlement remaining Settlement, so all other areas refer to the UK only. Annual land use matrices for the GBR submission are shown in Table 6-4. Total areas in each year summed across all LULUCF categories may not equal the total land area in some years because of small rounding differences.

Table 6.3 Annual land-use change matrices for the GBR submission, kha (Total land area is 25 763.4 kha) (GBR - UK, 3 CDs, 4 OTs)

Year	Forest area at start of year	Forest Land converted to Cropland	Forest land converted to Grassland	Forest land converted to Wetland	Forest Land converted to Settlement	Cropland area at start of year	Cropland converted to Forest Land	Cropland converted to Grassland	Cropland converted to Wetland	Cropland converted to Settlement	Grassland area at start of year	Grassland converted to Forest Land	Grassland converted to Cropland	Grassland converted to Wetland	Grassland converted to Settlement	Wetland area at start of year	Settlement area at start of year	Settlement converted to Forest Land	Settlement converted to Cropland	Settlement converted to Grassland	Other land area at start of year
1990	3086.7	0.0	0.3	0.0	0.7	5376.2	6.3	63.3	0.0	2.6	14022.2	40.8	66.8	0.0	8.6	953.7	1710.4	1.0	0.4	1.8	421.3
1991	3133.8	0.0	0.3	0.0	0.7	5368.3	3.0	71.3	0.0	0.8	13987.4	23.5	68.5	0.9	7.4	953.7	1718.7	0.9	0.8	2.0	421.3
1992	3160.3	0.0	0.3	0.0	0.6	5367.0	2.9	66.4	0.0	1.5	13960.7	24.2	67.9	0.0	8.2	954.6	1724.8	0.4	0.5	1.9	421.3
1993	3186.7	0.0	0.3	0.0	0.6	5359.7	4.0	68.9	0.0	2.8	13929.9	24.2	66.4	0.0	8.8	954.6	1732.2	0.4	0.5	2.0	421.3
1994	3214.3	0.0	0.3	0.0	0.6	5353.8	3.6	68.1	0.0	1.2	13900.7	29.1	65.8	0.0	5.5	954.6	1740.4	1.1	0.3	2.6	421.3
1995	3247.2	0.0	0.3	0.0	0.6	5337.2	4.3	74.9	0.0	3.5	13877.1	24.4	61.6	0.3	8.3	954.6	1745.4	0.7	0.3	1.4	421.3
1996	3275.6	0.0	0.3	0.0	0.6	5322.6	3.7	70.7	0.0	2.2	13863.4	24.3	61.8	0.0	4.3	954.9	1754.3	0.6	0.6	2.2	421.3
1997	3303.0	0.0	0.4	0.0	0.7	5311.9	3.4	66.9	0.0	2.8	13848.1	25.9	58.2	0.0	4.4	954.9	1758.5	0.8	0.7	1.3	421.3
1998	3332.2	0.0	0.3	0.0	0.7	5302.7	3.0	63.6	0.0	1.5	13830.7	25.8	57.6	0.0	2.6	954.9	1763.5	0.5	0.6	1.7	421.3
1999	3360.4	0.0	0.3	0.0	0.8	5294.8	4.6	60.8	0.0	0.8	13816.1	24.1	53.4	0.0	2.7	954.9	1763.8	0.8	0.6	3.0	421.3
2000	3386.6	0.0	2.6	0.3	0.3	5262.5	2.7	81.8	0.0	1.8	13804.0	26.5	46.5	0.0	3.2	955.0	1765.3	0.8	0.1	1.9	421.3
2001	3413.0	0.0	3.1	0.3	0.3	5228.1	2.7	77.4	0.3	0.6	13817.3	19.2	51.3	0.0	2.6	955.3	1766.2	1.1	0.7	2.5	421.3
2002	3432.7	0.0	2.7	0.3	0.3	5195.0	2.7	81.0	0.3	1.1	13834.2	19.1	44.9	0.0	2.2	955.9	1767.0	0.8	0.3	1.5	421.3
2003	3451.1	0.0	3.1	0.3	0.6	5157.8	3.2	77.7	0.3	1.3	13851.5	17.1	48.4	0.2	2.3	956.5	1767.5	0.4	0.2	2.4	421.3
2004	3468.2	0.0	2.2	0.3	1.0	5131.7	2.4	71.1	0.3	1.0	13864.8	13.5	53.4	0.2	2.9	957.3	1769.2	0.8	0.2	1.6	421.3
2005	3481.1	0.0	2.4	0.3	0.9	5109.5	1.4	72.6	0.3	1.6	13874.4	12.4	49.6	0.2	3.0	958.2	1771.4	0.6	0.3	1.6	421.3

Year	Forest area at start of year	Forest Land converted to Cropland	Forest land converted to Grassland	Forest land converted to Wetland	Forest Land converted to Settlement	Cropland area at start of year	Cropland converted to Forest Land	Cropland converted to Grassland	Cropland converted to Wetland	Cropland converted to Settlement	Grassland area at start of year	Grassland converted to Forest Land	Grassland converted to Cropland	Grassland converted to Wetland	Grassland converted to Settlement	Wetland area at start of year	Settlement area at start of year	Settlement converted to Forest Land	Settlement converted to Cropland	Settlement converted to Grassland	Other land area at start of year
2006	3492.9	0.0	2.0	0.3	0.3	5058.8	3.6	95.1	0.3	1.7	13886.2	11.5	50.0	0.1	3.3	959.0	1774.3	0.8	0.5	1.3	421.3
2007	3504.8	0.0	2.8	0.5	0.7	5022.0	1.7	84.3	0.3	1.0	13917.3	10.1	54.2	0.1	2.9	959.6	1777.0	0.7	0.4	1.5	421.3
2008	3513.9	0.0	2.5	0.5	0.6	4988.3	1.2	86.0	0.3	0.9	13943.4	9.0	50.4	0.2	3.0	960.4	1779.0	0.2	0.5	1.9	421.3
2009	3520.7	0.0	2.6	0.5	0.5	4960.4	0.3	77.6	0.3	0.5	13974.6	8.7	48.6	0.1	1.9	961.3	1781.1	0.0	0.7	1.6	421.3
2010	3525.8	0.0	2.6	0.5	1.0	4920.2	1.3	85.8	0.3	2.2	13994.6	10.8	49.2	0.1	1.8	962.1	1781.8	0.5	0.2	1.4	421.3
2011	3535.1	0.0	2.0	0.5	0.9	4903.1	1.5	63.9	0.3	0.8	14011.0	15.4	55.4	0.0	2.5	962.9	1783.9	0.8	0.3	1.8	421.3
2012	3549.6	0.0	1.9	0.5	0.8	4889.0	1.4	67.7	0.3	0.4	14004.5	14.7	56.2	0.7	2.6	963.7	1785.1	0.9	0.2	1.9	421.3
2013	3563.5	0.0	1.9	0.3	0.8	4875.2	2.0	67.2	0.3	0.9	14005.2	12.8	56.3	0.0	1.7	965.1	1786.1	0.3	0.2	2.3	421.3
2014	3575.7	0.0	2.1	0.1	0.6	4859.6	1.4	69.1	0.3	1.4	14010.5	10.0	53.6	0.0	2.4	965.7	1787.2	0.3	0.2	1.7	421.3
2015	3583.0	0.0	1.4	2.3	0.8	4853.5	0.2	58.6	0.3	0.8	14018.0	6.6	56.2	0.0	2.7	966.1	1788.8	0.3	0.5	2.0	421.3
2016	3586.3	0.0	1.5	0.4	1.8	4825.5	0.7	82.2	0.3	1.6	14015.9	5.5	56.3	0.1	2.2	968.7	1790.7	0.3	0.0	2.1	421.3
2017	3589.6	0.0	1.4	0.3	1.4	4813.3	0.7	66.2	0.3	1.4	14035.7	7.7	55.3	0.0	3.0	969.4	1794.2	0.2	0.4	1.5	421.3
2018	3593.8	0.0	1.3	1.5	1.7	4782.4	1.9	81.2	0.3	3.3	14043.4	10.3	46.1	0.0	5.0	970.0	1797.4	0.4	0.1	2.1	421.3
2019	3601.2	0.0	1.1	2.7	1.4	4769.1	1.1	56.5	0.3	1.5	14058.8	12.0	53.5	0.0	3.6	971.8	1803.4	0.6	0.5	2.9	421.3
2020	3611.7	0.0	1.3	0.7	1.1	4753.0	0.7	65.0	0.3	4.2	14053.1	11.8	49.5	0.0	4.9	974.8	1806.9	0.9	0.2	1.9	421.3
2021	3622.0	0.0	1.4	0.6	1.1	4732.4	0.7	65.1	0.3	4.2	14054.9	12.1	49.4	0.0	4.9	975.8	1814.0	0.9	0.2	1.9	421.3

6.2 CATEGORY 4A – FOREST LAND

6.2.1 Description

Emissions sources	4A Forest Land: carbon stock change 4(I) Direct nitrous oxide (N_2O) emissions from nitrogen (N) inputs to managed soils 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils 4(III) Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils 4(V) Biomass burning
Gases Reported	CO_2, CH_4, N_2O
Methods	T3 for carbon stock changes, T2 for direct CO_2 and CH_4 and N_2O, T1 for other emissions
Emission Factors	Country-specific for T3 methods
Key Categories	4A: Forest land - CO_2 (L1, L2, T1, T2), N_2O (L2)
Key Categories (Qualitative)	None identified
Completeness	N/A
Major improvements since last submission	Revision of assumed planting on organic soils to adjust for deforestation in all countries and pre-1900 planting on organic soils in Northern Ireland. Revision of Emission Factor for Particulate Organic Carbon (POC) losses from organic soils.

This section describes LULUCF emissions and removals from Forest Land in the UK. A description of LULUCF emissions and removals from the OTs and CDs is given in **Section 6.8**.

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 74% 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, assessed tree age class area distributions and productivity (yield class) estimates, and assumptions over approaches to forest management. Forest carbon stock changes and fluxes are modelled by CARBINE, the Forest Research forest carbon stock and carbon balance 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 on both mineral and organic soils are calculated. Conversion of 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. Associated direct N_2O emissions from N mineralization are reported under Table 4(III).

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. N_2O emissions from this fertilisation are reported under 4.A.2 in CRF Table 4(I). Nitrogen fertilisers are not generally applied to native woodlands, mature forests or re-planted forests in the UK, so emissions of N_2O from N fertilisation of forests (CRF Table 4(I)) for 4.A.1 are reported as Not Occurring.

Drainage of forest land occurs in UK forests planted 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. CO_2 emissions from drainage are included with carbon stock changes in Table 4.A. CH_4 and N_2O emissions from drainage are included in Table 4(II). Rewetting of forests on organic soils results in a land use change and emissions are reported under 4D2.3.1 Forest converted to other wetlands and Table 4(II).

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), Scottish Forestry and Forest and Land Scotland, Natural Resources Wales and the Northern Ireland Forest Service. Areas of forest planted annually are published in Forestry Statistics[87] 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 and the Northern Ireland Woodland Register. 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 data assimilation of multiple land-use data sources (see **Section 6.3** and **Annex 3.4**). More information on the stratification of the UK forest area can be found in the UK National Forestry Accounting Plan 2021-2025[88].

The area of forests on organic soils in the UK was based on peatland extent and condition mapping outputs from the BEIS-funded project to implement the 2013 IPCC Wetlands Supplement (Evans *et al*. 2017). These have been updated in this submission (see Annex A 3.4.6).

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;

[87] https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2022/

88 https://www.gov.uk/government/publications/uk-national-forestry-accounting-plan-2021-to-2025

- Minimum height of 2 metres, or the potential to achieve it.

This definition includes felled areas awaiting restocking and integral open spaces (open areas up to 1 hectare). The annual Forestry Statistics publication uses a minimum area assumption of 0.5 ha, with the “Tree cover outside woodland” report providing the additional area of woodlands between 0.1-0.5 ha[74]. The definitions are consistent with information provided by the UK to the Food and Agriculture Organization of the United Nations (FAO). If an international source uses a different minimum area definition, for example 0.5 ha in the Global Forest Resource Assessment 2010, the UK areas are adjusted to this different definition (FAO, 2010).

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.

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 revisions to the activity data for afforestation for this submission: these revisions and their impact are described in the recalculations (**Section 6.2.7**). Emissions from fluvial carbon from forest on organic soils are reported using the Tier 1 emission factors from the 2013 IPCC Wetlands Supplement for dissolved organic carbon and particulate organic carbon.

Areas of forest planted on organic soils are estimated by overlaying a map of soils with the forest map from the National Forest Inventory in England, Scotland and Wales. For Northern Ireland a similar method was used to estimate areas based on the NI woodland basemap. Further details on this work are given in **Annex 3.4.6**. In this inventory, there is a very small inconsistency in forest areas on organic soils in England, caused by matching the area afforested on organic soils to the area of forests estimated to exist on organic soils. This is due to slight discrepancy matching the area of deforestation on organic soils between 1990 and 2013, leading to a small over-estimate of afforestation on organic soils. Because the area involved is so small(~59ha), the difference in estimates caused by assuming these areas to be on mineral soils rather than organic soils will be close to zero.

Other greenhouse gas emissions, including those arising from forest fertilisation and wildfires together with estimates of N_2O emissions from forest drainage, are estimated using Tier 1 or Tier 2 approaches, and are described in **Annex 3.4.**

6.2.5 Uncertainties and Time-Series Consistency

The uncertainty in 1990 and 2021 respectively are estimated at 20% and 15% for CO_2, 90% and 90% for CH_4, and 85% and 95% for N_2O. These uncertainties are based on an updated uncertainty analysis, broadly following the methodology of the previous uncertainty analysis, but using the updated activity data and methodology for this submission. Details are provided in **Annex 3.4.12**.

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.
- Emissions from forests on organic soils: it is assumed that all organic soils planted with forests are drained and there has been no recorded planting of new planting on organic soils since 2012. An area of 13.2 kha has been rewetted to Wetland since 2000.

A significance analysis has been undertaken for key categories in the LULUCF sector. In Forest Land carbon stock changes in living biomass, dead wood and litter in the 4.A.1 Forest Land remaining Forest land and 4A2.2 Grassland converted to Forest Land are the most significant sub-categories/pools (**Table 6.5**).

Table 6.4 Significance analysis of the key sub-categories/pools in the Forest Land category

Sub-category	Pool	Percentage contribution to 1990 total[1]	Percentage contribution to 2021 total[1]
CO_2			
4(V) Biomass burning		0%	0%
A1. Forest Land remaining Forest Land		**68%**	**91%**
	Carbon stock change in above-ground biomass, below-ground biomass, dead wood and litter	**57%**	**70%**
	Mineral Soils	8%	21%
	Organic Soils	2%	0%
A2.1. Cropland converted to Forest Land		2%	1%
A2.2. Grassland converted to Forest Land		**29%** (biomass,	7%

Sub-category	Pool	Percentage contribution to 1990 total[1]	Percentage contribution to 2021 total[1]
		dead wood and litter)	
A2.4. Settlements converted to Forest Land		1%	0%
CH_4			
4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils – organic soils		**96%**	**98%**
4(V) Biomass burning		4%	2%
N_2O			
4(I) Direct N_2O Emissions from N Inputs to Managed Soils - forest fertilization		2%	0%
4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils – mineral soils		6%	8%
4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils – organic soils		**60%**	**76%**
4(III) N from mineralization resulting from land use change		**31%**	16%
4(V) Biomass burning		0%	0%

[1] Percentages may not sum to 100% due to rounding

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 1.6**. 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 UKCEH 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 2022).

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; Laganiere, Angers et al. 2010; Poeplau, Don et al. 2011 respectively). The treatment of the litter layer in these studies is a significant uncertainty, as it is possible that some of the reported decreases in soil carbon following afforestation were compensated by increases in carbon stocks of the above-ground litter layer which is not included in the soil samples.

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 broad terms, the comparisons done so far show that the model gives broad-scale soil carbon stock results that are consistent with collected data and reported estimates. Verification of the carbon stock changes in soils is made more difficult by the general lack of repeat measurement and we are attempting to identify potential sources of additional data.

In 2018, a new automatic algorithm was introduced in CARBINE 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.

6.2.7 : Category-Specific Recalculations

The reported overall net GHG sink in category 4A has changed between -0.2 and -0.5 Mt CO_2e (-1 to -3%) across the time series compared to the previous inventory.

The changes were mainly seen in the carbon stock changes in the above-ground biomass pool under Forest Remaining Forest. The main cause of this change was updates to the estimated activity data for afforestation and deforestation on organic soils.

The changes and their justification are:

- **Updated activity data.** Updated afforestation and deforestation statistics were included for all nations. The consistency of forest reporting across all UK nations was improved by updating the woodland area in Northern Ireland. The assumed Felled Area on the NI Forest Service estate was adjusted to match the revised 2018 woodland area, calculated to be consistent with the 2021 NI woodland area and new planting.
- **Updated EF for POC emissions from organic soils.** Particulate organic carbon (POC) EFs were updated for all soil categories using an IPCC Tier 1 methodology (IPCC 2014 Appendix Eq.2A.1).
- **Updated forest area on organic soils.** The assumed planting on organic soils was adjusted for deforestation to achieve consistency with the revised peat soil map (for 2013 in England, 1990 in Scotland and Wales, and 2007 in NI). Forest planting in Northern Ireland in 1880-1899 was correctly assigned to organic rather than mineral soil.
- **Minor changes to average biomass densities used for wildfire emission calculations**
- **Updated N_2O and CH_4 EFs from organic soils.** An updated (2022) Tier 2 analysis of organic soil emission factors (EFs) from the Defra Peatland Code Project SP0822 was implemented (Evans et al. 2022a). This update incorporates new UK datasets published since 2019, including data from the UK flux tower network, as well as international data from climatically similar regions.

The magnitude of the changes and the abbreviated justification are given in **Table 6.5**.

Table 6.5 4A Category specific recalculations since previous submission (UK only)

IPCC Category	Source Name	Old 1990 value	Old 2020 value	New 1990 value	New 2020 value	Units	Comment / Justification
4A1/4(V)	Biomass burning - wildfires	10.23	35.71	10.23	35.70	Gg C	Minor changes to average biomass densities used for wildfire emission calculations
4A1	Carbon stock change in living biomass - gains	-10418.24	-16031.55	-10423.75	-16066.95	Gg C	Updated activity data. Updated forest area on organic soils. Updated EF for POC emissions from organic soils.
4A1	Carbon stock change in living biomass - losses	7791.00	13404.74	7814.24	13350.81	Gg C	
4A1	Net carbon stock change in dead wood	-627.54	-1012.33	-630.40	-994.28	Gg C	
4A1	Net carbon stock change in litter	-146.30	-130.52	-145.81	-132.32	Gg C	
4A1	Net carbon stock change in soils - mineral soils	-499.45	-1141.75	-498.05	-1138.12	Gg C	
4A1	Net carbon stock change in soils - organic soils	133.72	1.59	130.88	0.20	Gg C	
4A2.1	Carbon stock change in living biomass - gains	-85.14	-35.41	-85.00	-35.40	Gg C	
4A2.1	Carbon stock change in living biomass - losses	17.69	7.03	17.66	7.02	Gg C	
4A2.1	Net carbon stock change in dead wood	-2.76	-0.97	-2.75	-0.97	Gg C	
4A2.1	Net carbon stock change in litter	-2.33	-0.87	-2.33	-0.87	Gg C	
4A2.1	Net carbon stock change in soils - mineral soils	50.54	26.27	50.46	26.31	Gg C	

IPCC Category	Source Name	Old 1990 value	Old 2020 value	New 1990 value	New 2020 value	Units	Comment / Justification
4A2.1	Net carbon stock change in soils - organic soils, afforestation	13.71	1.28	13.78	1.29	Gg C	Updated activity data. Updated forest area on organic soils. Updated EF for POC emissions from organic soils.
4A2.1	Net carbon stock change in soils - organic soils, POC & DOC	3.00	0.30	2.92	0.30	Gg C	
4A2.2	Carbon stock change in living biomass - gains	-1037.32	-248.58	-1037.03	-251.78	Gg C	
4A2.2	Carbon stock change in living biomass - losses	211.97	49.20	211.93	49.63	Gg C	
4A2.2	Net carbon stock change in dead wood	-34.77	-7.18	-34.76	-7.23	Gg C	
4A2.2	Net carbon stock change in litter	-31.04	-6.66	-31.04	-6.73	Gg C	
4A2.2	Net carbon stock change in soils - mineral soils	428.43	186.30	427.66	187.13	Gg C	
4A2.2	Net carbon stock change in soils - organic soils, afforestation	345.68	18.22	348.24	19.62	Gg C	
4A2.2	Net carbon stock change in soils - organic soils, POC & DOC	74.51	4.24	72.77	4.42	Gg C	
4A2.4	Carbon stock change in living biomass - gains	-17.71	-11.26	-17.68	-11.38	Gg C	
4A2.4	Carbon stock change in living biomass - losses	3.58	2.23	3.57	2.24	Gg C	
4A2.4	Net carbon stock change in dead wood	-0.58	-0.33	-0.58	-0.33	Gg C	

IPCC Category	Source Name	Old 1990 value	Old 2020 value	New 1990 value	New 2020 value	Units	Comment / Justification
4A2.4	Net carbon stock change in litter	-0.50	-0.30	-0.50	-0.31	Gg C	Updated activity data. Updated forest area on organic soils. Updated EF for POC emissions from organic soils.
4A2.4	Net carbon stock change in soils - mineral soils, afforestation	7.32	8.30	7.32	8.34	Gg C	
4A2.4	Net carbon stock change in soils - organic soils, afforestation	6.20	0.86	6.23	0.92	Gg C	
4A2.4	Net carbon stock change in soils - organic soils, POC & DOC	1.29	0.20	1.26	0.21	Gg C	
4A1/4(II)	Emissions and removals from drainage and rewetting and other management of organic and mineral soils	3.34	3.60	3.39	3.67	Gg CH_4	Updated forest area on organic soils. Updated N_2O and CH_4 EFs from organic soils.
4A2.1/4(III)	Direct N_2O from N mineralisation	0.053	0.028	0.053	0.028	Gg N_2O	Updated activity data. Updated forest area on organic soils.
4A2.2/4(III)	Direct N_2O from N mineralisation	0.449	0.195	0.448	0.196	Gg N_2O	
4A2.4/4(III)	Direct N_2O from N mineralisation	0.008	0.009	0.008	0.009	Gg N_2O	
4A2/4(I)	Direct N_2O Emissions from N Inputs to Managed Soils	0.041	0.003	0.041	0.003	Gg N_2O	
4A/4(II)	Emissions and removals from drainage and rewetting and other management of organic and mineral soils	1.967	2.127	1.098	1.195	Gg N_2O	Updated forest area on organic soils. Updated N_2O and CH_4 EFs from organic soils.

6.3 CATEGORY 4B – CROPLAND

6.3.1 Description

Emissions sources	4B Cropland: carbon stock change 4B: 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils 4B: 4(III) Direct N_2O emissions from N mineralisation. 4B: 4(V) Biomass burning
Gases Reported	CO_2, CH_4, N_2O
Methods	T3 for carbon stock changes, T2 for organic soils, T1 for other emissions
Emission Factors	Country-specific for T3 methods, T2 for direct CO_2 and CH_4 emissions from organic soils, T1 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	Inclusion of a new CO_2 Emission Factor for Cropland on wasted peat (peat < 40cm). Updated T2 organic soil Emission Factors and organic soils activity data. Revision of Emission Factor for Particulate Organic Carbon (POC) losses from organic soils.

This section describes LULUCF emissions and removals from Cropland in the UK. A description of LULUCF emissions and removals from the OTs and CDs is given in **Section 6.8**.

Net emissions from the Cropland category include carbon stock gains and losses and GHG emissions due to land-use change (LUC), cropland management, drainage and biomass burning. Overall, the Cropland category 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 non-organic 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. Carbon emissions from drainage of cropland on organic soils are the next largest component and are calculated using Tier 2 country-specific emission factors.

Other contributors to the Cropland net total emissions are:

- CH_4 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;
- N_2O 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 for some carbon stock changes and emissions.

Ongoing N_2O emissions from soil as a result of land-use change > 20 years ago and from drainage of organic soils are reported in the Agricultural sector inventory as N_2O emissions from managed agricultural soils. UKCEH provide the appropriate areas and emission factors 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 N_2O emissions from managed agricultural soils.

Emissions of CO_2, CH_4 and N_2O 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 6.11** and **Annex 3.4.2.1** 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 (DAERA 2016, UKCEH 2020a) which gives repeated field surveys of stratified 1km sample squares.
    - Monitoring Landscape Change (MLC 1986) habitat survey based on aerial photo interpretation.
- Extent of cropland on organic soils and rewetting of cropland back to wetland (Evans et al. 2017 and further updates).
- Agricultural survey data
    - Areas of the main crop types are obtained from the June Agricultural Censuses for each UK administration.
    - Agricultural holdings data: farm-level detail on agricultural land areas.
    - IACS: field-level register of agricultural subsidy claims under the EU Common Agricultural Policy.
    - CROME: crop classification of satellite imagery for England, with ground-truth data from agricultural subsidy inspectors
    - The areas of Cropland receiving inputs of manure, fertiliser and crop residues are obtained from the British Survey of Fertiliser Practice.
- Land-cover from satellite imagery classification
    - Land Cover Map (UKCEH 2020b): thematic land-cover classification of satellite image data covering the UK;
    - Land Cover® plus: Crops (UKCEH 2016): Based on the LCM parcel framework with additional crop information from satellite data
    - CORINE Land Cover (CORINE 2020): Survey of European land cover and land cover change from semi-automatic interpretation of high resolution satellite imagery.
- 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). The crop types in the different data sources that contribute to the Cropland category are described in **Annex 3.4.2.1.**

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**.

Land use change on organic soils is split out from the land-use change matrices to produce a non-organic soil set of LUC change matrices. Emissions arising from land-use and land-use change on organic soils are calculated using methodologies consistent with chapters 2 and 3 of the 2013 IPCC Wetlands supplement described in **Annex 3.4.6**.

A dynamic model of carbon stock change is used with the non-organic LUC matrices to estimate non-organic soil carbon stock changes due to LUC. Non-organic 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.

The carbon stocks on non-organic soils 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/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.

N_2O emissions associated with non-organic 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, country-specific soil carbon densities 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, bioenergy crops and shrubby perennial crops (see **Annex 3.4** for details).

6.3.4.3 Drained organic soils

Emissions of carbon and CH_4 from Cropland on drained organic soils are reported using Tier 2 emission factors (**Annex 3.4.6**). Emissions of N_2O from cropland on organic soils are calculated using the same activity data and are reported in category 3.D in the Agriculture sector.

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 **Section 6.3.2**).

6.3.5 Uncertainties and Time-Series Consistency

The uncertainty in 1990 and 2021 respectively are estimated at 15% and 20% for CO_2, 65% and 70% for CH_4, and 35% for N_2O. These uncertainties are based on an updated uncertainty analysis, broadly following the methodology of the previous uncertainty analysis, but using the updated activity data and methodology for this submission. Details are provided in **Annex 3.4.12**. The areas undergoing land-use change are the biggest source of uncertainty in the LULUCF inventory (see **Annex 3.4.12**).

With regard to time series consistency:

- Drainage of organic soils: it is assumed that all drainage of organic soils on Cropland occurred before 1971 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. A small area has been rewetted to Wetland since 2000 (5.5 kha), all of which is in England.
- Changes in biomass and soil carbon due to LUC: the land-use change data assimilation methodology draws on multiple data-sources and takes account of random uncertainty and false positive rates. The time series now show more inter-annual variation but more gradual temporal trends (see **Figure A 3.6** in **Annex 3.4.2.1**).
- Controlled biomass burning after conversion of Forest Land to Cropland: there is good time series consistency as there has been continuity in the activity data source.
- 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.

A significance analysis has been undertaken for key categories in the LULUCF sector. In Cropland the 4.B2.2 Grassland converted to Cropland and the 4.B1 Cropland remaining Cropland are the most significant sub-categories (**Table 6.6**), with soil carbon stock change in mineral and organic soils the biggest pool contributions**.**

Table 6.6 Significance analysis of the key sub-categories/pools in the Cropland category

Sub-category	Pool	Percentage contribution to 1990 total[1]	Percentage contribution to 2021 total[1]
CO_2			
4(V) Biomass Burning		0%	0%
B1. Cropland remaining Cropland		40%	**63%**
	Carbon stock change in living biomass	0%	0%
	Carbon stock change due to cropland management (soils and biomass)	0%	0%
	Mineral Soils (due to land use change)	12%	**33%**
	Organic Soils	**28%**	**30%**
B2.1. Forest Land converted to Cropland		1%	0%
B2.2. Grassland converted to Cropland		**58%** (mineral soils)	**37%** (mineral soils)
B2.4. Settlements converted to Cropland		1%	1%

- [1] Percentages may not sum to 100% due to rounding

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 1.6.**

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 decreased by -1.7 Mt CO_2e (-10 to -11%) across the time series compared to the previous inventory. The changes were mainly in organic soil carbon emissions in Cropland remaining Cropland.

The changes and their justification are:

- **Updated EFs from organic soils.** An updated (2022) Tier 2 analysis of organic soil emission factors (EFs) from the Defra Peatland Code Project SP0822 was implemented (Evans et al. 2022a). This update incorporates new UK datasets published since 2019, including data from the UK flux tower network, as well as international data from climatically similar regions. This included the introduction of a new emission factor for direct CO_2 from Cropland on wasted peat (peat < 40cm) from the BEIS Wasted Peat Project (Evans et al. 2022b). Particulate organic carbon (POC) EFs were updated for all soil categories using an IPCC Tier 1 methodology (IPCC 2014 Appendix Eq.2A.1).

- **Revisions to organic soil areas.** Revisions to the organic soils maps were included from a BEIS Ad-hoc project to edit and check the geometry of the maps and clarify activity data and the assumptions used to create the maps in Evans et al. 2017.
- **Updated deforestation activity data.** Updated deforestation statistics were included for all nations.

Changes in emissions are described in **Table 6.7**.

Table 6.7 4B Category specific recalculations since previous submission (UK only)

IPCC Category	Source Name	Old 1990 value	Old 2020 value	New 1990 value	New 2020 value	Units	Comment / Justification
4B1	Carbon stock change in living biomass	6.16	-1.18	6.16	-0.74	Gg C	Revisions to organic soil areas.
4B1	Net carbon stock change in soils - mineral soils	496.19	1200.87	496.86	1201.51	Gg C	
4B1	Net carbon stock change in soils - organic soils	1614.77	1545.36	1145.96	1081.46	Gg C	Updated EFs from organic soils.
4B2.1/4(V)	Biomass Burning	0.24	0.00	0.24	0.00	Gg C	Updated deforestation activity data
4B2.1	Net carbon stock change in dead organic matter	0.08	0.00	0.08	0.00	Gg C	
4B2.1	Net carbon stock change in soils - organic soils	0.00	0.08	0.00	0.07	Gg C	Updated deforestation activity data Revisions to organic soil areas.
4B2.1	Net carbon stock change in living biomass	0.34	0.00	0.34	0.00	Gg C	Updated deforestation activity data
4B2/4(II)	Emissions and removals from drainage and rewetting	11.671	11.169	11.863	11.368	Gg CH_4	Updated EFs from organic soils. Revisions to organic soil areas.

6.3.8 Category-Specific Planned Improvements

The second step in implementing the BEIS-funded Land-Use Tracking project is in progress in 2022-23 (see **Annex 3.4.1.2**). This will revise the soil carbon dynamics model and LULUCF inventory reporting methods to use vectors of land-use change rather than independent annual land-use change matrices, which will improve the representation of rotational management of cropland and improved grassland. We also plan to undertake further analysis of the relationship between soil type and land-use vectors, and the potential for priming the soil carbon dynamic model with pre-1950 land-use change history.

A BEIS-funded research project on GHG emissions from lowland wasted peat soils under intensive agriculture was delayed by the COVID-19 pandemic. Flux tower measurements from this study have been used to develop a specific Tier 2 CO_2 EF for Cropland on Wasted Peats, which has been implemented in this inventory (see Table A 3.4.26) (Evans et al. 2022b). At present, separate EFs for grassland on wasted peat cannot be derived due to lack of data, and measurements are ongoing for N_2O, with further results expected in 2023.

The 2019 UNFCCC review team inquired about the estimation, and reporting of, inorganic carbon stock change in soil. A subsequent review team stated that this only needs to be considered when the necessary data, a monitoring system for routinely collecting such data, and appropriate (Tier 3) soil process-modelling capacity becomes available. Therefore, no further work on inorganic soil carbon stocks is currently planned.

6.4 CATEGORY 4C – GRASSLAND

6.4.1 Description

Emissions sources	4C Grassland: carbon stock change 4C: 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils 4C: 4(III) Direct N_2O emissions from N mineralisation. 4C: 4(V) Biomass burning
Gases Reported	CO_2, CH_4, N_2O
Methods	T3 for carbon stock changes, T2 for organic soils, T1 for other emissions
Emission Factors	Country-specific for T3 methods, T2 for direct CO_2 and CH_4 emissions from organic soils, T1 for other emissions
Key Categories	4C: Grassland - CO_2 (L1, T1, T2), CH_4 (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	Updated T2 organic soil Emission Factors and organic soils activity data. Revision of Emission Factor for Particulate Organic Carbon (POC) losses from organic soils.

This section describes LULUCF emissions and removals from Grassland in the UK. A description of LULUCF emissions and removals from the OTs and CDs is given in **Section 6.8**.

Net emissions from the Grassland category include carbon stock gains and losses and GHG emissions due to land-use change (LUC) and GHG emissions from grassland management, drainage and rewetting and biomass burning. Grassland is a small net source that reduces across the time series.

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 carbon stock changes and CO_2 emissions from mineral and organic soils are the largest components of the category total emissions and removals. Carbon stock changes on mineral soils are calculated using a Tier 3 dynamic soil carbon model and CO_2 emissions from organic soils are calculated using Tier 2 country-specific emission factors.

The area of undisturbed grassland on mineral soils which has not been converted from other land uses in the past is reported in 4.C.1. "Undisturbed" grassland. This sub-category 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, organic soil areas etc.) for each year. No anthropogenic emissions or removals are associated with this undisturbed area.

The Evans *et al.* (2017) report identified large areas of grassland on organic soils in the UK that are not intensively cultivated but nevertheless have been degraded by anthropogenic activities, for example by over-grazing or management for game species. Emissions of N_2O from these unintensive grassland areas are reported under 4C Grassland, while N_2O emissions from intensive cultivated grassland on organic soils are reported under 3D in the Agriculture sector.

Other contributors to the Grassland net total emissions are:

- CH_4 emissions resulting from drainage and rewetting of organic soils;
- N_2O emissions from drainage and rewetting of unintensive grassland on organic soils;
- carbon stock changes in biomass resulting from changes in grassland management;
- biomass carbon stock changes due to LUC;
- N_2O emissions from mineral 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.

Full details of the methods and activity data are given in **Annex 3.4**

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** and **Annex 3.4.2.1** for details).

Data sources that contain area information for reporting carbon stock changes and/or emissions from Grassland are:

- Habitat/landscape surveys (see **Section 6.3.2**).
- Extent of grassland on organic soils and rewetting of grassland that stays within the grassland category (Evans et al. 2017 and further updates).
- Agricultural survey data (see **Section 6.3.2**).
- Land-cover from satellite imagery classification (see **Section 6.3.2**).

- 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.
- 1990-1999 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**.
- Data on wildfires on agricultural land and moorland from Fire and Rescue service and satellite data (see **Section 6.3.2** for further details).

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 on mineral soils, 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 semi-natural peatland habitats that would otherwise fall within in the Wetland category, so areas of peatland habitat not used for peat extraction or not explicitly identified as near-natural bog or fen, are included in the Grassland category. Areas of grassland that have undergone rewetting (or other activities that restore peatland habitats and reduce emissions) remain within the Grassland category.

The grassland and semi-natural habitat types in the different data sources that contribute to the Grassland category are described in **Annex 3.4.2.1.**

6.4.4 Methodological Issues

6.4.4.1 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 the Grassland activities are given in **Annex 3.4.2**.

Land use change on organic soils is split out from the land-use change matrices to produce a non-organic soil set of LUC change matrices. Emissions arising from land use and land-use change on organic soils are calculated using methodologies consistent with chapters 2 and 3 of the 2013 IPCC Wetlands Supplement described in **Annex 3.4.6**. 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.

N_2O emissions associated with the non-organic soil disturbance from LUC are reported using the appropriate areas of Grassland remaining Grassland and 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. All carbon stock changes associated with changes in the length and condition of hedgerows are reported under this activity.

6.4.4.3 Drained organic soils

Emissions of carbon and CH_4 from Grassland on drained and undrained organic soils, and N_2O emissions from unintensive grassland, are reported using Tier 2 emission factors (**Annex 3.4.6**). Emissions of N_2O from intensive grassland on organic soils are calculated using the same activity data and are reported in category 3.D in the Agriculture sector.

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. See **Annex 3.4.5** for further discussion of controlled burning for game management on upland habitats.

Emissions from wildfires on Grassland (agricultural grassland and semi-natural grassland) are reporting 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

The uncertainty in 1990 and 2021 respectively are estimated at 15% for CO_2, 35% for CH_4, and 45% for N_2O. These uncertainties are based on an updated uncertainty analysis, broadly following the methodology of the previous uncertainty analysis, but using the updated activity data and methodology for this submission. Details are provided in **Annex 3.4.12**. The areas undergoing land-use change are the biggest source of uncertainty in the LULUCF inventory (see **Annex 3.4.12**).

With regard to time series consistency:

- Drainage of organic soils: it is assumed that all drainage of organic soils under 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. An area of 90.92 kha of grassland has been rewetted since 1990, and an area of 1.52 kha has been converted to peat extraction since 1990.
- Changes in biomass and soil carbon due to LUC: the land-use change data assimilation methodology draws on multiple data-sources and takes account of random uncertainty and false positive rates. The time series now show more inter-annual variation but more gradual temporal trends (see **Figure A 3.6** in **Annex 3.4.2.1**).
- Controlled biomass burning after conversion of Forest Land to Grassland: there is good time series consistency as there has been continuity in the activity data source.
- 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.

A significance analysis has been undertaken for key categories in the LULUCF sector (**Table 6.8**). The largest contributing sub-categories/pools for carbon dioxide are from Grassland remaining Grassland organic and mineral soils and Cropland converted to Grassland mineral soils. The largest contributory sub-category for methane is almost entirely emissions from drainage and rewetting of organic soils.

Table 6.8 Significance analysis of the key sub-categories/pools in the Grassland category

Sub-category	Pool	Percentage contribution to 1990 total[1]	Percentage contribution to 2021 total[1]
CO_2			
4(V) Biomass burning		0%	1%
C1. Grassland remaining Grassland		**61%**	**66%**
	Carbon stock change in living biomass due to land use change	0%	0%
	Carbon stock change in living biomass due to grassland management	5%	0%
	Mineral Soils	12%	**32%**
	Organic Soils	**44%**	**33%**
C2.1. Forest Land converted to Grassland		1%	4%
C2.2. Cropland converted to Grassland		**35%** (mineral soils)	**27%** (mineral soils)
C2.4. Settlements converted to Grassland		3%	3%
CH_4			
4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils		**100%**	**99%**
4(V) Biomass burning		0%	1%

[1] Percentages may not sum to 100% due to rounding

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 1.6**.

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 Category 4C net source has decreased by between -0.6 to -0.7 Mt CO_2e (-22 to -67%) across the time series compared to the previous inventory. The changes were mainly in organic soil carbon stock change in Grassland remaining Grassland.

The changes and their justification are:

- **Updated EFs from organic soils.** An updated (2022) Tier 2 analysis of organic soil emission factors (EFs) from the Defra Peatland Code Project SP0822 was implemented. This update incorporates new UK datasets published since 2019, including data from the UK flux tower network, as well as international data from climatically similar regions. Particulate organic carbon (POC) EFs were updated for all soil categories using an IPCC Tier 1 methodology (IPCC 2014 Appendix Eq.2A.1).

- **Revisions to organic soil areas.** Revisions to the organic soils maps were included from a BEIS Ad-hoc project to edit and check the geometry of the maps and clarify activity data and the assumptions used to create the maps in Evans et al. 2017. This resulted in a revision of the restoration data for intensive grassland, where an error was identified in the Peatland Compendium dataset, which overestimated intensive grassland to rewetted fen restoration in south-west England. Updated restoration data were supplied by Natural England and the RSPB.
- **Updated deforestation activity data.** Updated deforestation statistics were included for all nations.
- **Minor changes to average biomass densities used for wildfire emission calculations**

Changes in emissions are described in **Table 6.9**.

Table 6.9 4C Category specific recalculations since previous submission UK only)

IPCC Category	Source Name	Old 1990 value	Old 2020 value	New 1990 value	New 2020 value	Units	Comment / Justification
4C1	Net carbon stock change in soils - organic soils	1792.18	1574.30	1592.34	1363.84	Gg C	Revisions to organic soil areas. Updated EFs from organic soils.
4C2.1/4(V)	Biomass burning - controlled burning	5.67	50.35	5.67	46.13	Gg C	Updated deforestation activity data
4C2.1	Carbon stock change in living biomass - Losses	8.03	66.14	8.03	60.20	Gg C	
4C2.1	Net carbon stock change in dead organic matter	1.91	22.11	1.91	20.66	Gg C	
4C2.1	Net carbon stock change in soils - organic soils	0.08	16.13	0.10	24.11	Gg C	Revisions to organic soil areas Updated deforestation activity data
4C/4(II)	Emissions and removals from drainage and rewetting and other management of organic and mineral soils	94.98	95.99	99.80	100.96	Gg CH_4	Updated EFs from organic soils. Revisions to organic soil areas.
4C1/4(V)	Biomass burning - wildfires	0.34	0.23	0.34	0.24	Gg CH_4	Minor changes to average biomass densities used for wildfire emission calculations
4C2.1/4(V)	Biomass burning - controlled burning	0.06	0.55	0.06	0.51	Gg CH_4	Revisions to organic soil areas Updated deforestation activity data
4C/4(II)	Emissions and removals from drainage and rewetting and other management of organic and mineral soils	0.59	0.50	0.42	0.37	Gg N_2O	Revisions to organic soil areas. Updated EFs from organic soils.

IPCC Category	Source Name	Old 1990 value	Old 2020 value	New 1990 value	New 2020 value	Units	Comment / Justification
4C1/4(V)	Biomass burning - wildfires	0.031	0.021	0.031	0.022	Gg N_2O	Minor changes to average biomass densities used for wildfire emission calculations
4C2.1/4(V)	Biomass burning - Controlled Burning	0.003	0.031	0.003	0.028	Gg N_2O	Revisions to organic soil areas Updated deforestation activity data

6.4.8 Category-Specific Planned Improvements

The second step in implementing the BEIS-funded Land-Use Tracking project is in progress in 2022 (see **Section 6.3.8**).

A BEIS-funded research project on GHG emissions from lowland wasted peat soils under intensive agriculture was delayed by the COVID-19 pandemic. Flux tower measurements from this study have been used to develop a specific Tier 2 CO_2 EF for Cropland on Wasted Peats, which has been implemented in this inventory (see Table A 3.4.26) (Evans et al. 2022b). At present, separate EFs for grassland on wasted peat cannot be derived due to lack of data, and measurements are ongoing for N_2O, with further results expected in 2023.

6.5 CATEGORY 4D – WETLANDS

6.5.1 Description

Emissions sources	4D Wetlands: Carbon stock change 4D: 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils 4C: 4(V) Biomass burning
Gases Reported	CO_2, CH_4, N_2O
Methods	T2 for organic soils, T1 for water bodies
Emission Factors	T2 for direct CO_2 and CH_4 emissions from organic soils, T1 for other emissions
Key Categories	4D Wetlands- CH_4 (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	Updated T2 organic soil Emission Factors and organic soils activity data. Revision of Emission Factor for Particulate Organic Carbon (POC) losses from organic soils.

This section describes LULUCF emissions and removals from Wetland in the UK. A description of LULUCF emissions and removals from the OTs and CDs is given in **Section 6.8**.

Net emissions from the Wetlands category includes emissions from: peatlands that are cleared and drained for peat production (for energy or horticultural purposes); areas of near-natural peatland; areas of former peat extraction, forest and cropland that are now rewetted; and areas converted to permanently flooded land (reservoirs).

Emissions from on-site peat production and off-site emissions from horticultural peat are reported under 4.D.1 Wetlands remaining Wetlands. Areas of former peat extraction that are now rewetted are reported under 4D 1.3. There are areas of conversion to Wetland of grassland converted to Wetland for peat extraction (4.D.2.1), grassland converted to flooded land (4.D.2.2) and rewetted former forest and cropland (4 D.2.3). The associated emissions and living biomass carbon stock changes estimated using the appropriate Tier 1 or 2 methodologies.

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.

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. The area of wetlands on organic soils in the UK was revised based on peatland extent and condition mapping outputs from the BEIS-funded project to implement the IPCC Wetland Supplement (Evans *et al*. 2017). This included areas of near-natural wetlands and rewetted organic soils as well as areas of inactive peat extraction. These peatlands maps were updated for use in this submission (see **Annex 3.4.6** for details).

This information is supplemented by the areas of active peat extraction obtained 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 site operations data provided by Growing Media Association. These sources 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 active 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, and do not convert back to functioning peatlands without restoration intervention. 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 and evidence of rewetting (ditch blocking) from online documentation of the restoration works and communication with site managers.

"Near-natural" peatlands are areas that were identified in Evans et al (2017) as having no anthropogenic degradation, but can still be considered as managed e.g. for biodiversity purposes. They are a carbon sink but also a source of CH_4 emissions. Rewetted peatlands are those that have undergone restoration activities to restore normal peatland biogeochemical functioning. These have been identified from a database of peatland restoration projects (see **Annex 3.4.6**) and more recent government-funded restoration.

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 km^2 (100 hectares) in area. 'Open' tracts of water, e.g. rivers, canals and streams are excluded from this definition. Reservoirs (flooded land) were identified either by their inclusion in the Public Register of Large Raised Reservoirs or by their classification as "Heavily modified" in the SEPA Water Body Classification database. 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 Tier 1 and Tier 2 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. . For on-site emissions due to extraction activities and drainage, a Tier 2 CO_2 emission factor is employed for Industrial (horticulture) Extraction, and a Tier 1 CO_2 emission factor (IPCC, 2014) is used for Domestic (fuel) Extraction. A Tier 2 CH_4 emission factor and Tier 1 N_2O emission factor is applied to emission estimates for both Industrial and Domestic Peat Extraction (see Annex Table A 3.4.26). Off-site carbon emissions from horticultural peat that has been extracted is assumed to be emitted during the extraction year. Mapping outputs from Evans et al. (2017) and administrative records categorise sites as producing horticultural or energy source (fuel) peat. Further information is given in **Annex 3.4.8**.

Google Earth imagery is used to track the change in the area of individual extraction sites over time. Google Earth is imagery is checked annually and extraction site areas are updated as new imagery becomes available.

The site records show that the area under active horticultural peat extraction between 1990 and 2021 diminished for England, and decreased slightly overall for Scotland, and decreased slightly then increased recently for Northern Ireland. No peat extraction is reported in Wales. The time series of active fuel peat extraction has decreased across the UK. 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 identified as potentially being restored to rewetted Wetland and investigated further. As these sites are often part of peatland restoration schemes managed by UK nature reserves, information on site history and success of the restoration (rewetting) works are gathered online and from reserve managers to support a condition change. Changes in organic soil carbon from this condition change are reported using a Tier 2 approach based on the IPCC 2014 Guidelines.

A small area of land conversion to Wetlands (all from Grassland) occurs across the time series. This area and the associated on-site emissions are reported under 4D.2.1.2 Land converted to Wetlands. Rewetted former peat extraction sites remain as Wetland and are reported under 4D.1.3.

6.5.4.2 Land converted to Flooded Land

A Tier 1 methodology was applied for emissions from Flooded Lands (4D.2.2.3). 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 were 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.

6.5.4.3 Land converted to other wetlands

Forest and cropland on organic soils that undergo rewetting are converted to Wetlands, as they do not retain their original land use. A Tier 2 methodology using areas and EFs from Evans et al (2017) is applied. Emissions from controlled burning following deforestation and carbon stock changes in biomass and dead organic matter are also calculated for conversion of forest land to wetland.

6.5.5 Uncertainties and Time-Series Consistency

The uncertainty in 1990 and 2021 respectively are estimated at 40% for CO_2, 50% and 45% for CH_4, and 120% and 100% for N_2O. These uncertainties are based on an updated uncertainty analysis, broadly following the methodology of the previous uncertainty analysis, but using the updated activity data and methodology for this submission. Details are provided in **Annex 3.4.12**.

Time-series consistency for activity data for peat extraction sites is affected by uncertainty in survey dates but has been improved by the incorporation of additional site data from the Growing Media Association. Time-series consistency for flooded lands was good due to the complete nature of the data set.

Methane emissions from category 4D are a key category and are entirely due to emissions from drainage and rewetting (CRF table 4(II)) of organic soils.

6.5.6 Category-Specific QA/QC and Verification

Operational site areas are provided by the Growing Media Association. The UKCEH peat extraction database matched the GMA data closely for Scotland, Wales, and Northern Ireland, but were adjusted accordingly where more robust data were available. For England, the inventory areas were revised downwards based on improved on-site information primarily for complicated sites.

The peat extraction site activity dataset has also 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 Category 4D net source has increased by between 0.1 and 0.2 Mt CO_2e (4-5%) across the time series compared to the previous inventory.

The changes and their justification are:

- **Updated EFs from organic soils.** An updated (2022) Tier 2 analysis of organic soil emission factors (EFs) from the Defra Peatland Code Project SP0822 (Evans et al. 2022a) was implemented. This update incorporates new UK datasets published since 2019, including data from the UK flux tower network, as well as international data from climatically similar regions. Particulate organic carbon (POC) EFs were updated for all soil categories using an IPCC Tier 1 methodology (IPCC 2014 Appendix Eq.2A.1).
- **Revisions to organic soil areas.** Revisions to the organic soils maps were included from a BEIS Ad-hoc project to edit and check the geometry of the maps and clarify activity data and the assumptions used to create the maps in Evans et al. 2017. This resulted in a revision of the restoration data for intensive grassland, where an error was identified in the Peatland Compendium dataset, which overestimated intensive grassland to rewetted fen restoration in south-west England. Updated restoration data were supplied by Natural England and the RSPB.
- **Minor adjustments to peat extraction areas.** Minor adjustments were made to the Google Earth derived areas of active peat extraction for Scotland and Northern Ireland

Table 6.10 4D Category specific recalculations since previous submission (UK only)

IPCC Category	Source Name	Old 1990 value	Old 2020 value	New 1990 value	New 2020 value	Units	Comment / Justification
D1.1	Net carbon stock change in soils	637.65	553.24	678.32	586.12	Gg C	Minor adjustments to peat extraction areas. Updated EFs from organic soils. Revisions to organic soil areas.
D1.3	Net carbon stock change in soils	-482.12	-470.40	-496.27	-495.84	Gg C	Updated EFs from organic soils. Revisions to organic soil areas.
D2.1	Net carbon stock change in soils	0.23	4.91	0.31	6.23	Gg C	Minor adjustments to peat extraction areas. Updated EFs from organic soils.
D2.3.1/4(V)	Biomass Burning	0.00	25.11	0.00	25.20	Gg C	Revisions to organic soil areas. Updated deforestation activity data
D2.3.1	Carbon stock change in living biomass - losses	0.00	32.85	0.00	33.02	Gg C	
D2.3.1	Net carbon stock change in dead organic matter	0.00	11.16	0.00	11.14	Gg C	
D2.3.1	Net carbon stock change in soils	0.00	0.95	0.00	0.99	Gg C	Revisions to organic soil areas. Updated EFs from organic soils. Updated deforestation activity data
D2.3.2	Net carbon stock change in soils	0.00	7.44	0.00	0.27	Gg C	Revisions to organic soil areas. Updated EFs from organic soils.
D/4(II)	Emissions and removals from drainage and rewetting and other management of organic and mineral soils	78.47	81.47	82.62	84.73	Gg CH_4	Updated EFs from organic soils. Revisions to organic soil areas.
D/4(II)	Emissions and removals from drainage and rewetting and other management of organic and mineral soils	0.071	0.068	0.071	0.067	Gg N_2O	Updated EFs from organic soils. Revisions to organic soil areas.

6.5.8 Category-specific planned improvements

There are ongoing discussions with policy experts and peatland managers to improve the register of peat restoration activities across all nations of the UK, and update the rewetting activity data as appropriate. BEIS commissioned a review of current knowledge and gaps of GHG emissions and removals from UK coastal wetlands, which provided recommendations for moving towards inclusion of saltmarshes in the UK GHGI (Burden and Clilverd, 2022). Evidence gaps identified in this report are being addressed in a Defra-funded project (30120) to provide a road-map for inclusion of saltmarsh in the UK GHGI by defining terminology, and mapping implications of different terminologies on saltmarsh areal extent.

6.6 CATEGORY 4E – SETTLEMENTS

6.6.1 Description

Emissions sources	4E Settlements: Carbon stock change 4C: 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils 4E: 4(III) Direct N_2O emissions from N mineralization 4E: 4(V) Biomass burning
Gases Reported	CO_2, CH_4, N_2O
Methods	T3 for carbon stock changes, T2 for organic soils, T1 for other emissions
Emission Factors	Country-specific for T3 methods, T2 for direct CO_2 and CH_4 emissions from organic soils, T1 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	No major improvements.

This section describes LULUCF emissions and removals from Settlement in the UK. A description of LULUCF emissions and removals from the OTs and CDs is given in **Section 6.8**.

Net emissions from the Settlements category include carbon stock gains and losses due to land-use change (LUC) and associated GHG emissions. It is the second largest net source in the LULUCF sector.

Ongoing carbon stock changes in soils and direct N_2O 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 non-organic 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:

- Carbon, CH_4 and N_2O emissions resulting from drainage of organic soils;
- biomass carbon stock changes due to LUC;
- N_2O 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.**

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** and **Annex 3.4.2.1** for details).

Data sources that contain area information for reporting carbon stock changes and/or emissions from Settlements are:

- Habitat/landscape surveys (see **Section 6.3.2**).
- Extent of settlement on organic soils (Evans et al. 2017 and further updates).
- Land-cover from satellite imagery classification (see **Section 6.3.2**).
- 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**.

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).

The settlement land-cover types in the different data sources that contribute to the Settlement category are described in **Annex 3.4.2.1.**

6.6.4 Methodological Issues

6.6.4.1 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 the Settlement activities are given in **Annex 3.4.2**.

Land use change on organic soils is split out from the land-use change matrices to produce a non-organic soil set of LUC change matrices. Emissions arising from land use and land-use change on organic soils are calculated using methodologies consistent with chapters 2 and 3 of the 2013 IPCC Wetlands Supplement described in **Annex 3.4.6**. 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. Detailed descriptions of the methods, emission factors and data flows used for the Settlement category are given in **Annex 3.4.7**.

N_2O emissions associated with the non-organic soil disturbance from LUC are reported using the areas from the LUC matrices and the IPCC Tier 1 emission factors.

6.6.4.2 Drained organic soils

Emissions of carbon, CH_4 and N_2O from Settlements on drained organic soils are reported using Tier 2 and Tier 1 emission factors (**Annex 3.4.6**).

6.6.4.3 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

The uncertainty in 1990 and 2021 respectively are estimated at 45% and 50% for CO_2, 60% and 50% for CH_4, and 130-135% for N_2O. These uncertainties are based on an updated uncertainty analysis, broadly following the methodology of the previous uncertainty analysis, but using the updated activity data and methodology for this submission. Details are provided in **Annex 3.4.12**. The areas undergoing land-use change are the biggest source of uncertainty in the LULUCF inventory (see **Annex 3.4.12**).

With regard to time series consistency:

- Drainage of organic soils: It is assumed that all existing Settlement areas on organic soils are drained. The only land use change from Settlement on organic soils is to and from Forest land and the areas involved are small (1.66 kha to Forest Land since 1990, and 3.70 kha from Forest Land since 1990) and all assumed to be drained.
- Changes in biomass and soil carbon due to LUC: the land-use change data assimilation methodology draws on multiple data-sources and takes account of random uncertainty and false positive rates. Estimated rates of change are lower and more gradual than in previous submissions, although the uncertainty bounds are larger.
- 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.

A significance analysis has been undertaken for key categories in the LULUCF sector. Carbon stock changes in mineral soils in 4E1 Settlements remaining Settlements and 4.E2.3 Grassland converted to Settlement are the most significant sub-categories/pools (**Table 6.11**).

Table 6.11 Significance analysis of the key sub-categories/pools in the Settlement category

Sub-category	Pool	Percentage contribution to 1990 total[1]	Percentage contribution to 2021 total[1]
4(V) Biomass burning		1%	4%
E1. Settlements remaining Settlements		**27%**	**42%**
	Carbon stock change in biomass due to land use change	0%	0%
	Mineral Soils	**27%**	**42%**
	Organic Soils	0%	0%
E2.1. Forest Land converted to Settlements		9%	19%
E2.2. Cropland converted to Settlements		9%	7%
E2.3. Grassland converted to Settlements		**55%** (mineral soils)	**29%** (mineral soils)

[1] Percentages may not sum to 100% due to rounding

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 6.11**.

6.6.7 Category-Specific Recalculations

The reported overall net GHG source in category 4E has decreased by 0.0 to -0.2 Mt CO_2e (3-6 %) across the time series compared to the previous inventory. The changes were mainly in mineral soil carbon stock change in Settlement remaining Settlement and Land converted to Settlement.

The changes and their justification are:

- **Updated EFs from organic soils.** An updated (2022) Tier 2 analysis of organic soil emission factors (EFs) from the Defra Peatland Code Project SP0822 was implemented. This update incorporates new UK datasets published since 2019, including data from the UK flux tower network, as well as international data from climatically similar regions. Particulate organic carbon (POC) EFs were updated for all soil categories using an IPCC Tier 1 methodology (IPCC 2014 Appendix Eq.2A.1).
- **Revisions to organic soil areas.** Revisions to the organic soils maps were included from a BEIS Ad-hoc project to edit and check the geometry of the maps and clarify activity data and the assumptions used to create the maps in Evans et al. 2017.**Revised deforestation activity data.** Deforestation to Settlement area updated to match information reported in the latest Forestry Commission key corporate indicators and to include the data for 2019 and 2020.Changes in emissions are described in **Table 6.12.**
- **Minor changes to average biomass densities used for wildfire emission calculations**

Table 6.12 4E Category specific recalculations since previous submission (UK only)

IPCC Category	Source Name	Old 1990 value	Old 2020 value	New 1990 value	New 2020 value	Units	Comment / Justification
4E1	Net carbon stock change in soils - organic soils	3.39	3.21	3.15	2.94	Gg C	Revisions to organic soil areas. Updated EFs from organic soils.
4E2.1/4(V)	Biomass burning - controlled burning	13.33	57.44	13.34	36.53	Gg C	Updated deforestation activity data
4E2.1	Carbon stock change in living biomass - losses	18.89	77.28	18.89	47.60	Gg C	
4E2.1	Net carbon stock change in dead organic matter	4.48	23.39	4.49	16.44	Gg C	
4E2.1	Net carbon stock change in soils - organic soils	0.01	0.67	0.01	0.58	Gg C	Revisions to organic soil areas Updated deforestation activity data
4E2.1/4(V)	Emissions and removals from drainage and rewetting and other management of organic and mineral soils	0.51	0.58	0.53	0.59	Gg CH_4	Updated EFs from organic soils. Revisions to organic soil areas.
4E2.1/4(V)	Biomass burning - controlled burning	0.15	0.63	0.15	0.40	Gg CH_4	Minor changes to average biomass densities used for wildfire emission calculations
4E/4(II)	Emissions and removals from drainage and rewetting and other management of organic and mineral soils	0.001	0.002	0.002	0.002	Gg N_2O	Revisions to organic soil areas. Updated EFs from organic soils.
4E2.1/4(V)	Biomass burning - controlled burning	0.008	0.035	0.008	0.022	Gg N_2O	Minor changes to average biomass densities used for wildfire emission calculations

6.6.8 Category-Specific Planned Improvements

The second step in implementing the BEIS-funded Land-Use Tracking project is in progress in 2022 (see **Section 6.3.8**).

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. The land-cover types in the different data sources that contribute to the Other Land category are described in **Annex 3.4.2.1.** As described in **Section 6.4**, areas of inland water exceeding $1km^2$ are included in 4D Wetlands, but water bodies below this threshold would still be included under Other Land.

6.7.4 Category-specific recalculations

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 (L1, T1)
Key Categories (Qualitative)	None identified
Completeness	No known omissions
Major improvements since last submission	Changes to forest planting areas in 4A had a knock-on effect on HWP outputs. Assumed management was revised to best match to the updated data (including new estimates of wood production in Northern Ireland).

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, producing a time series from 1961 to the latest inventory year. 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 15-20% for CO_2.

These uncertainties are based on an updated uncertainty analysis, broadly following the methodology of the previous uncertainty analysis, but using the updated activity data and methodology for this submission. Details are provided in **Annex 3.4.12**.

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 using Forestry Commission reported statistics and from 1961-1975 using FAO timber production data. 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.

A significance analysis has been undertaken for key categories in the LULUCF sector. In Harvested Wood Products HWP Produced and Consumed Domestically is the most significant sub-category (**Table 6.13**).

Table 6.13 Significance analysis of the key sub-categories/pools in the Harvested Wood Products category

Sub-category	Pool	Percentage contribution to 1990 total	Percentage contribution to 2021 total
HWP Produced and Consumed Domestically		**85%**	**95%**
	Paper and Paperboard	11%	-3%
	Solid Wood	32%	51%
	Wood panels	43%	47%
HWP Produced and Exported		15%	5%

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 1.6**. The timber production predicted has been compared to the national timber production statistics produced by the Forestry Commission based on data from sawmills.

6.8.5 Category-Specific Recalculations

The reported overall net GHG sink in category 4G has increased by between 0.0 and 0.2 Mt CO_2e (0 to 6%) across the time series compared to the previous inventory.

The changes resulted from **updated activity data** for afforestation and deforestation, as described in **Section 6.2.7.**

The changes are described in **Table 6.15**.

Table 6.14 4G Category specific recalculations to activity data since previous submission (UK only)

IPCC Category	Source Name	Old 1990 value	Old 2020 value	New 1990 value	New 2020 value	Units	Comment / Justification
4G	HWP produced and consumed domestically	-485.85	-550.10	-487.83	-510.18	Gg C	Updated activity data
4G	HWP produced and exported	-83.53	-30.46	-83.85	-33.67	Gg C	Updated activity data

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, 4D Wetlands, 4E Settlements 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils (4A Forest Land, 4B Cropland, 4C Grassland) 4(III) Direct N_2O emissions from N mineralization (4B Cropland, 4C Grassland, 4E Settlements) 4(V) Biomass Burning (4A Forest Land, 4C Grassland)
Gases Reported	CO_2, CH_4, N_2O
Methods	Tier 1, T2 for organic soils
Emission Factors	T1 and T2 for direct CO_2, CH_4 and N_2O emissions from organic soils, T1 for other emissions
Key Categories	None identified
Key Categories (Qualitative)	None identified
Completeness	No known emissions
Major improvements since last submission	Soils in the Isle of Man (IoM) have been split between mineral and organic soils, and emissions from organic soils in the IoM are reported for first time in this submission.

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 submission (**Table 6.15**). Emissions estimates are made for the CDs of Jersey, Guernsey and the Isle of Man and the OTs of the Falkland Islands, Cayman Islands and Bermuda. Gibraltar has only one land-use category of Settlement remaining Settlement, with no associated GHG emissions. **Annex 3.4.11** provides detailed descriptions of the methods and emission factors used.

Table 6.15 LULUCF net emissions in all Overseas Territories and Crown Dependencies (Mt CO_2e)

LULUCF Categories	GBR Old 1990 value	GBR Old 2020 value	GBR New 1990 value	GBR New 2020 value
Total LULUCF	0.07	0.11	0.07	0.08
A. Forest Land	-0.04	-0.04	-0.04	-0.04
B. Cropland	0.01	0.03	0.01	0.02
C. Grassland	0.00	-0.01	0.00	-0.01
D. Wetlands	0.00	0.00	0.00	0.00
E. Settlements	0.10	0.13	0.10	0.11
G. Harvested Wood Products	-	-	-	-

LULUCF Categories	GBR Old 1990 value	GBR Old 2020 value	GBR New 1990 value	GBR New 2020 value
Indirect N_2O emissions	0.00	0.00	0.00	0.00

The Forest Land and Grassland categories are net sinks in the OTs and CDs while other land use categories are net sources. The LULUCF sector in the OTs and CDs is a net source in all years. The individual territory trends are:

- Isle of Man: net sink, with net sources in cropland and settlement counterbalanced by net sinks in forest and grassland
- Guernsey: small net sink, with net sources in cropland and settlement counterbalanced by net sinks in forest and grassland
- Jersey: moves between being a small net source to a small net sink across the time series, with net sources from cropland and settlements and a net sink in grassland.
- Falkland Islands: stable net source 1990-2005, then variable slowly decreasing source due to reduced emissions from cropland
- Cayman Islands: stable net source 1990-2006, then a variable net source primarily due to conversion of mangrove (organic) soils to settlement and forest conversion to wetlands and grasslands.
- Bermuda: small stable net source 1990-2011 due to forest conversion to settlement, becoming a very small net sink from 2012 due to a net sink in settlement.

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, 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 is maintained at a constant area by including a small area of unmanaged wetland to account for land reclamation from the sea 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.

6.9.3 Methodological Issues

Similar climate and land management parameters are assumed as for the UK for Guernsey, Jersey and the Isle of Man. Appropriate parameters for the OTs have been taken from the IPCC 2006 and 2013 guidance (**Annex 3.4.11**). There is incomplete information on land areas for all territories so land areas have been interpolated between, or extrapolated from, land area surveys as required. A Tier 1 method has been used to estimate forest carbon stock changes for all territories, using the appropriate emission factors for the climatic region and forest type. The IPCC Tier 1 default factors from the 2006 Agriculture, Forestry, and Land Use (AFOLU) Guidelines and the Tier 1 EFs for mangroves from the 2013 Wetland Supplement 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 an reduction of 0.01 Mt CO_2e in the net source across the time series, predominantly in the Falkland Islands.

Carbon stock changes in Cropland in the Falkland Islands have been recalculated to correctly take account of ley grasslands within the Cropland remaining Cropland sub-category. The annual increase in Grassland converted to Settlement in the Falkland Islands from 1991 onwards was reduced to correct a transcription error in the area required per dwelling. For the Isle of Man there were minor changes due to the updated Tier 2 EFs for emissions from organic soils affecting Cropland and Grassland emissions.

There were also minor changes due to a recalculation of the indirect N_2O emissions (error correction), new estimates of emissions from domestic peat extraction in the Falkland Islands, and the incorporation of new activity data for Bermuda and Jersey.

6.9.5 Planned improvements

The UK Government is funding longer-term research into organic soils and emissions in the Falkland Islands. Peat extent and depths have been mapped by the Darwin Plus project DPLUS083, and there are ongoing projects to map undisturbed reference habitats, estimate above-ground biomass stocks and measure CO_2 and CH_4 fluxes. The Falkland Islands have different peat-forming species to the Northern Hemisphere, and UK Tier 2 emission factors are an imperfect analogue for Falkland conditions, hence the need for additional research.

6.10 INDIRECT N_2O EMISSIONS FROM LULUCF ACTIVITIES

Indirect emissions of N_2O from atmospheric deposition are estimated according to IPCC (2006, equation 11.9) using the default value for EF4 from the 2019 Refinement value for wet climates (0.014 kg N_2O-N) and the fraction of N that is volatilised from inorganic fertiliser N applications to forest land (FracGasF). The change in the EF4 value was implemented for consistency with the value used in the Agriculture sector. The amount of synthetic fertiliser applied is that used to estimate emissions reported in CRF table 4(I).

Indirect emissions of N_2O from leaching and runoff are estimated according IPCC (2006, equation 11.10) using the default value for EF5. The sources of nitrogen considered are synthetic fertiliser application to forest land and direct N_2O emissions from mineralisation arising from land-use change and land management (reported in CRF Table 4(III)) on mineral soils. The default IPCC (2006) FracLEACH values are used for both sources.

There were no significant changes in indirect emissions of N_2O in this submission.

Indirect N_2O emissions from LULUCF activities are estimated to have a combined uncertainty of 160-165% for N_2O.

6.11 GENERAL COMMENTS ON QA/QC

UKCEH 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. UKCEH 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 UKCEH. 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 spreadsheets 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, as part of the European Union Monitoring Mechanism.

A programme of upgrade to the LULUCF models ran from 2016 to 2020. This included verification of model calculations, improvement of documentation, addition of built in QA checks and storage in a version control repository. 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. In collaboration with Ricardo Energy & Environment, UKCEH 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_2O, NO_x, CO, NMVOC, SO_2
Key Categories ('T' or 'L' indicates whether it's been identified in the trend or level assessment respectively and the number indicates which KCA approach it was identified in)	5A: Solid waste disposal – CH_4 (L1, T1, L2, T2) 5B: Biological treatment of waste – CH_4 (T1, L2, T2) 5B: Biological treatment of waste – N_2O (L2, T2) 5C: Waste incineration – CO_2 (L2, T2) 5D: Wastewater handling – CH_4 (L1, L2) 5D: Wastewater handling – N_2O (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	Revised estimates for 5D2, industrial wastewater treatment, based upon a new tier 1 approach.

Emissions from the waste sector contributed 4.4% to greenhouse gas emissions in 2021. Emissions consist of CO_2, N_2O and CH_4 from waste incineration, CH_4 from solid waste disposal on land, and both CH_4 and N_2O from wastewater handling and biological treatment of solid waste. Overall emissions from the waste sector have decreased by 74% 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 the 2021[89]

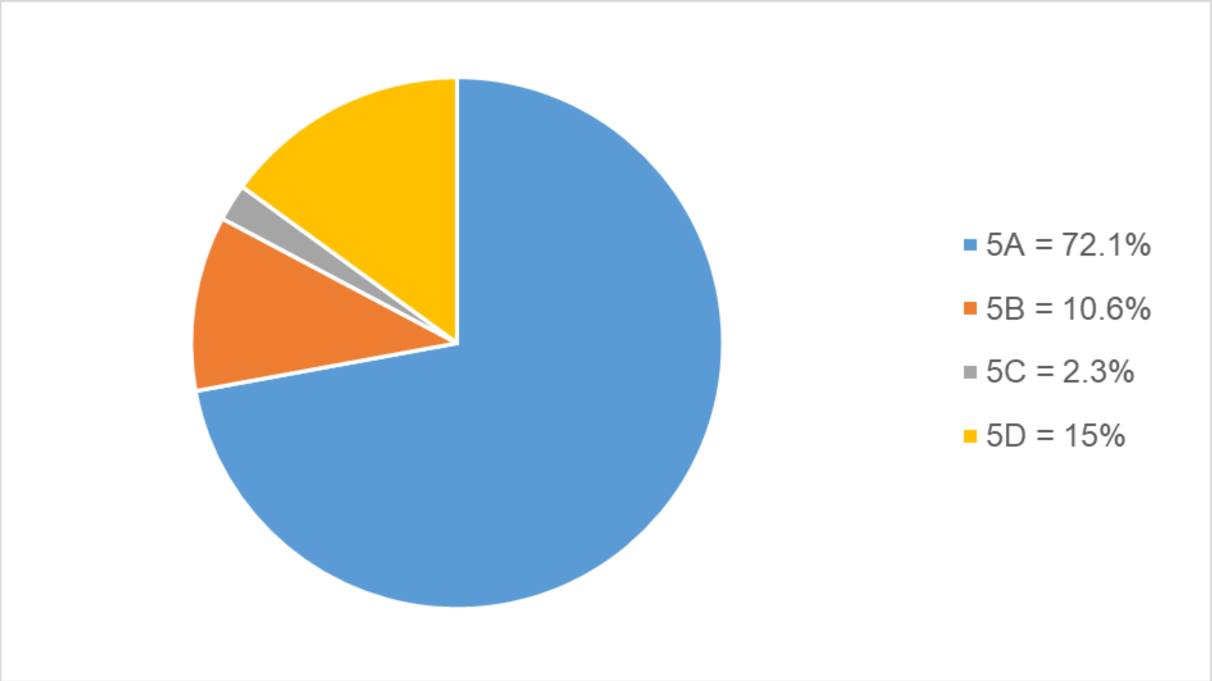
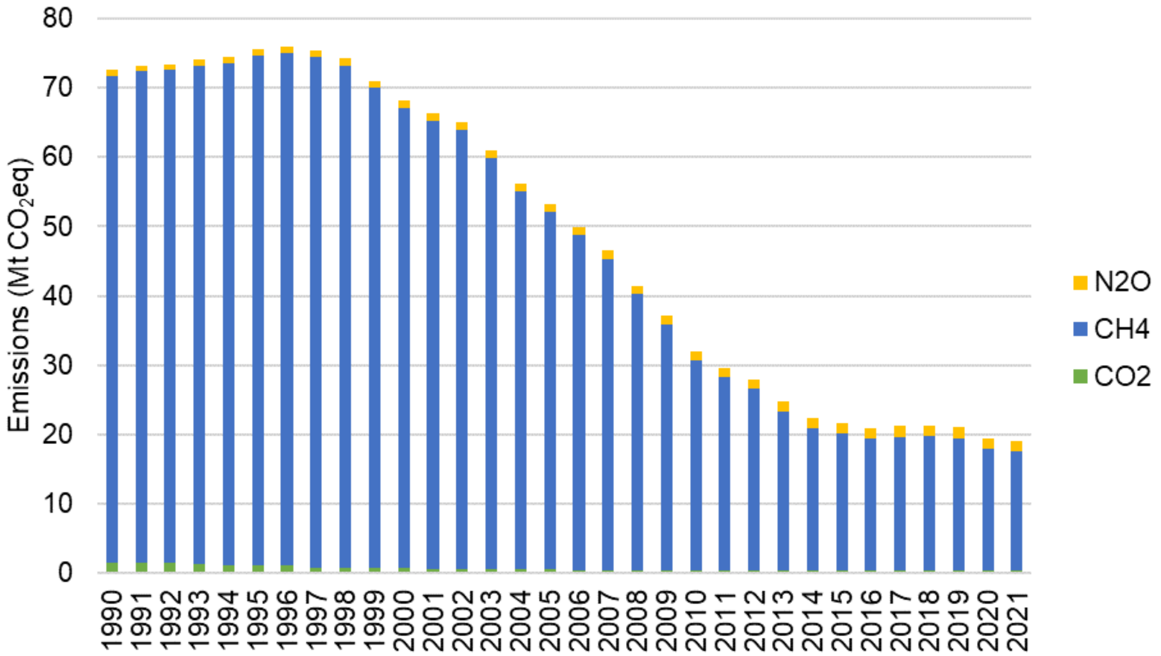


Figure 7.2 Trend in total GHG emissions in the Waste sector



7.1.1 Waste Related Activities Reported In Other Sectors

The waste sector as defined in the 2006 IPCC guidelines relates to emissions from processes associated with the treatment and disposal of waste. However, if waste or waste-derived products are utilised for another process, emissions associated with this is reported according to the process, and therefore excluded from waste sector reporting.

[89] The categories in the Waste sector are explained in the IPCC categories section.

This section discusses such sources, where those sources are reported in the inventory, and how they relate to waste-sector processes and reporting. **Figure 7.3** presents at a high level how waste management, waste disposal and waste utilisation interact in the waste, energy and agriculture sectors, and where these are reported in the inventory.

Figure 7.3 Flow diagram of waste treatment and disposal route

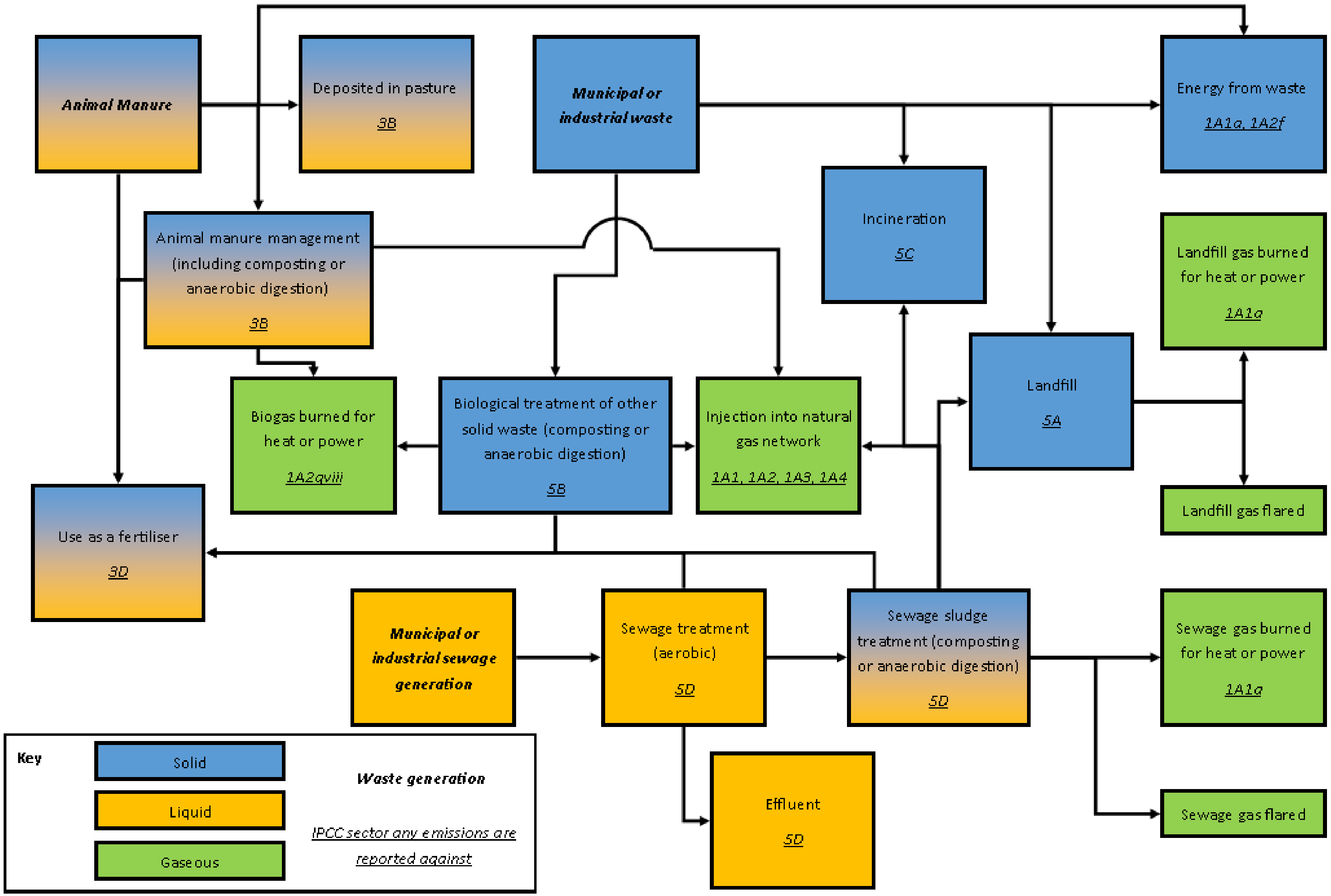


Figure 7.4 presents trends in solid waste disposal routes. It demonstrates a long-term trend of increasing redirecting of waste away from landfill and into either biological treatment of waste or energy from waste; this is further illustrated in the decline in digestible and combustible waste sent to landfill presented in **Figure 7.5**. What is not presented are trends in quantities of non-degradable waste recycling (such as plastics, glass, and metals) or exported from the UK, as within this context these do not directly generate emissions, and therefore are not explicitly referred to in the inventory. It is expected that at least some of the decline in total waste presented will be due to increase in non-degradable recycling rates.

Figure 7.4 Trend in solid waste disposed by disposal route[90]

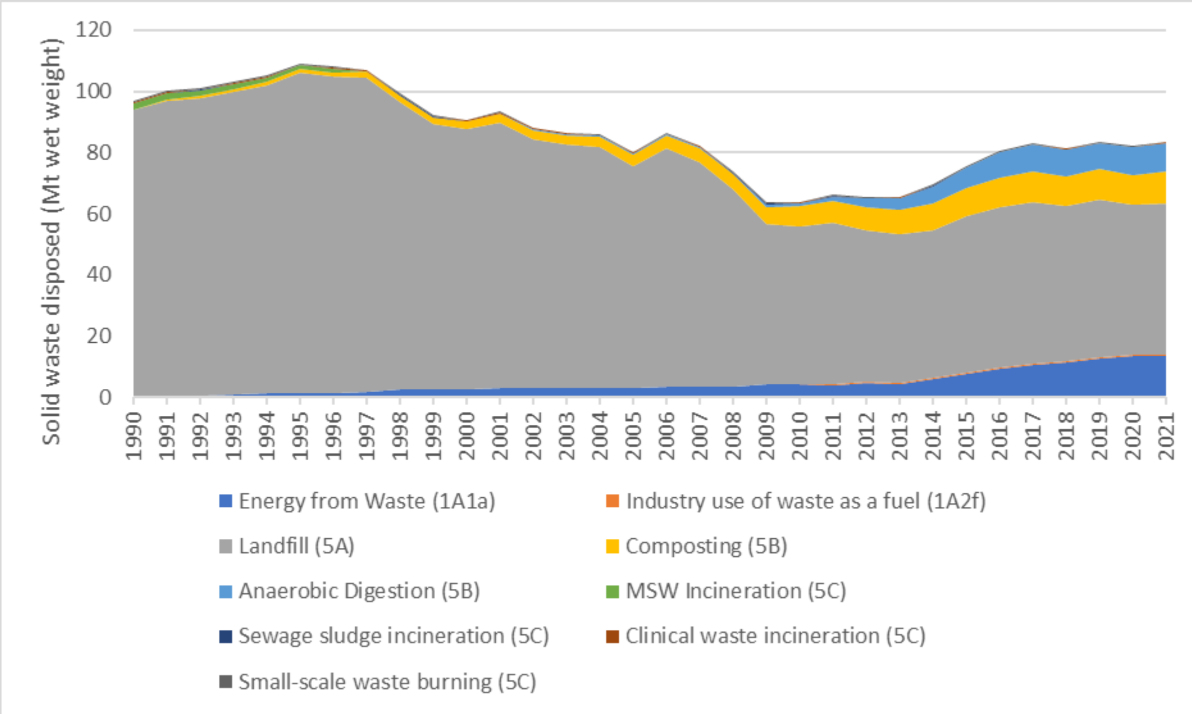
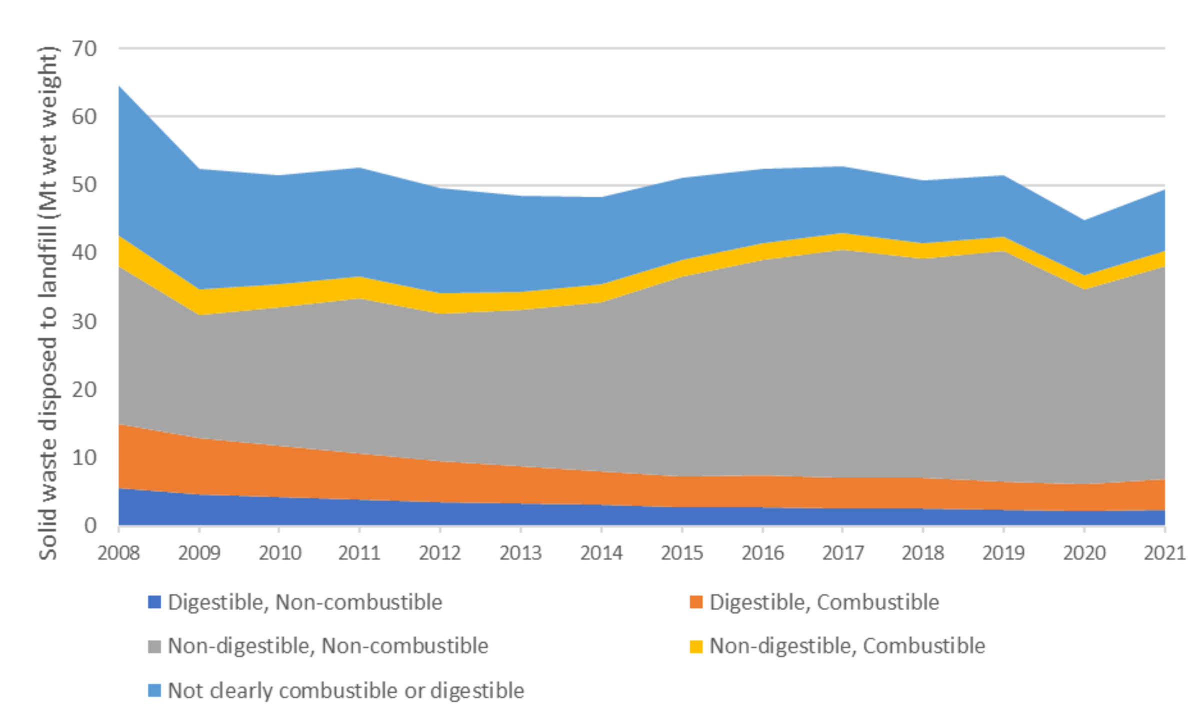


Figure 7.5 presents composition of solid waste disposed to landfill by general consideration of its combustibility and digestibility. Data are presented only for 2008 onwards as detailed breakdown of waste composition by European Waste Catalogue classification is available for these years only. Note that a large proportion of waste is classified as unspecified mixtures of waste, meaning that there is significant uncertainty as to the classification presented; the assumed composition of these categories is presented in **Table A 3.5.1**.

[90] Recycling or waste exported are not included, as these do not result in direct emissions occurring in the UK, and therefore the Inventory Agency does not collect estimates of the quantities of waste disposed by these routes

Figure 7.5 Trend in landfill composition



7.1.1.1 Utilisation of Waste-Derived Biogas

A large proportion of methane generated in the anaerobic digestion of biodegradable material, occurring in sewage treatment plants, landfills and sites conducting biological treatment of solid wastes is captured and utilised as a fuel. Fuel use is typically on-site with the energy used for other activities on the site, or exported as electricity, but also increasingly, some methane is injected into the national natural gas distribution network for use as a fuel by any user of natural gas. Using methane as a fuel oxidises it, preventing it being released into the atmosphere as methane, instead releasing carbon dioxide and very small quantities of methane and nitrous oxide. The emissions as a result of combustion of biogases for energy is reported in sector 1A, including biogases that are injected into the national natural gas distribution network. The UK includes emissions from the utilisation of biogases for energy as follows:

- Sewage gas and landfill gas used to generate electricity or heat are reported in sector 1A1a, described in **MS 1**
- Other biogases used for energy are reported in sector 1A2gviii, described in **MS 3**; and,
- Any biogases that are injected into the natural gas network are reported in energy statistics as a transfer from the renewables balance to the natural gas balance and are therefore included in the inventory as part of natural gas in all downstream uses of natural gas, mostly in various sub-sectors in 1A, described in various sub-sections in **Section 3**. Data on the quantity of biogases transferred to natural gas are used to determine the proportion of CO_2 emissions from natural gas combustion which are of biogenic and fossil origin.

Note that for all sources of biogas, in the 2022 update of DUKES data reported for 2019 onwards has been reduced significantly. In most cases this creates a divergence in the agreement between DUKES and the NAEI for recent years, and we are engaging with the UK energy stats team to understand how to interpret this.

Figure 7.6 presents an agreement within 8% for 2013-2018 between the municipal wastewater company reported estimates of sewage gas utilisation and UK energy statistics on sewage gas when noting that methane flaring is not a fuel use application, so is excluded from energy statistics. Data are only presented for 2013 onwards, as company reported data in this format is only available for these years; estimates of methane recovered for earlier years are extrapolated based on UK energy statistics. When capture is compared to emission rates, we see implied capture rates of 95-98% in these years, which are a level that would be expected for mature centralised anaerobic digestion.

Figure 7.6 Comparison of Estimates of Sewage Gas Utilisation

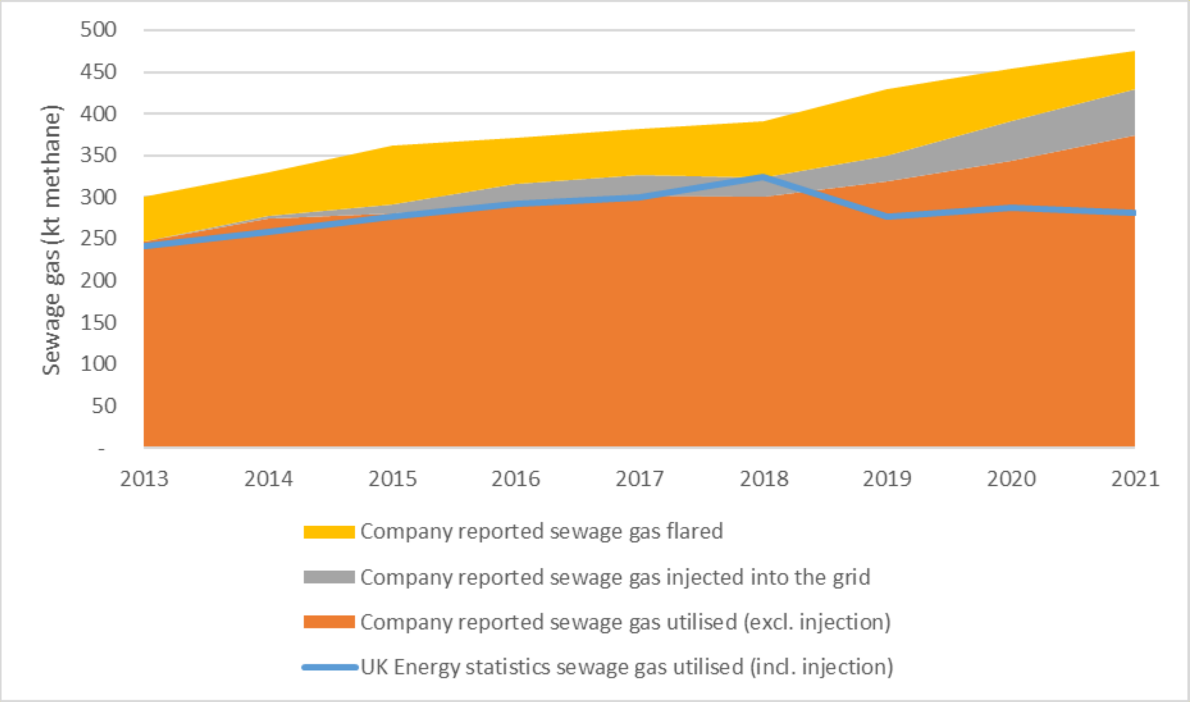


Figure 7.7 presents the strong agreement between the estimate of landfill gas captured for utilisation and UK energy statistics on landfill gas when noting that methane flaring is not a fuel use application, so is excluded from energy statistics. Both UK energy statistics and landfill gas capture estimates for landfill gas utilisation are based on data on electricity generated from engines consuming landfill gas, however, for landfill gas capture estimates we estimate that these engines improve in efficiency in more recent years, reducing the landfill gas required to generate the electricity observed. The UK Inventory Agency and energy statistics team are aware of this difference and are considering whether these can be aligned.

Figure 7.7 Comparison of Estimates of Landfill Gas Utilisation

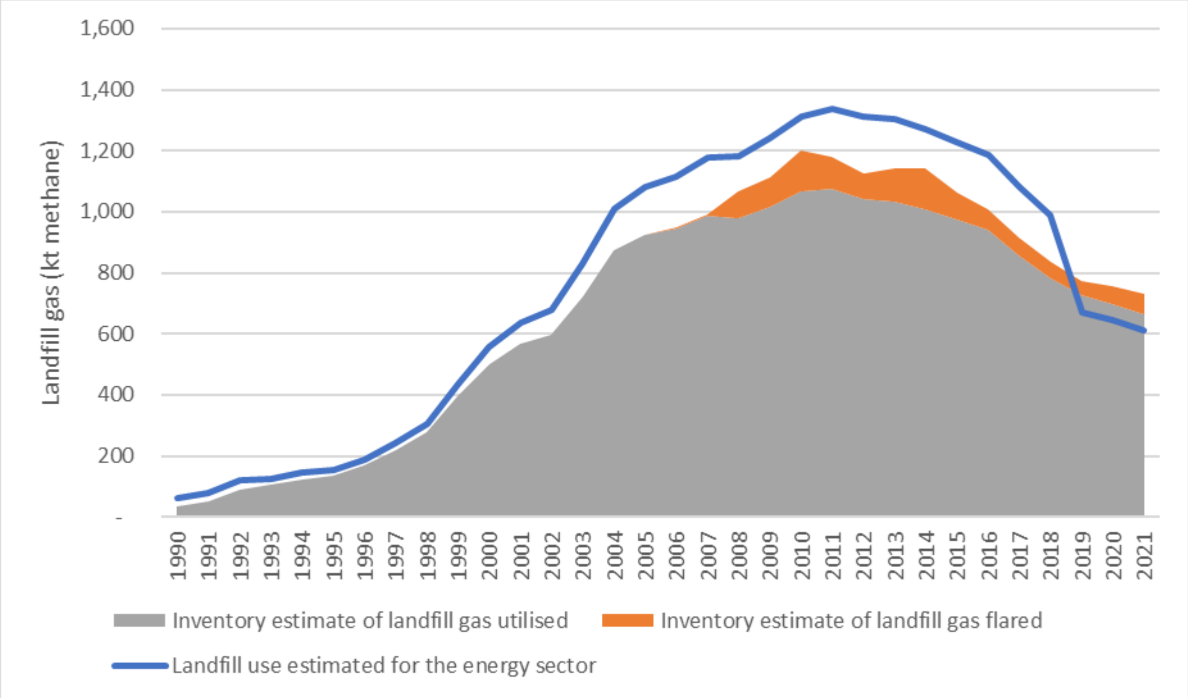
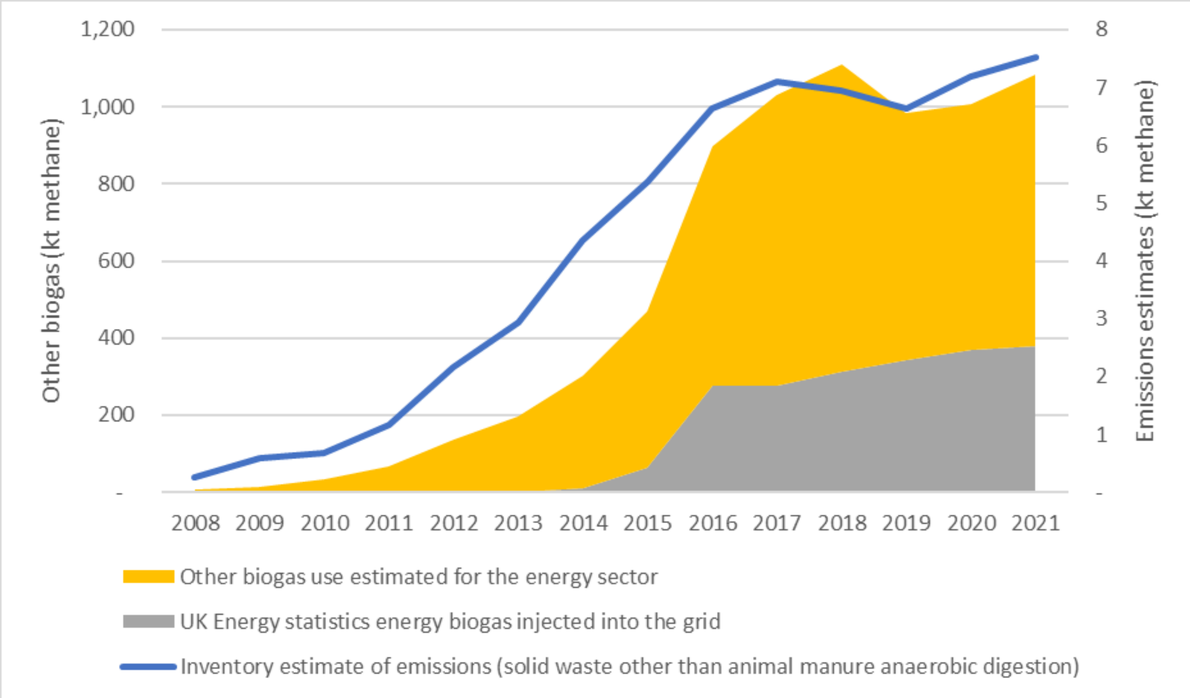


Figure 7.8 presents the strong correlation between methane emissions from non-animal manure solid waste anaerobic digestion emissions estimates and UK energy statistics on other biogas use. Data are only presented for 2008 onwards, as all datasets present extremely low values in the early part of the time-series. It is not currently feasible to make more direct comparisons between the waste and energy sector due to the energy sector biogas including biogas derived from animal manures and the non-animal manures solid wastes estimates being a tier 1 method.

If comparing non-animal manure solid waste anaerobic digestion emissions estimated to total biogas utilisation, the implied capture rate strictly increases from 95% in 2009 to over 99% since 2017. We suspect that the very high implied capture rate in recent years reflects an increasing contribution from manure anaerobic digestion biogas capture and utilisation, which will be included in the methane utilisation data, but not in the non-manure anaerobic digestion emissions data presented.

Figure 7.8 Comparison of Estimates of Other[91] Biogas Utilisation



7.1.1.2 Energy from Waste

Information about the methods and data relating to waste incineration is reported under **Section 7.4** and emissions are reported under sector 5C. However, if useful energy is extracted from waste incineration, then for inventory reporting purposes, the activity is considered an energy sector process and emissions are reported under 1A. Due to a ban on the incineration of MSW without energy recovery in 1996, the quantity of emissions that are allocated to 5C fell significantly, as illustrated in **Figure 7.4**.

The UK includes emissions from the combustion of waste for energy as follows:

- Energy from Waste plants are reported in sector 1A1a, described in **MS 1**; and,
- Minerals industries use of waste are reported in sector 1A2f, described in **MS 2**.

7.1.1.3 Biological Treatment of Waste

The reporting of biological treatment (composting or anaerobic digestion) of waste depends on the nature of the waste treated. Specifically:

- For animal manure emissions are reported against 3B, described in **Section 5.3**;
- For sewage, industrial liquid wastes, or sludge derived from these wastes that are treated at a wastewater treatment plant emissions are reported against 5D, described in **Section 7.5**; and,
- For other solid wastes emissions are reported against 5B, described in **Section 7.3**.

7.1.1.4 Utilisation of Digestates and Sewage Sludge

If digestates or sewage sludge are utilised as a fertiliser, then any emissions from the spreading of these products are reported as an agricultural soils emission, specifically:

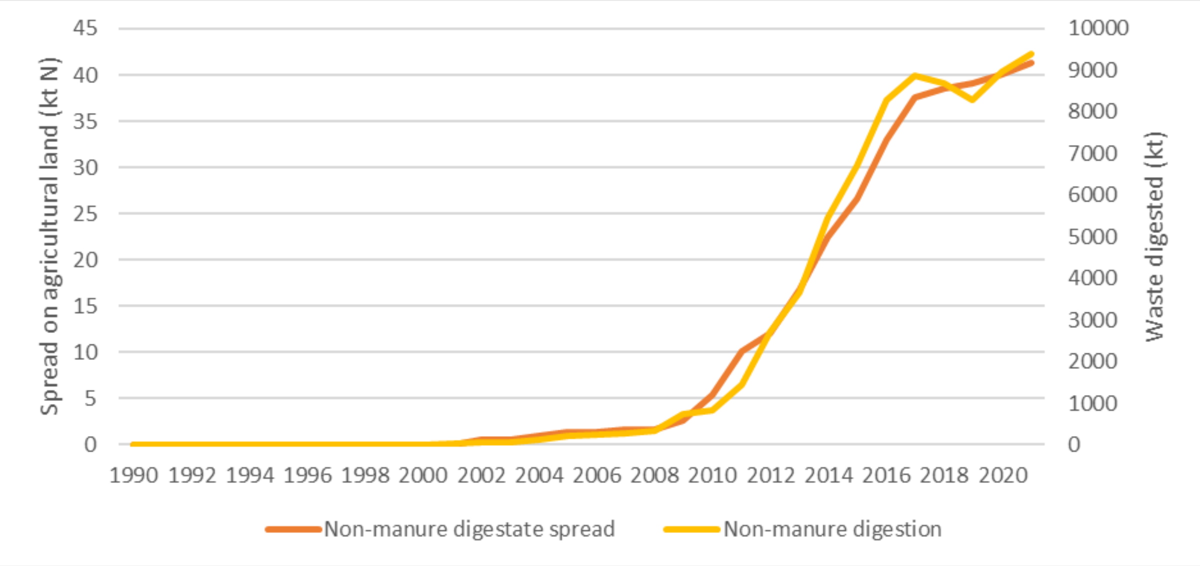
- For digestates spread on agricultural land emissions are reported against 3D12c, described in **Section 5.5.2.3.2**; and,

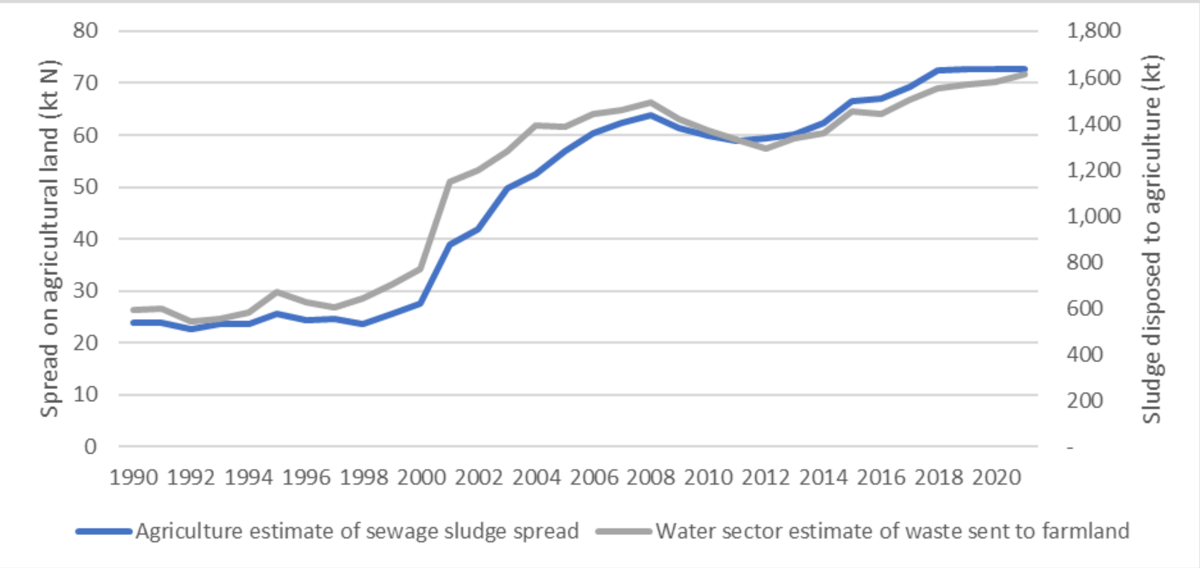
[91] i.e., not sewage gas or landfill gas

- For sewage sludge spread on agricultural land emissions are reported against 3D12b, described in **Section 5.5.2.3.1**.

Figure 7.9 demonstrates the strong correlation between the Nitrogen content of wastes spread on agricultural land and waste digested or waste sector estimates of sewage sludge disposed to agricultural land. For agricultural waste spreading, a nitrogen balance approach is used to estimate N_2O emissions, and hence activity data for those sources are in terms of Nitrogen content instead of total mass.

Figure 7.9 Comparison of Estimates of Agriculture and Waste Sector Estimates for Digestates and Sewage Sludge





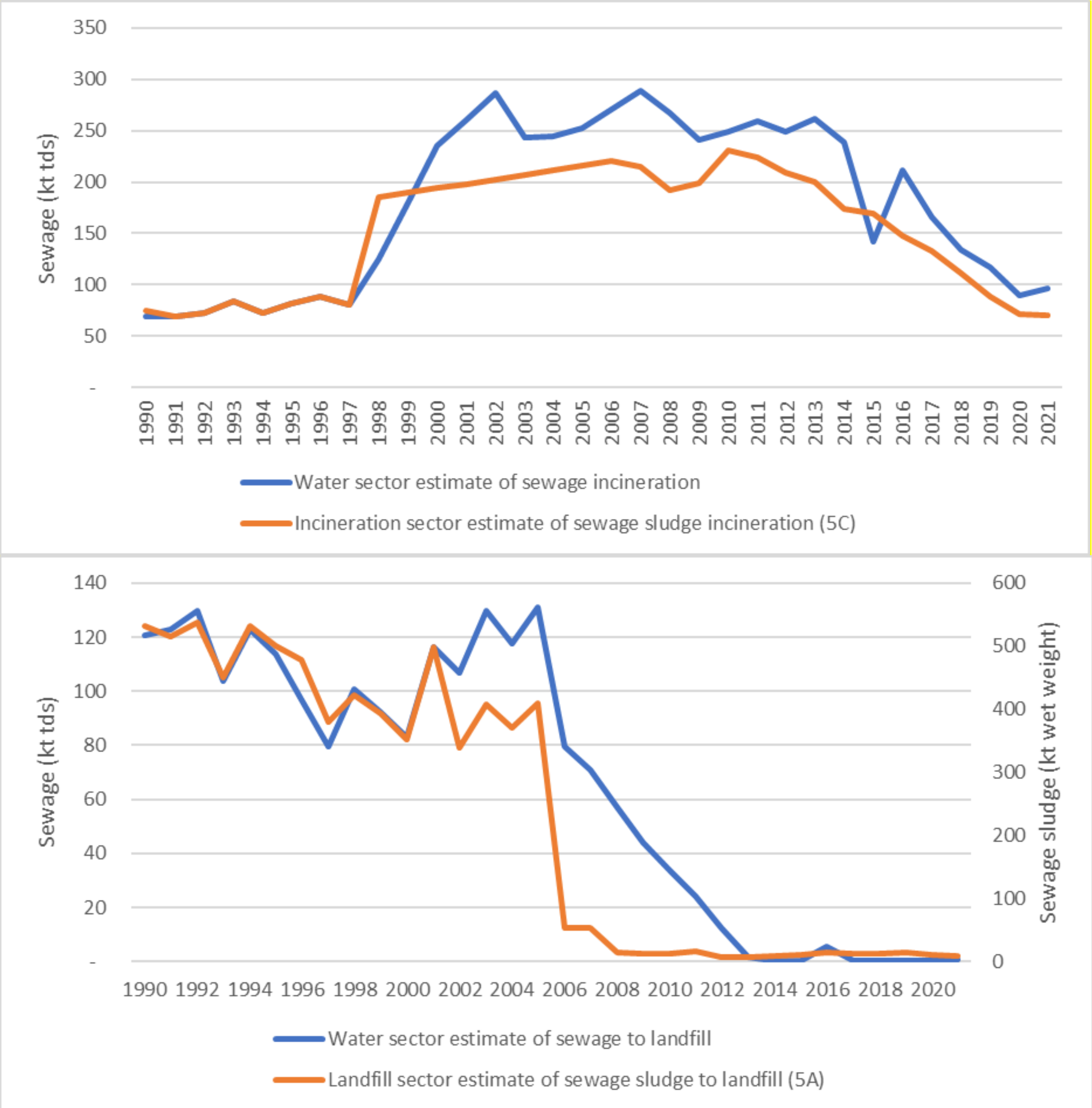
7.1.1.5 Disposal Routes of Sewage Sludge (Other than Utilisation)

The reporting of disposal emissions of biologically treated waste depends on the nature of the disposal route. Specifically:

- For sewage sludge disposed to landfill emissions are reported against 5A, described in **Section 7.2**; and,
- For sewage sludge incinerated without energy recovery emissions are reported against 5C, described in **Section 7.4.**

Figure 7.7.10 demonstrates the strong agreement between water sector estimates of sewage sludge disposal to landfill or incineration and the estimates of sewage sludge received at landfills and incineration plants. Note that data for sewage sludge received at landfills are the total weight of matter received, which means it includes a large proportion of water which would not be included in the wastewater data presented in kt tds.

Figure 7.7.10 Comparison of Estimates of Landfill/Incineration sector and Water Sector Estimates for Sewage Sludge disposal



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	No major improvements.		

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 2021 were 13.6 Mt CO_2e. Emissions have been on a downward trend in almost every year since 1996.

In addition to CH_4, anaerobic decomposition also produces an approximately equivalent amount of CO_2, further CO_2 is produced by other 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. For this reason, emissions of CO_2 from landfills are not estimated as they are considered to be entirely biogenic in origin and therefore not counted towards the national total as this would introduce a double count with net carbon losses reported in the LULUCF sector (this is also discussed in **Section 1.8.2.3**). Landfilled Solid Waste also contains fossil-derived organic matter, predominantly in the form of plastics, but these are essentially non-biodegradable under landfill conditions, and so emissions of fossil-derived CO_2 from solid waste disposal sites (SWDS) are not considered further.

Non-methane volatile organic compounds (NMVOCs) are also released by SWDS. These are estimated using an emission factor relating the NMVOC to the amount of CH_4 emitted. An emission factor of 0.0036 kg NMVOC/tonne landfill gas was used (Broomfield et al., 2010).

The IPPC 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 CH_4 for many years from biodegradable 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, and their ongoing applicability confirmed through the Environmental Permitting (England and Wales) (Amendment) (EU Exit) Regulations 2018. 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)[92] decay under the anaerobic 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.

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

92 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 x DOC_F where DOC_F is the fraction of DOC that dissimilates.

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 the methodology set out in the 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).

EQUATION 3.1
CH_4 EMISSION FROM SWDS

$$CH_4\ Emissions = \left[\sum_x CH_4\ generated_{x,T} - R_T\right] \bullet (1 - OX_T)$$

The IPCC 2006 Guideline default value of 0.1 is used for OX_T, the proportion of methane oxidised on passing through the landfill surface.

- 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). These are taken from the IPCC 2006 Guidelines.

EQUATION 3.2
DECOMPOSABLE DOC FROM WASTE DISPOSAL DATA

$$DDOCm = W \bullet DOC \bullet DOC_f \bullet MCF$$

The following values are used for DOC (derived from Eunomia Consulting and Research, 2011) (there is some overlap between categories because of historical definitions used to characterise residual waste landfilled):

Table 7.1 DOC values used to calculate landfill methane emissions (%dry matter)

	Lignin	Hemicellulose	Cellulose	Starch	Sugar	Fat	Proteins	Fibre	Readily soluble	Inert
Paper	8%	3%	21%	0%	0%	0%	0%	0%	0%	0%
Card	8%	3%	20%	0%	0%	0%	0%	0%	0%	0%
Nappies	0%	0%	7%	0%	0%	0%	0%	0%	0%	0%
Textiles and footwear	0%	5%	5%	0%	0%	0%	0%	0%	0%	0%
Miscellaneous combustible	0%	9%	8%	0%	0%	0%	0%	0%	0%	0%
Wood	14%	4%	14%	0%	0%	0%	0%	0%	0%	0%
Food	1%	1%	3%	2%	1%	3%	2%	2%	0%	0%
Garden	6%	3%	4%	0%	0%	1%	0%	0%	5%	0%
Soil and other organic	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Lignin	Hemicellulose	Cellulose	Starch	Sugar	Fat	Proteins	Fibre	Readily soluble	Inert
Furniture	1%	4%	4%	0%	0%	0%	0%	0%	0%	0%
Mattresses	0%	5%	5%	0%	0%	0%	0%	0%	0%	0%
Non-inert Fines	0%	7%	6%	0%	0%	0%	0%	0%	0%	0%
Inert	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Commercial [1]	0%	2%	19%	0%	0%	0%	0%	0%	0%	0%
Paper and Card	8%	3%	21%	0%	0%	0%	0%	0%	0%	0%
General industrial waste [1]	0%	2%	19%	0%	0%	0%	0%	0%	0%	0%
Food and Abattoir	1%	1%	1%	5%	1%	1%	2%	0%	0%	0%
Food effluent	0%	9%	1%	0%	0%	0%	0%	0%	0%	0%
Construction and Demolition	0%	3%	2%	0%	0%	0%	0%	0%	0%	0%
Miscellaneous processes [1]	0%	4%	3%	0%	0%	0%	0%	0%	0%	0%
Other waste [1]	0%	9%	8%	0%	0%	0%	0%	0%	0%	0%
Sewage sludge	0%	2%	2%	0%	0%	0%	0%	0%	0%	0%
Textiles / Carpet and Underlay	0%	5%	5%	0%	0%	0%	0%	0%	0%	0%
Sanitary	0%	0%	7%	0%	0%	0%	0%	0%	0%	0%
Other [1]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Note 1: This category no longer used in waste descriptions

These values are calculated by multiplying the dry matter content of each waste component by the organic component content and the carbon content of each organic component (**Table A 3.5.2** and below)

The following carbon content values are used to calculate the DOC data in **Table 7.1**.

- Lignin 65.1% dry matter
- Hemicellulose 44.6% dry matter
- Cellulose 40.0% dry matter
- Starch 44.4% dry matter
- Sugar 42.1% dry matter
- Fat 76.0% dry matter
- Proteins 40.0% dry matter
- Fibre 45.0% dry matter
- Readily soluble 45.0% dry matter
- Inert 0% dry matter

The following values are used for moisture content and DOC_f (Eunomia Consulting and Research, 2011):

Table 7.2 Moisture content and DOC_f values used to calculate landfill methane emissions

Component	Moisture content (% fresh matter)	Lignin bio-degradability DOC_f	Non-lignin bio-degradability DOC_f
Paper	15%	5.0%	65.0%
Card	20%	5.0%	65.0%
Nappies	65%	5.0%	65.0%
Textiles and footwear	20%	5.0%	65.0%
Miscellaneous combustible	20%	5.0%	65.0%

Component	Moisture content (% fresh matter)	Lignin bio-degradability DOC_f	Non-lignin bio-degradability DOC_f
Wood	17%	5.0%	65.0%
Food	70%	15.0%	70.0%
Garden	55%	10.0%	65.0%
Soil and other organic	30%	5.0%	65.0%
Furniture	12%	5.0%	65.0%
Mattresses	20%	5.0%	65.0%
Non-inert Fines	40%	0.0%	50.0%
Inert materials	0%	0.0%	0.0%
Commercial [1]	37%	5.0%	65.0%
Paper and Card	15%	5.0%	65.0%
General industrial waste [1]	37%	5.0%	65.0%
Food and Abattoir	70%	15.0%	70.0%
Food effluent	65%	15.0%	70.0%
Construction and demolition	30%	5.0%	65.0%
Miscellaneous processes [1]	20%	5.0%	65.0%
Other waste	20%	5.0%	65.0%
Sewage sludge	70%	5.0%	65.0%
Textiles / Carpet and Underlay	20%	5.0%	65.0%
Sanitary	65%	5.0%	65.0%
Other [1]		5.0%	65.0%

Note 1: This category no longer used in waste descriptions

There are no equivalent values to those set out in **Table 7.1** and **Table 7.2** in the IPCC 2006 Guidelines. However, the IPCC Tier 1 model contains default DOC values for some waste types. These are generally higher than the values used in the UK model, as shown in **Table 7.3**. However, the sensitivity test set out in **Section 7.2.5** indicates that the UK values are more representative of wastes landfilled in the UK

Table 7.3 DOC values used in UK model and IPCC default values

Component	Value used in UK model	Value in IPCC Tier 1 default model	UK value as % of IPCC Tier 1 value
Food waste	0.14	0.15	93%
Garden	0.18	0.20	90%
Paper	0.32	0.40	80%
Wood and straw	0.32	0.43	74%
Textiles	0.1	0.24	42%
Disposable nappies	0.07	0.24	29%
Sewage sludge	0.04	0.05	80%

The values used for the MCF are in accordance with the IPPC 2006 default values for managed and unmanaged sites (see below).

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.

EQUATION 3.3
TRANSFORMATION FROM DDOCm TO L_O

$$L_o = DDOCm \bullet F \bullet 16/12$$

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
DDOCm ACCUMULATED IN THE SWDS AT THE END OF YEAR T

$$DDOCma_T = DDOCmd_T + \left(DDOCma_{T-1} \bullet e^{-k}\right)$$

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
DDOCm DECOMPOSED AT THE END OF YEAR T

$$DDOCm\ decomp_T = DDOCma_{T-1} \bullet \left(1 - e^{-k}\right)$$

The decomposition rate constants used for rapidly, medium and slowly decaying wastes are the relevant default values given in the IPCC 2006 Guidelines Volume 5 Chapter 3 Table 3.3 for a wet boreal climate. The average of two default values for slowly decaying waste was used. These are allocated to the organic components of waste as follows:

- Rapidly decaying waste: Starch, Sugar, Fat, Proteins, Fibre, Readily soluble
- Medium decaying waste: Hemicellulose, Cellulose
- Slowly decaying waste: Lignin

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
CH_4 GENERATED FROM DECAYED DDOCm

$$CH_4\ generated_T = DDOCm\ decomp_T \bullet F \bullet 16/12$$

The values used for DOC and DOC_f 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 lower 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 2021 are published by the Environment Agency.
- Data on waste consignments landfilled in Scotland for the period 2005 to 2021 are published by the Scottish Environmental Protection Agency.
- Data on waste consignments landfilled in Wales for the period 2006 to 2021 are published by Natural Resources Wales.
- Data on waste consignments landfilled in Northern Ireland for the period 2008 to 2021 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. In summary, the quantity of methane combusted was calculated as follows:

Mass of methane combusted (kT) = Electricity generated (GWh)
× 3600 (GJ per GWh)
/ Net calorific value of methane (50,000 GJ/kT)
/ Engine efficiency (%)

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). Engine efficiency was assumed to be 30% up to 1996, and 36% from 2012 onwards. Between 1996 and 2012, engine efficiency was assumed to increase linearly from 30% to 36%

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, 2022), is given in **Table A 3.5.4**. In 2021, 3,313 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 365 individual sites in 2021. 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 Table A 3.5.5**.

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. 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, 2022). 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 46% to 58% for the period 2009 to 2021[93] derived in this analysis appear reasonable. Lower collection efficiencies in the years between 1990 and 2008 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

[93] See **Table A 3.5.4**

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 CH_4 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 2019 is based on records from a total of 186 individual facilities in England, 40 in Scotland, 17 in Wales, and 3 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.*" There was no change in parameters between 2017 and 2019.

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 in 2017 emissions for the period 1990-2015 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 7.4**.

Table 7.4 UK calculated emissions compared to Ireland and Italy

Year	Waste landfilled (Mt): UK	Waste landfilled (Mt): EI (approx.)	Waste landfilled (Mt): IT	Methane generated (kt): UK	Methane generated (kt) EI	Methane generated (kt) IT	Methane collected (%) UK	Methane collected (%) EI	Methane collected (%) 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%

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 are 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.

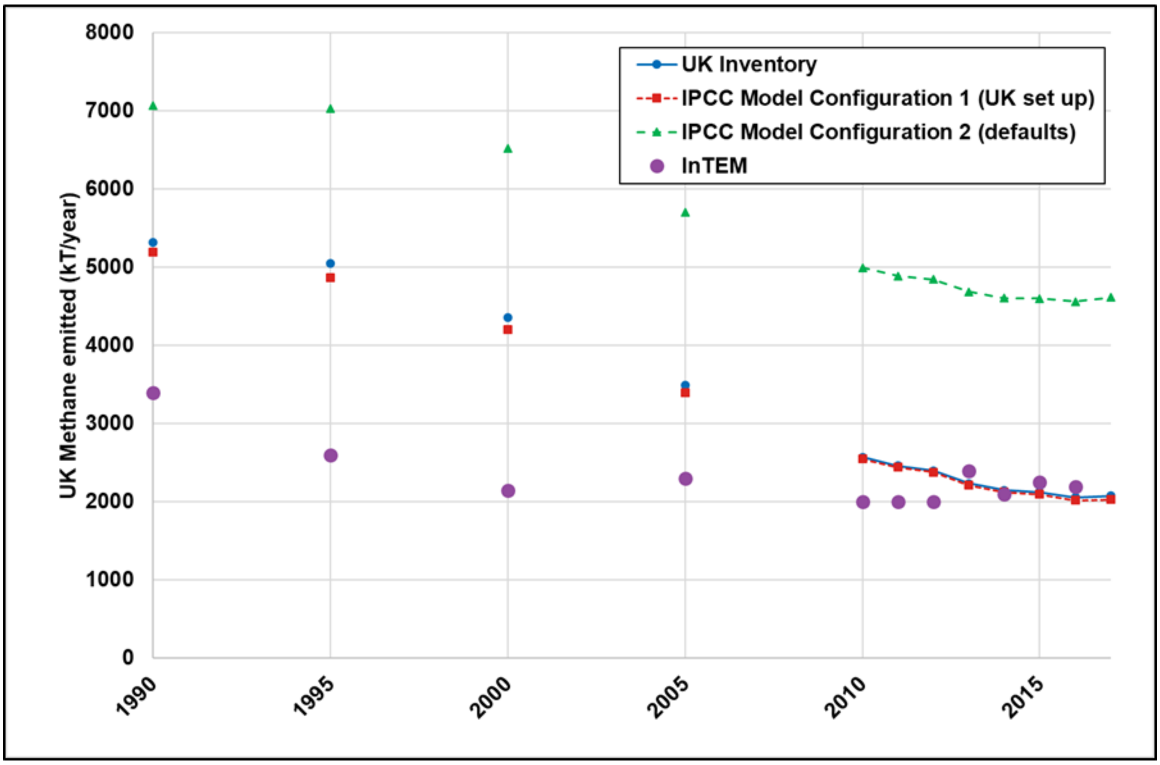
This onetime comparison was specifically performed to compare the methane collection efficiencies between the countries but was not carried out for the purposes of verification of MELMod model.

For the 2019 submission, an ad-hoc verification of the MELMod model was also carried out by comparing the estimation of emissions for 1990-2017 from the UK (Tier 2) model with the IPCC Tier 1 model. The IPCC model was set up in two ways: firstly, to reflect the UK Tier 1 model inputs so far as possible, and secondly, to reflect IPCC default inputs. The key methodological differences between MELMod and the IPCC-waste model with IPCC defaults are as follows:

- The MELMod model contains a more detailed breakdown of waste types with different categories to those used in the IPCC model. Hence it was not possible to accurately represent the MELMod inputs in the IPCC default model.
- The UK model allows for different waste types to have a range of rapidly, moderately and slowly decaying wastes, compared to the single value for each waste type used in the IPCC model.
- Additionally, the IPCC model includes a category of “Industrial waste” whereas the UK model is based on the EWC codes for every waste consignment, and so does not have an equivalent to the “industrial waste” category. This category was therefore not used in the IPCC model, further restricting the range of inputs available.

The model results are compared with each other, and with results derived from analysis of environmental methane measurements, in **Figure 7.11**.

Figure 7.11 Comparison of UK GHG inventory for Sector 5A with IPCC Tier 1 model results and estimates derived from environmental measurements ("InTEM")



The following conclusions were drawn from this analysis:

a) In view of the similarity between the UK model and the IPCC Model Configuration 1, the UK model does not appear to have significant errors in how it is set up.

b) The results obtained using the UK Tier 2 model and IPCC Tier 1 Model set up to reflect UK waste and landfill management practices are more reliable than the results obtained using the IPCC Tier 1 Model default inputs.

c) The UK landfill methane model provides a reliable calculation of landfill methane emissions for the period 2010 to 2016.

d) The UK landfill methane model diverges from the estimated quantities calculated from environmental measurements for the period 1990 to 2005. This is currently under review via a separate initiative.

e) The IPCC Tier 1 model using default inputs does not provide a robust estimate of UK landfill methane emissions.

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. In conclusion, this analysis provides confidence in the UK greenhouse gas inventory for Sector 5.A.

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.

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 the total UK methane emissions, whereas the GHGI for sector 5A 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

Changes to the UK landfill methane inventory for 2021, as follows:

- Data on waste landfilled for Wales and Northern Ireland in 2020 was updated following a revision to waste allocation based on EWC codes
- Revision of methane flaring data for England and Wales for 2019-2020.

As a result, slight changes to the landfill methane inventory for England, Scotland, Wales and Northern Ireland were calculated. The UK inventory of methane emissions from this sector is set out in **Table A 3.5.4**. 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 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 (InTEM is discussed in **Annex 6**).

7.3 SOURCE CATEGORY 5B – BIOLOGICAL TREATMENT OF SOLID WASTE

7.3.1 Source Category Description

Emissions sources	Sources included	Method	Emission Factors
	5B: Composting (non-household) Composting (household) Anaerobic digestion (non-agricultural) Mechanical biological treatment	T2 T2 T2 T2	D D D D
Gases Reported	CH_4, N_2O		
Key Categories	5B: Biological treatment of solid waste - CH_4 (T1, T2, L2) 5B: Biological treatment of solid waste – N_2O (T2)		
Key Categories (Qualitative)	None identified		
Overseas Territories (OT) and Crown Dependencies (CD) 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	No major improvements have been made since the last submission.		

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 are 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 2021). The reported inputs to each site in NNFCC reflect the actual tonnes inputted by feedstock category.

*[The UK activity data are summarised in **Annex 3.5.2**]*

Emissions from the anaerobic digestion of agricultural residues are not considered in the waste sector. These emissions are reported in the agriculture sector (CRF Sector 4), as it is suggested by the IPCC 2006 Guidelines.

Emission factors for source category 5.B.1 and the anaerobic digestion component of 5.B.2 were taken from IPCC (2006) default emission factors. IPCC 2006 Guidelines published an update for the waste sector in July 2015. This update is related to the default CH_4 and N_2O emission factors proposed for composting and anaerobic digestion and it has been applied to the complete time series. CO_2, in line with the IPCC methodology, is not included in the Inventory calculation as it comes from material of biogenic origin. 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 CH_4 and N_2O have been applied.

7.3.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

Activity data for industrial activities over the time series were taken from relevant publications and are considered to provide robust and accurate data. Activity data for home composting is less reliable, but now represents a small proportion (approximately 3%) of total composting activity carried out in the UK.

IPCC Tier 1 default emission factors were used for this analysis. These are considered to be less reliable, and hence subject to greater uncertainty. This is the key source of uncertainty in emissions from the 5.B sector.

Time series consistency is based on activity data and is considered to be reasonably representative of activity in this sector between 1990 and 2021.

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 inputs to anaerobic digestion plants have been revised and the historic timeline updated based on a new methodology to calculate composting emissions (UKCEH 2022).This resulted in an decrease in the quantity of waste assumed to be processed at permitted composting facilities (~-6% in the latest year), and associated methane and nitrous oxides 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 carcases Crematoria 5C2: Accidental fires: dwellings Accidental fires: other buildings Accidental fires: vehicles Bonfire night Fireworks Small-scale waste burning	T2,T1 T1 T1 T2, T1 T1 CS CS CS CS CS CS CS	CS, D CR, D OTH, D CS, D CS CS OTH OTH OTH OTH OTH OTH
Gases Reported	CO_2, CH_4, N_2O, NO_x, CO, NMVOC, SO_2		
Key Categories	None identified		
Key Categories (Qualitative)	None identified		
Overseas Territories and Crown Dependencies Reporting	Included in the CRF with the UK MSW incineration, since the same emission factors are applied, apart from 5C2.1b, incineration of waste from small scale burning, where estimates are now made for Guernsey using IPCC default method.		
Completeness	A general assessment of completeness for the inventory is included in **Section 1.8**		
Major improvements since last submission	No major improvements have been made since the last submission.		

This source category covers the incineration of wastes (excluding waste-to-energy facilities which are reported in X). 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 2021. A total of 26 incinerators regulated under the Industrial Emissions Directive (IED) have been identified as operating in 2021 - 2 burning sewage sludge, 15 burning clinical wastes, and 9 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 312 in 2021 compared with 239 in 1999 (based on statistics published by the Cremation Society of Great Britain, website at http://www.cremation.org.uk/).

This source category also includes emissions from the open burning of wood waste in Guernsey.

7.4.2 Methodological Issues

Emissions of CO_2, CO, NO_x, SO_2, and NMVOC from chemical waste incinerators are estimated based on analysis of emissions data reported to the Pollution Inventory (Environment Agency, 2021), the Welsh Emissions Inventory (NRW, 2021) and the Northern Ireland Pollution Inventory (NIEA, 2021). 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 occurs, using estimates of waste burnt at each site as a basis. The gaps in reported data are usually for smaller plants but the need for extrapolation of data may contribute to significant variations in the quality of the estimates. Emissions of N_2O from chemical waste incinerators are estimated using the 100 g N_2O / t waste default factor for industrial waste incineration given in the IPCC guidelines (2006). Waste tonnages burnt at the largest individual chemical waste incinerators for the period 2006 – 2018 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 196,000 tonnes. The use of reported emissions data for pollutants other than N_2O avoids the need to rely upon the highly uncertain activity data.

Emissions of CH_4, CO, N_2O, SO_2 and NMVOC from sewage sludge incineration are estimated using literature-based emission factors, while emissions of NO_x are estimated using Pollution Inventory data. The factor for N_2O is the average of the range of emission factors given in the 2000 IPCC good practice guidance for UK sewage sludge incineration. Emission factors for other pollutants are taken from the EMEP/EEA Emission Inventory Guidebook. The quantity of waste burnt annually is estimated using data from various sources, specifically:

1990	RCEP, 1993
1991-1998	Digest of Environmental Statistics (Defra, 2004)
2006-2021	Environment Agency, waste disposal data for individual sites in England
2004-2021	Inventory Agency estimates for Northern Ireland, based on design capacity of incinerator plant at only site.
2013, 2015-2018	Scottish Environment Protection Agency, estimates of total sewage sludge incinerated in Scotland

Interpolation between the various estimates is used to fill the gaps in the activity data time series.

Emissions of CO_2, CH_4, CO, N_2O, NO_x, SO_2, and NMVOC from clinical waste incineration are estimated using literature-based emission factors. The factors for CO_2 and N_2O are 2006 IPCC and 2000 IPCC default factors respectively. Emission factors for other pollutants are largely taken from the EMEP/EEA Emission Inventory Guidebook. The quantity of waste burnt annually is also estimated, these estimates being based on information given in the following sources:

1991	RCEP, 1993
1997	Wenborn *et* al, 1998
2002	Entec, 2003
2006-2021	Environment Agency, waste disposal data for individual sites in England and Wales
2004-13, 2015-21	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, SO_2 and NMVOC 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 (2021).

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 (Home Office, 2022). 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 & NMVOC 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 3.5.8** and **Table A 3.5.9**.

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

The following recalculations apply to the estimates submitted in this compilation cycle:

- Analysis of installation-level reported data in the early 1990s has led to the addition of methane estimates for a number of chemical waste facilities, e.g. to fill gaps for sites that reported methane in later years. In addition, a minor revision to clinical waste incineration estimates due to an improved EF.
- Update to the Crown Dependency incineration data.

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	CS, D CS, D
Gases Reported	CH_4, N_2O		
Key Categories	5D: Wastewater Handling - N_2O (L2, T2) 5D: Wastewater treatment and discharge - CH_4 (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	Revised estimates for 5D2, industrial wastewater treatment, based upon a new Tier 1 approach.		

Emissions reported in 5D2 arise from wastewater handling in a number of industry sectors in the UK where organic content of effluent is high.

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 microorganisms.

Nitrous oxide is released from human sewage during wastewater handling due to the release of nitrogenous material from proteins and from treatment of industrial wastewaters which contain nitrogen.

7.5.2 Methodological Issues

The emissions from 5D1 and 5D2 are estimated for the following sources in the UK:

- **5D1 Domestic and Commercial Wastewater.** Which consists of 4 main aspects:
    - **UK CH_4 emissions from municipal wastewater 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 operators reported data since 2013 and extrapolated back to 1990;
    - **UK CH_4 emissions from private wastewater management.** Default IPCC methodology using UK-specific per capita Biochemical Oxygen Demand (BOD) and estimated population using private waste-water management systems;

- **UK N_2O emissions.** Default IPCC methodology applied to UK time series of population and protein intake estimates from food surveys;
- **OT and CD Sewage Treatment.** For the majority of overseas territories and crown dependencies, wastewater emissions are estimated using UK data and scaled by population. Data specific to Bermuda were provided by the territory and used within the time series, interpolating and extrapolating where necessary.

- **5D2 Industrial Wastewater Treatment.** Default IPCC methodology[94] applied to UK production data from a range of wastewater generating industrial sectors.

7.5.2.1 5D1: UK CH_4 emissions from municipal waste-water treatment

The UK estimates for methane from municipal domestic and commercial wastewater 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 operator activity since 1990, which reflects shifts in UK water sector regulation and management.

7.5.2.1.1 UK Industry Overview

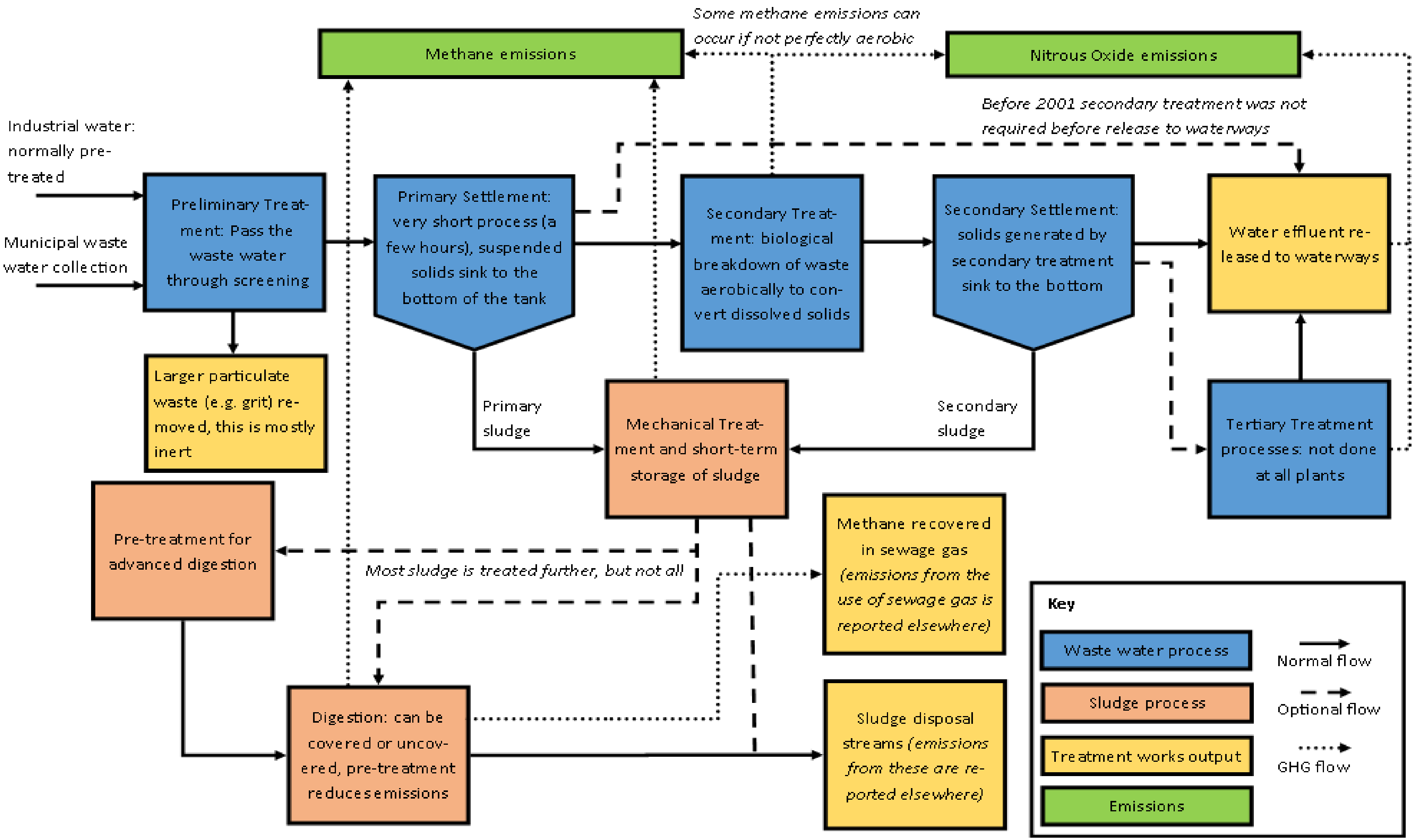
The UK wastewater treatment industry is a highly-regulated sector that has undergone a high level of investment in infrastructure and improvement of management practices over several decades in order to deliver a service that achieves high environmental standards and meets key performance indicators (e.g. treatment parameters and volumes, economic and water quality standards). Even prior to 1990 the UK network of wastewater treatment plants were at the forefront 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 Wastewater 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 over a dozen individual companies and a statutory cooperation that operate regional networks and infrastructure. There is a long history of UK-wide research and co-operation across these operators, and in response to the challenge to monitor and report environmental performance, all major UK water operators engage via a central body, UK Water Industry Research (UKWIR), through which common reporting frameworks and systems are researched, developed and updated to reflect latest science and industry practices.

In the UK, a typical Wastewater 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 wastewater arising characteristics (especially where high volumes of industrial waste are combined and treated together with municipal wastewater, altering the wastewater input characteristics away from “typical” municipal wastewater 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 wastewater sector and the existing infrastructure. This research underpins the UK GHGI estimates of methane emissions, as the country-specific model uses operator-reported data via the Carbon Accounting Workbook (CAW) which accounts for plant specific processes using CS emission factors that reflect UK circumstances. **Figure 7.12** illustrates the major flows in UK WWTPs.

[94] Note that in the case of N2O this means a 2019 refinement to the 2006 IPCC guidelines default methodology, as there is no method presented in the 2006 IPCC guidelines.

Figure 7.12 Wastewater flow diagram



7.5.2.1.1.1 Preliminary Treatment

All wastewater 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 wastewater 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, 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 WWTPs in 2001 under the Urban Wastewater Treatment Directive. Before 2001 this treatment practice was widespread but was not implemented at all UK WWTPs. 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 wastewater 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 operator 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 wastewater goes through an initial mechanical treatment and to short term storage. This process thickens, dewaters and homogenises the sludge to reduce the volume of the sludge and prepare it for further treatments. The gravity thickening process and storage of sludge under anaerobic conditions leads to methane emissions which are reported by wastewater operators 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 operator 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 distinct groups of microbes. These processes increase higher biogas yields and associated reductions in sludge volume, relative to conventional anaerobic 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 wastewater operators 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 wastewater operators 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 operators 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 operator includes data that are used to estimate operator 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 operator 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, m^3 for biogas use and kt tds otherwise); CH_4 and N_2O emissions were reported for the following:

- Mechanical treatment and short-term storage of sludge (activity and CH_4 emissions only);
- Secondary treatment (activity and N_2O emissions only);
- Digestion (activity and CH_4 emissions only);
- Advanced digestion (activity and CH_4 emissions only);
- Composting (activity and CH_4 emissions only);
- Digested sludge to land;
- Advanced digested sludge to land;
- Composted sludge to land;
- Raw and limed sludge to land;
- Raw and composted sludge to landfill (activity and CH_4 emissions only);
- Digested sludge to landfill (activity and CH_4 emissions only);
- Sludge to incineration (activity and N_2O emissions only);
- Biogas used in CHP for energy generation (activity only); and
- Biogas used for combustion other than by CHP (activity only).

From 2000 to 2009, each of the 10 water operators 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, operator 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 operators. The overlap in time-series between the EPSIM data and operator 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 operators 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 operator reported data very well, but because the disposal split fits very poorly in the overlapping years the operator 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 operator 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 operators 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 operators utilise. The UKWIR tool provides emission factors for sub-processes within the industry, enabling water operators 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 operator 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 operators in any one year before 2013; for example, in 2009, emission reporting by water operators was estimated to cover around 53% of total UK water treatment.

During 2013 the Inventory Agency met with all UK water operator carbon managers and the authors of the UKWIR reporting tool that all operators use under a voluntary mechanism for GHG emissions reporting. Through this consultation, 9 out of 12 water operators provided 2012 emissions data, covering around 65% of UK water operator 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 operators in most years. 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 operators 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.

7.5.2.1.4 Reporting of Methane Recovery from Sewage Treatment

As part of the data supplied by water operators through the CAW, volumes of sewage gas captured are reported, including whether the sewage gas is flared, burned for energy on site, or exported to be upgraded and injected into the natural gas network. However, this is only available for years where CAW data are reported, i.e., for 2013 onwards.

Data on the annual amount of sewage gas being produced are provided in DUKES (BEIS, 2022), and in combination with older publications of DUKES, there is a timeseries of sewage gas utilisation for 1990 onwards. These data are used to extrapolate the data reported in the CAW for 1990-2012.

Note that these data are not used as part of methane emissions estimates, so are presented in the CRF for information only.

7.5.2.2 5D1: UK CH_4 emissions from private waste-water management

An estimate of the number of households that are likely to be using off-grid systems in the UK in 2013 has been made based on data provided by the Environment Agency (EA), the Scottish Environmental Protection Agency (SEPA), the Northern Ireland Department of the Environment (NIEA) and Natural Resources Wales (NRW).

A time series of emissions has been developed using population data. This time series of number of households has been combined with ONS data for average household occupancy and the calculated volume of waste produced per person per year based on water operator statistics to produce an estimate of total wastewater being disposed of via off-grid systems.

The emissions are then calculated following the method set out in the IPCC 2006 guidelines Volume 5, Chapter 6: Wastewater treatment and discharge. Equation 6.2 in the GLs, reproduced below, calculates the emission factor.

$$\mathrm{EF_j} = \mathrm{B_0} * \mathrm{MCF_j}$$

Where:

$\mathrm{EF_j}$= emission factor, kg CH_4/kg BOD (Biochemical Oxygen Demand)

j = each treatment/discharge pathway or system

$\mathrm{B_0}$= maximum CH_4 producing capacity, kg CH_4/kg BOD

$\mathrm{MCF_j}$= methane correction factor (fraction), See Table 6.3 of the GLs.

Table 7.5 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 7.5 New emission factors added as a result of completeness checks

Parameter	Description	Units	Value
B_o	Maximum CH_4 producing capacity	kg CH_4/kg BOD	0.6
MCF	Methane correction factor	Fraction	0.5
EF	Emission factor	kg CH_4/kg BOD	0.3

The emission factor is then combined with total amount of organically degradable material in the wastewater (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 operators. Data on BOD values applied and estimated population connected to private wastewater management systems are presented in **Annex 3.5.4**.

7.5.2.3 5D1: UK N_2O emissions from Domestic and Commercial Waste-water

Nitrous oxide emissions from the treatment of human sewage are based on the 2006 IPCC default methodology. The most recent average protein consumption per person is based on the Expenditure and Food Survey (Defra, 2020); see **Table 7.6.** 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, 2021).

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 7.6 Per capita protein consumption in the UK (kg/person/yr), 1990-2021

Year	Protein consumption (kg/person/yr)
1990	27.9
1995	28.6
2000	29.9
2005	29.8
2010	28.7
2015	27.3
2016	27.1
2017	27.4
2018	27.3

Year	Protein consumption (kg/person/yr)
2019	27.7
2020	27.9
2021	27.9

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),
5. the fraction of municipal nitrogen load from commercial and industrial sources, as per the 2006 IPCC guidelines (1.25); and,
6. The default emission factor ($EF_{EFFLUENT}$) for N_2O-N (0.005 kg N_2O-N/kg –N)
7. The conversion factor 44/28, from kg N_2O-N into kg N_2O.

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, emissions from waste incineration are included in 5C, and some sewage sludge is disposed to landfill sites, where N_2O emissions do not generally occur due to the anaerobic conditions. Therefore, to avoid a double-count in the UK GHG inventory, the estimated nitrogen content of sewage sludge disposed via these other routes is removed from the total N estimated to be in wastewater effluent.

7.5.2.3.1Use 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, 2020). 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 wastewater is disposed to the municipal sewer system and treated by water operators together with the sewage and effluent from domestic and commercial sectors.

In the data reported by the water operators and used to generate methane emission estimates in 5D1 (see above), some of the annual reporting to water regulators includes explicit data on the COD from “trade waste” and the total COD 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 operators and industry operators) is variable across the UK and across years. This is removed from estimates of COD generated by industrial activity, to mitigate double-counting and leave only the COD treated through on-site treatment systems within the industrial sector. It is this source of emissions considered under IPCC category 5D2.

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.

In 2020, Ricardo Energy & Environment developed a new tier 1 estimate and timeseries for both methane and nitrous oxide emissions from industrial waste-water treatment, with regard to previous review comments (**Section 10.4**) and in preparation for the 2019 Refinement to the 2006 IPCC Guidelines yet to be formally adopted. This was part of a larger research project, funded by BEIS, to improve the GHG emission estimates from wastewater handling. The previous approach was thought to be an overestimate owing to the use of a ‘methane correction factor’ (MCF) originating from the 1996 Guidelines, representative of the factor for Australia, Canada and USA, and was assumed representative of UK treatment practices. This factor was likely too high given the degree of aerobic treatment occurring in the UK. This new tier 1 estimate employs the methodology detailed in the 2006 IPCC Guidelines, which includes MCFs per treatment pathway (or treatment technology), therefore offering a more refined approach, provided data describing treatment pathways/technologies can be sourced.

7.5.2.4.1Summary of Estimation method for UK 5D2 Estimates

The new Tier 1 approach uses production data for each of the specific industries identified within the 2019 Refinement as wastewater intensive. Production data was sourced from Eurostat’s ‘Prodcom’ database, which provides a detailed disaggregation of UK production by product. This enables a bottom up approach to defining the coverage of each industry specified within the 2019 Refinement, by combining the production estimates for various products. In total, data for 481 individual products was sourced and allocated to industry sectors. As this data is used as the fundamental activity data for both Tier 1 estimates of CH_4 and N_2O emissions, this was a joint exercise for both pollutants. Industries highlighted as emissive for CH_4 emissions include:

- Alcohol refining
- Beer & malt
- Coffee
- Dairy products
- Fish processing
- Meat & Poultry
- Organic chemicals
- Petroleum refineries
- Soap & detergents
- Plastics & resins
- Pulp & Paper
- Starch production
- Sugar refining
- Vegetable oils
- Vegetables, fruits & juices
- Wine & vinegar

It should be noted that the Prodcom database typically includes production estimates for the UK from 1995 onwards, meaning production data prior to 1995, back to 1990, has been estimated using the 'splicing' techniques described in Section 5.3.3 of Volume 1, Chapter 5 of the 2006 IPCC Guidelines. A 'surrogate' approach is used, where a proxy dataset, related to the specific industry, is used to simulate the trend in activity data. Surrogates selected pertain to value indexes from the UK's Blue Book, an official dataset published by the ONS, describing economic activity in the UK. Specific indexes were mapped onto specific industries above (e.g. the 'Manufacture of chemicals and chemical products' index was applied to the 'organic chemicals' sector) and the Blue Book dataset provides a timeseries back to 1990.

*[The UK activity data are summarised for selected years across the time series in **Annex 3.5.4**]*

In addition to the production data detailed above, the remainder of the estimation methodology for CH_4 is based on the combination of the following data and assumptions:

- Default values for Chemical Oxygen Demand (COD) per unit of wastewater, and amount of wastewater generated per tonne of industrial product, taken from Table 6.9 of Volume 5, Chapter 6, of the 2006 IPCC GLs or Table 6.12 of Volume 5, Chapter 6, of the 2019 Refinement to the 2006 IPCC GLs; complemented where possible by country-specific values derived from permits supporting the Industrial Emission Directive (IED) or values identified from literature research;
- The Factor B_0 (0.25 kg CH_4/kg COD), representing the IPCC COD-default factor for the maximum methane producing capacity of Industrial Wastewater;
- Default Methane Correction Factors for each type of treatment and discharge pathway or system, taken from Table 6.8 of Volume 5, Chapter 6, of the 2006 IPCC GLs;
- The percentage utilisation of treatment or discharge pathways sourced through analysing the Environment Agency's Discharge Consent Database. These are presented by industry, so that each industry has a specific treatment split, generating an industry specific weighted EF.

- 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.

CH_4 emissions from Industrial wastewater treatment are calculated using the above data and assumptions in accordance with equations 6.4, 6.5 and 6.6 of Volume 5, Chapter 6, of the 2006 IPCC GLs.

N_2O emissions from Industrial wastewater treatment are based on the same Prodcom data and wastewater generation factors detailed above, following equations 6.13 and 6.11 of Volume 5, Chapter 6, of the 2019 Refinement. For these equations:

- Parameter TN_i, the total nitrogen in untreated wastewater for each industrial sector, uses the default factors presented in Table 6.12 of Volume 5, Chapter 6, of the 2019 Refinement;
- Emission factors for each treatment/discharge pathway or system are taken from Table 6.8A of Volume 5, Chapter 6, of the 2019 Refinement; and,
- The percentage utilisation of treatment or discharge pathways per industry, or parameter T_{ij} in equation 6.11, is the same as that used above for CH_4, for the purposes of consistency.

The Inventory Agency considers that these new emission estimates are an improvement upon the previous approach and likely to be more representative of actual emissions. There remains uncertainty within this approach owing to:

- Whether wastewater generation factors are appropriate, relative to wastewater practices in the UK. As a result, these should be periodically reviewed in compilation.
- The percentage utilisation of treatment or discharge pathways. This is currently based upon a one-off exercise and held constant for the timeseries but should be periodically updated when and if new data is made available. In addition, efforts should be made to determine changes in the percentage utilisation of treatment or discharge pathways over time, to represent improvement in treatment practice relative to legislation.

7.5.2.5 Overseas Territories and Crown Dependencies

Estimates from the OTs and CDs are calculated using the Tier 1 approach from the 2006 IPCC Guidelines and default EFs. Country-specific parameters have been chosen based on information provided through a waste survey (distributed in 2014) and through expert judgement. Per capita protein consumption data were taken from FAOSTAT with data for Bermuda applied to all OTs other than Gibraltar, and data from the UK applied to all CDs and Gibraltar.

7.5.3 Uncertainties and Time-Series Consistency

As outlined in **Section 7.5.2**, the method for deriving methane emission estimates for 5D1 uses activity data from across the time series, and applies emission factors that are derived from reported emissions data from 2009 onwards. The method uses a published national set 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 operators 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 operators and from 2013 onwards obtained activity and emissions data from all of the 12 water operators. 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 operators 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 1.3.3**.

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 treatment[95]. Unfortunately, because it includes processes that are not included in the 2006 IPCC guidelines, it is not a like-for-like comparison. **Table 7.7** sets out a comparison of parameters used to estimate methane emissions in the guidance with the most similar parameters in the UK methodology. The presentation of **Table 7.7** below does not assume equivalence between BOD and raw dry solids (DS), but rather serves to preface the comparison in total magnitude of emissions relative to the IPCC default method. UK industries use dry solids (DS) as units and emission factors linked to the CAW, originate in the report 'Carbon accounting in the water industry: non-CO_2 emission' (UKWIR, 2009).

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 IPCC Volume 5 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 7.7 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 / kg BOD	2.7 kg / tonne raw DS	IPCC MCF is 0 for Centralized, aerobic treatment plant. UK factors from the CAW, which additionally includes emissions from sewage treatment processes associated with temporary storage and gravity thickening of sludge.
Flowing sewer (closed)	0 kg / 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 / kg BOD	0.3 kg / kg BOD	UK uses IPCC default methodology for this source.
Sea, river and lake discharge	0.06 kg / kg BOD	0.06 kg / kg BOD	UK uses IPCC default methodology for this source.
Digestion (Volume 5 Chapter 4 of the 2006 IPCC guidelines)	2 kg / tonne dry waste treated	4.46 to 18.1 kg / tonne raw DS	UK factors from the CAW, this accounts for several different methods of digestion. The Chapter 4 IPCC Digestion factor includes the impact of methane recovery; the Chapter 6 digestion factor does not. Given that anaerobic digestion is rarely done without methane recovery it is very conservative to assume it does not occur.
Digestion (volume 5 Chapter 6 of the 2006 IPCC guidelines)	0.48 kg / kg BOD		

[95] See the factor in **Table 7.7** for "Sewage treatment processes and the temporary storage and gravity thickening of sludge"

Source/Parameter	2006 IPCC Default Parameter	UK Parameter	Comments
Composting	10 kg / tonne dry waste treated	10 kg / 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.** **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.**
Total Emissions for 2015	**16 to 594 kt**	**29 kt**	

7.5.5 Source Specific Recalculations

As part of integrating a change to the format of CAW data received from water operators, there has been a revision to the approach to splicing and gap-filling the various datasets used to generate complete, time-series consistent and process-specific estimates for centralised municipal wastewater treatment data. A large number of small changes have been made throughout the time-series, with some of the larger changes including:

- Revising assumptions about the uptake of advanced digestion in the early 1990s; previously as assumption based on data for later years was used, but now the strong increasing trend in the available data has been utilised to justify assigning much less advanced digestion in early years.
- Interpolations, extrapolations, and splicing is now done at an operator level first where available, and then a regional level. Previously some of these data were aggregated further before splicing, extrapolating or interpolating, which might have lost some of the operator, or region-specific features. This has a particularly large impact on how

the approach to gap filling approach to estimating untreated wastewater disposed to sea.

While these data are primarily used for methane emissions reported in sector 5D1, some of the data are utilised for refining the estimates for nitrous oxide 5D1 emissions (specifically around the nitrogen balance calculations), and these data also include the industrial co-discharge, which is removed from 5D2 to avoid a double count, and therefore most emissions estimates for wastewater have been impacted by these revisions.

Estimates for CH_4 and N_2O emissions from industrial wastewater treatment for 5D2 have been revised in this submission. This is primarily due to the adjustment to the activity data (e.g. the industrial production estimates for various products allocated to industry) and to a method improvement to extrapolation from 1990 to 1995, which previously was flat-lined backwards from 1995 and now uses the ONS Industry indices. Moreover, CH_4 and N_2O emissions for 2020 have decreased between this submission and the previous in the 2021 NIR, as a consequence of updated 2020 Prodcom data for refinery production and for alcohol refining production, which not available last year and therefore were extrapolated. For information on the magnitude of recalculations, see **Section 10**.

7.5.6 Source Specific Planned improvements

It is noted that N_2O emissions from wastewater has been highlighted as a key category, and we are currently using a tier 1 method. It should be noted that the 2006 IPCC GLs do not provide a higher tier method, however the 2019 Refinement to the 2006 IPCC Guidelines does. This is, however, yet to be a formal requirement towards the UK GHGI.

The BEIS research project detailed in **Section 7.5.2.4** considered, in addition to industrial wastewater treatment, improvements to both domestic wastewater handling and emissions from the OTs and CDs. For domestic wastewater handling, it was noted the 2019 Refinement now considers emissions from the discharge of effluent into water bodies as a potential source of N_2O. Work has been undertaken to explore the provision of a country specific method already part of the CAW, that would characterise this source. This work will continue with UKWIR, and water operators as part of stakeholder engagement. Aether, as partner to the research project, liaised with a range of contacts in the OTs and CDs, to explore further data provision, and to characterise the further sources in the 2019 Refinement (such as emissions from discharge). Data supplied as part of this contact may results in minor revisions in future cycles, but the inclusion of new sources is largely contingent on the progress of the 2019 Refinement. Similarly, estimates have been developed for emissions from the discharge of effluent of industrial wastewater, which will be included based upon the progression of the 2019 Refinement.

8 Other (CRF Sector 6)

8.1 OVERVIEW OF SECTOR

No emissions are reported in Sector 6.

9 Indirect CO_2 and Nitrous Oxide Emissions

9.1.1 Description of Sources of Indirect Emissions in GHG Inventory

The calculation of indirect CO_2 and N_2O is not mandatory. The UK calculates indirect emissions of N_2O from emissions of NO_X and NH_3 from non-AFOLU sources. These are reported as a memo item.

The methods and data sources for the calculation of NO_X and NH_3 emissions are described in the UK's Informative Inventory Report (IIR), as submitted under the Convention on Long Range Transboundary Air Pollution.

9.1.2 Methodological Issues

Emissions of indirect N_2O are calculated using Equation 7.1 of Volume 1 of IPCC, 2006. EF4 within the equation is the IPCC default of 0.01 kg N_2O-N/kg NH_3-N or NO_X-N emitted.

9.1.3 Uncertainties and Time-Series Consistency

No formal uncertainty or trend analysis for indirect N_2O emissions has been carried out. Uncertainties and trends for NO_X and NH_3 are described in the IIR.

9.1.4 Category-Specific QA/QC and Verification

Emissions of NO_X and NH_3 reported under the GHG inventory are cross checked with those reported under CLRTAP and are consistent.

9.1.5 Category-Specific Recalculations

Indirect nitrous oxide emissions will change in line with changes made to the NO_x and NH_3 inventories. These are described in the IIR.

9.1.6 Category-Specific Planned Improvements

Indirect nitrous oxide emissions will change in line with changes made to the NO_X and NH_3 inventories. Air quality pollutants are subject to a separate improvement programme to the GHG inventory, this is described in the IIR.

10 Recalculations and Improvements

This section of the report summarises the recalculations and improvements made to the UK GHG inventory since the 2022 NIR submission (1990-2020 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 1.5** 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 including a new inventory year. For example, the previous report covered years up to and including 2020. This report gives emission estimates for 2020 and also includes estimates for the year 2021. 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 10.14** summarise the recalculations that have occurred in estimates of CO_2, CH_4, N_2O and F-gases since the 2022 NIR submission (1990-2020 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 (2020).

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 DESNZ GHG inventory management team; all major recalculations and systematic improvements to the UK GHG inventory are approved and managed via the National Inventory Steering Committee (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 country-specific) EFs in estimation methods;
- ✓ Improved **transparency** of the inventory estimates, e.g. the restructuring of inventory data reporting to improve the level of detail of the UK inventory (e.g. 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 Guidelines and Good Practice Guidance, (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.
- ✓ Improved **consistency** of the inventory estimates, e.g. to implement new or revised methods that deliver estimates based on more consistent underlying data or assumptions across the time series.

Table 10.1 Recalculations to CO_2 in 1990 (kt CO_2)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
1. Energy					
A. Fuel combustion activities	550069.21	550928.41	859.20	0.16%	**see explanations below in individual categories**
1. Energy Industries	238058.47	238059.49	1.02	0.00%	No significant recalculations
2. Manufacturing industries and construction	77047.10	75237.16	-1809.93	-2.35%	Reallocation from 1A2gvii and 1A2gviii to 1A4ai based on DUKES data
3. Transport	119750.59	120222.30	471.71	0.39%	No significant recalculations
4. Other sectors	109919.62	112116.02	2196.40	2.00%	Reallocation from 1A2gvii and 1A2gviii to 1A4ai based on DUKES data
5. Other	5293.44	5293.44	0.00	0.00%	No significant recalculations
B. Fugitive emissions from fuels	6787.08	6787.09	0.01	0.00%	**see explanations below in individual categories**
1. Solid fuels	1698.56	1698.56	0.00	0.00%	No significant recalculations
2. Oil and natural gas	5088.52	5088.53	0.01	0.00%	No significant recalculations
2. Industrial Processes and product use					
A. Mineral industry	10133.32	10234.92	101.61	1.00%	Methodological update to extrapolate back to 1990 using more representative data for process emissions from brick manufacture
B. Chemical industry	6975.59	6975.59	0.00	0.00%	No significant recalculations
C. Metal industry	25429.25	25429.25	0.00	0.00%	No significant recalculations
D. Non-energy products from fuels and solvent use	552.81	552.81	0.00	0.00%	No significant recalculations
G. Other product manufacture and use	NO	NO			
H. Other	IE,NE,NO	IE,NE,NO			
3.Agriculture					

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
G. Liming	1016.78	1019.16	2.38	0.23%	No significant recalculations
H. Urea application	327.68	293.75	-33.93	-10.35%	Revisions of application rates of urea-based fertiliser.
4. Land use, Land-use change and forestry					
A. Forest land	-13992.50	-13940.16	52.34	-0.37%	No significant recalculations
B. Cropland	15947.46	14230.88	-1716.59	-10.76%	Incorporation of new EF for cropland on wasted peat and revised organic soil areas
C. Grassland	114.65	-618.75	-733.41	-639.67%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revised organic soil areas
D. Wetlands	571.12	668.77	97.65	17.10%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revised organic soil areas
E. Settlements	5427.63	5426.53	-1.09	-0.02%	No significant recalculations
G. Harvested wood products	-2087.72	-2096.17	-8.45	0.40%	No significant recalculations
5. Waste					
C. Incineration and open burning of waste	1360.37	1445.17	84.80	6.23%	Latest submission now includes GHG emissions from small-scale waste burning.

Table 10.2 Recalculations to CO_2 in 2020 (kt CO_2)

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					
A. Fuel combustion activities	300819.52	300902.16	82.64	0.03%	**see explanations below in individual categories**
1. Energy Industries	76089.41	75904.16	-185.25	-0.24%	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
2. Manufacturing industries and construction	38946.24	40301.99	1355.76	3.48%	DUKES revision to natural gas use
3. Transport	96405.28	97035.93	630.65	0.65%	No significant recalculations
4. Other sectors	87974.70	86285.57	-1689.13	-1.92%	DUKES revision to natural gas use
5. Other	1403.89	1374.51	-29.38	-2.09%	Revision to DUKES data for gas oil use in shipping
B. Fugitive emissions from fuels	3442.60	3440.39	-2.21	-0.06%	**see explanations below in individual categories**
1. Solid fuels	197.11	197.11	0.00	0.00%	No significant recalculations
2. Oil and natural gas	3245.49	3243.28	-2.21	-0.07%	No significant recalculations
2. Industrial processes and product use					
A. Mineral industry	5659.21	5542.54	-116.67	-2.06%	Revision to clay production and consumption activity data.
B. Chemical industry	4513.43	4513.43	0.00	0.00%	No significant recalculations
C. Metal industry	10672.94	10732.34	59.40	0.56%	No significant recalculations
D. Non-energy products from fuels and solvent use	379.49	373.26	-6.23	-1.64%	Revision to vehicle engine use of lubricants
G. Other product manufacture and use	NO	NO			
H. Other	IE,NE,NO	IE,NE,NO			
3. Agriculture					
G. Liming	950.29	1119.74	169.45	17.83%	Adjustment in the application of BSFP data to Northern Ireland
H. Urea application	234.27	234.12	-0.15	-0.06%	No significant recalculations
4. Land use, land-use change and forestry					
A. Forest land	-17933.72	-18195.11	-261.39	1.46%	Updates to the provisional Forestry Statistics and revised organic soil areas

IPCC category name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
B. Cropland	14403.93	12696.55	-1707.38	-11.85%	Incorporation of new EF for cropland on wasted peat and revised organic soil areas
C. Grassland	-1873.95	-2659.79	-785.83	41.93%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revised organic soil areas
D. Wetlands	605.99	613.59	7.60	1.25%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revised organic soil areas
E. Settlements	4032.04	3804.91	-227.13	-5.63%	Revised organic soil areas and updated deforestation data
G. Harvested wood products	-2128.72	-1994.14	134.58	-6.32%	Updated activity data for afforestation and deforestation
5. Waste					
C. Incineration and open burning of waste	248.95	306.22	57.28	23.01%	Latest submission now includes GHG emissions from small-scale waste burning.

Table 10.3 Recalculations to CH_4 in 1990 (kt CH_4)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
1. Energy					
A. Fuel combustion activities	3624.30	3630.42	6.11	0.17%	**see explanations in individual categories**
1. Energy Industries	261.17	261.17	0.00	0.00%	No significant recalculations
2. Manufacturing industries and construction	128.49	114.70	-13.80	-10.74%	Implementation of new NRMM model
3. Transport	1419.08	1423.29	4.21	0.30%	No significant recalculations
4. Other sectors	1811.58	1827.28	15.70	0.87%	No significant recalculations
5. Other	3.98	3.98	0.00	0.00%	No significant recalculations
B. Fugitive emissions from fuels	38269.25	38281.98	12.74	0.03%	**see explanations in individual categories**
1. Solid fuels	24446.08	24446.08	0.00	0.00%	No significant recalculations
2. Oil and natural gas	13823.17	13835.90	12.74	0.09%	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. Industrial processes and product use					
A. Mineral industry	34.84	34.84	0.00	0.00%	No significant recalculations
B. Chemical industry	248.23	248.23	0.00	0.00%	No significant recalculations
C. Metal industry	43.92	43.92	0.00	0.00%	No significant recalculations
3 Agriculture					
A. Enteric fermentation	27644.97	27680.22	35.25	0.13%	No significant recalculations
B. Manure management	4657.83	4646.15	-11.68	-0.25%	No significant recalculations
F. Field burning of agricultural residues	209.47	209.47	0.00	0.00%	No significant recalculations
4. Land use, land-use change and forestry					
A. Forest land	98.04	99.49	1.45	1.48%	Revised organic soil areas
B. Cropland	326.98	332.36	5.39	1.65%	Incorporation of updated Tier 2 analysis of organic soil emission factors
C. Grassland	2672.17	2807.05	134.87	5.05%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revised organic soil areas
D. Wetlands	2197.10	2313.24	116.14	5.29%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revised organic soil areas
E. Settlements	18.26	19.03	0.77	4.19%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revised organic soil areas
5. Waste					
A. Solid waste disposal	67636.28	67633.35	-2.93	0.00%	No significant recalculations
B. Biological treatment of solid waste	20.31	21.89	1.58	7.79%	Revision to composting at permit sites in Jersey
C. Incineration and open burning of waste	152.68	213.78	61.11	40.02%	Latest submission now includes GHG emissions from small-scale waste burning.

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
D. Waste water treatment and discharge	2558.25	2365.31	-192.94	-7.54%	Methodological change to extrapolate data back to 1990 based on ONS indices.

Table 10.4 Recalculations to CH_4 in 2020 (kt CH_4)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
1. Energy					
A. Fuel combustion activities	1350.11	1317.79	-32.32	-2.39%	**see explanations in individual categories**
1. Energy Industries	427.90	424.82	-3.07	-0.72%	No significant recalculations
2. Manufacturing industries and construction	150.27	131.70	-18.57	-12.36%	Implementation of new NRMM model
3. Transport	85.92	87.16	1.23	1.43%	Revision to DUKES data on natural gas use
4. Other sectors	684.98	673.08	-11.90	-1.74%	Implementation of new NRMM model
5. Other	1.05	1.04	-0.01	-0.86%	No significant recalculations
B. Fugitive emissions from fuels	5245.48	5311.24	65.77	1.25%	**see explanations in individual categories**
1. Solid fuels	531.67	531.67	0.01	0.00%	No significant recalculations
2. Oil and natural gas	4713.81	4779.57	65.76	1.40%	Incorporation of revised gas leakage timeseries

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					
A. Mineral industry	2.94	2.94	0.00	0.00%	No significant recalculations
B. Chemical industry	75.27	75.26	-0.01	-0.01%	No significant recalculations
C. Metal industry	12.24	12.24	0.00	0.00%	No significant recalculations
3 Agriculture					
A. Enteric fermentation	23450.11	23448.29	-1.83	-0.01%	No significant recalculations
B. Manure management	4269.45	4251.08	-18.37	-0.43%	No significant recalculations
4. Land use, land-use change and forestry					
A. Forest land	115.50	117.44	1.93	1.67%	Revised organic soil areas
B. Cropland	312.85	318.42	5.57	1.78%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revised organic soil areas
C. Grassland	2711.40	2849.26	137.86	5.08%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revised organic soil areas
D. Wetlands	2288.85	2380.39	91.54	4.00%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revised organic soil areas
E. Settlements	33.81	27.87	-5.94	-17.56%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revised organic soil areas
5. Waste					
A. Solid waste disposal	14461.60	14463.06	1.46	0.01%	No significant recalculations
B. Biological treatment of solid waste	1362.80	1289.45	-73.36	-5.38%	Methodological improvement for household composting
C. Incineration and open burning of waste	8.28	58.46	50.18	606.35%	Latest submission now includes GHG emissions from small-scale waste burning.
D. Waste water treatment and discharge	1916.51	1814.26	-102.26	-5.34%	Revisions to municipal and industrial waste water data

Table 10.5 Recalculations to N_2O in 1990 (kt N_2O)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
1. Energy					
A. Fuel combustion activities	3246.14	3226.70	-19.44	-0.60%	**see explanations in individual categories**
1. Energy Industries	1277.73	1277.73	0.00	0.00%	No significant recalculations
2. Manufacturing industries and construction	280.46	260.45	-20.01	-7.13%	Implementation of new NRMM model
3. Transport	1282.63	1289.90	7.28	0.57%	Revision to DfT data for minor roads
4. Other sectors	355.41	348.71	-6.71	-1.89%	Implementation of new NRMM model
5. Other	49.91	49.91	0.00	0.00%	No significant recalculations
B. Fugitive emissions from fuels	39.82	39.82	0.00	0.00%	**see explanations in individual categories**
1. Solid fuels	0.08	0.08	0.00	0.00%	No significant recalculations
2. Oil and natural gas	39.74	39.74	0.00	0.00%	No significant recalculations
2. Industrial processes and product use					
B. Chemical industry	21162.10	21162.10	0.00	0.00%	No significant recalculations
C. Metal industry	18.43	18.43	0.00	0.00%	No significant recalculations
G. Other product manufacture and use	529.93	533.61	3.68	0.69%	No significant recalculations
3 Agriculture					
B. Manure management	3053.54	3038.90	-14.63	-0.48%	No significant recalculations
D. Agricultural soils	12940.81	13428.41	487.60	3.77%	Methodological improvement to use Tier 2 EFs for histosols from cropland and intensive grasslands
F. Field burning of agricultural residues	51.40	51.40	0.00	0.00%	No significant recalculations
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
A. Forest land	669.53	438.95	-230.58	-34.44%	Incorporation of updated Tier 2 analysis of organic soil emission factors and updated forest areas
B. Cropland	653.25	653.25	0.00	0.00%	No significant recalculations
C. Grassland	180.00	134.86	-45.15	-25.08%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revision to intensive grassland areas revised organic soil areas
D. Wetlands	18.94	18.90	-0.04	-0.21%	No significant recalculations
E. Settlements	392.27	392.31	0.05	0.01%	No significant recalculations
H. Other **(Indirect N_2O)**	271.66	271.94	0.28	0.10%	No significant recalculations
5. Waste					
B. Biological treatment of solid waste	11.53	12.36	0.83	7.20%	Revision to composting at permit sites in Jersey
C. Incineration and open burning of waste	45.29	61.44	16.15	35.67%	Latest submission now includes GHG emissions from small-scale waste burning.
D. Waste water treatment and discharge	794.31	796.37	2.06	0.26%	No significant recalculations

Table 10.6 Recalculations to N_2O in 2020 (kt N_2O)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
1. Energy					
A. Fuel combustion activities	1887.92	1898.21	10.29	0.54%	**see explanations in individual categories**
1. Energy Industries	623.44	621.99	-1.45	-0.23%	No significant recalculations
2. Manufacturing industries and construction	222.87	222.02	-0.85	-0.38%	No significant recalculations
3. Transport	863.88	876.66	12.78	1.48%	Implementation of new NRMM model causing increase in DERV allocated to road transport
4. Other sectors	164.57	164.72	0.15	0.09%	No significant recalculations
5. Other	13.15	12.81	-0.35	-2.64%	Revision to MoD data

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
B. Fugitive emissions from fuels	27.49	27.47	-0.02	-0.07%	**see explanations in individual categories**
1. Solid fuels	0.01	0.01	0.00	0.00%	No significant recalculations
2. Oil and natural gas	27.47	27.45	-0.02	-0.07%	No significant recalculations
2. Industrial processes and product use					
B. Chemical industry	45.43	45.43	0.00	0.00%	No significant recalculations
C. Metal industry	6.33	6.33	0.00	0.00%	No significant recalculations
G. Other product manufacture and use	669.30	668.63	-0.67	-0.10%	No significant recalculations
3 Agriculture					
B. Manure management	2501.98	2477.82	-24.16	-0.97%	No significant recalculations
D. Agricultural soils	10358.49	10666.61	308.12	2.97%	Methodological improvement to use Tier 2 EFs for histosols from cropland and intensive grasslands
4. Land use, land-use change and forestry					
A. Forest land	633.38	386.80	-246.58	-38.93%	Incorporation of updated Tier 2 analysis of organic soil emission factors and updated forest areas
B. Cropland	354.35	354.35	0.00	0.00%	No significant recalculations
C. Grassland	164.29	127.61	-36.68	-22.32%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revision to intensive grassland areas and revised organic soil areas
D. Wetlands	22.06	21.82	-0.24	-1.10%	Incorporation of updated Tier 2 analysis of organic soil emission factors and revised organic soil areas
E. Settlements	261.39	255.56	-5.83	-2.23%	Methodological revision to align settlement organic soil areas
H. Other **(Indirect N_2O)**	152.75	153.42	0.67	0.44%	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
5. Waste					
B. Biological treatment of solid waste	635.83	618.01	-17.82	-2.80%	Methodological improvement for household composting
C. Incineration and open burning of waste	23.45	35.93	12.48	53.20%	Latest submission now includes GHG emissions from small-scale waste burning.
D. Waste water treatment and discharge	904.17	894.17	-10.00	-1.11%	Revisions to municipal and industrial waste water data

Table 10.7 Recalculations to SF_6 in base year (CO_2 eq., kt)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
2. Industrial processes and product use					
2.C.4. Magnesium production	399.06	399.06	0.00	0.00%	No significant recalculations
2.G.1. Electrical equipment	821.58	828.89	7.30	0.89%	Revision due to latest data becoming available
2.G.2. SF_6 and PFCs from other product use	62.92	62.92	0.00	0.00%	No significant recalculations

Table 10.8 Recalculations to SF_6 in 2020 (CO_2 eq., kt)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
2. Industrial processes and product use					
2.C.4. Magnesium production	28.29	28.29	0.00	0.00%	No significant recalculations
2.G.1. Electrical equipment	339.43	340.30	0.87	0.26%	Revision due to latest data becoming available
2.G.2. SF_6 and PFCs from other product use	51.72	51.68	-0.04	-0.08%	Revised proxy data in latest year

Table 10.9 Recalculations to HFCs in base year (CO_2 eq., kt)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
2. Industrial processes and product use					

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	14807.32	14807.32	0.00	0.00%	No significant recalculations
2.E.1. Integrated circuit or semiconductor	10.84	10.84	0.00	0.00%	No significant recalculations
2.F.1. Refrigeration and air conditioning	201.37	201.39	0.02	0.01%	No significant recalculations
2.F.2. Foam blowing agents	167.84	167.80	-0.03	-0.02%	No significant recalculations
2.F.3. Fire protection	1.01	1.01	0.00	-0.02%	No significant recalculations
2.F.4. Aerosols	407.72	407.71	-0.01	0.00%	No significant recalculations
2.F.6. Other applications	35.87	23.59	-12.29	-34.26%	Methodological improvement to use HFC Outlook data for refrigerant containers

Table 10.10 Recalculations to HFCs in 2020 (CO_2 eq., kt)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
2. Industrial processes and product use					
2.B.9. Fluorochemical production	NO	NO			
2.C.4. Magnesium production	1.34	1.34	0.00	0.00%	No significant recalculations
2.E.1. Integrated circuit or semiconductor	20.46	20.46	0.00	0.00%	No significant recalculations
2.F.1. Refrigeration and air conditioning	9661.49	9665.24	3.76	0.04%	No significant recalculations
2.F.2. Foam blowing agents	380.36	192.57	-187.79	-49.37%	Revision to OT and CD activity data
2.F.3. Fire protection	323.39	323.57	0.18	0.06%	No significant recalculations
2.F.4. Aerosols	1113.99	1086.54	-27.46	-2.46%	Methodological revision removing assumption that HFC-152a is used as a replacement for HFC-134a
2.F.5. Solvents	16.44	16.44	0.00	0.00%	No significant recalculations
2.F.6. Other applications	37.59	31.84	-5.75	-15.30%	Methodological improvement to use HFC Outlook data for refrigerant containers

Table 10.11 Recalculations to PFCs in base year (CO_2 eq., kt)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
2. Industrial processes and product use					
2.B.9. Flurochemical production	78.94	78.94	0.00	0.00%	No changes.
2.C.3. Aluminium production	0.00	0.00	0.00	0.00%	No changes.
2.F.3. Fire protection	0.00	0.00	0.00	0.00%	No changes.
2.G.2. SF_6 and PFCs from other product use	0.00	0.00	0.00	0.00%	No changes.

Table 10.12 Recalculations to PFCs in 2020 (CO_2 eq., kt)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
2. Industrial processes and product use					
2.B.9. Flurochemical production	1.53	1.53	0.00	0.00%	No changes.
2.C.3. Aluminium production	0.00	0.00	0.00	0.00%	No changes.
2.G.2. SF_6 and PFCs from other product use	0.00	0.00	0.00	0.00%	No changes.

Table 10.13 Recalculations to NF_3 in base year (CO_2 eq., kt)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
2. Industrial processes and product use					
2.E.1. Integrated circuit or semiconductor	0.26	0.26	0.00	0.00%	No changes.

Table 10.14 Recalculations to NF_3 in 2019 (CO_2 eq., kt)

IPCC name	Previous submission (CO_2 eq., kt)	Latest submission (CO_2 eq., kt)	Difference (CO_2 eq., kt)	Difference %	Explanation for recalculations
2. Industrial processes and product use					
2.E.1. Integrated circuit or semiconductor	0.34	0.34	0.00	0.00%	No changes.

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

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
2. Oil and natural gas and other emissions from energy production	Y	Y	Chapter 3
C. CO_2 transport and storage	N	N	
2. Industrial processes and product use	Y	Y	Chapter 4
A. Mineral industry	Y	Y	Chapter 4
B. Chemical industry	Y	Y	Chapter 4
C. Metal industry	Y	Y	Chapter 4
D. Non-energy products from fuels and solvent use	Y	Y	Chapter 4
E. Electronic industry	Y	Y	Chapter 4
F. Product uses as substitutes for ODS	Y	Y	Chapter 4
G. Other product manufacture and use	Y	Y	Chapter 4
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	

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
D. Agricultural soils	Y	Y	Chapter 5
E. Prescribed burning of savannahs	N	N	
F. Field burning of agricultural residues	N	N	Chapter 5
G. Liming	Y	Y	Chapter 5
H. Urea application	Y	Y	Chapter 5
I. Other carbon containing fertilisers	Y	Y	Chapter 5
J. Other	Y	Y	Chapter 5
4. Land use, land-use change and forestry	Y	Y	Chapter 6
A. Forest land	Y	Y	Chapter 6
B. Cropland	Y	Y	Chapter 6
C. Grassland	Y	Y	Chapter 6
D. Wetlands	Y	Y	Chapter 6
E. Settlements	Y	Y	Chapter 6
F. Other land	Y	Y	Chapter 6
G. Harvested wood products	Y	Y	Chapter 6

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
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	
6. Other (as specified in Summary 1.A)	N	N	

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**. The overall impact of all recalculations is a decrease of 0.9 Mt CO_2 equivalent in 1990, and a decrease of 2.5 Mt CO_2 equivalent in 2020.

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.

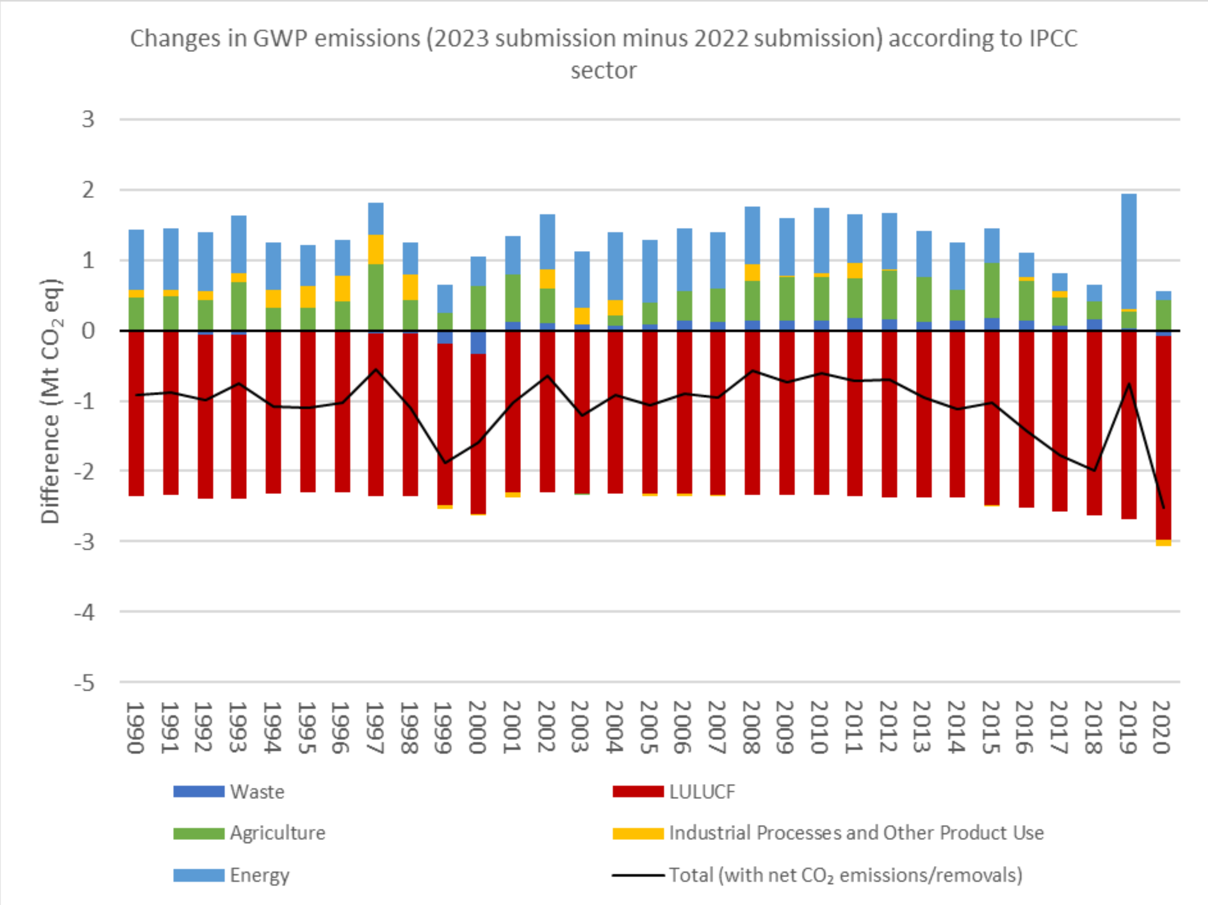
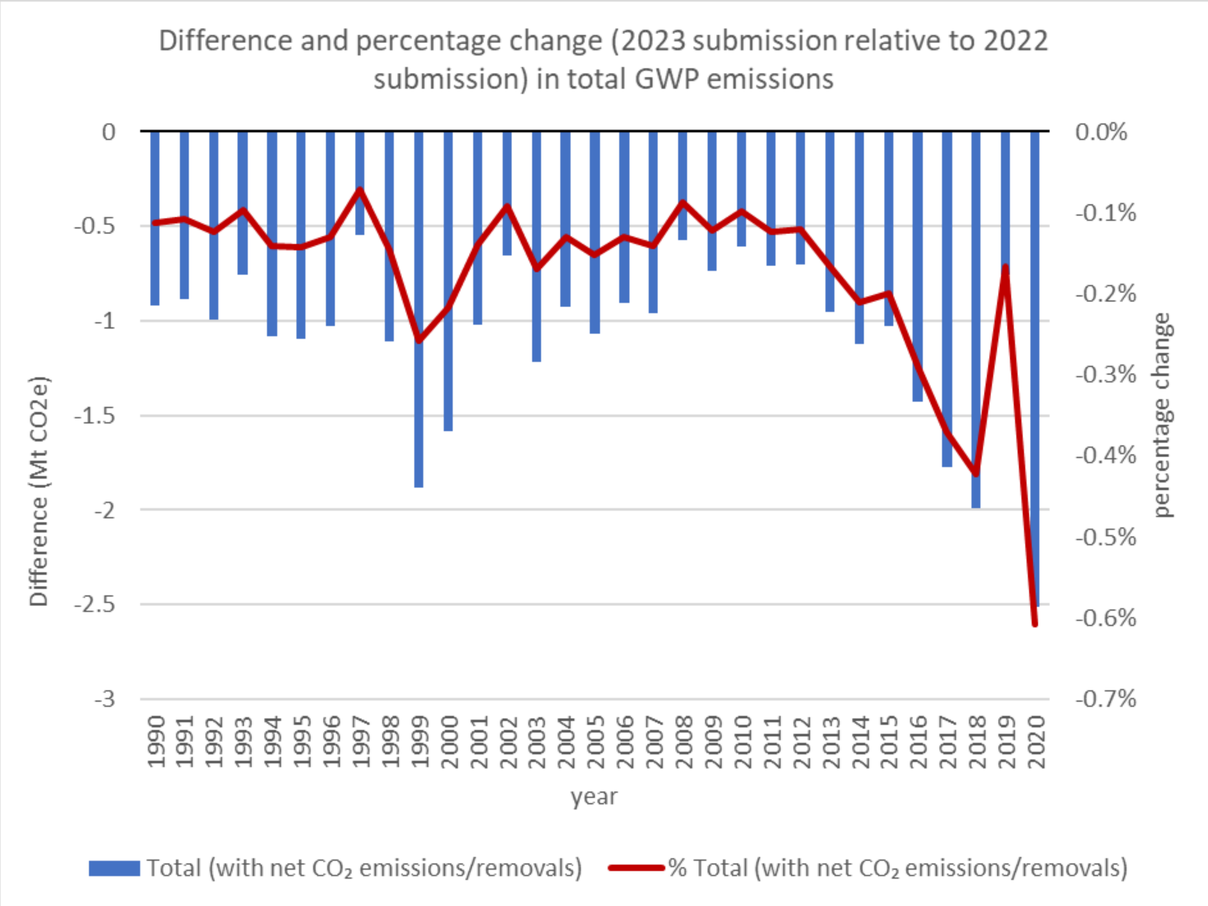


Figure 10.2 shows the net impact of all recalculations in absolute and percentage terms.

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.



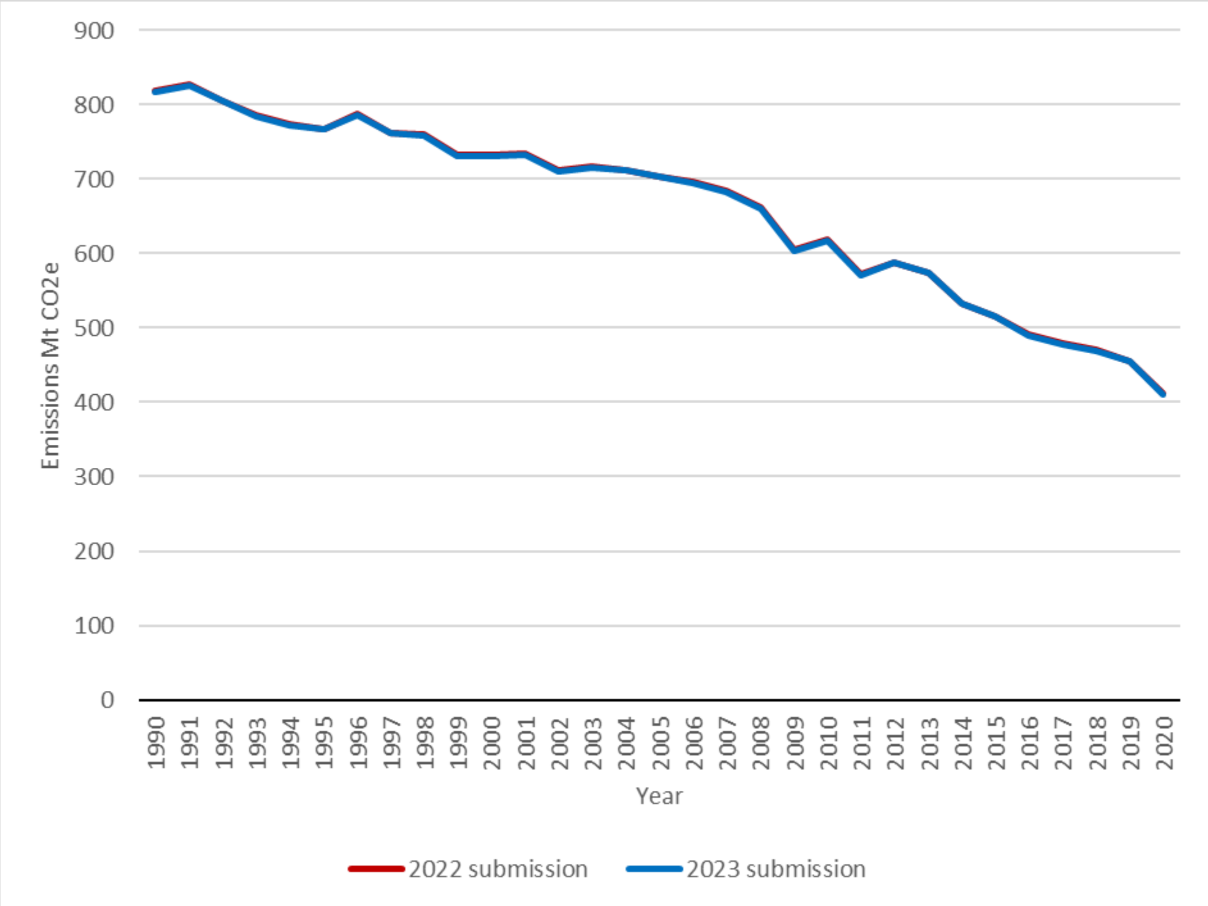
10.3 IMPLICATIONS FOR EMISSION TRENDS, INCLUDING TIME SERIES CONSISTENCY

10.3.1 GHG Inventory

There has been a very minor change in the reported trend in emissions. The reported trend from 1990 to 2020 in the 2022 inventory submission was a decrease of 49.6%. The recalculated trend from 1990 to 2020, as presented in the 2023 submission is a decrease of 49.8%.

The chart below displays the trend from both the 2022 and 2023 submissions.

Figure 10.3 Reported trends from the current and previous inventory submissions



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 desk review of the 2022 UK greenhouse gas inventory submission from the 19th September to the 24th September 2022, in accordance with the Article 8 review guidelines of the Kyoto Protocol (adopted by decision 22/CMP.1 and revised by decision 4/CMP.11). The final output of this review, the 2022 Annual Review Report, was published on the 10th of February 2023.The expert review team (ERT) did not identify any issues that required a resubmission of the 2022 submission. Each review report reconsiders items raised during the previous review (in this case the 2021 UNFCCC review), updating the item as to whether it has been resolved or not resolved, or whether the item is being addressed. The review report then details new items, specific to that review, within a separate table. **Table 10.16** details updated responses to the last UNFCCC review, for legacy items that also featured in the previous 2021 UNFCCC review. **Table 10.17** details updated responses for those items new to the 2022 UNFCCC review.

10.4.1 GHG Inventory Improvements

Table 10.16 Improvements to the UK GHG Inventory Submission in response to UNFCCC Review Findings 2021/2022

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
National registry KP reporting adherence	Make information related to the national registry publicly available and provide the correct link in the next annual submission.	G.1 2022 ARR (G.10, 2021 ARR)	**Resolved.** The Party reported in its NIR (p.584) that publicly accessible information is available from the United Kingdom's registry via the Kyoto Protocol Public Reports page at https://view-emissions-trading-registry.service.gov.uk/kp-reports.	Section 12.4
1. General (energy sector) – CO_2, CH_4 and N_2O Transparency	Clearly indicate the geographical coverage of the Digest of United Kingdom Energy Statistics and demonstrate how fuel consumption data at the subcategory level for each overseas territory and Crown dependency are obtained and incorporated into the national totals for that subcategory.	E.1 2022 ARR (E.1, 2021 ARR)	**Addressing.** Text has been added to Section 1.1.2.1 and A3.6 explaining that where the data is available, activity data on fuel consumption at the subcategory level is included for each overseas territory and Crown Dependency.	Section 1.1.2.1 and Annex A3.6
1.A Fuel combustion – sectoral approach – biomass fuels – CO_2, CH_4 and N_2O Comparability	Describe in the NIR how much biogas is blended with natural gas, consider ways of reporting AD on and related CO_2, CH_4 and N_2O emissions from biogas separately under biomass, ensuring that any changes do not affect the accuracy of the reporting on CH_4 and N_2O emissions, and update the NIR section on biomass (section 3.2.5) and the relevant method statements accordingly.	E.2 2022 ARR (E.9, 2021 ARR)	**Not resolved.** The UK improvement programme includes an item to consider this recommendation.	
1.A.1.a Public electricity and heat production – biomass fuels – CO_2, CH_4 and N_2O Transparency	Enhance the transparency of allocation and reporting of recovered CH_4 originating from the waste sector that is used in the energy sector.	E.3 2022 ARR (E.10, 2021 ARR)	**Resolved.** The Party reported in its NIR (p.437) how waste management, waste disposal and waste utilization are considered and interact among the waste, energy and agriculture sectors, and where waste management, disposal and utilization are reported in the inventory. Specifically, the United Kingdom has introduced a new section to the NIR (pp.437–446, "Waste Related Activities Reported In	Section 7.1.1

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			Other Sectors”), which includes a discussion of how CH_4 recovery data related to biogas fuel use are treated in the inventory.	
1.A.3.e.ii Other (other transportation) – liquid fuels – CO_2, CH_4 and N_2O Accuracy	Evaluate the relevance of the current equipment data used in the 2004 model for estimating off-road emissions, and on the basis of the results of the evaluation, either document in the NIR how the model still reflects current circumstances or make efforts to update the model and report on progress in the NIR.	E.4 2022 ARR (E.4, 2021 ARR)	**Resolved.** Databases and information for the new model were provided by industry trade associations and stakeholder groups including the Off Highway Engine and Equipment Group (OHEEG) the Agricultural Engineers Association (AEA), Department for Transport (DfT) and the Construction and Agriculture Equipment Security and Registration (CESAR) database. Machinery or engine-specific fuel consumption and emission factors (g/kWh) in the new model are based on stakeholder consultation and the 2019 EMEP/EEA Guidebook. The AEA were able to provide fuel consumption rates for different agricultural machinery types in litres per hour based on telemetry data. Exception were agricultural telehandlers which were adjusted to align with fuel consumption rate implied by Guidebook factors. Model includes detailed activity from base year 2018, various proxy statistics are used as activity drivers for different groups of machinery types to estimate fuel consumption across the full time-series, EMEP/ EEA Guidebook (2019), up to Stage V. The new model considers hours of use in two ways: Firstly, the new NRMM model allows hours of use assumptions for a given machinery type to vary by the sector in which it is used. This is to recognise that different sectors may have different hours of use for the same machinery type. Secondly, it also has the provision to adjust for decreasing operating hours with increasing age. Fuel reconciliation adjusts all bottom-up off-road estimates, including agricultural off-road.	MS 6

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
1.B.2 Oil, natural gas and other emissions from energy production – all fuels – CO_2 and CH_4 Accuracy	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).	E.5 2022 ARR (E.7, 2021 ARR)	**Resolved.** The Party included in its NIR a new annex 3 section (p.789), which has a description of the AD, methods and EFs for estimating upstream oil and gas production emissions. The description covers the split between fuel combustion and fugitive emissions, including emissions from well drilling, well testing and well completions in oil and gas exploration. Method Statement 18 summarizes the data, methods and results from the recently completed United Kingdom Oil and Gas Inventory Improvement project (Thistlethwaite et al., 2022). Further methodological details by category are provided in annex A3.1.6, including details of each source reported under category 1.B.2.a.1 (oil exploration) and category 1.B.2.b.1 (gas exploration).	MS 18, Annex A3.1.6
1.B.2.b Natural gas – gaseous fuels – CO_2 and CH_4 Completeness	Estimate and report CO_2 and CH_4 emissions from exploratory activities or, if they are considered 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.	E.6 2022 ARR (E.8, 2021 ARR)	**Resolved.** A new minor source was added under category 1.B.2.a.1 (oil exploration) across the entire time series incorporating the method from the 2019 Refinement to the 2006 IPCC Guidelines (vol. 2, chap. 4, pp.49–51) to estimate emissions from onshore oil well exploration (NIR p.229). The Party also estimated fugitive CO_2 and CH_4 emissions from unconventional gas well drilling activities during the period in which they occurred (2010–2020). For 2020, 0.07 kt CH_4 emissions and 6.26 kt CO_2 emissions were estimated for this category.	MS 18, Annex A3.1.6
2. General (IPPU) – N_2O Transparency	On page 236 of the NIR, correct the information stating that N_2O emissions from nitric acid production and adipic acid production were reported together for 1990– 1994 under category 2.B.3 (adipic acid production) to clarify that these emissions have been reported separately for the entire time series in CRF table 2(I)s1.	I.1 2022 ARR (I.1, 2021 ARR)	**Resolved**. The text in the NIR has been amended	Section 4.8

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
2. General (IPPU) – all gases Transparency	Report recalculations or reallocations of emissions in accordance with paragraphs 43– 45 of the UNFCCC Annex I inventory reporting guidelines.	I.2 2022 ARR (I.26, 2021 ARR)	**Resolved.** The ERT reviewed the explanations of the recalculations provided in the NIR of the 2022 submission and noted that the issues identified as not reported in compliance with the UNFCCC Annex I inventory reporting guidelines in the NIR of the 2021 submission (according to document FCCC/ARR/2021/GBR) have been fully addressed. This concerns documentation of recalculations in sections 4.5.5, 4.13.5, 4.34.5, 4.35.5, 4.36.5 and 4.42.5 of the NIR. The ERT noted that the Party documented significant recalculations in the "Source specific recalculation" sections of the NIR and used the wording "no significant recalculations" rather than "no recalculations" for minor recalculations. Furthermore, the Party summarized its explanations of non-minor recalculations in NIR tables 10.1–10.14. During the review, the Party expressed its intention to continue to review how recalculations are presented in the NIR.	
2.A.4 Other process uses of carbonates – CO_2 Comparability	Report CO_2 emissions from stone wool production under subcategory 2.A.4.d (other) along with emissions from other sources currently reported under that category to avoid disclosing confidential data, or, if the number of facilities reporting under that category is insufficient to enable the confidential data from stone wool producers to be masked, report them at an aggregated level under one of the other categories under the mineral industry and use the appropriate notation key under subcategory 2.A.4.d, if needed, providing a relevant explanation in the NIR as to where emissions are reported.	I.3 2022 ARR (I.6, 2021 ARR)	**Resolved.** The Party explained in NIR table 10.16 that an analysis of alternative approaches for reporting CO_2 emissions from stone wool production found that the number of facilities is too small to mask confidential data, if reported under category 2.A.4.d (other (other process uses of carbonates)), therefore, the Party continues to report these emissions under category 2.A.3 (glass production). Taking into consideration other options for following the recommendation and reporting emissions from stone wool production at an aggregated level under one of the other categories of the mineral industry (2.A.1 (cement production), 2.A.2 (lime production), 2.A.4.a (ceramics), 2.A.4.b (other uses of soda ash) or 2.A.4.c (non-metallurgical magnesium production)), the ERT agrees with the Party's judgment that	Section 4.29.2

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			reporting of emissions from stone wool production under category 2.A.3 is the most sensible option. The NIR (pp.254 and 515) clearly specifies that emissions from stone wool production are reported under category 2.A.3.	
2.A.4 Other process uses of carbonates – CO_2 Transparency	Complete the ongoing study on the non-glass uses of soda ash in the country and estimate and report CO_2 emissions from sodium bicarbonate use under subcategory 2.A.4.d (other) as well as update the NIR to include the relevant AD, EF and methods used for estimating these emissions.	I.4 2022 ARR (I.8, 2021 ARR)	**Resolved.** Activity data for soda ash and sodium bicarbonate have been added to the NIR	Section 4.39
2.A.4 Other process uses of carbonates – CO_2 Completeness	Estimate CO_2 emissions from ceramic products other than bricks either by using the assumption that the clay consumption of these products is on average 11 per cent of the clay consumption of brick production, according to the available data for 2008– 2012, or by applying a country-specific method (e.g. based on the AD for clay consumption for different applications as provided in the United Kingdom Minerals Yearbook 2018), and report these emissions under subcategory 2.A.4.a (ceramics).	I.5 2022 ARR (I.9, 2021 ARR)	**Resolved.** The Party reported CO_2 emissions from the use of clay for the production of ceramics other than bricks under category 2.A.4.a (ceramics) in CRF table 2(I).A-Hs1. The NIR (pp.257 and 260–261) provides details on the method applied to estimate the emissions and the EFs used. The resulting increase in CO_2 emissions for 2019 for category 2.A.4.a is 33.17 kt (9.8 per cent) compared with the level of emissions reported for 2019 for this category in the 2021 submission	Section 4.5.5, Section 4.13.5, Section 4.34.5, Section 4.35.5, Section 4.36.5, Section 4.42.5
2.A.4 Other process uses of carbonates – CO_2 Transparency	Update the descriptions of the emissions from sodium bicarbonate use and their allocation in the inventory.	I.6 2022 ARR (I.27, 2021 ARR)	**Resolved.** The Party corrected the text about allocation of emissions from sodium bicarbonate use. In the NIR (pp.258 and 264) it explained that these emissions are included partly under category 2.A.4.d (other (other process uses of carbonates)) and partly under category 1.B.2.d (flue gas desulfurization (other)).	
2.B Chemical industry – CO_2	Use the standard splicing techniques in the 2006 IPCC Guidelines (vol. 1, chaps. 5.5.3.1–5.5.3.4) to fill the gaps of AD and CO_2 emissions for categories 2.B.6 (titanium dioxide production) for 1990–1998,	I.7 2022 ARR (I.10, 2021 ARR)	**Resolved.** An improvement item has been raised to evaluate the potential application of splicing techniques to the categories identified by the ERT. This work is currently in draft form awaiting	Section 4.12

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
Consistency	2.B.7 (soda ash production) for 1990–1998, 2.B.8.a (petrochemical and carbon black production (methanol)) for 1990–1997, 2.B.8.d (petrochemical and carbon black production (ethylene oxide)) for 1990–1995 and 2.B.8.f (petrochemical and carbon black production (carbon black)) for 1990–1998, revise the CO_2 emission estimates accordingly, and explain in the NIR which techniques were used to fill the gaps (e.g. the ERT considers that the surrogate data or overlap approach may be appropriate for developing a consistent time series). If it is not possible to apply the standard splicing techniques, follow the 2006 IPCC Guidelines (vol. 1, chaps. 5.3.3.5–5.3.3.6) and apply an alternative technique for splicing, providing an explanation in the NIR as to why the standard techniques are not valid, documenting the alternative technique applied and comparing the results with one of the standard techniques contained in the 2006 IPCC Guidelines.		completion, however currently no changes are proposed to the categories identified by the ERT due to the lack of appropriate data. It should be noted, however, that many of the splicing techniques described in volume 1 of the 2006 IPCC Guidelines are not suited to the categories described as the gaps in activity data are within the early time series, from 1990 onwards, not between data points, as in the use of interpolation. Nor do they represent a higher tier methodology for a portion of the timeseries, as in the application of the 'overlap' technique described in section 5.3.3.1 of volume 1 of the IPCC guidelines. Two standard splicing techniques do apply, the use of 'surrogate data' to simulate the trend in emissions and trend extrapolation, although it should be noted that trend extrapolation should not be used if the change in trend is not constant over time. For each category, available surrogate datasets were evaluated, and the implications of trend extrapolation were considered. For the identification of surrogate datasets, the following order of preference was applied: • Production data by mass • Production data by weight • Production data by value • Export data by weight/value • Financial data of specific chemical sector • General financial/physical indices of chemical production This order of preference aimed to prioritise surrogate datasets that are most indicative of the chemical process accounted for by the category. Other considerations pertain to the coverage and completeness of the surrogate dataset, in comparison to the existing time series for each category. As described in section 5.3.3.2 of volume 1 of the IPCC guidelines, regression analysis is used to select appropriate surrogate data, specifically the use of	

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			common diagnostics like the Pearson correlation coefficient. The applicability of each surrogate is defined in the IPCC 2006 Guidelines as the indicative dataset 'most strongly correlated' with the emission factors, activity data or other estimation parameters in question. Surrogates evaluated included data pertaining to specific chemical production quantities, export quantities or export values from Eurostat or in the case of titanium dioxide (2.B.6), data from the British Geological Survey. General financial indices of chemical production from the UK's Office for National Statistics (ONS) was also evaluated. Ultimately none of these datasets were more correlated when tested against the current approach, involving the use of plant capacity as a surrogate. Trend extrapolation was considered, however the trend was thought to be non-linear and the change between years not constant over time, as observed in reported data. The UK approach therefore continues to consider plant capacity to be the best surrogate dataset, and the UK considers the current estimates to be consistent with the 2006 IPCC guidelines for splicing techniques when using plant capacity as a surrogate even if the surrogate is coincidentally constant over the period that the ERT have highlighted.	
2.B.1 Ammonia production – CH_4 and N_2O Transparency	Either avoid the double counting between categories 2.B.1 and 2.B.10 other (chemical industry) or explain in the NIR that double counting of the emissions may occur between these categories	I.8 2022 ARR (I.12, 2021 ARR)	**Resolved.** The Party clearly explained in its NIR (pp.265–267) the nature of the potential double counting between categories 2.B.1 (ammonia production) and 2.B.10 (other (other chemical production)), stating that CH_4 emissions from steam reforming processes are reported partly under category 2.B.1 and partly under category 2.B.10. N_2O emissions from natural gas combustion in ammonia production are estimated and reported under category 2.B.1. According to the NIR (p.281), the Party reports CH_4 emissions from general petrochemical processes	Section 4.5.2

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			under category 2.B.10; data on these emissions are obtained from the plant operator reports submitted to national regulators (NIR p.267). CH_4 emissions are reported together with process emissions from other chemical plants; these operator-reported emissions may include estimates of CH_4emissions from fuel combustion and hence there is a small risk of double counting in emissions reported between categories 2.B.1 and 2.B.10. The Party has decided that removing the CH_4 emissions from category 2.B.1could lead to a possible omission in reporting CH_4 emissions, as it is not certain that operators would include CH_4 emissions from combustion in their reports to national regulators, so the approach used in the 2022 submission was deemed most conservative given the available information.	
2.B.1 Ammonia production – CH_4 and N_2O Transparency	Provide in the NIR a description of the methodology used for estimating CH_4 and N_2O emissions from ammonia production reported under category 2.B.1 and provide the correct reference (i.e. to category 2.B.1 instead of 2.B.10) in CRF table 2(I).A-Hs1, where these emissions are reported.	I.9 2022 ARR (I.11, 2021 ARR)	**Resolved.** The Party provided in the NIR (p.267) a detailed description of the methodology used for estimating emissions of CH_4 and N_2O from ammonia production and correctly identified under which categories they are reported (2.B.1 and 2.B.10).	Section 4.5.2
2.C.1 Iron and steel production – CO_2 Comparability	Reallocate CO_2 emissions from iron and steel production related to the use of blast furnace gas, coke oven coke, fluxing agents, fuel oil and coal from the energy sector to the IPPU sector in accordance with the 2006 IPCC Guidelines (vol. 3, chap. 4)	I.10 2022 ARR (I.15, 2021 ARR)	**Resolved.** The Party reported in NIR table 10.16 and in Method Statement 3 and Method Statement 4 that CO_2 emissions from blast furnace gas and coke oven gas used at integrated iron and steel plants and fuel used in blast furnaces (except for fuel oil and coal, which the Party has concluded are used for energy purposes) have been reallocated from category 1.A.2.a (iron and steel) of the energy sector to category 2.C.1.b (pig iron (iron and steel production)) of the IPPU sector. The ERT considers that this allocation is in accordance with the 2006 IPCC Guidelines (vol. 3, chap. 4) in terms of the	Section 4.12 and 4.13

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			transparency of reporting for iron and steel production.	
2.F.1 Refrigeration and air conditioning – HFCs Transparency	Include in the NIR the tier level of the methodology for estimating emissions for subcategory 2.F.1.	I.11 2022 ARR (I.28, 2021 ARR)	**Resolved.** The Party reported in its NIR (p.301) that a tier 2a approach is used for estimating emissions for this category.	Section 4.6.2
2.G.2 SF_6 and PFCs from other product use – SF_6 and PFCs Accuracy	Continue to include in the 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.	I.12 2022 ARR (I.25, 2021 ARR)	**Resolved.** The Party explained in its NIR (p.332) that it has recently revised a semiconductor model with the primary purpose of improving the AD needed for estimating SF_6 and PFC emissions from semiconductor manufacture. As a result of this revision, SF_6 and PFC emissions for category 2.G.2 have been recalculated for the entire time series. The methodology used to estimate emissions for the 2022 submission is described in the NIR (pp.327–331) and the assumptions made about the AD (sector growth rates) are explained (p.328). In particular, in the 2022 submission, it is assumed that semiconductor production is constant from 2001 onward (p.328), while in the previous version of the semiconductor model a 10 per cent growth rate after 2010 was assumed (p.332); this, together with updated assumptions on abatement rates, justifies the increasing differences in emissions from 2010 to 2019 between the 2021 and 2022 submissions. The assumptions in the current version of the model have been revised and updated on the basis of consultations with stakeholders in the semiconductor industry and other stakeholders such as trading bodies. During the review, the Party provided a very detailed explanation of the assumptions made in the updated model, as well as of the recalculations and	Section 4.6.2

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			on the trends in the SF_6 and PFC emissions. The ERT concludes that the assumptions made are reasonable, and that the recalculations are justified. The ERT acknowledges the improvements made to the model, the reporting on progress in the NIR and the Party's intention to continue with stakeholder consultations in order to make further improvements over time. The ERT concludes that with the existing update to the model, the recommendation is resolved.	
3. General (agriculture) – CO_2, CH_4 and N_2O Completeness	Estimate and report emissions for categories 3.F, 3.G and 3.H for overseas territories and Crown dependencies or, if they are considered insignificant, report them as "NE" and provide a detailed explanation in the NIR on the likely level of emissions for categories 3.F, 3.G and 3.H for overseas territories and Crown dependencies in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.	A.1 2022 ARR (A.1, 2021 ARR)	**Addressed.** Text has been added to section 5.10 outlining the significance of emissions sources for categories 3.E, 3.G and 3.H reported as NE. A table has been added to this section to present the agricultural areas and emissions for the UK, Isle of Man, the Falkland Islands (Malvinas), and remaining overseas territories and Crown Dependencies.	Section 5.10
3. General (agriculture) – CO_2, CH_4 and N_2O Convention reporting adherence	Update the uncertainty analysis for all categories, including enteric fermentation, for which significant data or methodological changes have occurred since the previous uncertainty analysis was conducted.	A.2 2022 ARR (A.2, 2021 ARR)	**Resolved.** A full uncertainty run has been carried out for the 2023 annual submission including uncertainty analysis for enteric fermentation, the results of which are presented in the NIR. The uncertainty parameters will be kept under review in subsequent submissions but the uncertainty method does now reflect the higher Tier methodologies used in the UK GHGI.	Section 5.4.2.2 A3.3.7
3. General (agriculture) – CH_4 and N_2O Accuracy	Improve the accuracy of emission estimates for enteric fermentation, manure management and agricultural soils reported for the Crown dependencies by applying a splicing technique (e.g. extrapolation) from the 2006 IPCC Guidelines (vol. 1, chap. 5) to estimate the IEFs for the Crown dependencies instead of maintaining a constant IEF in years for which updated United Kingdom IEFs are not available	A.3 2022 ARR (A.3, 2021 ARR)	**Addressing**. The IEFs were updated in the 2023 submission. The accuracy of emissions estimates for reporting years where updated United Kingdom IEFs are not available in sufficient time will be improved by using extrapolation to estimate the IEFs for the Crown Dependencies.	Section 5.4.2.2

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
	in sufficient time to apply them to the emission estimates for the Crown dependencies.			
3. General (agriculture) – CH_4 and N_2O Convention reporting adherence	Implement general QC procedures in accordance with the QA/QC plan to avoid errors in future annual submissions such as the error found in the 2021 submission in the conversion of the uncertainty estimates for categories 3.B (manure management) and 3.D (agricultural soils) to percentages, where the value was divided by the range maximum rather than by the mean, causing these estimates to be underestimated	A.4 2022 ARR (A.13, 2021 ARR)	**Resolved**. The Party reported in its NIR (p.533) that the model used to transpose uncertainty parameters from the agriculture sector uncertainty outputs to the United Kingdom approach 1 uncertainties model has been corrected. Furthermore, the Party stated in its NIR (p.724) that within-model documentation has been added to minimize the risk of such errors. The ERT confirms that the error found in the 2021 annual submission has been corrected, suggesting that general QC procedures have been implemented.	Section 5.5.2.2
3. General (agriculture) – CH_4 and N_2O Transparency	Clearly report the methodology used to estimate emissions for each of the overseas territories and Crown dependencies in the relevant section of the NIR and ensure that this information is consistent across the NIR, including clearly stating that there are no agriculture activities in Gibraltar	A.5 2022 ARR (A.15, 2021 ARR)	**Addressing.** The UK continues to implement improvements in the agriculture sector for the OT and CDs. A separate chapter for the OT and CDs has been added within the agriculture sector, in order to clearly and transparently report the methodology used to estimate emissions for each of the overseas territories. Added information on the lack of activity data for the relevant OTs for sectors 3F-H are reported within this OT and CD agriculture chapter. The methodology used is outlined in table 5.10.1, as being a Tier 1 methodology. A note has been added to this chapter to clarify that there are no agricultural activities in Gibraltar.	Section 5.5.2.4
3. General (agriculture) – CH_4 and N_2O Transparency	Until a more transparent way of reporting emissions for overseas territories and Crown dependencies in the CRF tables is determined, enhance the transparency of reporting by correcting the CRF table references in the agriculture section of the NIR (the N_2O emissions from agricultural soils were said to be reported in CRF table 3.G (liming) but were actually reported in 3.G-I).	A.6 2022 ARR (A.16, 2021 ARR)	**Resolved.** The Party added in its NIR a new section (section 5.10, pp.378–380) on agriculture emissions in the overseas territories and Crown dependencies. Therein, the Party reported that in the CRF tables, all emission data for overseas territories and Crown dependencies are reported under category 3.J (other).	

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
3.B Manure management – CH_4 and N_2O Accuracy	Estimate the animal distribution in composting and digester MMS to estimate CH_4 and N_2O emissions from manure management, using expert judgment to estimate the animal distribution in both MMS until such time that country-specific data are available for inclusion in the submission.	A.7 2022 ARR (A.4, 2021 ARR)	**Addressing**. The UK team has not as yet found any activity data pertaining to composting on UK farms; we continue to work with the organisations that design farm surveys to seek to add more questions to try to determine whether this activity is "NO" or "NE" within the UK. To date we are very confident that this is a very low level (or "NO") activity in the UK, so we have retained the current approach to reporting. As the previous ERT noted, this does not lead to an underestimation of emissions that would be significant for the UK, and all waste manures are accounted for within the current UK model.	CRF tables
3.B Manure management – CH_4 and N_2O Transparency	Include the methane conversion factor for anaerobic digestion in NIR table 3.3.3 and include in the NIR details on and a reference for the methane conversion factor used for manure managed in digesters for cattle, pig and poultry manure provided during the review.	A.8 2022 ARR (A.17, 2021 ARR)	**Resolved.** The Party reported in its NIR (p.354) and in NIR table A3.3.3 that the methane conversion factors used for anaerobic digestion of livestock manure are based on the values used in the German inventory. The methane conversion factors for anaerobic digestion for cattle, pig and poultry manure are reported in NIR table A3.3.3. The values are consistent with the values in CRF table 3.B(a)s2.	Section 5
3.B Manure management – N_2O Transparency	Include a summary in the NIR of the research and justification used to determine the different MMS used in the United Kingdom, together with the relevant references.	A.9 2022 ARR (A.18, 2021 ARR)	**Resolved.** The Party provided in its NIR (pp.356–357 and 864–865) a comprehensive summary of the research, including relevant references, and justification applied in determining the MMS used in the United Kingdom.	CRF tables
3.B Manure management – N_2O Transparency	Clarify the data source, methodology used and references for the country-specific N_2O EFs in the NIR	A.10 2022 ARR (A.18, 2021 ARR)	**Resolved.** The Party reported in its NIR (pp.356–357) and in NIR tables A3.3.6(c–d) the data sources, methodologies and references used in developing the country-specific N_2O EFs for manure management. United Kingdom data relating to direct N_2O emissions from manure management were reviewed as part of a Department for Environment, Food and Rural Affairs	Section A2.1

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			project (AC0114) (Topp et al., in preparation). Country-specific EFs are derived from United Kingdom measurements, as described in documents available on request and summarized in N_2O Emission Factors for Manure Management in UK Agriculture (Misselbrook, 2017)	
3.B.4 Other livestock – N_2O Transparency	Include in the NIR an explanation of the poultry manure management practice and the final destination of the manure.	A.11 2022 ARR (A.6, 2021 ARR)	**Resolved.** The Party reported in its NIR (p.357) an explanation of the poultry manure management practice and the final destination of the manure. Manure types going to incineration are assumed to be broiler and turkey litter and the reported quantities incinerated are converted to a proportion of the total manure for these poultry categories on the basis of estimated manure output per bird. Quantities incinerated are given in NIR table A3.3.6(a) and quantities exported from Northern Ireland to England and Scotland in NIR table A3.6.6(b). The quantities incinerated are deducted from the AD prior to the calculation of emissions from manure spreading on land.	
3.D.a.2 Organic N fertilizers – N_2O Transparency	Include in the NIR references for all assumptions made for managed manure N applied to grassland and cropland, whether it be a published reference, a reference or report under preparation, or simply expert judgment	A.12 2022 ARR (A.19, 2021 ARR)	**Resolved.** The Party provided in its NIR (pp.364–365) references for the sources of data underpinning the assumptions applied in the United Kingdom inventory regarding managed manure N applied to grassland and cropland.	Section 5.10
3.D.a.3 Urine and dung deposited by grazing animals – N_2O Transparency	Include in future annual submissions a summary of how the country-specific N_2O EFs for sheep urine and dung were determined, including references.	A.13 2022 ARR (A.20, 2021 ARR)	**Resolved**. The Party reported in its NIR (p.367) a summary of how the country-specific N_2O EFs for sheep urine and dung were determined. According to the 2006 IPCC Guidelines (vol. 4, chap. 11, table 11.1), the N_2O EF for sheep excreta is 50 per cent of the value of the EF for cattle excreta. This EF is supported, for sheep urine, by mean EF values in the 2019 Refinement to the 2006 IPCC Guidelines (vol. 4,	

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			chapter 11, table 4A.1, wet climates), while the EF for sheep dung in the same table is less than 50 per cent of the value of the EF for cattle dung (0.04 per cent for sheep compared with 0.13 per cent for cattle). On the basis of this information, the United Kingdom derived N_2O EFs for sheep urine and dung by halving the country-specific values for cattle urine and dung	
3.D.a.6 Cultivation of organic soils (i.e. histosols) – N_2O Transparency	Provide in the NIR an explanation and further supporting evidence for the classification of organic soils in the Falkland Islands (Malvinas) as unmanaged and explain why the areas of organic soils in overseas territories and Crown dependencies are not included as a contributing source to N_2O emissions from the cultivation of organic soils	A.14 2022 ARR (A.7, 2021 ARR)	**Addressing.** Peat organic soils occur in the Falkland Islands and Isle of Man but not in the other Overseas Territories and Crown Dependencies. Emissions from the drainage and rewetting of organic soils on the Isle of Man were reported in this years inventory submission, with text included in the NIR text. There is a longer term research project into organic soils and emissions in the Falkland Islands (funded through the UK Government Darwin Initiative project DPLUS083), the results of which will feed into the inventory in due course.	Table A3.3.3
3.J Other (CO_2 emissions from liming, urea application and other carbon-containing fertilizers) – CO_2, CH_4 and N_2O Comparability	Report emissions from overseas territories and Crown dependencies in the respective categories (3.A (enteric fermentation), 3.B (manure management), 3.D (direct and indirect N_2O emissions from agricultural soils), 3.G (liming) and 3.H (urea application)).	A.15 2022 ARR (A.8, 2021 ARR)	**Resolved.** The documentation boxes in the CRF for categories 3.A-H have been updated to transparently clarify that the data for OTs and CDs are reported against 3.J.	Section 5.4.2.2 A3.3.7
4. General (LULUCF) 4.B Cropland – CO_2 4.C Grassland – CO_2 Comparability	Provide 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).	L.1 2022 ARR (L.3, 2021 ARR)	**Resolved.** The Party reported in its NIR (pp.368 and table 10.16) that the area of cultivated histosols, in hectares, is reported in CRF table 3.D as the sum of drained cropland in CRF table 4.B and intensive grassland. The area of grassland on organic soils reported in CRF table 4.C comprises both intensive	Section 5.5.2.7

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			and non-intensive/semi-natural grassland condition categories, hence the differences in areas of organic soils reported in CRF tables 4.B, 4.C and 4(II).	
4. General (LULUCF) – CO_2 and N_2O Accuracy	Calculate SOC change values for each soil type, under each land-use category and for each devolved administration and use those values to calculate SOC changes associated with land-use changes.	L.2 2022 ARR (L.23, 2021 ARR)	**Addressing.** The implementation of the land-use tracking vector approach will enable the UK to move towards resolving this issue, by analysing areas of stable land-use. This needs to be combined with an updated assessment of SOC estimates by land use type to ensure that the most accurate and robust soil information is used in the inventory modelling. Both of these items have been proposed for addition to the Inventory Improvement plan.	
4. General (LULUCF) – CO_2 and N_2O Consistency	Implement methodological changes to avoid any artefact trends in SOC changes in mineral soils associated with land-use changes or identify how the accumulation of land that has undergone a land-use change but not yet reached a new equilibrium, rather than a change in the rate of land-use changes, contributes to the trend in total SOC changes in mineral soils.	L.3 2022 ARR (L.24, 2021 ARR)	**Addressing**. Work has been commissioned to explore the effect of an extended land use change time series (beginning in 1900 vs beginning in 1950) on the resulting soil carbon stock change from 1990 onwards. Results of this will be reported in the 2024 NIR report.	
4.A Forest land – CO_2 Convention reporting adherence	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).	L.4 2022 ARR (L.10, 2021 ARR)	**Addressing**. The results from the second cycle of the NFI are not yet available, but will be used as part of verification efforts once the data has been analysed.	
4.A Forest land – CO_2 Accuracy	Estimate and report carbon stock changes in biomass from forests not used for timber production in accordance with the 2006 IPCC Guidelines (vol. 4, chap. 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.	L.5 2022 ARR (L.12, 2021 ARR)	See KP.2	

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
4.A Forest land – CO_2 and N_2O Convention reporting adherence	Provide in the NIR verification information consistent with the 2006 IPCC Guidelines (vol. 1, chap. 6.10, p.6.19) on estimates of emissions and/or removals prepared using tier 3 models, in accordance with paragraph 41 of the UNFCCC Annex I inventory reporting guidelines, and continue the model soil carbon stocks and flux verification exercise and report the results in future NIRs	L.6 2022 ARR (L.25, 2021 ARR)	**Addressing**. We will continue efforts to verify the changes is soil carbon estimated by the SCOTIA model and publish the results, along with identifying any potential additional data for verification.	
4.C Grassland – CO_2 Comparability	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.	L.7 2022 ARR (L.16, 2021 ARR)	**Resolved.** The Party reported in its NIR (pp.409 and 520) that the land-use change methodology has been revised to assimilate multiple sources of information on land use and land-use change, removing the inconsistency in the definition of hedgerows arising from the use of data on broad habitats from the UK Centre for Ecology & Hydrology Countryside Survey. The biomass carbon stock changes were calculated from a different (linear) Countryside Survey source (Haines-Young et al., 2000) and all carbon stock changes were reported under grassland.	
4.D.1.1 Peat extraction remaining peat extraction – CO_2, CH_4 and N_2O Completeness	Collect the necessary data to enable reporting of emissions/removals from peat extraction remaining peat extraction in overseas territories and Crown dependencies.	L.8 2022 ARR (L.17, 2021 ARR)	**Resolved.** Estimates of peat extraction remaining peat extraction for domestic fuel use in the Falkland Islands are included in the 1990-2021 inventory. This was based on a new data source (household census repeated every 5-6 years from 1991) on households using fuel peat combined with expert local knowledge to produce an activity time series using interpolation between census values. It is assumed that abandoned peat extraction areas have not been restored.	
4.D Wetlands – CO_2, CH_4 and N_2O Transparency	Provide in the NIR detailed information to describe that land conversion to peat extraction in overseas territories and Crown dependencies is not occurring.	L.9 2022 ARR (L.18, 2021 ARR)	**Resolved.** Estimates of land converted to peat extraction for domestic fuel use in the Falkland Islands are included in the 1990-2021 inventory. This	

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			was based on a new data source (household census repeated every 5-6 years from 1991) on households using fuel peat combined with expert local knowledge to produce an activity time series using interpolation between census values. It is assumed that abandoned peat extraction areas have not been restored.	
4(V) Biomass burning – CO_2, CH_4 and N_2O Accuracy	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 overseas territories and Crown dependencies.	L.10 2022 ARR (L.21, 2021 ARR)	**Resolved**. To address this issue, the United Kingdom assessed several sources of information on wildfires in the overseas territories and Crown dependencies, including published government data on fire occurrence, and contacted local experts in all overseas territories and Crown dependencies (NIR annex, p.934). This assessment found no occurrence of fires and zero burned areas for 2002–2019 for the Cayman Islands, Guernsey, the Isle of Man and Jersey. Bermuda fire statistics show no wildfire areas for either forest land or grassland. For the Falkland Islands (Malvinas), the Global Wildfire Information System recorded 11 fires between 2002 and 2019 on an estimated total area of 5,024 ha based on pixel size, although the total burned area is recorded as zero. Owing to the lack of publicly available data for wildfires in the overseas territories and Crown dependencies, a geographical proxy burning rate was used to estimate wildfire emissions.	
4.G.3 Other (HWP) – CO_2 Transparency	Include verifiable production data from the CARBINE model and the corresponding factors used to convert the production data to carbon, and report those data	L.11 2022 ARR (L.22, 2021 ARR)	**Resolved.** In the 2021 submission, the Party reported a truncated time series of production data from the CARBINE model in CRF table 4.Gs2 and values for converting production data to carbon were absent	

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
	in CRF table 4.Gs2 to enable a more thorough verification of the HWP estimates		from the table. In the 2022 submission, the full time series is reported (1960–2020) and the values for converting production units to carbon are provided.	
5.A Solid waste disposal on land – CH_4 Transparency	Implement the proposed improvements of the emission estimates for SWDS in overseas territories and Crown dependencies by providing further information on the methodologies used to estimate the emissions and by completing the CRF tables with specific parameters such as AD, methane correction factor and degradable organic carbon.	W.1 2022 ARR (W.1, 2021 ARR)	**Resolved.** The Party provided in its NIR the AD for total MSW disposal for Crown dependencies (NIR table A3.6.12) and overseas territories (NIR table A3.6.13). NIR table A3.5.5 lists all the relevant parameters used for estimating emissions for SWDS in addition to defaults provided in the IPCC landfill model. The United Kingdom indicated in the documentation box of CRF table 5.A that the AD reported are for mainland United Kingdom only, while the emissions reported include contributions from overseas territories and Crown dependencies. During the review, the United Kingdom confirmed that in CRF table 5.A, AD and other non-emission data represent mainland United Kingdom only, while emissions include activities in mainland United Kingdom as well as in overseas territories and Crown dependencies. The Party explained that it considers this approach (in combination with the documentation box pointing readers to the section of the NIR where parameters for the overseas territories and Crown dependencies are documented) to be pragmatic. The Party noted that the alternative to presenting modified AD and other non-emission data in the CRF tables reflecting specific overseas territories and Crown dependencies that fall within the scope of each of the United Kingdom's three different CRF submissions (i.e. Convention, Kyoto Protocol and European Union) would lead to a disproportionate effort for little value. The ERT agrees that the reporting is sufficiently transparent, and that emissions are not affected by the choice of reporting approach. The ERT considers that this recommendation has been fully addressed in	Annex tables A3.6.12, A3.6.13, A3.5.5

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			accordance with paragraph 73 of the UNFCCC review guidelines.	
5.A Solid waste disposal on land – CH_4 Accuracy	Investigate the availability of alternative data sources for the composition of mixed waste and update the waste composition data used for estimating emissions from this category accordingly, or, if this is not possible for a given annual submission, provide a justification in the NIR that the waste composition data used are representative of current national circumstances.	W.2 2022 ARR (W.3, 2021 ARR)	**Addressing.** A project is underway to sample and characterise the composition of mixed wastes disposed to landfills. This should also provide a methodology to estimate the composition in historic years and into the future.	
5.D.1 Domestic wastewater – CH_4 Comparability	Report CH_4 recovery consistently with the energy statistics.	W.3 2022 ARR (W.8, 2021 ARR)	**Resolved.** The Party revised the data on CH_4 recovery in CRF table 5.D and discussed in its NIR (pp.441–445) how data reported by operators compare with energy statistics on sewage gas utilization for 2013 onward. Prior to 2013, CH_4 recovered is extrapolated on the basis of United Kingdom energy statistics. The ERT concludes that the discussion in the NIR and reporting in CRF table 5.D is sufficient.	CRF tables
5.D.1 Domestic wastewater – N_2O Accuracy	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	W.4 2022 ARR (W.9, 2021 ARR)	**Resolved.** The Party reviewed the calculations for N_2O emissions from domestic wastewater and updated them by applying an N-balance-based calculation reflecting the estimated N content of sewage sludge removed and used in agriculture, incinerated or landfilled (NIR table 10.16 and NIR p.476), in accordance with equations 6.7 and 6.8 in the 2006 IPCC Guidelines. The Party revised the AD in CRF table 5.D accordingly.	Section 7.5

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
5.D.2 Industrial wastewater – CH_4 Accuracy	Report on any progress in collecting the data needed to report AD and emissions from industrial wastewater separately from domestic wastewater.	W.5 2022 ARR (W.11, 2021 ARR)	**Resolved.** As described in the 2nd paragraph of Section 7.5.2.4, data from municipal wastewater operators on industrial co-discharge referred to as 'trade load' are reported by water operators, and these data are used to remove the expected proportion of industrial wastewater which is treated via municipal wastewater systems rather than in-situ.	Section 7.5.2.4
5.D.2 Industrial wastewater – CH_4 Accuracy	Collect information on the proportions of aerobic and anaerobic treatment systems and revise the methane correction factor used accordingly.	W.6 2022 ARR (W.12, 2021 ARR)	**Resolved.** The Party deployed a revised methodology developed in 2021 for estimating CH_4 emissions from industrial wastewater that involves estimating the proportions of aerobic and anaerobic treatment systems and using a revised methane correction factor. As indicated in the NIR (p.478), default methane correction factors from the 2006 IPCC Guidelines are used for each type of treatment and discharge pathway or system, taking into account aerobic and anaerobic treatment (2006 IPCC Guidelines, vol. 5, chap. 6, table 6.8).	Section 7.5.4
5.D.2 Industrial wastewater – CH_4 Accuracy	Collect the necessary data to complete the estimates of CH_4 recovery from industrial wastewater.	W.7 2022 ARR (W.16, 2021 ARR)	**Not resolved.** The United Kingdom environmental reporting system does not include yet the amount of CH_4 recovered nor data allowing to estimate CH_4 recovery within the industrial wastewater treatment plants. This issue will be considered for action alongside all other potential inventory improvements and acted upon subject to data and funding	
General (KP-LULUCF) – CO_2, CH_4 and N_2O Transparency	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.	KP.1 2022 ARR (KL.1, 2021 ARR)	**Resolved.** The Party reported in its NIR (pp.553–562 and 574) and confirmed during the review that the land-use tracking project is being implemented in two phases, and that the phase one results are available, allowing the Party to use, in the 1990–2020 inventory, spatially explicit data to track land-use change across the United Kingdom that are then simplified to non-	Section 11

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			spatial information for use in the LULUCF and KPLULUCF models. During the review, the Party also clarified that implementation of phase two of the project will not change the land representation as the same underlying set of land-use vectors will be used	
FM – CO_2 Accuracy	Estimate and report, in accordance with the 2006 IPCC Guidelines (vol. 4, chap. 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.	KP.2 2022 ARR (KL.10, 2021 ARR)	**Resolved.** The ERT has assessed that this issue does not influence the Party's ability to fulfil its commitments for the second commitment period of the Kyoto Protocol. This same issue will be tracked for convention reporting as issue L.5.	
FM – CO_2 Accuracy	(a) Estimate the background level and margin using a consistent and initially complete time series containing emissions for 1990–2009, in accordance with decision 2/CMP.7, annex, paragraph 33, using, if appropriate, methodologies from the 2006 IPCC Guidelines (e.g. vol. 1, chap. 5); (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 provision (e.g. substitution of natural disturbances emissions in the FMRL by the background level estimated) is intended to be applied.	KP.3 2022 ARR (KL.12, 2021 ARR)	(a) **Resolved.** The Party recalculated the background level and margin and reported in NIR table 11.7 a complete time series containing emissions from wildfires (the only natural disturbance considered) for 1990–2009, in Gg CO_2 eq, for mainland United Kingdom and the overseas territories and Crown dependencies, in accordance with decision 2/CMP.7, annex, paragraph 33, using methodologies from the 2006 IPCC Guidelines (e.g. vol. 1, chap. 5). (b) **Resolved.** The default method in the Kyoto Protocol Supplement was used for estimating the background level of emissions and margins. The annual emissions from wildfires on FM and AR land reported in the United Kingdom's LULUCF sector GHG inventory were used for the calibration period, applying the same methodology for assigning the wildfire emissions. Avoidance of the expectation of net credits or net debits was achieved in the background level calculation by	Section 11

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			including only the emissions from natural disturbances explicitly included in the GHG inventory (namely, from wildfires) and, as noted by the ERT, the absence of an observable trend in the background time series. The United Kingdom calculated a technical correction to the FMRL for the current annual submission and one of the elements in the technical correction comprised the revised estimates of emissions from natural disturbances.	
FM – CO_2, CH_4 and N_2O KP reporting adherence	Correct the identified inconsistencies in the technical correction and all the information required by the Kyoto Protocol Supplement.	KP.4 2022 ARR (KL.16, 2021 ARR)	**Resolved.** The Party corrected the inconsistencies in the FMRL technical correction by including the estimates of emissions from FM land for overseas territories and Crown dependencies. The accounting quantity is reported and justified in the NIR (pp.577–580) in accordance with the requirements of the Kyoto Protocol Supplement.	Section 11
FM – CO_2 KP reporting adherence	Resolve the inconsistency resulting from the assumption that dead organic matter was instantaneously oxidized and recalculate the technical correction accordingly by using a recalculated and consistent background level of emissions.	KP.5 2022 ARR (KL.17, 2021 ARR)	**Resolved.** The Party recalculated the background level of emissions to ensure consistency with the estimates included in the GHG inventory, thus eliminating the inconsistency identified by the previous ERT (NIR pp.563 and 574). The technical correction was recalculated on the basis of the latest inventory and assumptions about the level and type of management that would be consistent with policies in place in 2009. These assumptions were based on the method detailed in the United Kingdom National Forestry Accounting Plan, 2021 to 2025. Among the changes in data and assumptions since the FMRL was calculated are a correction to double counting in the calculation of deadwood and the inclusion of estimates of emissions from FM land in overseas territories and Crown dependencies. NIR table 11.10	

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
			contains the FMRL and technical correction for 2013–2020.	
FM – CO_2 Transparency	Clarify in the NIR how the automated algorithm is used to prepare timber production statistics for the CARBINE model used to produce the technical correction on the one hand, and FM estimates during the second commitment period on the other.	KP.6 2022 ARR (KL.18, 2021 ARR)	**Resolved.** The Party reported in its NIR (pp.577–580) that the assumptions for FM in the FMRL technical correction were revised to be consistent with the methodology described in the United Kingdom National Forestry Accounting Plan, 2021 to 2025. The resulting divergence between the technical correction and FM estimates is documented in the NIR and explained as part of the accounting quantity. The Party switched from using the CARBINE model to using the C-Flow/CARBINE models, which can represent a wider range of tree species and management practices, though the Party informed the ERT during the review that the methodologies of both models are consistent with each other. The FMRL for the United Kingdom was calculated using the same methodology for estimating forest carbon stock changes and GHG emissions as the methodology used for the Convention LULUCF inventory, the KP-LULUCF inventory and national projections of LULUCF emissions and removals, but with assumptions about the level and type of management that would be consistent with policies in place in 2009.	Section 11
FM – CO_2 Transparency	Provide an assessment of whether and to what extent differing application of the algorithm to adjust the assumed FM harvest to harmonize with timber production statistics results in a divergence between the technical correction and the FM estimates during the second commitment period.	KP.7 2022 ARR (KL.18, 2021 ARR)	**Resolved.** The Party reported in its NIR (pp.577–580) that the assumptions for FM in the FMRL technical correction were revised to follow the methodology described in the United Kingdom National Forestry Accounting Plan, 2021 to 2025. The resulting divergence between the technical correction and FM estimates is documented in the NIR and explained as part of the accounting quantity. For further details, see ID# KL.6 above.	Section 11

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
GM – CO_2 Consistency	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.	KP.8 2022 ARR (KL.13, 2021 ARR)	**Resolved.** The Party stated in its NIR (p.906) that managed and unmanaged hedges are all reported under grassland and that biomass carbon stocks are estimated as the median of values relevant to the United Kingdom in the published literature, as determined from a literature review, supplemented by more recent data, for the entire time series. Full details of these values and data sources are included in the Party's Grassland Management Biomass calculation workbook. NIR table A3.4.14 contains the total biomass carbon stocks, the uncertainties and the root-to-shoot ratios for managed and unmanaged hedges applied in estimating emissions and removals for the 2022 submission.	Section 11
GM – CO_2, CH_4 and N_2O Completeness	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.	KP.9 2022 ARR (KL.14, 2021 ARR)	**Resolved.** During the review of the 2021 submission, information regarding controlled burning on grassland was provided to the ERT, including a preliminary assessment supporting the view that emissions from controlled biomass burning are insignificant (approximately 163 kt CO_2 eq without accounting for post-fire vegetation regrowth). The previous ERT considered that including a summary of this information in the next annual submission would resolve the recommendation. The Party reported in the NIR (pp.916–917) of the current annual submission a summary of the information, as recommended.	Section 11

Table 10.17 Improvements to the UK GHG Inventory Submission in response to UNFCCC Review Findings 2022

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
CPR	The Party reported in its NIR (p.585) the CPR value of 90 per cent of the assigned amount as 2,470,443,559 t CO_2 eq. The ERT noted that according to the Party's report to facilitate the calculation of the assigned amount for the second commitment period of the Kyoto Protocol, and through its own calculation of the information documented in the NIR (p.585), this value should be 2,470,443,599 t CO_2 eq. The ERT also noted that in the NIR (p.585), the comparison of 90 per cent of the assigned amount was made with eight times the total GHG emissions of the inventory for 2018 contained in the 2020 submission instead of with eight times the total GHG emissions of the inventory for the 2020 contained in the 2022 submission, as required by decision 11/CMP.1, annex, paragraph 6. During the review, the Party confirmed the CPR value to be an editorial error and that the correct value is 2,470,443,599. Regarding the comparison of the assigned amount, the Party clarified that it believes it should have used the total GHG emissions for 2019 contained in the 2021 submission. However, the ERT noted that as the 2022 submission will be the latest available reviewed annual submission at the time of publication of the 2022 annual review report, the comparison should have been made with the total GHG emissions for 2020 contained in the 2022 submission, which is equal to 404,834,197 × 8, or 3,238,673,576 t CO_2 eq. This value is higher than the value of the CPR as contained in the report to facilitate the calculation of the assigned amount for the second commitment period of the Kyoto Protocol. The ERT concludes that the final CPR is 2,470,443,599 t CO_2 eq. The ERT further concludes that this potential problem of a mandatory nature does not influence the Party's	2022 ARR G.2	**Resolved.** The ERT recommended that the calculation of the commitment period reserve in the 2022 submission should have used eight times the total GHG emissions of the inventory for 2020 contained in the same submission. The emissions total in the CPR calculation in the 2023 submission has been updated to use the ERT's recommended value of 2020 emissions from the 2022 submission, excluding KP LULUCF. Our rationale for continuing to use this figure (rather than updating it to 2021 emissions from the 2023 submission) is that the 2022 submission is the UK's most recently reviewed inventory submitted to fulfil reporting obligations under the Kyoto Protocol, and the final inventory to be compiled using the geographical scope of the Kyoto Protocol second commitment period. In addition, 2020 is the last year of the second commitment period of the Kyoto Protocol.	Section 12

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
	ability to fulfil its commitments for the second commitment period of the Kyoto Protocol and therefore this issue was not included in the list of potential problems and further questions raised.			
Uncertainty analysis	In several cases, the Party reported in its NIR (annex 2) uncertainty for aggregated categories (e.g. 1.A (coal) (CO_2) and 2.B (chemical industry) (CO_2)) instead of for each subcategory. The Party reported in its NIR (p.525) that it will consider the encouragement from the previous ERT to transparently explain in the NIR its rationale for estimating uncertainties for aggregated categories during future updates of annex 2 to the NIR. During the review, the Party clarified that according to the 2006 IPCC Guidelines (vol. 1, chap. 3), aggregation should be used as a means to make the uncertainty analysis more accurate by reducing unaccounted for correlations and dependencies. According to the Party, the biggest challenges with disaggregation are that (1) subcategories can have positive or negative correlations to one another that are either not accounted for in approach 1 or require additional work to adequately account for in approach 2 and (2) disaggregation without consideration of the	2022 ARR G.3	**Resolved.** The UK has added 2 sentences to the opening section of Annex 2 in the NIR in order to be more transparent about the rationale for not estimating uncertainties at higher levels of sectoral detail.	

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
	correlations changes the results of the uncertainty analysis in ways which make the results less valid. The ERT agrees with the Party's views. The ERT recommends that the Party explain in the NIR its rationale for aggregating category uncertainties to account for correlations and dependencies, rather than reporting uncertainty by subcategory.			
Fuel combustion – reference approach – other fossil fuels – CO_2	The Party reported in its NIR (p.141) fuels that are excluded from the United Kingdom's reference approach but are included in its sectoral approach, namely, waste oils, fossil-containing waste, scrap tyres and waste solvents. The Party also reported that the reference approach does not include emissions from these fuels because the reporting of the fuels is not complete in the United Kingdom energy statistics. The ERT noted that CRF table 1.A(c) shows a discrepancy in AD between the reference approach and the sectoral approach for other fossil fuels, specifically, for 2020, 69.85 PJ other fossil fuels are reported under the reference approach and 113.05 PJ are reported under the sectoral approach. The ERT noted a lack of transparency regarding which other fossil fuels are included in the reference approach and the main reasons for the observed differences. During the review, the Party clarified that the data on other fossil fuels used for the reference approach are data on MSW used as a fuel from the United Kingdom energy statistics and also that the MSW data in the energy statistics do not include all waste products accounted for under the sectoral approach. For	2022 ARR E.7	**Resolved**. The UK has updated Section 3.2.1.1.5 of the NIR to include a brief discussion of the comparison between the sectoral approach and reference approach for other fossil fuels	Section 3.2.1.1.5

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
	example, while some scrap tyres are included in the United Kingdom energy statistics as part of the MSW data, the Party is aware that some scrap tyres used as a fuel are not included in these statistics and, therefore, does not include these in the reference approach. The ERT recommends that the Party clarify in the NIR which fuels are included in the other fossil fuels portion of fuels considered under the reference approach, including, for example, what percentage of total MSW is captured by the United Kingdom energy statistics.			
1.A.4.c.iii Fishing – residual fuel oil – CO_2	The Party reported in CRF table 1.A(a)s4 the AD and CO_2 emissions associated with residual fuel oil use in fishing, which resulted in a CO_2 IEF of 535.00 t/TJ. The ERT noted that the reported IEF is higher than that for all other reporting Parties (maximum of 77.95 t/TJ for 2020) and higher than the default IPCC EF (77.40 t/TJ) (vol. 2, chap. 2, table 2.5 of the 2006 IPCC Guidelines). During the review, the Party clarified that the AD for this category are for mainland United Kingdom only while the emission data include the overseas territories and Crown dependencies. The use of these data resulted in an unrepresentative IEF, but the CO_2 EF used by the Party for residual fuel oil is 76.50 t/TJ, which is in line with the default	2022 ARR E.8	**Resolved.** After the ERT's review, it was noted that reporting residual fuel oil use in fishing is unusual since fuel oil is normally used by larger ships. After review by the Party, residual fuel oil use in overseas territories and Crown dependencies has been estimated as 0 and the equivalent energy use and associated emissions have been moved to gas oil activity instead. This results in IEFs that are comparable to other countries	1.A.4.c.iii Fishing – residual fuel oil – CO_2

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
	IPCC EF and those of the other reporting Parties. The Party explained that the AD for the overseas territories and Crown dependencies for this source are in a different format to those for mainland United Kingdom and cannot be aggregated and included in the CRF tables without manual intervention. The Party noted that it is working towards recording AD for overseas territories and Crown dependencies in a format consistent with that of the mainland United Kingdom AD, therefore making it easier to identify and aggregate these data and transpose them into the CRF tables. The ERT recommends that the Party continue to work to gather AD for residual fuel oil use in fishing (category 1.A.4.c.iii) for the United Kingdom's overseas territories and Crown dependencies in the appropriate format and report these AD in CRF table 1.A(a)s4 to allow comparability of the IEF with the other reporting Parties or describe in the NIR the differences in these AD from mainland United Kingdom AD and the reason for not including them in the CRF tables.			
1.B.1.b Solid fuel transformation – solid fuels – CO_2	The Party reported in CRF table 1.B.1 the AD and CO_2 IEFs associated with solid fuel transformation. The interannual change in the CO_2 IEF is significant for several years, for example, between 2015 (150.97 kg/t) and 2016 (217.23 kg/t), representing a 43.9 per cent increase, and between 2018 (214.75 kg/t) and 2019 (108.04 kg/t), representing a 49.7 per cent decrease. Methodological information on category 1.B.1.b was not provided in the NIR and the reasons for the inter-annual changes were not reported. During the review, the Party clarified that category 1.B.1.b (solid fuel transformation) covers three distinct sources: coke oven related sources at steelworks, and the use of coal and petroleum coke in the production of solid smokeless fuel (i.e. two sources). The two solid smokeless fuel production sources	2022 ARR E.9	**Resolved.** The UK has introduced a new method statement (**MS 20**, in chapter 3 of the NIR) which describes the methodology used for other sources reported in 1B1b, and included commentary on the time-series fluctuations in IEF and a reference to the energy background data that would help future reviewers see the justification for these IEF fluctuations.	MS 20

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
	dominate emissions for 2015–2019 and are mainly responsible for the inter-annual variation in the CO_2 IEF. The Party confirmed that emissions for these two sources tend to vary from year to year because their estimation is based on a simple carbon balance method and is affected by the ratio of coal to petroleum coke inputs and by the ratio of inputs to solid smokeless fuel outputs. The ERT recommends that the Party include in Method Statement 4 of its NIR information on solid smokeless fuel production (currently only coke oven related sources at steelworks is covered) and reference the relevant background spreadsheet for each year of the inventory, which includes the AD and CO_2 EFs for the input and output streams of solid smokeless fuel production and explain any inter-annual differences in the CO_2 IEF for category 1.B.1.b (solid fuel transformation).			
2.B.1 Ammonia production – CO_2	The Party reported in its NIR (p.265) that some of the CO_2 recovered from ammonia production is sold by the production facilities to other industrial plants, without specifying whether the emissions associated with the CO_2 sold are included elsewhere in the inventory. The ERT noted that according to the 2006 IPCC Guidelines (vol. 3, chap. 3, equation 3.3 and figure 3.1), CO_2 recovered for downstream use in certain applications should be subtracted from emissions under category 2.B.1 (ammonia production) if reported elsewhere in the inventory. During the review, the Party clarified the applications of the CO_2 sold, stating that it is used, for example, in the production of carbonated drinks, as a refrigerant, as a cover gas for the brewing industry, as a feedstock for other chemical industries, and at slaughterhouses. The Party confirmed that emissions from CO_2 used in these applications are included in the GHG inventory. The ERT did not identify any	2022 ARR I.13	**Resolved.** The UK has expanded the text of exported CO_2 from ammonia production in Section 4.6.1 of the NIR, including listing likely uses for the CO_2 and discussing how those are reported in the UK inventory.	Section 4.6.1

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
	underestimation of CO_2 emissions resulting from the accounting for CO_2 sold. The ERT recommends that the Party include in the NIR (section 4.6.1 or 4.6.2, for example, in tabular or list format) the applications of CO_2 that is recovered from ammonia production and sold to other industrial plants, clearly specifying for each application whether the associated emissions are reported under categories other than 2.B.1 (ammonia production), and if so, which categories.			
2.C.1 Iron and steel production – CO_2, CH_4 and N_2O	For the 2022 submission, in response to a recommendation (see ID# I.10 in table 3), the Party reallocated a large part of the emissions occurring at integrated iron and steel plants from category 1.A.2.a (manufacturing industries and construction (iron and steel)) to category 2.C.1.b (iron and steel production (pig iron)). Specifically, all blast furnace gas and coke oven gas used at integrated iron and steel plants and all fuel used in blast furnaces were reallocated. The ERT noted that the description of the methodology to estimate emissions from iron and steel production in the NIR (pp.282285) has not been updated accordingly; in particular, on page 283, the Party states that emissions from the use of blast furnace gas and coke oven gas are reported by the process in which they are used (i.e. under category 1.A.2.a) rather than under category 2.C.1. The ERT noted the lack of consistency between the actual allocation of emissions to categories 1.A.2.a and 2.C.1.b (as reported in CRF tables 1.A(a)s2 and 2(I).AHs2 respectively) and the text explaining that allocation in the NIR (pp.282–285). During the review, the Party	2022 ARR I.14	**Resolved.** The text in Source Category 2C1 has been amended in the 2023 submission.	Section 4.16

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
	noted the error on NIR page 283 identified by the ERT, but clarified that this reallocation of emissions between categories 1.A.2.a and 2.C.1.b is documented (NIR Method Statement 3, Method Statement 4 and p.517).The ERT recommends that the Party correct the text in the NIR (pp.282-–285 in the 2022 annual submission) regarding the allocation of emissions from the use of blast furnace gas and coke oven gas at integrated iron and steel plants to ensure that it reflects the allocation of these emissions between category 1.A.2.a (manufacturing industries and construction (iron and steel)) and category 2.C.1.b (iron and steel production (pig iron)).			

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
2.D.1 Lubricant use – CO_2	In CRF table 2(I).A-Hs2, the Party reported CO_2 emissions from lubricant use while it reported the AD for this category as "NO". The Party reported AD on lubricant use in CRF table 1.A(d) (11,933.93 TJ in 2020). During the review, in response to a question raised by the ERT, the Party provided the ERT with the complete set of AD (amounts of lubricants used, in kt) covering the entire time series. The ERT recommends that the Party report AD on lubricant use in CRF table 2(I).A-Hs2 in accordance with the UNFCCC Annex I inventory reporting guidelines.	2022 ARR I.15	**Resolved.** The party has reported AD in CRF table 2(I).A-Hs2	CRF tables

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
3.B Manure management – N_2O	The ERT conducted an N balance check for manure management from the point of Nex entering MMS to the point of land application on the basis of data available in CRF tables 3.B(a)s2, 3.B(b) and 3.D. The amount of N leaving manure storage estimated by the ERT was lower than the reported amount of N applied to soils for 1990–2013 and higher than the amount reported for 2014–2020. During the review, the Party clarified that the values calculated by the ERT differ from the reported values owing to several factors not taken into account by the ERT: (1) consideration of emissions of N (dinitrogen/nitrogen gas) throughout manure management, (2) removal of poultry manure N going to incineration, (3) categorization of manure processed through anaerobic digestion as digestate when applied to land, with this manure therefore being included under category 3.D.2.c (other organic fertilizers applied to soils) (CRF table 3.D), and (4) inclusion of bedding N in the N amounts reported in CRF table 3.D but not in CRF table 3.B(b). Taking these factors into account, the ERT considers that the approach applied by the United Kingdom for calculating the N balance along the manure cascade is correct; however, it is not transparently described in the NIR. The Party also clarified that the structure of the CRF tables for reporting emissions from manure management do not align well with the more disaggregated nature of the United Kingdom's agriculture model and stated that it will therefore provide more detailed output in the NIR and the annex to the NIR, including a full N balance check from the point of Nex entering MMS to the point of land application. The ERT recommends that the Party provide in the NIR information on all N flows from the point of Nex entering MMS to the point of land application in order to allow a transparent assessment of the N balance.	2022 ARR A.18	**Resolved**. A full balance check for manure management has been provided as a supplementary file to the NIR, including a full N balance check from the point of Nex entering MMS to the point of land application as requested by the previous ERT.	Supplemental file

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
3.B.4 Other livestock – N_2O	During the review, in response to the issue raised by the ERT under ID# A.20 below, the Party noted that incorrect values for poultry Nex were entered in CRF table 3.B(b) for 1991–2020 (the 1990 value was used throughout). The United Kingdom emphasized that this error has no impact on reported emissions for this category for those years. The ERT agreed that the reported emissions are not affected by the incorrect values for poultry Nex. The ERT recommends that the Party provide the correct values for poultry Nex in CRF table 3.B(b) for 1991–2020.	2022 ARR A.19	**Resolved.** The poultry Nex in CRF table 3.B(b) values have been corrected across the time series and the UK has strengthened its QAQC of the data submitted within the CRF.	CRF tables

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
4.G HWP – CO_2	The ERT noted the following information relevant to HWP in SWDS: (1) in CRF table 4.Gs1, the information item for reporting HWP in SWDS was reported as “IE”, with the comment “included with HWP consumed domestically”; (2) in CRF table 4.Gs1, the documentation box contains the note that “the amount of HWP in SWDS are not currently estimated”; and (3) in CRF table 5, the memo item for the annual change in the long-term carbon storage in HWP waste is reported as “NO”. These three pieces of information are inconsistent with one another and present different potential issues depending on which of the entries is correct. During the review, the Party clarified that the information in the documentation box to CRF table 4.Gs1 is correct and the amount of HWP in SWDS are not currently estimated, allowing the ERT to have confidence that neither an underestimation of CH_4 emissions for the waste sector nor a problem in KP-LULUCF reporting regarding the fulfilment of the requirements of decision 2/CMP.7, annex, paragraph 32, has occurred. The Party informed the ERT that it was unable to identify wood entering SWDS from domestic production as distinct from imports, consistent with the elected production approach, and therefore was unable to estimate the potential emissions from HWP in SWDS. The ERT recommends that the Party (1) follow the guidance in the 2006 IPCC Guidelines (vol. 4, chap. 12, section 12.2.1), which advises using the methods of the waste sector (which are consistent with the consumption approach for HWP) to assess whether emissions from HWP in SWDS are likely to be significant (i.e. larger than any other key category), and include information consistent with this assessment in its reporting for the LULUCF sector; and (2) if the likely emissions from HWP in SWDS are found to be significant, develop a methodology	2022 ARR L.12	**Resolved.** The CRF has been corrected for the 2023 submission to report HWP in SWDS as NE in all relevant tables. Investigation of the significance of the emissions/removals relating to HWP in SWDS has been added as a potential improvement item and will be discussed by the Scientific Steering Group. Any progress will be documented in the NIR.	CRF tables

CRF category/issue	Recommendation made in previous review report	Review report / paragraph	Response	Chapter / section in the NIR
	consistent with the 2006 IPCC Guidelines that is appropriate to its national circumstances for estimating the emissions/removals of HWP in SWDS and include these emissions/removals in its reporting for the LULUCF sector.			

11 KP-LULUCF

All reporting of information required under Article 3, paragraphs 3 and 4 of the Kyoto Protocol for the purposes of the second commitment period of the Kyoto Protocol has now taken place. This information is available in the UK's 1990-2020 greenhouse gas inventory, published in 2022, which will be used to assess compliance with the UK’s targets under the Doha Amendment. The 2022 NIR submission is available at https://naei.beis.gov.uk/reports/reports?report_id=1072.

12 Information on Accounting of Kyoto Units

12.1 BACKGROUND INFORMATION

The UK's Standard Electronic Format report for 2022 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_2022_2_1.xls for commitment period 2.

12.2 SUMMARY OF INFORMATION REPORTED IN THE SEF TABLES

12.2.1 Commitment Period 2

At the end of 2022, the total CP2 holdings for the UK Registry was 33,243,067 CERs, of which 10,894,859 were in the voluntary cancellation account and 22,061,304 in entity holding accounts. There was also a total of 12,275,645 ERUs.

In total for 2022, the UK Registry received 19,298,577 CERs and 0 ERUs. Conversely, 11,987,502 CERs and 15,509 ERUs were externally transferred to other national registries. No other CP2 units were transferred or acquired.

0 CERs or ERUs were cancelled.

Full details are available in the SEF tables.

Information on legal entities authorised to participate in mechanisms under Articles 6, 12 and 17 of the Kyoto Protocol can be found on the UK Emissions Registry website in the Kyoto Protocol Public Reports area at

https://view-emissions-trading-registry.service.gov.uk/kp-reports/

Annual Submission Item	Reporting Guidance
15/CMP.1 Annex I.E paragraph 11: Standard electronic format (SEF)	UK's Standard Electronic Format report for 2022 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_2022_2_1.xlsx (Commitment Period 2 only).

12.3 DISCREPANCIES AND NOTIFICATIONS

Annual Submission Item	Reporting Guidance
15/CMP.1 Annex I.E paragraph 12: List of discrepant transactions	No discrepant transactions occurred in 2022. This is confirmed in the table named "R2" in the Excel file included, SIAR Reports 2022-GB v1.0.xls
15/CMP.1 Annex I.E paragraph 13 & 14: List of CDM notifications	No CDM notifications occurred in 2022. Refer to Separate Electronic Attachment "SIAR Reports 2022-GB v1.0.xls" Worksheet R3.
15/CMP.1 Annex I.E paragraph 15: List of non-replacements	No non-replacements occurred in 2022. Refer to Separate Electronic Attachment "SIAR Reports 2022-GB v1.0.xls" Worksheet R4.
15/CMP.1 Annex I.E paragraph 16: List of invalid units	No invalid units exist as at 31 December 2022. Refer to Separate Electronic Attachment "SIAR Reports 2022-GB v1.0.xls" Worksheet R5.
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://view-emissions-trading-registry.service.gov.uk/kp-reports/ 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.

Annual Submission Item	Reporting Guidance
	Account Information (Paragraph 45) Certain information listed in paragraph 45 of the Decision is considered confidential. This is in line with the data protection requirements of Regulation EUR2016/279 as amended by the Data Protection, Privacy and Electronic Communications (Amendments etc) (EU Exit) Regulations 2019; the Data Protection Act 2018; and Article 110 of EUR389/2013 as amended by the Greenhouse Gas Emissions (Kyoto Protocol Registry) Regulations 2021. JI projects in UK (Paragraph 46) Note that no Article 6 (Joint Implementation) project is reported as conversion to an ERU under an Article 6 project, as this did not occur in the specified period. The United Kingdom has taken the decision not to host any domestic JI projects, clarification of which is on our registry public reports page https://view-emissions-trading-registry.service.gov.uk/kp-reports/ Paragraph 47 a/d/f - Holding and transaction information of units Holding and transaction information is provided on a holding type level, due to more detailed information being declared confidential by EU Regulation. Holding and transaction information pursuant to paragraph 47 is provided on holding type level. The detailed information on transactions is considered confidential according to Article 110 of EUR389/2013 as amended by the Greenhouse Gas Emissions (Kyoto Protocol Registry) Regulations 2021. Paragraph 47c The United Kingdom is not hosting domestic JI projects as per paragraph 46 above.
	Paragraph 47e The United Kingdom is currently not participating in any LULUCF projects for 2022. Paragraph 47g No ERUs, CERs, AAUs and RMUs have been cancelled on the basis of activities under Article 3, paragraphs 3 and 4 to date. Paragraph 47h No ERUs, CERs, AAUs and RMUs have been cancelled following determination by the Compliance Committee that the Party is not in compliance with its commitment under Article 3, paragraph 1 to date. Paragraph 47j No ERUs and CERs have been retired in 2022 for CP2.

Annual Submission Item	Reporting Guidance
	Paragraph 47k No carry-over took place in 2022. Account holders authorised to hold Kyoto units in their account (Paragraph 48) The legal entity contact information required by paragraph 48 is considered confidential. This is in line with the data protection requirements of Regulation EUR2016/279 as amended by the Data Protection, Privacy and Electronic Communications (Amendments etc) (EU Exit) Regulations 2019; the Data Protection Act 2018; and Article 110 of EUR389/2013 as amended by the Greenhouse Gas Emissions (Kyoto Protocol Registry) Regulations 2021.

12.5 CALCULATION OF THE COMMITMENT PERIOD RESERVE CPR

15/CMP.1 Annex I.E paragraph 18 CPR Calculation	The Annex to Decision 11/CMP.1 (paragraph 6), and decision 1/CMP.8, paragraph 18, '*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***'. Therefore, the UK's commitment period reserve is calculated as: Either UK's Assigned Amount Units **x** 90% 2,744,937,332 **x** 0.90 = 2,470,443,559 Or 2020 Total Emissions* **x** Total years of the second commitment period 404,834,197 **x** 8 = 3,238,673,576

	*Emissions total is taken the 2022 submission, excluding KP LULUCF. Our rationale for using this figure is that the 2022 submission is the UK's most recently reviewed inventory submitted to fulfil reporting obligations under the Kyoto Protocol, and the final inventory to be compiled using the geographical scope of the Kyoto Protocol second commitment period. In addition, 2020 is the last year of the second commitment period of the Kyoto Protocol. The lower of the two numbers is that calculated as 90 per cent of the UK's assigned amount. The UK's Commitment Period Reserve is therefore 2,470,443,559 tonnes of CO_2 equivalent (or assigned amount units).

13 Information on Changes to the National System

13.1 CHANGES TO THE NATIONAL SYSTEM

As of the 7th February 2023, the Department for Business, Energy & Industrial Strategy (BEIS), which served as the UK's Single National Entity was restructured, and now the Department for Energy Security and Net Zero (DESNZ) has taken the role of the UK's Single National Entity. The teams within BEIS who implemented BEIS' obligations as the Single National Entity, and all contracts to BEIS relating to the UK's obligations for national GHG reporting have been transferred to DESNZ, and therefore there are no changes to the operational delivery of the UK National System beyond the department under which it is delivered.

14 Information on Changes to the National Registry

The following changes to the national registry of United Kingdom of Great Britain and Northern Ireland have occurred in 2022. Note that the 2022 SIAR confirms that any 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	The Party reports no change to the name or contact during this period.
15/CMP.1 annex II.E paragraph 32.(b) Change regarding cooperation arrangement	The Party reports no significant change to the cooperation arrangements. The UK Registry entered live service in January 2021. DESNZ is accountable for the UK Emissions Trading Scheme (UK ETS) and Kyoto Protocol (KP) on behalf of UK Government. DESNZ delivers Registry services via third-party delivery partners and provides governance in the form of legislation, policy and Authority-level operations (including public reports). Environment Agency (EA) is responsible for the day-to-day administration of the Registry, including KYC checks, helpdesk and scheme operations (including enforcement). Trasys-Unisystems – is responsible for technical matters including Registry service design, development, ongoing maintenance/support and delivery of live service*. Fordway – is responsible for the integration of service delivery, including issue handling, monitoring of service levels, change/release management, and service-level reporting. Responsibility for live Registry services was transferred from BEIS (DevOps) to Trasys-Unisystems in Q1 2022. All necessary readiness documentation requested by the UNFCCC was provided in order to successfully connect to the ITL. These documents submitted in 2021 include all supporting data that was required in order to satisfy the information needed when a significant change is made to the Registry. Since the registry has been operating, no significant changes have been performed during 2022 and all documentation provided in 2021 continues to be current and valid.
15/CMP.1 Annex II.E paragraph 32.(c) Change to database structure or the capacity of national registry	The Party reports there have been no changes to the database structure or capacity of the national registry in 2022.
15/CMP.1 Annex II.E paragraph 32.(d) Change regarding conformance to technical standards	The Party report there has been no change to the conformance to technical standards during 2022.
15/CMP.1 annex II.E paragraph 32.(e) Change to discrepancies procedures	The Party report there has been no change to discrepancies procedures.

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(f) Change regarding security	The Party reports no changes have been applied regarding security during 2022. Penetration test sessions have been performed as part of the annual foreseen security review process. These have revealed a series of issues of minor importance that have been prioritized for being looked at in 2023.
15/CMP.1 annex II.E paragraph 32.(g) Change to list of publicly available information	The Party reports no changes to its list of publicly available information. during the reporting period. In 2021, the UK implemented new Registry software to accommodate a new scheme (United Kingdom Emissions Trading Scheme) and the existing Kyoto Protocol National Registry. Therefore its publicly available information is now located at URL https://view-emissions-trading-registry.service.gov.uk/kp-reports/ The information continues to be subject to certain confidentiality clauses. This is in line with the data protection requirements of Regulation EUR2016/279 as amended by the Data Protection, Privacy and Electronic Communications (Amendments etc) (EU Exit) Regulations 2019; the Data Protection Act 2018; and Article 110 of EUR389/2013 as amended by the Greenhouse Gas Emissions (Kyoto Protocol Registry) Regulations 2021.
15/CMP.1 annex II.E paragraph 32.(h) Change of Internet address	The Party reports no change to the registry internet address during the reported period.
15/CMP.1 annex II.E paragraph 32.(i) Change regarding data integrity measures	The Party reports no change to the data integrity measures.
15/CMP.1 Annex II.E paragraph 32.(j) Change regarding test results	The Party reports no additional changes to its test during the reporting period. As part of the Party's reconnection to the ITL, all test results, plans and reports were submitted as part of its readiness documentation requirements provided in 2021.

15 Information on minimization of adverse impacts in accordance with Article 3, paragraph 14

All reporting of information required under Article 3, paragraph 14 for the purposes of the second commitment period of the Kyoto Protocol has now taken place. This information is available in the UK's 1990-2020 greenhouse gas inventory, published in 2022, which will be used to assess compliance with the UK's targets under the Doha Amendment. The 2022 NIR submission is available at https://unfccc.int/documents/461922.

The UK remains committed to action aimed at minimising the impacts from climate change, including any adverse impacts resulting from action taken to mitigate climate change. The UK's 8th National Communication provides a detailed overview of the UK's climate change impact and adaptation measures, financial assistance provided to developing countries to support emissions reductions, and the UK's activities in climate research and observations.

The UK's 8th National Communication is available at https://unfccc.int/documents/624711.

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.

17.1 CHAPTER 1 [INTRODUCTION]

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17.11 ANNEX 3, SECTOR 3

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Table 18.1 Contributors to this National Inventory Report and the CRF

Person	Technical work area and responsibility
Main authors	
Brown, Peter	Project Manager for the UK Greenhouse Gas Inventory with overall responsibility for the NIR and the CRF[96]. Lead Author. Author of the key category analysis annex. Reviewed F-gas sections. Contributions to many chapters.
Cardenas, Laura[97]	Sector expert for Agriculture; author of sections of the NIR and other reporting requirements on agriculture.
Del Vento, Sabino	Lead author of Chapter 7 and Annex 3.5
Karagianni, Eirini	Sector expert and NIR text author for road transport and off-road machinery.
MacCarthy, Joanna	NAEI Contract Manager, lead author of Chapter 1. Contributions to many chapters.
Mullen, Paddy	UK Greenhouse Gas Inventory Report Manager, contribution to many chapters.
Passant, Neil	Industry and combustion sector expert. Lead compiler and NIR author for Energy (stationary combustion), IPPU (except F-gases) and industry and waste incineration.
Richmond, Ben	Contributions to Annex 4 and Annex 10. Development of UK GHGI quality checking models.
Thistlethwaite, Glen	UK GHG Inventory Technical Director at Ricardo. Inventory compiler and QC of Agriculture sector.
Thomson, Amanda[98]	Sector expert for LULUCF and KP-LULUCF. Main author of LULUCF Chapters 6 and 11, Annex 3.4 and LULUCF sections in Chapters 1 and 2. Contributor to compilation of Sector 4.
Wakeling, Daniel	Transport sector lead compiler and NIR text author, including for: road transport, off-road machinery, shipping and fishing.
Willis, Daniel	Author of Annex 4 and the Trends chapter

[96] The UK greenhouse gas inventory is part of the UK National Atmospheric Emissions Inventory contract. The UK National Atmospheric Emissions Inventory is funded by the UK Department for Environment, Food & Rural Affairs and the Department for Business, Energy & Industrial Strategy and is contracted to a consortium led by Ricardo Energy & Environment.

[97] Rothamsted Research

[98] UK Centre for Ecology & Hydrology

Person	Technical work area and responsibility
Contributors	
Anthony, Steven[99]	Sector expert for Sheep and Grasslands and Senior Analyst for the Agriculture SMART inventory model. Author of sector text.
Aston, Clare	Data acquisition
Broomfield, Mark	Sector expert for solid waste disposal on land.
Buys, Gwen[98]	UKCEH project manager for the LULUCF inventory team. Data and QA/QC manager for LULUCF and KP-LULUCF sectors. Compilation of Sector 4 of the CRF.
Carnell, Ed[98]	Agriculture sector expert, including pre-processing of June Agricultural Census data, derivation of RFT dataset and high-definition mapping of Agriculture sector estimates.
Clilverd, Hannah[98]	LULUCF contributing author for Cpt 6 and Annex 3.4. Contributor to compilation of sector 4.
Dragosits, Ulli[98]	Agriculture sector expert, lead for pre-processing of June Agricultural Census data, derivation of RFT dataset and for high-definition mapping of Agriculture sector estimates.
Gibbs, Mark[100]	Compilation of rail emissions estimates and text for this sector.
Gilhespy, Sarah[97]	Inventory compilation for Dairy, Pig, Poultry, Other Livestock sectors. Contributions to agriculture sector NIR text.
Glendining, Margaret[97]	Contributions to agriculture inventory compilation and text
Gluckman, Ray[101]	Author of the section on f-gases in Cpt 4.
Gorji, Sam	Author of MS1, MS19, Source Categories 2A1, 2A2, 2A3, 2B2, 2B7, 2C2, and Annex 7
Hampshire, Kathryn[100]	QA/QC of OTs and CDs inventory compilation and NIR text update
Henshall, Paul[102]	CARBINE modelling for LULUCF inventory for 4A Forestry, 4G Harvested Wood Products and KP, contributions to text for sections in Cpt chapter 6, Cpt 11 and Annex 3.4.
Hobson, Melanie[100]	Compilation of rail emissions estimates and text for this sector
Kelsall, Alex	Author of MS2, MS18, Source Categories 2B6, 2C3, 2G2A, 2G2B, 2G2E, and Uncertainties Annex.
King, Katie[100]	QA/QC of OTs and CDs inventory compilation and NIR text update
Lambert, Neil	BEIS GHGI contract manager. NIR review and author of UK Government-focused text.
Levy, Peter[98]	Lead on the land-use change methodological improvement in LULUCF sector.
Malcolm, Heath98	Contribution to LULUCF QA/QC.
Manning, Alistair[103]	Verification of the UK greenhouse gas inventory (Annex 6)
Matthews, Robert[3]	CARBINE modelling for LULUCF inventory for 4A Forestry, 4G Harvested Wood Products and KP, contributions to text sections in Cpt chapter 6, Cpt 11 and Annex 3.4
Milne, Alice[97]	Agriculture sector uncertainties lead.

[99] ADAS Consulting https://adas.co.uk/

[100] Aether

[101] Gluckman Consulting

[102] Forest Research

[103] The Met Office

Person	Technical work area and responsibility
Misra, Anne	QA/QC support
Misselbrook, Tom[97]	UK Agriculture SMART inventory technical lead and project manager. Sector expert for Dairy, Pig, Poultry, Other Livestock. Contributions to agriculture inventory compilation and text.
Murrells, Tim	Technical Director of NAEI Programme. Transport sector manager.
Nickerson, Rachel[98]	Contributor to compilation of LULUCF sector 4.
O'Doherty, Simon[103]	Verification of the UK greenhouse gas inventory (Annex 6)
Pang, Yvonne	QA/QC support
Pearson, Ben	Database manager; compilation support.
Pitt, Joe[103]	Verification of the UK greenhouse gas inventory (Annex 6)
Quinn, Paul	Author of MS 4, Source Categories 2B1 and 2C1.
Raine, Beth[98]	Contributor to the land-use change methodological improvement for the LULUCF sector.
Redington, Alison[103]	Verification of the UK greenhouse gas inventory (Annex 6)
Sandars, Daniel[104]	Cattle Tracing System data lead analyst for the Agriculture SMART inventory and compiler for the Beef sector.
Skirvin, Dave[98]	Agriculture SMART inventory model developer and code author.
Stanley, Kieran[105]	Verification of the UK greenhouse gas inventory (Annex 6)
Stewart, Robert	Combustion expert.
Szanto, Courtney[100]	Responsible for compilation of emission estimates for the OTs and CDs, and updating the OTs and CDs Annex tables.
Thornton, Annie[100]	Compilation of rail emissions estimates and text for this sector.
Tomlinson, Sam[98]	Contributor to the land-use change methodological improvement for the LULUCF sector.
Walker, Charles	Sector expert for aviation in the NAEI and author of NIR aviation text. NAEI QAQC Manager.
Watterson, John	Review of LULUCF chapters and Annex. Contribution to chapter 10.
Williams, Adrian[104]	Sector expert for Beef and Arable sectors in the Agriculture SMART inventory model. Author of sector text.
Wong, Jason	Author of MS8
Young, Dickon[105]	Verification of the UK greenhouse gas inventory (Annex 6)
Young, Hannah[98]	Contributor to compilation of LULUCF sector 4.
Additional assistance	
Black, Ross	BEIS GHGI Statistics Lead
Blake Lynsay	Defra Head of Resources ad Waste Science
Brown, Kathryn	DNV QAQC technical lead
Bruintjes, Rick	Defra Agriculture sector lead, commissioning improvements for the 2022 submission.
Sam Bradley	BEIS LULUCF Lead
Durcan, Rose	BEIS LULUCF Lead
Esegbue, Onoriode	BEIS GHGI Science Lead
Forrest, Tom	BEIS GHGI, Head Science Team
Grainger, Mark	DNV QAQC project manager
Spadavecchia, Luke	Review of the Agriculture chapter and annex.

[104] Cranfield University

[105] University of Bristol

Person	Technical work area and responsibility
National Inventory Steering Committee	Review of the draft versions of the NIR; feedback on inventory improvements; scrutiny of GHGI updates.
Richardson, Joe	NAEI compilation, GIS expert.
Rose, Jake	BEIS GHGI statistician
Saxby, Jennifer	BEIS GHGI international reporting and verification
Scott, Kate	BEIS QAQC lead
Waite, Christopher	BEIS GHGI statistician

Table 18.2 Key Data Providers to the Greenhouse Gas Inventory

Organisation	Summary of Data Provided
DESNZ	Energy statistics (DUKES) including fuel activity, NCVs and GCVs; Oil and gas production; upstream oil and gas emissions (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.
OGA	Petroleum Production Reporting System data, including: oil and gas production per field, throughput per terminal; gas density and NCV per field or terminal. Wells Operations Notification System, wellbore database on number of wells drilled and their status (e.g. suspended, abandoned).
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, landfill gas flaring 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;
National Grid Gas	National Transmission System (NTS) operator, providing gas leakage and natural gas compositional data for the NTS.
Cadent Gas, Northern Gas Networks, Scotland Gas Networks, Southern Gas Networks, Wales & West Utilities.	Gas Distribution Network operators, each providing: Natural gas compositional analysis provided annually per Local Distribution Zone (LDZ); Gas leakage estimates from the UK distribution network per LDZ.
ISSB	Iron and steel production statistics, by technology; Iron and steel fuel use, by fuel, by source;
Tata Steel British 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	Facility emissions data by source, aligned to specific inventory reporting requirements for the chemicals and petrochemicals sectors.

Organisation	Summary of Data Provided
Kemira GrowHow SABIC Shell	