# UK Greenhouse Gas Inventory, 1990 to 2018

## Annual Report for Submission under the Framework Convention on Climate Change

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# Preface

This is the United Kingdom's National Inventory Report (NIR) submitted in 2020 to the United Nations Framework Convention on Climate Change (UNFCCC). It contains national greenhouse gas emission estimates for the period 1990-2018, and descriptions of the methods used to produce the estimates. The report is prepared in accordance with decision 24/CP.19[1] and includes elements required for reporting under the Kyoto Protocol, as outlined in the Annotated outline of the National Inventory Report including reporting elements under the Kyoto Protocol[2]. This submission constitutes the UK's submission under the Kyoto Protocol.

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

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

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

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[1] FCCC Decision 24/CP.19. Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention, 2014, available at: http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf

[2] Annotated outline of the National Inventory Report including reporting elements under the Kyoto Protocol, 2009, available at: http://unfccc.int/files/national_reports/annex_i_ghg_inventories/reporting_requirements/application/pdf/annotated_nir_outline .pdf

# Units and Conversions

Emissions of greenhouse gases presented in this report are normally given in 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 | $\mu$ |

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 |
| 1A1b | Petroleum refining |
| 1A1c | Manufacture of Solid Fuels and Other Energy Industries |
| **1A2** | **Manufacturing Industries and Construction** |
| 1A2a | Iron and Steel |
| 1A2b | Non-ferrous Metals |
| 1A2c | Chemicals |
| 1A2d | Pulp, Paper and Print |
| 1A2e | Food Processing, Beverages and Tobacco |
| 1A2f | Non-metallic minerals |
| 1A2gvii | Mobile combustion in manufacturing industries and construction |
| 1A2gviii | Stationary combustion in manufacturing and construction: Other |
| **1A3** | **Transport** |
| 1A3ai | International Aviation |
| 1A3aii | Civil Aviation |
| 1A3b | Road Transportation |
| 1A3c | Railways |
| 1A3di | International Navigation |
| 1A3dii | National Navigation |
| 1A3e | Other (to be specified) |
| **1A4** | **Other sectors** |
| 1A4a | Commercial / Institutional Combustion |
| 1A4b | Residential |
| 1A4c | Agriculture / Forestry / Fishing |
| **1A5** | **Other (not elsewhere specified)** |
| 1A5a | Other, Stationary (including Military) |

| IPCC Category | Source Description |
|---|---|
| 1A5b | Other, Mobile (including military) |
| **1B** | **Fugitive Emissions from Fuels** |
| **1B1** | **Fugitive Emissions from Solid Fuels** |
| 1B1a | Coal Mining and Handling |
| 1B1b | Solid fuel transformation |
| 1B1c | Other (to be specified) |
| **1B2** | **Oil and natural gas** |
| 1B2a | Oil |
| 1B2b | Natural gas |
| 1B2c | Venting and flaring |
| **2A** | **Mineral Products** |
| 2A1 | Cement Production |
| 2A2 | Lime Production |
| 2A3 | Glass Production |
| 2A4 | Other Process uses of Carbonates |
| **2B** | **Chemical Industry** |
| 2B1 | Ammonia Production |
| 2B2 | Nitric Acid Production |
| 2B3 | Adipic Acid Production |
| 2B4 | Caprolactam, Glyoxal and Glyoxylic Acid Production |
| 2B5 | Carbide production |
| 2B6 | Titanium Dioxide Production |
| 2B7 | Soda Ash Production |
| 2B8 | Petrochemical and Carbon Black Production |
| 2B9 | Fluorochemical Production |
| 2B10 | Other |
| **2C** | **Metal Production** |
| 2C1 | Iron and Steel production |
| 2C2 | Ferroalloys Production |
| 2C3 | Aluminium Production |
| 2C4 | Magnesium Production |
| 2C5 | Lead Production |
| 2C6 | Zinc Production |
| 2C7 | Other Metal Production |
| **2D** | **Non-energy Products from Fuels and Solvent Use** |
| 2D1 | Lubricant Use |
| 2D2 | Paraffin Wax Use |
| 2D3 | Other |
| **2E** | **Electronics Industry** |
| 2E1 | Integrated Circuit or Semiconductor |
| 2E2 | TFT Flat Panel Display |
| 2E3 | Photovoltaics |
| 2E4 | Heat Transfer Fluid |
| 2E5 | Other |
| **2F** | **Product Uses as Substitutes for ODS** |
| 2F1 | Refrigeration and Air Conditioning Equipment |
| 2F2 | Foam Blowing Agents |
| 2F3 | Fire Extinguishers |
| 2F4 | Aerosols |

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

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# Executive Summaries

## ES 1    BACKGROUND INFORMATION

### ES 1.1    Climate Change

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

The second commitment period of the Kyoto Protocol applies from 2013 to 2020 inclusive. For this second commitment period, the EU, 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 is based on the understanding that it will be fulfilled jointly by the European Union, the Member States and Iceland. The EU2020 target is unconditional and supported by EU legislation in place since 2009 (The EU Climate and Energy Package). This Kyoto target will cover the UK, and the relevant Crown Dependencies (CDs) and Overseas Territories (OTs) for whom the ratification is extended.

The Climate Change Act[3] became UK Law on the 26th November 2008. This legislation introduced a new, more ambitious, and legally binding target for the UK to reduce GHG emissions to 80% below base year by 2050, with legally binding five-year GHG budgets. The independent Committee on Climate Change (CCC) was set up to advise the UK Government on the setting and meeting of UK carbon budgets, as well as monitoring progress against them. In June 2019, the UK government furthered this ambition by setting a legally binding target[4] to achieve net zero greenhouse gas emissions across the UK economy by 2050. The UK is the first major economy in the world to legislate for a net zero target.

Further information on the UK's action to tackle climate change can be found on the Department for Business, Energy, and Industrial Strategy's website[5]. Information towards climate adaptation can be found on the UK Government's topic page[6].

### 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).

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

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

[5] Department for Business, Energy & Industrial Strategy. https://www.gov.uk/government/organisations/department-for-business-energy-and-industrial-strategy

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

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This is the United Kingdom's National Inventory Report (NIR) submitted in 2020 to the UNFCCC and covering both the UK's submission under the Kyoto Protocol and the Convention. It contains national greenhouse gas emission estimates for the period 1990-2018, and the descriptions of the methods used to produce the estimates. The report is prepared in accordance with decision 24/CP.19[7] and includes elements required for reporting under the Kyoto Protocol.

The UK Greenhouse Gas Inventory is compiled and maintained by a consortium led by Ricardo Energy & Environment – the **Inventory Agency** – under contract to the UK Department for Business, Energy, and Industrial Strategy (BEIS). Ricardo Energy & Environment is directly responsible for producing the emissions estimates for CRF categories Energy (CRF sector 1), Industrial Processes and Product Use (CRF Sector 2), and Waste (CRF Sector 5). Ricardo Energy & Environment is also responsible for inventory planning, data collection, QA/QC and inventory management and archiving. Aether, a member within the consortium, is responsible for compiling emissions from railways and for the UK's Overseas Territories (OTs) and Crown Dependencies (CDs). 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 Rothamsted Research, under contract to the UK Department for Environment, Food and Rural Affairs (Defra).

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

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

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

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

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

Emissions of indirect $N_2O$ from emissions of $NO_x$ and $NH_3$ are 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

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[7]  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

including all relevant Overseas Territories and Crown Dependencies, consistent with the UK's submission to the UNFCCC.

The UK inventory provides data to assess progress of the UK's commitments under the Kyoto Protocol, the UK's contribution to the EU's targets under the KP, progress towards the UK Government's own Carbon Budgets and to meet commitments as a Party to the UN Framework Convention on Climate Change. Geographical coverage for these four purposes differs to some extent, because of the following:

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

Emissions data for the first geographical coverage (Coverage 1) are reported here for information and to facilitate comparison between different publications. Coverage 2 is used for the data in the CRF tables submitted to the UNFCCC under the Kyoto Protocol. These tables also form part of the UK's submission under the MMR. Coverage 3 is used for the data in the CRF tables submitted under the MMR only. Coverage 4 is used for the data in the CRF tables submitted to the UNFCCC under the Convention. **Table ES 1 to Table ES 2** show $CO_2$ and the direct greenhouse gases, disaggregated by gas and by sector for geographical Coverage 4. **Table ES 4** and **Table ES 5** show emissions for the Kyoto basket based on Coverage 2 and 3, respectively.

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

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

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

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

## ES 2.1 GHG Inventory

**Table ES 1** **Emissions of GHGs in terms of carbon dioxide equivalent emissions including all estimated GHG emissions from the Crown Dependencies and relevant Overseas Territories, 1990-2018. (Mt CO$_2$ Equivalent)**

| | Mt CO$_2$ Equivalent | | | | | | | | | | % change |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 | 2015 | 2016 | 2017 | 2018 | 1990 - 2018 |
| CO$_2$ (Inc. net LULUCF) | 598.9 | 563.0 | 562.0 | 561.7 | 502.2 | 428.7 | 411.9 | 388.6 | 377.4 | 369.2 | -38% |
| CO$_2$ (Exc. net LULUCF) | 601.2 | 567.5 | 568.2 | 570.7 | 512.9 | 439.8 | 423.2 | 399.8 | 388.8 | 380.8 | -37% |
| CH$_4$ (Inc. net LULUCF) | 133.1 | 126.6 | 109.1 | 87.4 | 64.3 | 54.0 | 53.1 | 51.6 | 52.0 | 52.0 | -61% |
| CH$_4$ (Exc. net LULUCF) | 133.1 | 126.5 | 109.0 | 87.4 | 64.2 | 53.9 | 53.1 | 51.5 | 52.0 | 51.9 | -61% |
| N$_2$O (Inc. net LULUCF) | 48.7 | 39.0 | 29.0 | 24.8 | 21.7 | 21.2 | 20.7 | 20.6 | 20.9 | 20.8 | -57% |
| N$_2$O (Exc. net LULUCF) | 46.2 | 36.7 | 26.7 | 22.7 | 19.9 | 19.5 | 19.0 | 18.9 | 19.3 | 19.2 | -58% |
| HFCs | 14.4 | 19.1 | 9.9 | 13.1 | 16.5 | 16.0 | 16.0 | 15.2 | 14.2 | 13.1 | -9% |
| PFCs | 1.7 | 0.6 | 0.6 | 0.4 | 0.3 | 0.3 | 0.3 | 0.4 | 0.5 | 0.3 | -84% |
| SF$_6$ | 1.3 | 1.3 | 1.9 | 1.1 | 0.7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | -58% |
| NF$_3$ | 0.0004 | 0.0008 | 0.0017 | 0.0003 | 0.0003 | 0.0004 | 0.0004 | 0.0005 | 0.0005 | 0.0006 | 41% |
| Total (Inc. net LULUCF) | 797.9 | 749.6 | 712.4 | 688.5 | 605.6 | 520.6 | 502.5 | 476.8 | 465.5 | 456.0 | -43% |
| Total (Exc. net LULUCF) | 797.8 | 751.7 | 716.3 | 695.4 | 614.5 | 530.0 | 512.1 | 486.4 | 475.3 | 465.9 | -42% |

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 81% to total net emissions in 2018. Methane emissions account for the next largest share (11%), and $N_2O$ emissions make up a further 5%. Emissions of all these gases have decreased since 1990, contributing to an overall decrease of 43%.

## ES 2.2   KP-LULUCF Activities

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

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

**Table ES 2** details the emissions and removals from these activities which are included in the UK's emissions total for reporting under the KP.

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**Table ES 2 KP- LULUCF activities (Mt CO$_2$e) under GBK submission**

| | Base Year | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Article 3.3 | 0.4 | 0.4 | 0.5 | 0.6 | 0.7 | 0.7 | 0.8 | 0.9 | 0.9 | 1 | 1 | 1.6 | 1.7 | 1.7 | 1.9 | 1.7 | 1.8 | 1.3 | 1.7 | 1.4 | 1.3 | 1.3 | 0.9 | 0.7 | 0.4 | 0.1 | -0.3 | -0.2 | -0.8 | -1.1 |
| Article 3.7 | 0.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Article 3.4 FMRL | | | | | | | | | | | | | | | | | | | | | | | | | -8.3 | -8.3 | -8.3 | -8.3 | -8.3 | -8.3 |
| Article 3.4 Technical Correction to FMRL | | | | | | | | | | | | | | | | | | | | | | | | | -9.7 | -9.7 | -9.7 | -9.7 | -9.7 | -9.7 |
| Article 3.4 Forest Management removals compared to FMRL and Technical Correction (capped) | | | | | | | | | | | | | | | | | | | | | | | | | -1.4 | -1 | -0.6 | -0.3 | 0.2 | |
| Article 3.4 Cropland Management | 14.8 | 14.8 | 14.9 | 14.9 | 15.1 | 15.2 | 15.5 | 15.5 | 15.5 | 15.6 | 15.8 | 15.7 | 15.4 | 15.1 | 14.8 | 14.6 | 14.4 | 14.2 | 13.9 | 13.8 | 13.8 | 13.6 | 13.4 | 13.3 | 13.1 | 12.9 | 12.9 | 12.7 | 12.7 | 12.5 |
| Article 3.4 Grazing Land Management | -6.6 | -6.6 | -6.4 | -6.2 | -6.1 | -6 | -5.9 | -5.8 | -5.7 | -5.6 | -4.8 | -4.8 | -4.8 | -4.8 | -4.8 | -4.9 | -5 | -5 | -5.1 | -5.1 | -5.2 | -5.3 | -5.3 | -5.3 | -5.5 | -5.5 | -5.6 | -5.6 | -5.7 | -5.8 |

| | Base Year | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Article 3.4 Wetland Drainage and Rewetting | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | | |

*Not yet reported (data and methodology under development)

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

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

## ES 3.1 GHG Inventory

**Table ES 3** details total net emissions of GHGs, aggregated by IPCC sector.

**Table ES 3** **Aggregated emission trends per source category, including all estimated GHG emissions from the Crown Dependencies and selected relevant Overseas Territories (Mt CO$_2$ equivalent)**

| Source Category | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Energy | 614.9 | 572.8 | 565.9 | 562.4 | 507.7 | 432.2 | 416.0 | 393.8 | 382.4 | 375.3 |
| 2. Industrial Processes and Product Use | 66.8 | 61.2 | 40.9 | 40.0 | 35.8 | 34.4 | 33.9 | 31.0 | 30.6 | 28.5 |
| 3. Agriculture | 49.2 | 48.0 | 46.0 | 43.6 | 40.9 | 41.8 | 41.2 | 41.2 | 41.6 | 41.2 |
| 4. LULUCF | 0.1 | -2.1 | -3.9 | -7.0 | -8.9 | -9.4 | -9.6 | -9.6 | -9.8 | -10.0 |
| 5. Waste | 67.0 | 69.7 | 63.4 | 49.4 | 30.0 | 21.5 | 21.0 | 20.4 | 20.7 | 21.0 |
| **Total (net emissions)** | 797.9 | 749.6 | 712.4 | 688.5 | 605.6 | 520.6 | 502.5 | 476.8 | 465.5 | 456.0 |

**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

Total net emissions have decreased by 43% since 1990.

The largest contribution to greenhouse gas emissions is from the energy sector. In 2018 this contributed 82% to the total net emissions. Emissions of CO$_2$, CH$_4$ and N$_2$O 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 39%.

The second largest source of greenhouse gases is the agricultural sector, contributing 9% in 2018. Emissions from this sector are mostly CH$_4$ and N$_2$O, contributing 62% and 35% respectively. Only a small amount of CO$_2$ is emitted in comparison. Since 1990, emissions from this sector have declined by 16%.

Industrial processes and product use make up the third largest sector for greenhouse gas emissions in the UK, contributing 6% to the national total in 2018. Emissions of all seven direct greenhouse gases occur from this sector. Since 1990, emissions from this sector have declined by 57%.

Land-Use, Land-Use Change, and Forestry contains sinks as well as sources of CO$_2$ emissions. LULUCF was a net sink in 2018. Emissions from this sector occur for CO$_2$, N$_2$O and CH$_4$.

The remaining sector that contributes to direct greenhouse gas totals is waste. In 2018 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 92% of all emissions. Emissions from this sector have declined and in 2018 were 69% below 1990 levels.

## ES 3.2    KP Basket and KP-LULUCF Activities

**Table ES 4** presents final UK emissions for the first KP commitment period. The fixed base year figure is taken from the 1990 – 2004 inventory and is the total used to calculate the UK's Assigned Amount. The 2008 – 2012 figures are the final, reviewed figures for the UK inventory submitted in 2014. This was re-submitted following the UNFCCC review in September 2014; therefore, the figures differ from the NIR submitted in April 2014. **Table ES 5** presents the same information as Table ES 4 using MMR geographical coverage.

**Table ES 6** presents the base year, and 2013 to 2018 emissions calculated from the 2020 inventory submission. KP LULUCF activities are defined differently under the second commitment period – Article 3.3 now includes Harvested Wood Products (HWP), and Article 3.4 (Forest Management) now reports emissions relative to the Forest Management Reference Level (FMRL). The FMRL does not apply prior to 2013, and therefore it is not appropriate to report a full time series.

The data in this table are all taken from the 2020 inventory submission (1990 – 2018).

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

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

**Table ES 4        Kyoto basket of emissions, and emissions associated with Articles 3.3, 3.4 and 3.7 for the first commitment period (in Mt $CO_2$ equivalent) – KP1 Coverage.**

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

| | Fixed base year | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|
| Article 3.7 | | | | | | |
| **Kyoto Protocol Total** | 779.9 | 648.9 | 594.3 | 610.3 | 566.2 | 583.1 |

**Footnotes:**

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

**Table ES 5     Kyoto basket of emissions, and emissions associated with Articles 3.3, 3.4 and 3.7 for the first commitment period (in Mt $CO_2$ equivalent) – MMR Coverage.**

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

**Footnotes:**

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

**Table ES 6     Kyoto basket of emissions, and emissions associated with Articles 3.3, 3.4 and 3.7 for the second commitment period (in Mt $CO_2$ equivalent) - KP2 coverage**

| | Base year | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Base Year - 2018 |
|---|---|---|---|---|---|---|---|---|
| $CO_2$ | 600.5 | 477.9 | 439.1 | 422.5 | 399.1 | 388.1 | 380.1 | -37% |
| $CH_4$ | 133.0 | 56.0 | 53.9 | 53.1 | 51.5 | 51.9 | 51.9 | -61% |
| $N_2O$ | 46.2 | 18.9 | 19.5 | 19.0 | 18.9 | 19.3 | 19.2 | -58% |
| HFCs | 19.1 | 15.8 | 16.0 | 16.0 | 15.2 | 14.2 | 13.1 | -31% |
| PFCs | 0.6 | 0.32 | 0.3 | 0.3 | 0.4 | 0.5 | 0.3 | -57% |
| $SF_6$ | 1.3 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | -58% |
| $NF_3$ | 0.0008 | 0.0004 | 0.0004 | 0.0004 | 0.0005 | 0.0005 | 0.0006 | -30% |

| | Base year | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Base Year - 2018 |
|---|---|---|---|---|---|---|---|---|
| **Grand Total** | 800.7 | 569.4 | 529.2 | 511.3 | 485.6 | 474.5 | 465.2 | -42% |
| Article 3.3 | | 0.3 | 0.0 | -0.4 | -0.3 | -0.9 | -1.2 | |
| Article 3.4 Forest Management removals and HWP compared to FMRL and Technical Correction to FMRL (capped) | | -1.9 | -1.2 | -0.9 | -0.5 | 0.0 | 0.4 | |
| Article 3.4 Cropland Management | | 13.1 | 12.9 | 12.9 | 12.7 | 12.7 | 12.5 | |
| Article 3.4 Grazing Land Management | | -5.5 | -5.5 | -5.6 | -5.6 | -5.7 | -5.8 | |
| Article 3.7 | 0.3 | | | | | | | |
| **Kyoto Protocol Total** | 800.7 | 575.5 | 535.5 | 517.4 | 491.9 | 480.6 | 471.2 | -41% |

**Footnotes:**

- The data in this table are all taken from the 2020 inventory submission (1990 – 2018).
- The base year emissions are made up of 1990 emissions for $CO_2$, $CH_4$ and $N_2O$, and 1995 for the F-Gases
- Emissions are presented as Mt $CO_2$ equivalent, using GWP values taken from the IPCC's Fourth Assessment Report (AR4).
- Emissions and removals associated with KP-LULUCF enter the table only through the rows labelled Article 3.3, Article 3.4, and Article 3.7. The definitions of Article 3.3 and 3.4 have changed from the first commitment period and so the time series is not comparable.
- Geographical coverage of this table includes the Crown Dependencies Jersey, Guernsey and the Isle of Man, and the Overseas Territories which are included in the scope for the second commitment period of the Kyoto Protocol. These are the Cayman Islands, Falkland Islands, and Gibraltar.

**Table ES 7    Kyoto basket of emissions, and emissions associated with Articles 3.3, 3.4 and 3.7 for the second commitment period (in Mt CO$_2$ equivalent) – MMR Coverage**

| | Base year | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Base Year - 2018 |
|---|---|---|---|---|---|---|---|---|
| $CO_2$ | 598.4 | 475.5 | 436.6 | 420.1 | 396.8 | 385.7 | 377.7 | -37% |
| $CH_4$ | 132.5 | 55.6 | 53.5 | 52.7 | 51.1 | 51.5 | 51.5 | -61% |
| $N_2O$ | 46.0 | 18.7 | 19.3 | 18.8 | 18.8 | 19.1 | 19.0 | -58% |
| HFCs | 19.1 | 15.7 | 15.9 | 15.9 | 15.1 | 14.1 | 13.0 | -26% |
| PFCs | 0.6 | 0.3 | 0.3 | 0.3 | 0.4 | 0.5 | 0.3 | -17% |
| $SF_6$ | 1.3 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | -61% |
| $NF_3$ | 0.0008 | 0.0004 | 0.0004 | 0.0004 | 0.0005 | 0.0005 | 0.0006 | -36% |
| **Grand Total** | 797.9 | 566.3 | 526.1 | 508.3 | 482.7 | 471.5 | 462.1 | -41% |
| Article 3.3 | | 0.1 | 0.0 | -0.4 | -0.3 | -0.9 | -1.2 | |
| Article 3.4 Forest Management removals and HWP compared to FMRL and Technical Correction to FMRL (capped) | | -1.9 | -1.2 | -0.8 | -0.5 | 0.0 | 0.5 | |

| | Base year | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Base Year - 2018 |
|---|---|---|---|---|---|---|---|---|
| Article 3.4 Cropland Management | | 13.1 | 12.9 | 12.8 | 12.7 | 12.6 | 12.5 | |
| Article 3.4 Grazing Land Management | | -5.7 | -5.7 | -5.8 | -5.9 | -5.9 | -6.0 | |
| Article 3.7 | 0.2 | | | | | | | |
| **Kyoto Protocol Total** | 798.1 | 572.0 | 532.1 | 514.1 | 488.7 | 477.3 | 467.9 | -40% |

**Footnotes:**

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

# ES 4    OTHER INFORMATION

**Table ES 8** lists the indirect greenhouse gases for which the UK has made emissions estimates. Nitrogen oxides, carbon monoxide and NMVOCs are included in the inventory because they can result in an increase in tropospheric ozone concentration, increasing radiative forcing. Sulphur oxides are included because they contribute to aerosol formation.

**Table ES 8**        **Emissions of Indirect Greenhouse Gases in the UK, 1990-2018 (in kt).**

| Gas | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| $NO_x$ | 3087 | 2535 | 1980 | 1743 | 1236 | 1044 | 1008 | 908 | 882 | 834 |
| CO | 7377 | 6136 | 4214 | 3060 | 2050 | 1768 | 1700 | 1584 | 1560 | 1556 |
| NMVOC | 2830 | 2236 | 1589 | 1160 | 867 | 799 | 798 | 784 | 793 | 806 |
| $SO_2$ | 3783 | 2469 | 1299 | 780 | 454 | 325 | 255 | 182 | 178 | 163 |

**Footnotes:**

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

Since 1990, emissions of all indirect gases have decreased. The largest source of emissions for all the indirect gases is the energy sector. For $NO_x$, CO and $SO_2$, over 80% of emissions arise from activities within this sector. For NMVOC, 53% of emissions are from the industrial processes and product use sector, with other significant contributions from the energy sector.

# Contacts

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

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# 1    Introduction

This is the UK's 2020 National Inventory Report (NIR). From 2008 onwards, the NIR contains information required for reporting under the Kyoto Protocol as set out in decision 15/CMP.1[8].

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 15th April of each year. The NIR is compiled in accordance with the revised UNFCCC reporting guidelines, see decision 24/CP.19[9].

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

The UK is a signatory to the Convention and is also a Party to the Kyoto Protocol. This means the UK must report supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol[10], with the inventory submission due under the Convention, in accordance with paragraph 3(a) of decision 15/CMP.1. This NIR contains this supplementary information in the appropriate sections.

## 1.1    BACKGROUND INFORMATION ON GREENHOUSE GAS INVENTORIES, AND CLIMATE CHANGE

### 1.1.1    Background Information on Climate Change

Countries that have signed and ratified the Kyoto Protocol are legally bound to reduce their 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) runs for eight years, from 2013 to 2020 inclusive. For this second commitment period, alongside the EU and its member States, the UK (including Gibraltar) communicated an independent quantified economy-wide emission reduction target of a 20% 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 covers the UK, and the relevant Crown Dependencies and Overseas Territories to whom ratification has

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[8]  15/CMP.1 Guidelines for the preparation of the information required under Article 7 of the Kyoto Protocol.
http://unfccc.int/resource/docs/2005/cmp1/eng/08a02.pdf#page=54

[9] 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

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

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

The Climate Change Act[11] became UK Law on the 26th November 2008. This legislation introduced a new, more ambitious, and legally binding target for the UK to reduce GHG emissions to 80% below base year by 2050, with legally binding five-year GHG budgets. The independent Committee on Climate Change (CCC) was set up to advise the UK Government on 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. The UK is the first major economy in the world to legislate for a net-zero target.

Further information on the UK's action to tackle climate change can be found on the Department for Business, Energy, and Industrial Strategy's website[12]. Information towards climate adaptation can be found on the UK Government's topic page[13].

## 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] and includes elements required for reporting under the Kyoto Protocol, as outlined in the Annotated outline of the National Inventory Report including reporting elements under the Kyoto Protocol[15]. In addition, the UK also reports GHG emissions by sources and removals by sinks in the CRF tables. The estimates are consistent with the IPCC 2006 Guidelines.

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

This report and corresponding CRF tables provide annual emission estimates submitted by the UK to the UNFCCC for the period 1990 to 2018. To fulfil both European Union Monitoring Mechanism Regulation (MMR)[16] and UNFCCC reporting requirements the UK prepares three sets of CRF tables and officially reports all sets. These three sets of tables present emission estimates for different geographical coverages:

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

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11Climate Change Act 2008.
http://www.legislation.gov.uk/ukpga/2008/27/contents

12 Department for Business, Energy & Industrial Strategy, available at:
https://www.gov.uk/government/organisations/department-for-business-energy-and-industrial-strategy

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

15Annotated NIR outline, UNFCC, available at:
http://unfccc.int/files/national_reports/annex_i_ghg_inventories/reporting_requirements/application/pdf/annotated_nir_outline.pdf

16REGULATION (EU) No 525/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC
http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0525&from=EN

2. **Kyoto Protocol CRF** (the 'GBK' submission)**:** Includes UK, Crown Dependencies (Jersey, Guernsey, Isle of Man) and the Overseas Territories (Cayman Islands, Falkland Islands, Gibraltar only). Other Overseas Territories have not signed up to the Kyoto Protocol. Reporting under the first commitment period also included Bermuda under this scope.

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

The main section of this report presents GHG emissions for the years 1990-2018, 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[17] and are uploaded as part of the UK's official submission.

The CRF consists of a series of detailed spreadsheets, with one set for each year. A copy of the CRF for each reported geographical coverage accompanies this report, available on the NAEI website[17].

### 1.1.2.2   Geographical coverage of UK emissions

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

A major source of activity data (AD) for the UK inventory is provided by BEIS through the publication of the Digest of UK Energy Statistics (DUKES) (see **Table 1.6**). The geographical coverage of DUKES is the United Kingdom (BEIS, 2019). Shipments to the Channel Islands and the Isle of Man from the United Kingdom are not classed as exports and supplies of solid fuel and petroleum to these islands are therefore included as part of the United Kingdom inland consumption or deliveries.

The definition of the UK used by BEIS accords with that of the "economic territory of the United Kingdom" used by the UK Office for National Statistics (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. The Crown Dependencies are not members of the European Union.

- **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 Kyoto Protocol and are not included in the NIR. Overseas Territories are constitutionally not part of the

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

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, Her Majesty the Queen, 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 or with BEIS. These data are used to supplement UK national statistics (such as DUKES) to compile and report a complete inventory for all territories.

### 1.1.2.3  Greenhouse Gases Reported in the UK Inventory

The greenhouse gases reported are:

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

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 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 according to the Fourth Assessment Report (IPCC, 2007). These are the GWP values required by FCCC/CP/2013/10/Add.3. 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 | $CH_4$ | 25 |
| Nitrous oxide | $N_2O$ | 298 |
| Sulphur hexafluoride | $SF_6$ | 22,800 |
| Nitrogen trifluoride | $NF_3$ | 17,200 |
| Hydrofluorocarbons | | |
| HFC-23 | $CHF_3$ | 14,800 |
| HFC-32 | $CH_2F_2$ | 675 |
| HFC-41 | $CH_3F$ | 92 |
| HFC-43-10mee | $CF_3CHFCHFCF_2CF_3$ | 1,640 |
| HFC-125 | $C_2HF_5$ | 3,500 |
| HFC-134 | $C_2H_2F_4$ | 1,100 |
| HFC-134a | $C_2H_2F_4$ | 1,430 |
| HFC-143 | $C_2H_3F_3$ | 353 |
| HFC-143a | $C_2H_3F_3$ | 4,470 |
| HFC-152 | $CH_2FCH_2F$ | 53 |
| HFC-152a | $C_2H_4F_2$ | 124 |
| HFC-161 | $CH_3CH_2F$ | 12 |
| HFC-227ea | $C_3HF_7$ | 3,220 |
| HFC-236cb | $CH_2FCF_2CF_3$ | 1,340 |
| HFC-236ea | $CHF_2CHFCF_3$ | 1,370 |
| HFC-236fa | $C_3H_2F_6$ | 9,810 |
| HFC-245ca | $C_3H_3F_5$ | 693 |
| HFC-245fa | $CHF_2CH_2CF_3$ | 1030 |
| HFC-365mfc | $CH_3CF_2CH_2CF_3$ | 794 |
| Perfluorocarbons | | |
| Perfluoromethane | PFC-14 -$CF_4$ | 7,390 |
| Perfluoroethane | PFC-116 - $C_2F_6$ | 12,200 |
| Perfluoropropane | PFC-218 - $C_3F_8$ | 8,830 |
| Perfluorobutane | PFC-3-1-10 - $C_4F_{10}$ | 8,860 |
| Perfluorocyclobutane | PFC-318 - c-$C_4F_8$ | 10,300 |
| Perfluouropentane | PFC-4-1-12 - $C_5F_{12}$ | 9,160 |
| Perfluorohexane | PFC-5-1-14 - $C_6F_{14}$ | 9,300 |
| Perfluorodecalin | PFC-9-1-18b - $C_{10}F_{18}$ | >7,500 |
| Perfluorocyclopropanec | c-$C_3F_6$ | >17,340 |

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

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

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

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

| Reporting element | Background information |
|---|---|
| Supplementary inventory information for activities under Article 3, Paragraphs 3 and 4 | The reporting of KP-LULUCF is carried out by the UK Centre for Ecology and Hydrology (UKCEH) on behalf of BEIS. The UK has chosen to elect Forest Management, Cropland Management, Grazing Land Management and Wetland Drainage and Rewetting as activities under Article 3.4. The calculations follow the same method and use the same models as the UNFCCC estimates for LULUCF, which are also prepared by UKCEH. Further information can be found in **Chapter 11**. |
| Information on Kyoto Protocol units | The UK National Registry is operated and maintained by the Environment Agency on behalf of BEIS. Information on accounting of Kyoto Protocol units, including a summary of information reported in the standard electronic format (SEF) tables is provided in **Chapter 12**. SEF tables are reported alongside this report. |
| Changes in National Systems | The UK National System is managed and maintained by BEIS, who is the Single National Entity. Changes to the National System are reported in **Chapter 13** of this report. |
| Changes in National Registry | The UK National Registry is operated and maintained by the Environment Agency on behalf of BEIS. The National Registry is represented on the National Inventory Steering Committee. All changes in the National Registry are reported in **Chapter 14**. |
| Minimisation of adverse impacts in accordance with Article 3, Paragraph 14 | The UK has undertaken several assessments, reviews, and analysis projects to better understand the impacts its policies could have on developing countries, and how they could be addressed. We have supported many initiatives to advance knowledge transfer, research collaboration and capacity building. Further details on the UK's efforts to minimise adverse impacts is provided in **Chapter 15**. |

## 1.2    INSTITUTIONAL    ARRANGEMENTS    FOR    INVENTORY PREPARATION

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

The UK greenhouse gas inventory is compiled and maintained by a consortium led by Ricardo Energy & Environment – the **Inventory Agency** - under contract to the SICE Directorate in BEIS. Ricardo Energy & Environment is responsible for producing the emissions estimates for CRF categories Energy (CRF sector 1), Industrial Processes and Product Use (CRF sector 2), and Waste (CRF sector 5). Land-Use, Land-Use Change and Forestry emissions (CRF sector 4) are calculated by the UK Centre for Ecology and Hydrology (UKCEH) with the support of Forest Research. The KP-LULUCF information is also produced by UKCEH with the support of Forest Research. The mechanism for generating the KP-LULUCF data and the quality control and assurance procedures applied are an integral part of the UK's National System. Ricardo Energy & Environment is also responsible for inventory planning, data collection, QA/QC and inventory management and archiving.

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

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

The Marrakesh Accords of the KP (Decision 20/CP.7[18]) define the requirements for National Inventory Systems (NIS), including the need to establish legal, procedural and institutional arrangements to ensure that all parties to the Protocol estimate and report their GHG emissions in accordance with relevant decisions of the Conference of the Parties (COP), facilitate UNFCCC Reviews and improve the quality of their inventories. Under related EU legislation set out in Decision 280/2004/EC[19] the UK was required to have in place its NIS by 31st December 2005. **Figure 1.1** summarises the key organisational structure of the UK NIS and **Section 1.2.2** includes further detailed information on the roles and responsibilities of each of the key organisations.

**Figure 1.1        Key organisational structure of the UK National Inventory System**
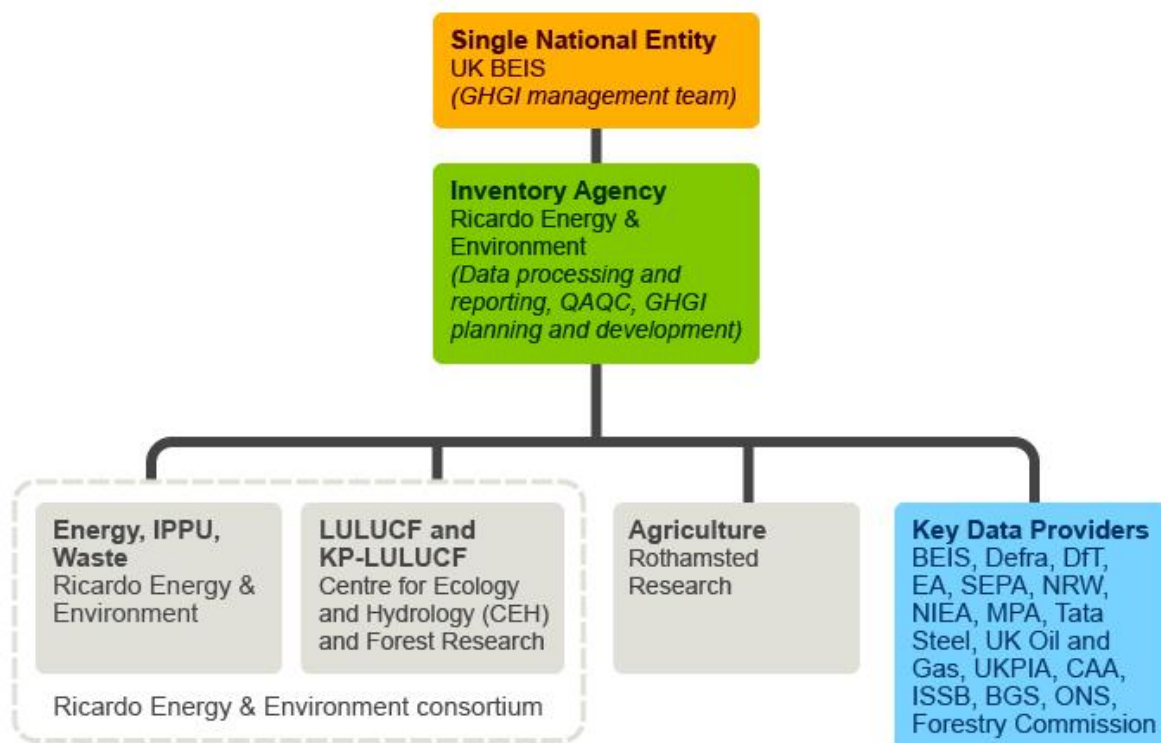


**Figure 1.2** shows the main elements of the UK National Inventory System, including provision of data to the European Union under the terms of the Monitoring Mechanism Regulation. BEIS is the Single National Entity responsible for submitting the UK's GHGI to the UNFCCC. The Inventory Agency compiles the GHGI on behalf of BEIS and produces disaggregated estimates for the DAs within the UK.

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[18]    20/CP.7 Guidelines for national systems under Article 5, paragraph 1, of the Kyoto Protocol
http://unfccc.int/resource/docs/cop7/13a03.pdf

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

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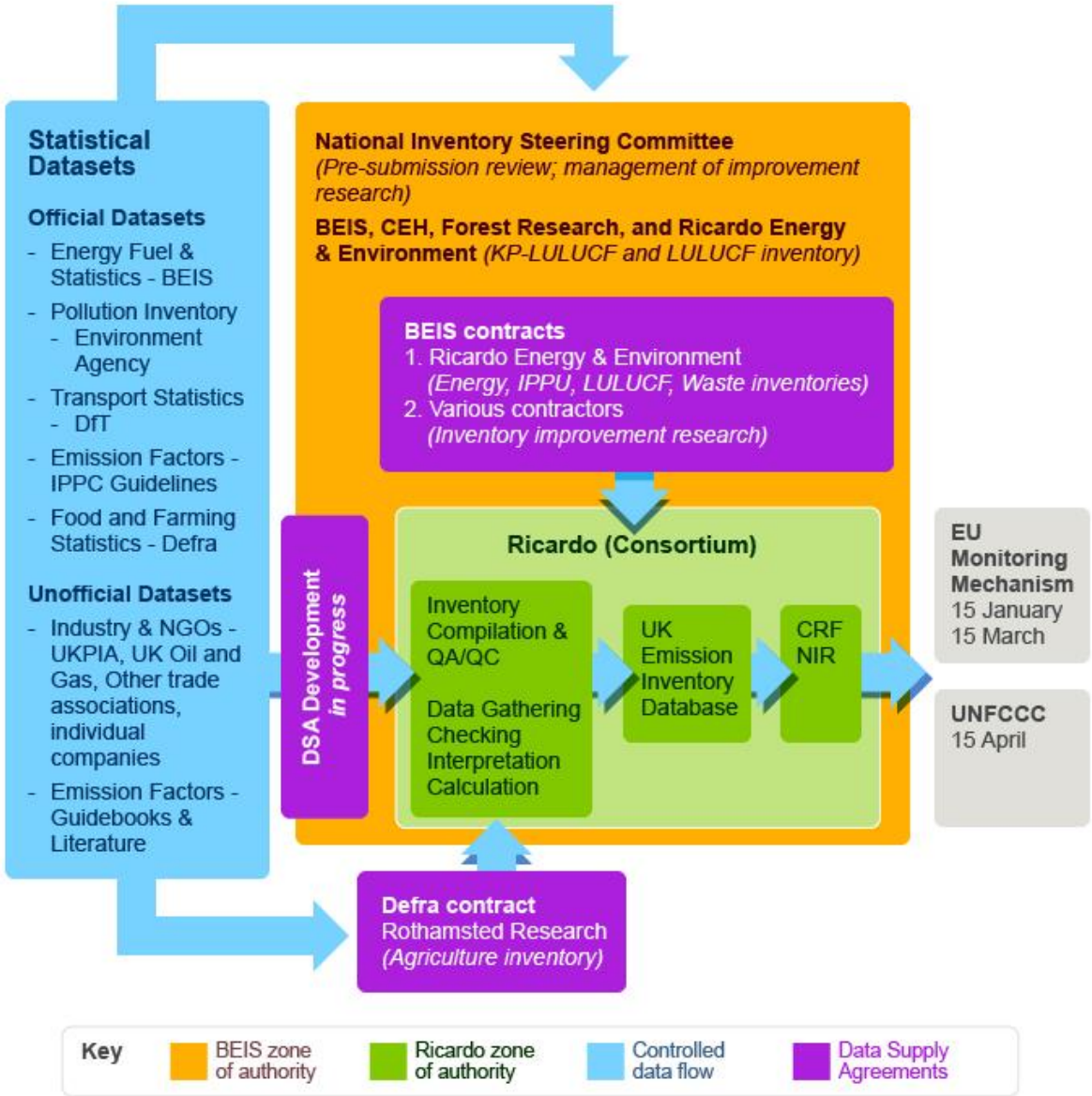


There has been one minor change to the UK's National Inventory System. The UK Centre for Ecology and Hydrology is now an independent entity and no longer forms part of the National Environmental Research Council. The team, and sub-contractor relationship with the Inventory Agency remains the same.

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

**1.2.1.2 Legal Framework**

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

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

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

To meet the standards required under the KP, the UK introduced new legislation specifically for national inventory purposes which took effect from November 2005[20]. This legislation makes provision for BEIS's Secretary of State to issue a notice in the event that information required for the inventory that has been sought voluntarily is not provided. The UK values voluntary participation and this legislation is intended as a last resort once all other avenues to elicit the required data, in the format and to the timing specified, have failed. This legislation was updated in 2014 (The Greenhouse Gas Emissions Trading Scheme (Amendment) Regulations 2014[21]). To ensure that the system works most effectively and to minimise the need for legislative action, BEIS is establishing data supply agreements (DSAs) with relevant organisations to build upon existing relationships with data supply organisations. These agreements formalise the acquisition of data and clarify the main requirements of quality, format, security, and timely delivery of data for the national inventory. This process is on-going, through the NISC which is a forum of inventory stakeholders that BEIS chairs (see **Section 1.2.2.4** below).

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

## 1.2.2 Overview of Inventory Planning

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

**1.2.2.1 Single National Entity – BEIS**

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

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

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

[21] The Greenhouse Gas Emissions Trading Scheme (Amendment) and National Emissions Inventory (Amendment) Regulations 2014, available at: http://www.legislation.gov.uk/uksi/2014/3075/contents/made

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

- **National Inventory System management and planning**
  - Overall control of the NIS development and function;
  - Management of contracts and delivery of the GHG inventory; and,
  - Definition of performance criteria for NIS key organisations.
- **Development of legal and contractual infrastructure**
  - Review of legal and organisational structure; and,
  - Implementation of legal instruments and contractual developments as required to meet guidelines.

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

### 1.2.2.2 Inventory Agency – Ricardo Energy & Environment Consortium

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

- Ricardo Energy & Environment – lead contractor;
- UKCEH – overall responsibility for the LULUCF and KP-LULUCF estimates.
- Forest Research – responsible for forestland estimates that feed into the LULUCF and KP-LULUCF estimates.
- Aether – responsible for estimates from railways and the OTs and CDs; and DA inventories.
- Ray Gluckman Consulting – contributions to the F-gas inventory.
- Hartley McMaster – provide independent QA/QC of the system of inventory models

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

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

*Planning*

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

*Preparation*

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

*Management*

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

*Inventory compilation*

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

The Inventory Agency has formal systems in place to ensure that staff working on the inventory are well trained and able to carry out their duties effectively and efficiently. The technical competence of the staff is facilitated through a combination of the formal Ricardo Energy & Environment and inventory-specific staff management and training systems. Roles and responsibilities for all inventory team members are clearly defined, and a comprehensive system of QA/QC is in place. **Section 1.6** sets out the QA/QC plan in detail. Ricardo Energy & Environment systems ensure subcontractors are managed actively and deliver inputs to the inventory on time and to the specified quality.

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

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

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

### 1.2.2.3  Key Data Providers and Reference Sources

The organisations that provide the raw data to the UK GHGI include a wide range of government departments, non-departmental public bodies and government agencies, private companies, and industrial trade associations.

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

*Data quality, Format, Timeliness, Security*

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

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

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

- The Environment Agency's (EA) Pollution Inventory for England (PI);

- Natural Resources Wales's (NRW) Emissions Inventory for Wales (WEI);
- The Scottish Environment Protection Agency's (SEPA) Scottish Pollutant Release Inventory (SPRI);
- The Northern Ireland Environment Agency's (NIEA) Northern Ireland Pollution Inventory (NIPI); and
- The BEIS Offshore Petroleum Regulator for Environment & Decommissioning (BEIS OPRED) Environmental and Emissions Monitoring System (EEMS)

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

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

The UK 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.

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

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

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

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

Members of the Steering Committee include the Inventory Agency team at Ricardo Energy & Environment, other contractors, plus appropriate sector, legal and economic experts. These experts are responsible for reviewing methodologies, activity data, emission factors and emission estimates at a sectoral level and report their findings and recommendations to the Steering Committee on a regular basis. The committee is responsible for ensuring that the inventory meets international standards of quality, accuracy, and completeness, and is delivered on time each year to the EU Monitoring Mechanism Regulation and the UNFCCC. The NISC is responsible for agreeing the priorities for the UK GHGI improvement programme. Where inventory improvement research is commissioned by the NISC, the research reports

are reviewed and approved for use within the UK GHGI compilation by members of the NISC, managed by BEIS, as part of the pre-submission review process.

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

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

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

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

- UK government departments – including BEIS, the Department for Environment, Food and Rural Affairs (Defra), and Department for Transport (DfT)
- DAs in Scotland, Wales, and Northern Ireland
- Inventory contractors (who compile data for the Inventory among other tasks)
- Government agencies (e.g. environmental regulators)
- Industry bodies or associations
- Consultants and invited experts

The development of the inventory is driven through the NISC, which meets twice a year to discuss the outcomes of recent peer, internal and expert reviews and to agree the prioritisation, funding, implementation, and review of items on the UK inventory improvement programme. The Key Category Analysis and the uncertainty analysis, qualitative analysis from Inventory Agency experts as well as recommendations from reviews of the UK GHGI are used as guidance to help the members of the NISC make decisions on which improvements are the most important. Key categories with high uncertainty are given priority over non-key categories or categories with a low uncertainty. The annual inventory review feedback from the UNFCCC and outcomes from QA/QC checks and reviews carried out under the MMR and Effort Sharing Decision (ESD), as well as sector-specific peer- or bilateral review findings are also considered to guide decisions on UK GHGI improvement priorities.

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 MMR and UNFCCC ERTs.

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

**Table 1.3**    **UK GHG National Inventory Steering Committee composition and responsibilities**

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

| Organisation | Role in relation to NISC | Key NISC responsibilities |
|---|---|---|
| | | • Provide information on future international developments and changes to expectations<br>• Provide advice on the implications of domestic changes to the inventory in an international arena |
| BEIS – SICE Division | • LULUCF Inventory manager | • Provide LULUCF inventory data that conforms to EU and UNFCCC international standards and requirements<br>• Work with the NISC to ensure highest quality data |
| Defra – Farming and Food Science | • Agriculture Inventory Manager | • Providing agriculture inventory data that conforms to EU and UN international standards and requirements<br>• Work with the NISC to ensure highest quality data |
| Defra – Water policy | • Wastewater | • To provide water policy expertise to the inventory<br>• To assist in improving waste-water data quality |
| Defra – Waste | • Waste | • To provide waste policy expertise to the inventory, including landfill waste<br>• To assist in improving landfill waste data quality |
| BEIS – Energy Statistics (DUKES) | • Energy statistics | • Annual publication of Digest of UK Energy Statistics (DUKES)<br>• Providing energy statistics to inform the UK inventory |
| Regulators:<br>• Environment Agency for England<br>• Natural Resources Wales<br>• Scottish Environment Protection Agency<br>• Northern Ireland Environment Agency | • Pollution inventory<br>• EU 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<br>• 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<br>• Collate information in annual emission reports for EU ETS |
| BEIS OPRED | • Offshore oil and gas regulator (EEMS, EU ETS) and technical expertise | • Providing offshore oil and gas industry annual activity and emission data to inform the UK inventory<br>• Regulation of the offshore oil and gas industry, including management of the Environmental and Emissions Monitoring System (EEMS) of environmental emissions from that sector |

| Organisation | Role in relation to NISC | Key NISC responsibilities |
|---|---|---|
| Ministry for Housing, Communities and Local Government (MHCLG) | • Housing statistics<br>• Local Government issues | • Publication of housing statistics each year, coordination of technical requirements of local authorities to assist in action on climate change<br>• Providing housing statistics to inform the UK inventory |
| Department for Transport (DfT) | • Transport | • Publication of transport statistics each year<br>• Providing transport statistics to inform the UK inventory |
| Devolved Administrations | • Inventories for Devolved Administrations<br>• Devolved administration climate change legislation and statutory GHG targets | • 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.<br>• 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<br>• Compile the annual National Inventory Report (NIR) and Common Reporting Format (CRF) submission to the UN and EU<br>• 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<br>• Joint role in managing the inventory improvement programme and development of QA/QC procedures |
| GHG inventory project partners (UKCEH) | • LULUCF inventory<br>• Kyoto Protocol LULUCF inventory | • Contractor responsible for LULUCF inventory, activity data, methods, emission factors and removals estimation<br>• Prepare and develop LULUCF inventory of emissions and removals and deliver on time for incorporation into the national inventory<br>• Participate in sectoral expert panels as required |

| Organisation | Role in relation to NISC | Key NISC responsibilities |
|---|---|---|
| Agricultural inventory contractor (Rothamsted) | • Agriculture Inventory compilation and development | • Contractor responsible for agriculture inventory; activity data, methods, emission factors and emission estimation<br>• Prepare and develop agriculture inventory and deliver on time for incorporation into national inventory<br>• Participate in sectoral expert panels as required |
| BEIS – Analysis | • Energy modelling and projections | • Produce UK $CO_2$ projections |

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

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

#### 1.2.2.5   UK Inventory Improvement Programme

Each year the inventory is updated to include the latest data available. Improvements to the methodology are made and are backdated to ensure a consistent time series. Methodological changes are made to take account of new research and data sources, any new guidance from IPCC, relevant work, or emission factors from sources such as the Cooperative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP), the European Environment Agency (EEA) and the US Environmental Protection Agency (EPA), or from specific research programmes sponsored by BEIS 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[22]. 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, Including for Supplementary Information Required under Article 7, Paragraph 1 of the Kyoto Protocol

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

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

Responsibilities of the Environment Agency include to:

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[22] 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

- 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[23].
- 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 1990-2018 was compiled in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

### 1.3.2   Data collection, processing, and storage

The data acquisition task provides the fundamental activity data from which the 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 BEIS, Defra or other organisations.

*Data request*

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

*Data verification*

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

*Data processing*

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

*Emission estimation*

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

*Emissions review*

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

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

*Emissions reporting (including background data)*

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

*Report generation*

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

*Report review*

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

*Report publication*

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

*Data archiving*

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

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

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

Ricardo Energy & Environment has work programmes in place with 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 5.9** respectively.

## 1.4    METHODOLOGIES AND DATA SOURCES

## 1.4.1  GHG Inventory

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

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

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

| CRF sector | Comments on methods |
|---|---|
| 1A | • Basic combustion module (fuel use * emission factor);<br>• Transport models (see **MS 6 to MS 15**); and,<br>• Carbon balance approach (See **MS 4**). |
| 1B | • Carbon Balance approach (See **MS 4**);<br>• BEIS EEMS inventory (See **Annex 3.1.2.3**); and,<br>• Gas leakage data from network operators (See **MS 19**). |
| 2A | • Cement production: IPCC Tier 2 approach (see **Section 4.2.2**);<br>• Lime production: Approach is comparable to IPCC Tier 2, although the Tier 1 default factor is used in the reporting of emissions;<br>• Glass: IPCC Tier 2 approach, UK-specific factors from EU ETS;<br>• Brickmaking: IPCC Tier 2 approach, UK-specific factors from EU ETS; and,<br>• Other carbonates – FGD: Tier 1 approach for earlier part of time-series, Tier 2 for years covered by EU ETS. |
| 2B | • Emissions calculated based on emissions data from industry, EU ETS, and the environmental regulators' inventories, except for:<br>• Use of EU and other MS statistics to estimate methanol manufactured in the UK<br>• Use of IPCC default factors for $CH_4$ from ethylene oxide, acrylonitrile, carbon black in years where no environmental regulators' inventories data available; and,<br>• Use of IPCC default factor for $CO_2$ from ethylene dichloride across full time-series. |
| 2C | • Iron and Steel - 2 stage carbon balance and EU ETS/operator carbon factors for carbonate use and arc furnaces (see **MS 4**);<br>• Spreadsheet model and operator reported emissions for aluminium and magnesium production; and,<br>• Tier 1 approach for non-ferrous metal production. |
| 2D | • Emissions calculated based on IPCC defaults for non-energy use of fuels; and,<br>• 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;<br>• NHS research into anaesthetic use;<br>• Pollution inventory data for other uses of $N_2O$; and,<br>• Statistics on cream consumption and Danish inventory assumptions for $N_2O$ as a propellant for whipped cream. |
| 3A | • Emissions calculated based on animal population data and appropriate EFs. |
| 3B | • Emissions calculated based on animal population data and appropriate EFs. |
| 3D | • Emissions calculated based on animal population data, fertilizer data and appropriate EFs. |
| 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,<br>• CARBINE model used to estimate emissions and removals from Forestry, provided by Forest Research. |

| CRF sector | Comments on methods |
|---|---|
| 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,<br>• Data from operator returns to the regulator for water company waste-water management. |

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

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

| Source **(and publisher)**<br>*Short name/acronym* | Relevant activity data contained in the source |
|---|---|
| **Digest of UK Energy Statistics**<br>(UK Department for Business, Energy, and Industrial Strategy)<br>*DUKES* | • Energy statistics for the UK (imports, exports, production, consumption, demand) of liquid, solid and gaseous fuels; and,<br>• Calorific values of fuels and conversion factors. |
| **Emissions Trading System**<br>(EU ETS regulatory agencies in the UK; data supplied via UK Department for Business, Energy, and Industrial Strategy)<br>*EU ETS* | • Emissions from installations and characteristics of fuels consumed;<br>• Energy data are aggregated by sector and used to inform inventory estimates; and,<br>• Fuel quality data are used to derive up to date carbon emission factors for major fuels in energy intensive sectors. |
| **Transport Statistics GB**<br>(UK Department for Transport)<br>*TSGB* | • Vehicle km according to vehicle type and road type;<br>• Vehicle licensing statistics (split in vehicle km by fuel type); and,<br>• Selected domestic and international civil aviation aircraft km flown. |
| **Northern Ireland Statistics: Inventory of Statutory Releases, transport data**<br>(NI Department of Agriculture, the Environment and Rural Affairs, NI Department for Regional Development)<br>*ISR* | • Traffic count and vehicle km data for Northern Ireland; and,<br>• Information on regulated processes in NI. |
| **Civil Aviation Authority**<br>*CAA* | • Detailed domestic and international civil aviation aircraft km flown. |
| **Pollution Inventory** | • Information on emissions from regulated processes in England and Wales. |

| Source **(and publisher)** *Short name/acronym* | Relevant activity data contained in the source |
|---|---|
| (Environment Agency and Natural Resources Wales) *PI* | |
| **Scottish Pollutant Release Inventory** (Scottish Environment Protection Agency) *SPRI* | • Information on regulated processes in Scotland. |
| **United Kingdom Petroleum Industry Association** *UKPIA* | • Refinery emissions; and • Lead and sulphur contents of fuels, benzene content of petrol, RVP of petrol. |
| **Environmental Emissions Monitoring System (EEMS)** (BEIS 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) *UKMY* | • Statistical data on minerals production, consumption, and trade. |
| **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 1.7** to **Table 1.10** summarise the key source categories, for the latest reported year, and the base year, derived from the IPCC Approach 1 and 2 key category analyses. Tables are included for the analysis with and without LULUCF and for the base year and most recent year estimated. Details of the key source category analysis are given in **Annex 1**. A trend cannot be calculated for the base year alone, and so the tables for the base year only contain key source categories identified by level.

Note that **Table 1.7** to **Table 1.10** indicate key source categories only for the submission to the Convention (UNFCCC scope). A second analysis for the submission under the Kyoto Protocol (KP) scope has also been undertaken. Full details of this additional analysis are not presented here as results have been found to be very similar. **Table 1.11** has been included to present occasions where the outcomes of the analysis have differed between geographical coverage.

A key category ranking has been carried out, this is set out in **Table 1.11** - Differences between KCA under UNFCCC and KP geographical scopes

| KCA analysis | IPCC Code | Category | Greenhouse Gas | UNFCCC Identification Criteria | KP Identification Criteria |
|---|---|---|---|---|---|
| Latest Year (inc. LULUCF) | 1A3a | Domestic aviation: liquid fuels | CO2 | L1 | - |
| | 1A3c | Railways: liquid fuels | CO2 | - | L1 |
| Latest Year (exc. LULUCF) | 1A3a | Domestic aviation: liquid fuels | CO2 | L1 | - |
| | 1A3c | Railways: liquid fuels | CO2 | - | L1 |

Table 1.12**,** and is explained below; it is referred to in **Table 3.1** when referencing which categories are or contain key categories within the energy sector.

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

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

**Table 1.7**        **Key Source Categories for the latest reported year (including LULUCF) – UNFCCC scope**

| IPCC Code | Category | Greenhouse Gas | Identification Criteria |
|---|---|---|---|
| 1A | (Stationary) Oil | $CO_2$ | L2, T2 |
| 1A | Coal | $CO_2$ | L2, T2 |

| IPCC Code | Category | Greenhouse Gas | Identification Criteria |
|---|---|---|---|
| 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, T1 |
| 1A2 | Manufacturing industries and construction: gaseous fuels | $CO_2$ | L1, T1 |
| 1A3a | Domestic aviation: liquid fuels | $CO_2$ | L1 |
| 1A3b | Road transportation: liquid fuels | $CO_2$ | L1, T1 |
| 1A3b | DERV | $CO_2$ | L2, T2 |
| 1A3b | Gasoline/ LPG | $CO_2$ | L2 |
| 1A3b | Gasoline/ LPG | $CH_4$ | T2 |
| 1A3b | DERV | $N_2O$ | L2, T2 |
| 1A3d | Domestic Navigation: liquid fuels | $CO_2$ | L1, T1, 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 |

| IPCC Code | Category | Greenhouse Gas | Identification Criteria |
|---|---|---|---|
| 1A5 | Other: liquid fuels | $CO_2$ | T1 |
| 1B1 | Coal mining and handling | $CH_4$ | T1, T2 |
| 1B2 | Oil and gas extraction | $CH_4$ | L1, L2, T2 |
| 1B2 | Oil and gas extraction | $CO_2$ | L1, T1 |
| 2A1 | Cement production | $CO_2$ | L1 |
| 2B | Chemical industries | $CO_2$ | L2 |
| 2B | Chemical industries | $N_2O$ | T2 |
| 2B | Chemical industry | 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 |
| 2B9 | Fluorochemical production | HFCs, PFCs, $SF_6$ and $NF_3$ | T1 |
| 2C1 | Iron and steel production | $CO_2$ | L1 |
| 2F | Product Uses as Substitutes for ODS | HFCs | L2, T2 |
| 2F1 | Refrigeration and air conditioning | HFCs, PFCs, $SF_6$ and $NF_3$ | L1, T1 |
| 2F4 | Aerosols | HFCs, PFCs, $SF_6$ and $NF_3$ | T1 |
| 2G | Other Product Manufacture and Use | $N_2O$ | 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 |

| IPCC Code | Category | Greenhouse Gas | Identification Criteria |
|---|---|---|---|
| 3D | Agricultural soils | $N_2O$ | L1, T1, L2 |
| 4A | Forest land | $CO_2$ | L1, T1, L2, T2 |
| 4B | Cropland | $CO_2$ | L1, T1, L2, T2 |
| 4C | Grassland | $CO_2$ | L1, T1, L2, T2 |
| 4E | Settlements | $CO_2$ | L1, T1, L2, T2 |
| 4G | Harvested wood products | $CO_2$ | L1 |
| 5A | Solid waste disposal | $CH_4$ | L1, T1, L2, T2 |
| 5B | Biological treatment of solid waste | $CH_4$ | T1, L2, T2 |
| 5B | Biological treatment of solid waste | $N_2O$ | T2 |
| 5C | Waste Incineration | $CO_2$ | L2, T2 |
| 5D | Wastewater treatment and discharge | $CH_4$ | L1, T1, L2 |
| 5D | Wastewater Handling | $N_2O$ | L2, T2 |

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

| IPCC Code | 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 |

| IPCC Code | Category | Greenhouse Gas | Identification Criteria |
|---|---|---|---|
| 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 |
| 1A3d | Marine fuel | $CO_2$ | L2 |
| 1A4 | Other sectors: solid fuels | $CO_2$ | L1 |
| 1A4 | Other sectors: liquid fuels | $CO_2$ | L1 |
| 1A4 | Other sectors: gaseous fuels | $CO_2$ | L1 |
| 1A5 | Other: liquid fuels | $CO_2$ | L1 |
| 1B1 | Coal mining and handling | $CH_4$ | L1, L2 |
| 1B2 | Oil and gas extraction | $CH_4$ | L1, L2 |
| 1B2 | Oil and gas extraction | $CO_2$ | L1 |
| 2A1 | Cement production | $CO_2$ | L1 |
| 2B | Chemical industries | $CO_2$ | L2 |
| 2B | Chemical industries | $N_2O$ | L2 |
| 2B | Chemical industry | 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 |

| IPCC Code | Category | Greenhouse Gas | Identification Criteria |
|-----------|----------|----------------|------------------------|
| 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 | $N_2O$ | L1, L2 |
| 4A | Forest land | $CO_2$ | L1, L2 |
| 4B | Cropland | $CO_2$ | L1, L2 |
| 4C | Grassland | $CO_2$ | L1, L2 |
| 4E | Settlements | $CO_2$ | L1, L2 |
| 4E | Settlements | $N_2O$ | L2 |
| 5A | Solid waste disposal | $CH_4$ | L1, L2 |
| 5C | Waste Incineration | $CO_2$ | L2 |
| 5D | Wastewater treatment and discharge | $CH_4$ | L1, L2 |
| 5D | Wastewater Handling | $N_2O$ | L2 |

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

| IPCC Code | 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 |

| IPCC Code | Category | Greenhouse Gas | Identification Criteria |
|---|---|---|---|
| 1A1 | Energy industries: gaseous fuels | $CO_2$ | L1, T1 |
| 1A1 | Energy industries: other fuels | $CO_2$ | L1, T1 |
| 1A1 & 1A2 & 1A4 & 1A5 | Other Combustion | $CH_4$ | L2 |
| 1A1 & 1A2 & 1A4 & 1A5 | Other Combustion | $N_2O$ | L2 |
| 1A2 | Manufacturing industries and construction: solid fuels | $CO_2$ | L1, T1 |
| 1A2 | Manufacturing industries and construction: liquid fuels | $CO_2$ | L1, T1 |
| 1A2 | Manufacturing industries and construction: gaseous fuels | $CO_2$ | L1, T1 |
| 1A3a | Domestic aviation: liquid fuels | $CO_2$ | L1 |
| 1A3b | Road transportation: liquid fuels | $CO_2$ | L1, T1 |
| 1A3b | DERV | $CO_2$ | L2, T2 |
| 1A3b | Gasoline/ LPG | $CO_2$ | L2 |
| 1A3b | Gasoline/ LPG | $CH_4$ | T2 |
| 1A3b | DERV | $N_2O$ | L2, T2 |
| 1A3d | Domestic Navigation: liquid fuels | $CO_2$ | L1, T1, 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 | $CO_2$ | T1 |
| 1B1 | Coal mining and handling | $CH_4$ | T1, T2 |
| 1B2 | Oil and gas extraction | $CH_4$ | L1, L2, T2 |
| 1B2 | Oil and gas extraction | $CO_2$ | L1, T1 |

| IPCC Code | Category | Greenhouse Gas | Identification Criteria |
|-----------|----------|----------------|-------------------------|
| 2A1 | Cement production | $CO_2$ | L1 |
| 2B | Chemical industries | $CO_2$ | L2 |
| 2B | Chemical industries | $N_2O$ | T2 |
| 2B | Chemical industry | 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 |
| 2B9 | Fluorochemical production | HFCs, PFCs, $SF_6$ and $NF_3$ | T1 |
| 2C1 | Iron and steel production | $CO_2$ | L1 |
| 2F | Product Uses as Substitutes for ODS | HFCs | L2, T2 |
| 2F1 | Refrigeration and air conditioning | HFCs, PFCs, $SF_6$ and $NF_3$ | L1, T1 |
| 2F4 | Aerosols | HFCs, PFCs, $SF_6$ and $NF_3$ | T1 |
| 2G | Other Product Manufacture and Use | $N_2O$ | 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 | $N_2O$ | L1, T1, L2 |
| 5A | Solid waste disposal | $CH_4$ | L1, T1, L2, T2 |
| 5B | Biological treatment of solid waste | $CH_4$ | T1, L2, T2 |

| IPCC Code | Category | Greenhouse Gas | Identification Criteria |
|-----------|----------|----------------|-------------------------|
| 5B | Biological treatment of solid waste | $N_2O$ | L2, T2 |
| 5C | Waste Incineration | $CO_2$ | L2, T2 |
| 5D | Wastewater treatment and discharge | $CH_4$ | L1, L2 |
| 5D | Wastewater Handling | $N_2O$ | L2, T2 |

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

| IPCC Code | Category | Greenhouse Gas | Identification Criteria |
|-----------|----------|----------------|-------------------------|
| 1A | (Stationary) Oil | $CO_2$ | L2 |
| 1A | Coal | $CO_2$ | L2 |
| 1A | Natural Gas | $CO_2$ | L2 |
| 1A1 | Energy industries: 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 |

| IPCC Code | Category | Greenhouse Gas | Identification Criteria |
|---|---|---|---|
| 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, L2 |
| 1B2 | Oil and gas extraction | $CO_2$ | L1 |
| 2A1 | Cement production | $CO_2$ | L1 |
| 2B | Chemical industries | $CO_2$ | L2 |
| 2B | Chemical industries | $N_2O$ | L2 |
| 2B | Chemical industry | 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 |

**Table 1.11 - Differences between KCA under UNFCCC and KP geographical scopes**

| KCA analysis | IPCC Code | Category | Greenhouse Gas | UNFCCC Identification Criteria | KP Identification Criteria |
|---|---|---|---|---|---|
| Latest Year (inc. LULUCF) | 1A3a | Domestic aviation: liquid fuels | $CO_2$ | L1 | - |
| | 1A3c | Railways: liquid fuels | $CO_2$ | - | L1 |
| Latest Year (exc. LULUCF) | 1A3a | Domestic aviation: liquid fuels | $CO_2$ | L1 | - |
| | 1A3c | Railways: liquid fuels | $CO_2$ | - | L1 |

**Table 1.12        Key category ranking**

| KCA rank (KCs only) - UNFCCC | KCA rank (KCs only) – KP | IPCC Code | IPCC Category | Greenhouse Gas |
|---|---|---|---|---|
| 1 | 1 | 1A3b | Road transportation: liquid fuels | $CO_2$ |
| 2 | 2 | 1A4 | Other sectors: gaseous fuels | $CO_2$ |
| 3 | 3 | 1A1 | Energy industries: solid fuels | $CO_2$ |
| 4 | 4 | 5A | Solid waste disposal | $CH_4$ |
| 5 | 6 | 1A1 | Energy industries: gaseous fuels | $CO_2$ |
| 6 | 5 | 1A2 | Manufacturing industries and construction: gaseous fuels | $CO_2$ |
| 7 | 7 | 1A1 | Energy industries: liquid fuels | $CO_2$ |
| 8 | 8 | 1A2 | Manufacturing industries and construction: solid fuels | $CO_2$ |
| 9 | 9 | 3A1 | Enteric fermentation from Cattle | $CH_4$ |
| 10 | 10 | 1A2 | Manufacturing industries and construction: liquid fuels | $CO_2$ |
| 11 | 11 | 4A | Forest land | $CO_2$ |
| 12 | 12 | 1A4 | Other sectors: liquid fuels | $CO_2$ |
| 13 | 13 | 3D | Agricultural soils | $N_2O$ |
| 14 | 14 | 4B | Cropland | $CO_2$ |
| 15 | 15 | 1A4 | Other sectors: solid fuels | $CO_2$ |
| 16 | 16 | 4E | Settlements | $CO_2$ |
| 17 | 17 | 1B2 | Oil and gas extraction | $CH_4$ |
| 18 | 18 | 1B1 | Coal mining and handling | $CH_4$ |

| KCA rank (KCs only) - UNFCCC | KCA rank (KCs only) – KP | IPCC Code | IPCC Category | Greenhouse Gas |
|---|---|---|---|---|
| 19 | 19 | 4C | Grassland | $CO_2$ |
| 20 | 20 | 1A3d | Domestic Navigation: liquid fuels | $CO_2$ |
| 21 | 21 | 3B1 | Manure management from Cattle | $CH_4$ |
| 22 | 22 | 2F1 | Refrigeration and air conditioning | HFCs, PFCs, $SF_6$ and $NF_3$ |
| 23 | 23 | 1B2 | Oil and gas extraction | $CO_2$ |
| 24 | 24 | 3A2 | Enteric fermentation from Sheep | $CH_4$ |
| 25 | 25 | 1A5 | Other: liquid fuels | $CO_2$ |
| 26 | 26 | 5D | Wastewater treatment and discharge | $CH_4$ |
| 27 | 27 | 2C1 | Iron and steel production | $CO_2$ |
| 28 | 28 | 3B2 | Manure management from Sheep | $N_2O$ |
| 29 | 29 | 1A1 | Energy industries: other fuels | $CO_2$ |
| 30 | 30 | 2A1 | Cement production | $CO_2$ |
| 31 | 31 | 4G | Harvested wood products | $CO_2$ |
| 32 | n/a | 1A3a | Domestic aviation: liquid fuels | $CO_2$ |
| n/a | 32 | 1A3c | Railways: liquid fuels | $CO_2$ |
| 33 | 33 | 2B8 | Petrochemical and carbon black production | $CO_2$ |
| 34 | 34 | 2F4 | Aerosols | HFCs, PFCs, $SF_6$ and $NF_3$ |
| 35 | 35 | 2B9 | Fluorochemical production | HFCs, PFCs, $SF_6$ and $NF_3$ |
| 36 | 36 | 2B2 | Nitric acid production | $N_2O$ |
| 37 | 37 | 2B3 | Adipic acid production | $N_2O$ |
| 38 | 38 | 5B | Biological treatment of solid waste | $CH_4$ |

## 1.5.2 KP-LULUCF analysis

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

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

## 1.6 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

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

- ***Quality Control*** (e.g. raw data checks, calculation checks, output checks) to minimise the risk of errors within the available resources to deliver the inventory.

- ***Quality Assurance*** (e.g. peer reviews, bilateral reviews, expert reviews) whereby independent experts periodically review all or part of the inventory to identify potential areas for improvement.

- ***Verification*** where alternate independent datasets are available to compare against inventory data and trends

The current system complies with the Tier 1 procedures outlined in the Guidelines (IPCC, 2006) and has been extended to include a range of bespoke sector specific QA/QC activities to comply with Tier 2. Ricardo Energy & Environment, the Inventory Agency, is also fully accredited to ISO 9001:2015 and ISO 14001: 2015 (see **Box 1.1**). This accreditation provides additional institutional standards which the Inventory Agency has to apply to all projects and ensures that the wider company conforms to good practice in project management and quality assurance.

## 1.6.1 Description of the current QA/QC system

The NAEI and the UK Greenhouse Gas Inventory are compiled and maintained together by Ricardo Energy & Environment (the Inventory Agency), on behalf of the UK Department for Business, Energy & Industrial Strategy (BEIS) and the Department for Environment, Food and Rural Affairs (Defra). Ricardo Energy & Environment prepares the GHG submissions to the EC under the MMR and to the UNFCCC.

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 UK 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. BEIS, the Department for Transport, Defra, the Office of National Statistics and British Geological Survey) qualify as UK National Statistical Agencies (as defined in UN Guidance[24]) 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 EU ETS or the Industrial Emissions Directive) and to regulate other activity

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

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 NISC.

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

- inventory planning tasks, including: review of historic data and methods, identification of improvement priorities, data and method selection, inventory team training and development;

- inventory compilation and reporting tasks, including: management and documentation of data flows from raw data through calculation of emission estimates to reporting, input data requests/acquisition, management of compilation processes and quality checking systems, documentation of data, methods and assumptions, assessment of key source categories and uncertainties, reporting of inventory outputs;

- inventory checking tasks, including: raw data checks, inventory model / calculation checks, source-specific and cross-cutting output checks, checking reasons for changes compared to previous inventory estimates, emission trend checks, emission factor checks; and,

- inventory QA review tasks, including: pre-submission reviews, post-submission reviews, peer reviews, bilateral reviews, expert reviews.

### 1.6.1.1  Overview of the UK QA/QC system

An overview of the UK's GHGI QA/QC system is illustrated in **Figure 1.3** below. The UK inventory QA/QC system includes three core components.

1. The QA/QC Plan is a document maintained by the GHGI's QA/QC manager (at Ricardo Energy & Environment) and defines the specific quality objectives and QA/QC activities required in undertaking the compilation and reporting of GHG estimates. The plan sets out source-specific and general (cross-cutting) activities to ensure that quality objectives are met within the required inventory reporting timeframe. The QA/QC plan also assigns roles and responsibilities for the Inventory Agency team and records the key outcomes from inventory QA activities 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**
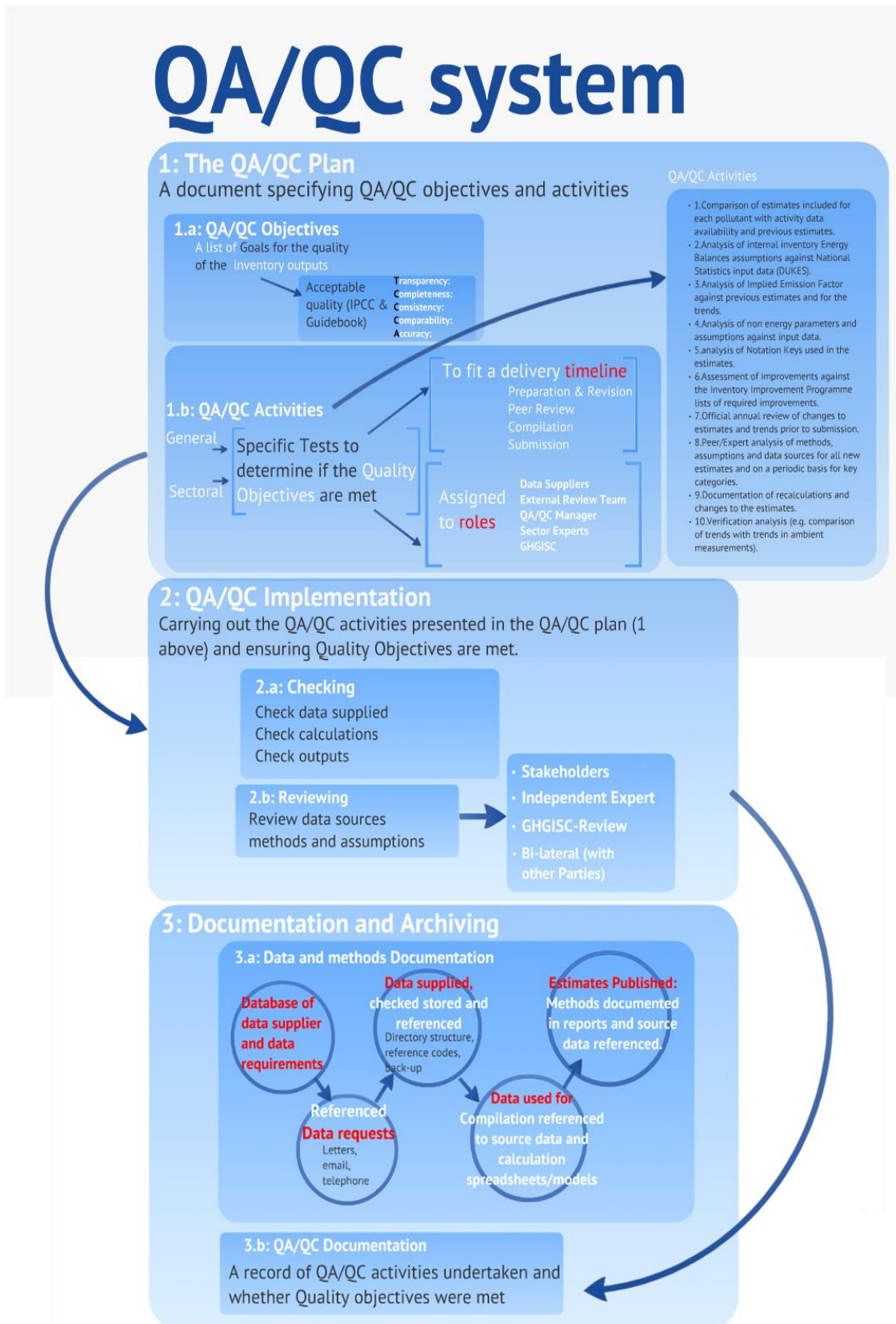
> **Box 1.2: ISO 9001:20 and ISO 14001: 2015 Accreditation**
>
> In addition to the UK's GHGI-specific QA/QC system, through Ricardo Energy & Environment, the Inventory has been subject to ISO 9000 since 1994 and is now subject to ISO 9001:2015, the international standard that specifies requirements 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 14 years. The emphasis of these audits was on authorisation of personnel to work on inventories, document control, data tracking and spreadsheet checking, and project management. As part of the Inventory management structure there is a nominated officer responsible for the QA/QC system – the QA/QC Co-ordinator. As part of the Ricardo Group certification, Ricardo Energy & Environment is currently accredited to ISO 9001:2015. Lloyds Register Quality Assurance carried out a three-yearly recertification audit of Ricardo Energy & Environment which was completed in October 2019. Ricardo Energy & Environment successfully passed the recertification, with no major non-compliances, and a new Ricardo Group certificate was issued in February 2020. 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 and MMR (including emissions and removals from all sources and gases)
2. Calculation of air pollutant estimates and reporting to UNECE (including emissions from all sources and pollutants)
3. Calculation of estimates and reporting to UK National Statistics
4. Identification and phased implementation of incremental improvements to the QA/QC system.

## 1.6.2  Improvements to the QA/QC System

The QA/QC plan and procedures are 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[25]). 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. 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.

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[25] 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

Improvements made to the inventory QA/QC system, including to some cross-cutting data compilation models, for the 2020 submission include:

- Improvement of pollutant-specific checking templates that facilitate a more consistent checking procedure for NAEI activity data (AD) and for the inventories for GHGs and air pollutants, and to collect information on recalculations and reported trends in a systematic, prioritised way. The worksheets used to document the analysis of reasons for changes and reasons for trends across pollutants were restructured to be more user-friendly; the AD and emission factors (EFs) were converted to function on an energy basis (rather than a mass basis, as previously) for solid and liquid fuels, and to consistently present information across all fuels in units of TJ (net) for AD and per TJ (net) for EFs, to facilitate checking against IPCC and EMEP-EEA default EFs.

- Improvement to the model developed to convert and manage the derivation of emission factors (EFs; often from literature defaults) into units applied in the NAEI database. This model, developed and first used in the 2018 submission, converts EFs from the original units as set out in the literature sources, to units consistent with the activity data and emissions reporting units in the NAEI database, and ensures that a consistent approach is taken (e.g. in selection of the most appropriate default factor for a specific UK emission source, where several may be presented in the literature). In the 2020 submission, the scope of this model has been extended to include more pollutants, including for carbon dioxide where defaults are used in the UK GHGI;

- Continued upgrading of the LULUCF models, including verification of model calculations and expansion of model quality checks.

- Continued development of agriculture inventory quality systems, to reflect the major methodological changes that were implemented (mostly in the 2018 submission), including:
    - Rothamsted Research and the team of other agriculture sector experts (ADAS, UKCEH and Cranfield University) have further improved the documentation of the new inventory methods, to develop central lists of data suppliers and planned inventory improvements to aid communication and tracking of changes within the Inventory Agency team and with key industry and government stakeholders.
    - Several source methods have now been converted from spreadsheet models to use either the C# coded model or to use other software code (e.g. R), including to improve consistency of data management of core datasets across the consortium.

- Regulators' Inventory Database (RIDB). This year's submission incorporated a new database system for processing emissions data for use in the NAEI that are sourced from the UK environmental regulator "pollution inventories", i.e. emissions data reported by operators of sites regulated under the EU Industrial Emissions Directive (IED) and the Pollutant Release and Transfer Register (PRTR) including large combustion plant industrial and manufacturing sites and waste management facilities. The new system has automated the data processing, leading to greater consistency in the application of assumptions used to deal with the gaps and outliers in the regulator inventory datasets. As part of the overhaul of the systems, many of the assumptions used in gap-filling procedures have been reviewed and updated, leading to some revisions to the emission estimates. Sectors affected include Energy, Waste and IPPU.

- Transition to energy units. Activity data and emission factors regarding the use of fuels are now handled in units of terajoules (net) (TJ) at the earliest practicable stage in the process of deriving emissions, within the NAEI suite of models. TJ (net) are the international standard units for inventory reporting and guidance; transitioning to these

units reduces the number of conversions required when utilising international data and reporting using common metrics.

The main impact of this change is to enable more rapid and transparent quality checks against default EFs and to improve the comparability of the NAEI reporting with other countries. The work has included a critical review of the time series and selection of Net Calorific Values (NCVs) within the calculations, and in some cases has led to the use of new data sources, for example in order to minimise the need for conversions. In other cases, the work may have led to changes in the precision of input parameters, with minor rounding errors addressed. The total impact of these changes has not been quantified, but is expected to be small, as the underlying methods and selection of most appropriate AD and EFs has not changed for the vast majority of sources; merely the units of calculation are now different. The changes will affect several IPCC source categories, and it is not practicable to assess the impact from the routine recalculations across multiple models.

### 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[26] and CLRTAP[27]. The inventory data quality objectives are to achieve the principles of Transparency, Completeness, Consistency, Comparability and Accuracy (TCCCA):

- **Transparent in:**

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

  o The documentation of QA/QC activities and their implementation using internal checklists and summarised in relevant public material (e.g. NIR).

- **Complete:** and include all relevant (anthropogenic) emission/removal activities, using representative data for the national territory for socio-economic assumptions and policies and measures for all required years, categories, gases, and scenarios.

- **Consistent:** across trends in emissions/removals for all years (especially where applicable between the historic and projected estimates) and that there is internal consistency in aggregation of emissions/removals. Where possible, the same methodologies are used for the base year and all subsequent years and consistent data sets are used to estimate emissions or removals from sources or sinks.

- **Comparable:** with other reported emission/removal estimates through use of the latest reporting templates and nomenclature consistent with reporting requirements. Using the correct IPCC category level and consistent units for expressing mass of emissions/removals by gas, split between EU ETS and non-EU ETS sources, scenarios, units for parameters

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[26] 2006 IPCC Guidelines for National Greenhouse Gas Inventories: http://www.ipcc-nggip.iges.or.jp/public/2006gl/

[27] 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/

and of input parameters with EU assumptions (e.g. energy prices, carbon price, population etc.).

- **Accurate:** ensuring the most accurate methods are used in the application of methods, minimising the uncertainty in assumptions and in use of data sources used for the estimates and inclusion of national and EU wide assumptions.

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

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

### 1.6.2.2   Roles and Responsibilities

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

- **QA/QC Manager ("Senior Analyst")**: Coordinates all QA/QC activities and manages the contributions from data suppliers, sector experts and independent experts and undertakes cross cutting QA/QC activities. Maintains the QA/QC plan, co-ordinates action across the team to: set quality objectives, communicate and implement QA/QC activities, identify training and development needs (individual, systematic);

- **Knowledge Leaders**: Lead the technical development and implementation of the NAEI programme, supporting the QA manager and project management team in delivering the project to meet technical requirements of international reporting as well as UK-specific and other output quality expectations. Manage periodic review and perform final checking activities on data and report submissions.

- **Project Manager**: Lead all key management activities including management of the project finances, commercial issues, liaison with BEIS and Defra, manage and attend project meetings, communicating project tasks and requirements to the team and oversee the day-to-day running of the project. Manage team resources and support QA Manager, Technical Director and Knowledge Leaders in identifying and resolving resource limitations (e.g. skills gaps, continuity planning);

- **Task Managers/Sector Experts**: Task managers (or sector experts) are responsible for the maintenance of task documentation (e.g. compiler manual, scope documents, quality checking records and correspondence) and task QA Plan to include: definition of checking requirements; timeline delivery of work; coordination of task sign-off; identification of team training requirements and risk management. They perform sector specific review and checking activities and report to the QA/QC Manager. Sector Experts also collaborate with data suppliers and other key stakeholders to review data quality (input data and outputs), perform quality checks on supplied information, assess and report on uncertainties associated with NAEI outputs. Identify improvement

requirements for their tasks/sectors and promote/implement cross cutting QA/QC improvements by sharing best practice and engaging in team communication activities; and,

- **External Review experts:** Provide expert/peer review of projections for specific sectors, identify key findings and inventory improvement recommendations, and report to the QA/QC Manager.

### 1.6.2.3  Timeline

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

### 1.6.2.4  Quality Control and Documentation

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

1. **Checking of input data for scope, completeness, consistency with data for recent years and (where available) verification against other independent datasets**. Compilers check the incoming data from data providers to assess whether the data are complete and consistent with data for recent years. In some cases, checks are performed to compare data between individual operators (e.g. gas composition data from multiple UK gas transporters) and between different reporting mechanisms (such as comparisons of operator-reported activity and emissions data between IED/PRTR and EU ETS). For several sources, production-based emission estimates can be compared with other data (e.g. sales data, plant capacity data) to check that the trends and values are reasonable.

2. **Analysis of internal inventory energy and mass balances** and other statistics assumptions against National Statistics input data (e.g. DUKES and ONS). Mass or energy balances are performed for each major fuel in the UK economy and any deviations from UK energy statistics are checked and documented. Several sector methods for key categories also have Tier 2 checks to assess internal consistency, such as carbon balance checks for the carbon flows through integrated iron and steel works.

3. **Completeness checks**. The database is checked for completeness and consistency of entry across the different pollutants and gases. For example, combustion sources are checked for inclusion of all relevant pollutants and the database checked for any missing estimates and appropriate use of notation keys.

4. **Recalculation checks**. The latest inventory dataset is compared against the previous inventory submission. Any recalculations are documented by inventory compilers and signed off by checkers. Reasons for the recalculations are documented, e.g. method improvements, revisions to input data or assumptions. These recalculation notes are referenced within the inventory database to facilitate reporting and transparency of recalculations.

5. **Time series checks and benchmarking checks**. The time series of emissions are checked for step changes, trends, and any outlier data (e.g. outlier EFs or peaks/dips in activity data trends). Any unusual features are checked and explained, with reasons for significant trends and outliers documented in the method sections of the NIR. Implied Emission Factors (IEFs) are checked against previous estimates and for key categories against defaults (from IPCC guidance) to identify any notable UK-specific EF outliers.

6. **Method implementation checks**. A range of common checks are performed across inventory calculation models, such as: checking that units are correct for input parameters; checking that selection of NCVs or default EFs is consistent across years/pollutants; checking for either new emission estimates (e.g. due to new UK data or new methodological guidance or new EFs within the IPCC guidance) or for any missing emission sources compared to previous submissions.

7. **Reporting checks**. Inventory submissions are checked to ensure correct allocation into the CRF categories. Emission totals at national and sub-category level are checked against the "master" dataset derived from the UK inventory database outputs, to minimise risks of data transcription errors into reporting templates.

**Figure 1.4      Quality Checks throughout the UK inventory compilation process**

Data requests are checked before being issued.

**Data Collection**

Data provided is checked on receipt: coverage, units, sources, mass balance checks, time series, comparison against previous year.

**Raw Data**

Spreadsheet checks allow internal consistency of raw data to be checked again: check sums against sub totals, units, conversions.

**Checked Input Data**

**Compilation**

Spreadsheets used for compilation are checked three times before database entry: method checks, time series consistency, energy balances, reasons for changes vs previous year, checks by pollutant experts, checks by sector experts.

Checks on the database include: completeness checks, checks on reporting formats, time series consistency, comparison with the previous year's inventory. A master data set is compiled,

**UK Emission Inventory Database**

**AQ pollutant emissions & reports**

**GHG emissions & reports**

Outputs are cross checked against the master data set. Checks include sectoral and geographical coverage, mass vs GWP reporting, total emissions cross check (by gas, by sector)

**CLRTAP & NECD**

**UNFCCC & EUMM**

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

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

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

2. **<u>Individual data processing tools</u>** are used to prepare the majority of source data into suitable AD and EFs for UK emissions estimates. These data processing tools (spreadsheets and database models) are uniquely identified and include QC procedures, summaries and source data referencing and documentation within them. QC procedures are embedded in the tools which provide sector specific checks (e.g. energy/mass balance) and implied emission factor checking for default and country specific emission factors. The QC procedures within each tool/spreadsheet include calculation input/output checking cells and flags to identify calculation errors. The QC summary sheets in each tool/spreadsheet include links to QC activities that need to be performed, flags for the QC activities, their status and sign off; details of source data; key assumptions, methods, data processing activities and progress; the scope of activities, gases and years included; relationships with other 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. **<u>A core database (NAEI database) of AD and EFs</u>** with embedded tier 1 QC routines and data source and data processing referencing. The database provides the quality assured dataset of UK emissions and removals used for EU, UNFCCC, and Kyoto Protocol (KP) reporting (including CRF population), responding to ad-hoc queries or deriving other downstream estimates (e.g. emissions by Devolved Government and emissions by Local Authority). The detailed Activity Data and Emission Factor components for each source or sink category estimate are held within the NAEI database and include all sources, activities, gases/pollutants (GHGI and API), territories and years. The majority of data in the database are imported directly from the individual data processing models (as described above). To ensure data source transparency, all data points in the database carry a reference to either the upstream data processing tools used to derive the data, the external data source and supplier or both. It also includes details of the date entered, the person uploading the data, its units (to ensure correct calculation), and a revision or recalculation code (which ensures that recalculations of historic data can be easily traced and summarised in reports). Automated data import routines used to populate the database minimise transcription errors and errors resulting from importing data that has not been properly checked. This process extracts output data from the upstream data processing models and can be controlled by the Inventory Agency via a data import dashboard. The automated system ensures that data is only uploaded to the database once it meets specified QA/QC criteria of data checking, completion, and consistency. 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)[28];

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 EU ETS and Industrial Emissions Directive (IED). These checks enable high-level checks on the data consistency for high-emitting source categories (e.g. power stations, refineries, cement kilns, iron and steel works) for priority pollutants (e.g. $CO_2$, $NO_X$);

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.

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

- At 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 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) review the emissions inventory datasets. The NISC is tasked with the official consideration and approval of the national inventory prior to submission to the UNFCCC. The NISC comprises key stakeholders, including the Single National Entity (BEIS) (see Institutional Arrangements section), who 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 1990-2018 inventory include:

Department for Business, Energy & Industrial Strategy

- The Inventory Agency met with the BEIS energy statistics team that produces DUKES to discuss changes (to both activity and methodology) in the 2019 publication of the statistics, to ensure correct interpretation of the new statistics in the 2020 submission. The Inventory Agency has regular contact with the DUKES team and works to ensure that any revisions in the DUKES data are reflected accurately in the inventory, and where necessary that time series recalculations are made in consultation with the DUKES team. For example, during 2019 the Inventory Agency worked with BEIS to address proposed revisions to the solid fuel use sector allocations, based on consultation with the Coal Merchants Federation.

- Consultation with BEIS OPRED to request clarifications on the scope and completeness of Environmental and Emissions Monitoring System (EEMS) reported data for several individual installations, to ensure correct interpretation of the available data. In the 2020 submission this was especially focussed around fugitive methane and well testing emissions.

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.

Other data providers

- 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; this might lead to changes in the fleet turnover assumptions for the next submission;

- Consultation with Tata Chemical (soda ash producer) and trade bodies representing soda ash users in order to gather data so that emissions from soda ash use could be estimated for inclusion in the 2020 submission of the UK inventory. Previously the inventory only included emissions from soda ash used to produce glass; this consultation enabled us to quantify soda ash consumption by other industries and related emissions;

- Consultation with Environmental Compliance team of the Ministry of Defence (MoD) to seek improved understanding of the fuels data the MoD provides for military aviation and naval shipping. Of particular interest was understanding the source of the MoD fuels data and how it is derived, how fuel supplied for overseas operations is accounted for, understanding the different types of fuels used for military aviation, emphasising the need for time-series consistency and getting information on ground-based machinery and military transport. The MoD was given a better understanding of the inventory requirements, and whilst it was unable to provide new, more granular data for this year's inventory submission, it agreed to work with its data providers to determine what may be possible for future submissions.

- Chemical Industries Association (chemicals manufacture), British Coatings Federation (manufacture of paints and inks), 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.

*1.6.2.5.3 Expert, Peer and Bilateral Reviews*

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

Since 2002, the UK has implemented a programme of peer reviews by experts outside of the organisation responsible for the estimates. 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 1.13     Summary of Expert, Peer and Bilateral review activities**

| Review description | Summary |
|---|---|
| **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, for which the review report was published in February 2020 during NIR preparation and checking. |
| **2019:** Bilateral review of the agriculture sector with Germany | 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 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, | 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 |

| Review description | Summary |
|---|---|
| focussing on energy and IPPU sectors. | 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 Technical Expert Review Team | The review focussed on non-LULUCF sectors and provided a report for each Member State (including the UK) highlighting recommendations for improvements as well as documentation of any revised estimates as a result of the review. The UK made 3 minor (in total ~ 0.1%) revisions as recommended by this review for lime production and burning of biomass for energy to address underestimates, and for dairy cattle to address an 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, CRH independent team | BEIS funded an external peer review of the research programme that provides LULUCF emissions estimates to the Greenhouse Gas Inventory in 2009. In addition, in 2009 the LULUCF inventory project was audited by an independent 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 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 |

| Review description | Summary |
|---|---|
| the French inventory team | 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) and funded by the EU and EEA through the European Topic Centre on Air and Climate Mitigation. The list below highlights some recent examples of these activities.

1. Knowledge sharing on emissions inventory compilation methods with Moscow State Government officials.

2. Study tour by representatives of the Israeli Ministry of Environmental Protection and Central Bureau of Statistics, who compile the GHG inventory for Israel.

3. Knowledge sharing with Chinese energy statisticians on GHG emissions trading and statistics.

4. Capacity building activities in South Africa in the agricultural sector.

5. Knowledge sharing with the Romanian GHG inventory team during December 2011 to support the improvement of energy sector reporting.

6. Knowledge sharing with the Chinese Energy Research Institute regarding the UK experience of integrating facility-level data into the national inventory and outlining all of the QA procedures that govern energy and emissions data from facility to sector to national level within the UK, to support their efforts in developing a national system of data management to account for GHG emissions, working from provincial and facility-level data.

7. Capacity building in Spain – invited presentation of the UK agricultural inventory improvements and further conversations with Spanish government representatives.

8. Knowledge sharing with Russian and French inventory teams.

9. UKCEH participation in annual yearly knowledge sharing with European LULUCF inventory compilers at EU Joint Research Council LULUCF meetings.

10. Knowledge sharing with the Vietnam inventory team.

11. Capacity building workshop with Balkan EU accession countries on National System development.

12. Study visit by delegation from the Chinese National Center for Climate Change Strategy and International Cooperation (NCSC) as part of their week-long visit to the UK arranged by BEIS. Ricardo hosted representatives from NCSC, BEIS and Welsh Government, presenting on compilation and usage of national, devolved, local and city inventories.

13. Knowledge sharing between UKCEH LULUCF inventory compilers and Maltese LULUCF inventory compilers in 2016.

14. In 2018 the UK inventory team collaborated with peers from the EU Working Group 1 to draft a note for circulation to all Member States regarding the fossil carbon content of road transport biofuels, based on our research with the UK fuel supply chain;

15. The UK experts on inventory verification and the InTEM (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.
16. NAEI experts provided capacity building project in the Kyrgyz Republic funded by the World Bank in 2018 (Ricardo with UKCEH).

## 1.6.3  Verification

BEIS has a research programme that derives independent emission estimates for the UK using in-situ high-precision high-frequency atmospheric observations of the Kyoto gases and a range of other trace gases at the Mace Head Atmospheric Research Station on the west coast of the Republic of Ireland. The UK Met Office employs the Lagrangian dispersion model NAME (Numerical Atmospheric dispersion Modelling Environment) to sort the observations made at Mace Head into those that represent northern hemisphere baseline air masses and those that represent regionally polluted air masses arriving from Europe. The Met Office inversion modelling system, InTEM, is then used to estimate the magnitude and spatial distribution of the UK and European emissions that best support the observations and provide a fully independent estimate of annual emission trends for the UK. The technique has been applied to 3 year rolling subsets of the data.

The work was extended to three new sites across the UK, at Angus (north of Dundee), Talcolneston (Norfolk), and Ridge Hill (Herefordshire), to create the UK DECC (Deriving Emissions linked to Climate Change) Network. The Angus site was replaced in 2015 by a site at Bilsdale in the north of England. The data from these additional sites have resulted in significant increases in the spatial and temporal resolution of the InTEM emission estimates, and hence, an improvement in the UK estimates. The uncertainties associated with the UK emission estimates have also decreased.

Most recently a comparison of inventory estimates of HFC-134a with those modelled through the InTEM system has suggested that the inventory may be 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[29].

## 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 EU ETS-regulated installations).

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

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 BEIS using file encryption with password protection;

- Confidential data, such as the EU 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, in order 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 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[30].

## 1.7    GENERAL UNCERTAINTY EVALUATION

### 1.7.1  GHG Inventory

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

Approach 2 (Monte Carlo simulation) suggests that the uncertainty in the combined GWP weighted emissions of all the greenhouse gases is 5% in 1990 and 3% in 2018. The trend in

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

the total GWP weighted emissions expressed as the fall between 1990 and 2018 is -43%, with a 95% confidence interval of between -40% and -46%.

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

## 1.8    GENERAL ASSESSMENT OF COMPLETENESS

### 1.8.1    GHG Inventory

The UK GHG inventory aims to include all anthropogenic sources of GHGs. 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.

**Table 1.14      Summary of Not Estimated (NE) Sources[31]**

| Source | No 2006 IPCC guidelines methodology | Explanation for not estimating | Estimate of Emission (Mt $CO_2e$) | % of national total[32] | Comments on how this estimate was determined |
|---|---|---|---|---|---|
| 1.B.2.b.1 Natural gas exploration - unconventional oil and gas | TRUE | To date there has been no production of natural gas from unconventional shale gas resources in the UK, however the Inventory Agency notes that since 2010 there have been ten shale gas wells spudded in the UK, eight of which have been completed. None of these sites are actively producing gas as UK planning applications have yet to be passed on a site-by-site basis. Therefore, none of the shale gas sites are yet under IED/PRTR regulation by the EA or SEPA, and there are no annual reported emission estimates by operators from their initial well spudding and completion activities. Also, as there has been no production of natural gas at any of these sites, there is no activity data that the inventory agency can use to apply a Tier 1 factor as provided in Table 4.2.4 in section 4.2.2.3 of the Fugitives chapter of the IPCC 2006 Guidelines. Any fugitive emissions from these initial well spudding and completion activities are expected to be well below the threshold of significance for UK reporting for sources that are Not Estimated. We note that using the fugitive EF 0.0023 Gg $CH_4$ per million $m^3$ gas produced, from Table 4.2.4 of the IPCC 2006 Guidelines (the upper value in the table, for onshore gas production) that for the source to exceed the 0.05% value of annual reported UK GHGI emissions from 2010 to 2016 would require an annual production each year of over 4,000 million $m^3$ gas. Annual production each year at these well sites to date is zero. | 0.0457 | 0.010% | This estimate is derived by applying the implied emissions per well explored to the number of shale wells explored, and assuming that all shale well exploration emissions occurred in one year. |
| 2.A.4.a Ceramics - non-brick ceramics | | There are limited data on non-brick ceramic products and how much emissions associated with producing these products are already accounted for in existing estimates of ceramics manufacture. | 0.0280 | 0.006% | Based on expert review team assessment, which estimated that if the share of clay consumption for ceramic products other than bricks was the same in 2017 as in the period 2008–2012, emissions from these other ceramic products would be about 28 kt $CO_2$ eq. |

[31] Where IE means "included elsewhere"

[32] Specifically the lowest national total annual emissions excluding LULUCF since 1990 with either UNFCCC or KP geographical coverage

| Source | No 2006 IPCC guidelines methodology | Explanation for not estimating | Estimate of Emission (Mt $CO_2e$) | % of national total[32] | 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 | 0.0025 | 0.001% | 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. |

| Source | No 2006 IPCC guidelines methodology | Explanation for not estimating | Estimate of Emission (Mt $CO_2e$) | % of national total[32] | Comments on how this estimate was determined |
|---|---|---|---|---|---|
| 3.D Agricultural Soils - $CH_4$ | TRUE | We have a very limited dataset and the science around this source is not currently well understood and therefore we are not currently able to generate a robust estimate of emissions. Note that there is no methodology presented for this source in the 2006 IPCC guidelines (including the 2019 refinement), and therefore generating an estimate for this source would be surplus to reporting obligations. While we are aware that other organisations have identified this as a potential gap in estimates, we are not aware of any countries that have been able to generate a robust estimate for inclusion in their inventory. The UK will consider further investigating this source in the improvement programme, but note that as this is surplus to requirement, it will be given lower priority to improvement work relating to sources we are obligated to estimate. | 6.25 | 1.344% | Taken from North Wyke Research, 'An appraisal of unknown sources/sinks of GHG, ammonia and other emissions from UK land management (including agriculture)', 2008[33]. |
| 3.F Field burning - Overseas Territories | | Data on Overseas Territory activity for this source are not available. | 0.0004 | 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. | 0.0022 | 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.H Urea application - Overseas Territories | | Data on Overseas Territory activity for this source are not available. | 0.0006 | 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. |

[33] http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=14937

| Source | No 2006 IPCC guidelines methodology | Explanation for not estimating | Estimate of Emission (Mt $CO_2e$) | % of national total[32] | Comments on how this estimate was determined |
|---|---|---|---|---|---|
| 4(II) Emissions and removals from drainage of organic and mineral soils | TRUE | Insufficient information for reporting $CH_4$ emissions from drainage. | NE | NE | The UK is developing an approach to estimating emissions from this source, but do not currently have suitable data to present. |
| 4(II) Emissions and removals from rewetting of organic and mineral soils | TRUE | Insufficient information for reporting emissions from rewetting. | NE | NE | The UK is developing an approach to estimating emissions from this source, but do not currently have suitable data to present. |
| 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. | 0.0366 | 0.008% | 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[32] | 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. | 0.1837 | 0.039% | 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. |
| 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 $CO_2$.<br>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. |

| Source | No 2006 IPCC guidelines methodology | Explanation for not estimating | Estimate of Emission (Mt $CO_2e$) | % of national total[32] | Comments on how this estimate was determined |
|---|---|---|---|---|---|
| 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. |
| 5.C.2 Open Burning of Waste/Accidental fires - $CO_2$ and $N_2O$ | TRUE | No suitable emission factor has been identified, emissions are believed to be negligible. | 0.0395 | 0.008% | Conservatively uses the highest activity data since 1990 and highest comparable combustion factors. |
| 5.D.2 Industrial Wastewater - $N_2O$ | TRUE | Emissions are believed to be insignificant compared to domestic wastewater, and no method is provided. | 0.0587 | 0.013% | Based on latest data available (mostly 2017) and the methodology presented in the 2019 refinement to the 2006 IPCC guidelines. Assumptions are chosen to be consistent with the methane estimates or consistent with PRTR Nitrogen releases to water, whichever is higher. Methane estimates from this source are believed to be very conservative, so while this is not necessarily a conservative estimate of $N_2O$ emissions from this source, if this estimate were included, overall emissions from this source would remain conservative. Note that the IPCC default methodology for Nitrogen releases to water is similar to the PRTR estimate, although the sectoral breakdown is quite different. |
| **Total** | | | **6.6555** | **1.431%** | |
| **Total excluding sources for which there is no 2006 IPCC guidelines methodology** | | | **0.0361** | **0.008%** | |

This summary confirmed that there are no sources for which emissions are not estimated with the main justification being that they are 'insignificant' which would be expected to be above 0.05% of the UK national total in any year, and that the sum of these sources is below 0.1%.

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. Note that with the exception of methane from agricultural soils, the sources reported as "NE" due to there not being a suitable methodology to generate an estimate are also each less than 0.05% of the national total and the sum of these are less than 0.1%.

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

# 2 Trends in Greenhouse Gas Emissions

**Figure 2.1    Total GWP weighted emissions by sector[34]**



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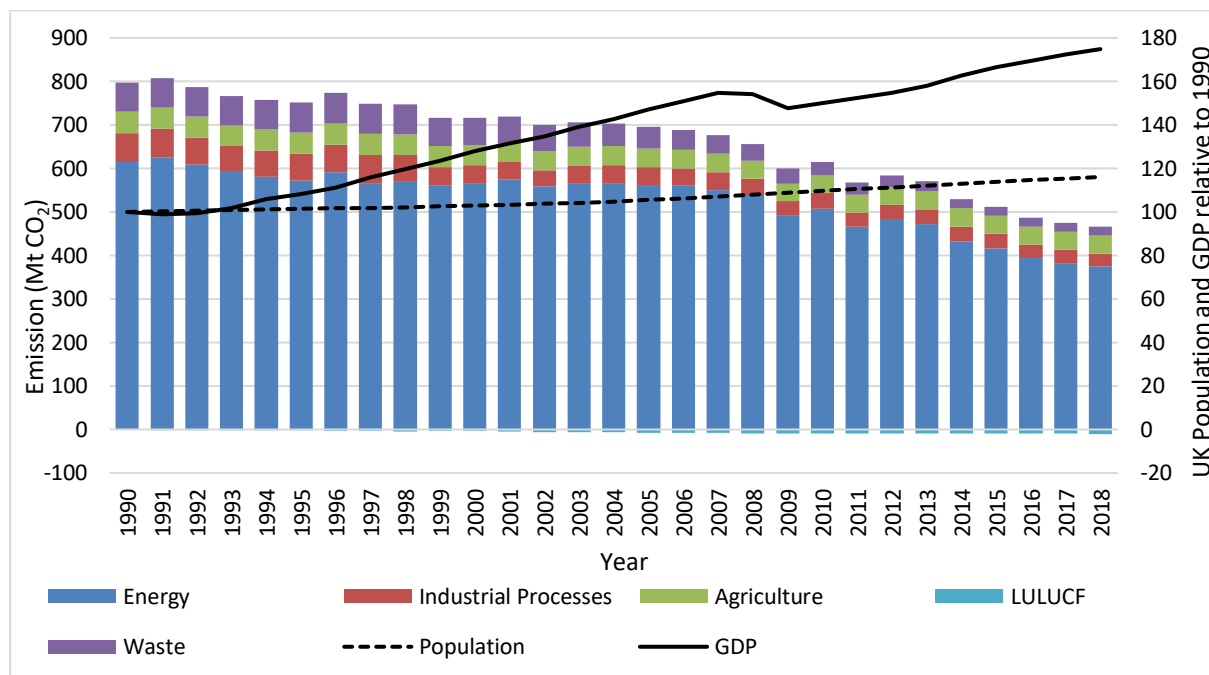
[34] Note that LULUCF is a net sink in most years, so appears below the x-axis.

**Figure 2.2** **Trends in emissions by sector relative to 1990[35]**
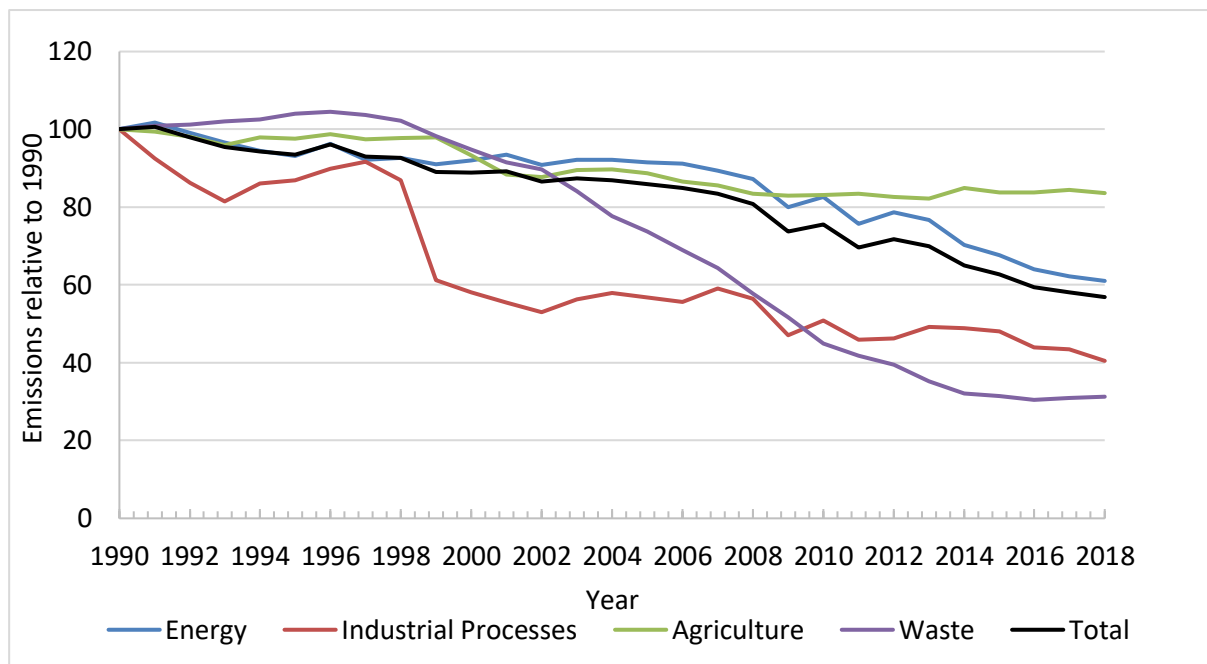


**Figure 2.3** **Contribution to National totals in the selected years and to overall trends between selected years by sector[36]**



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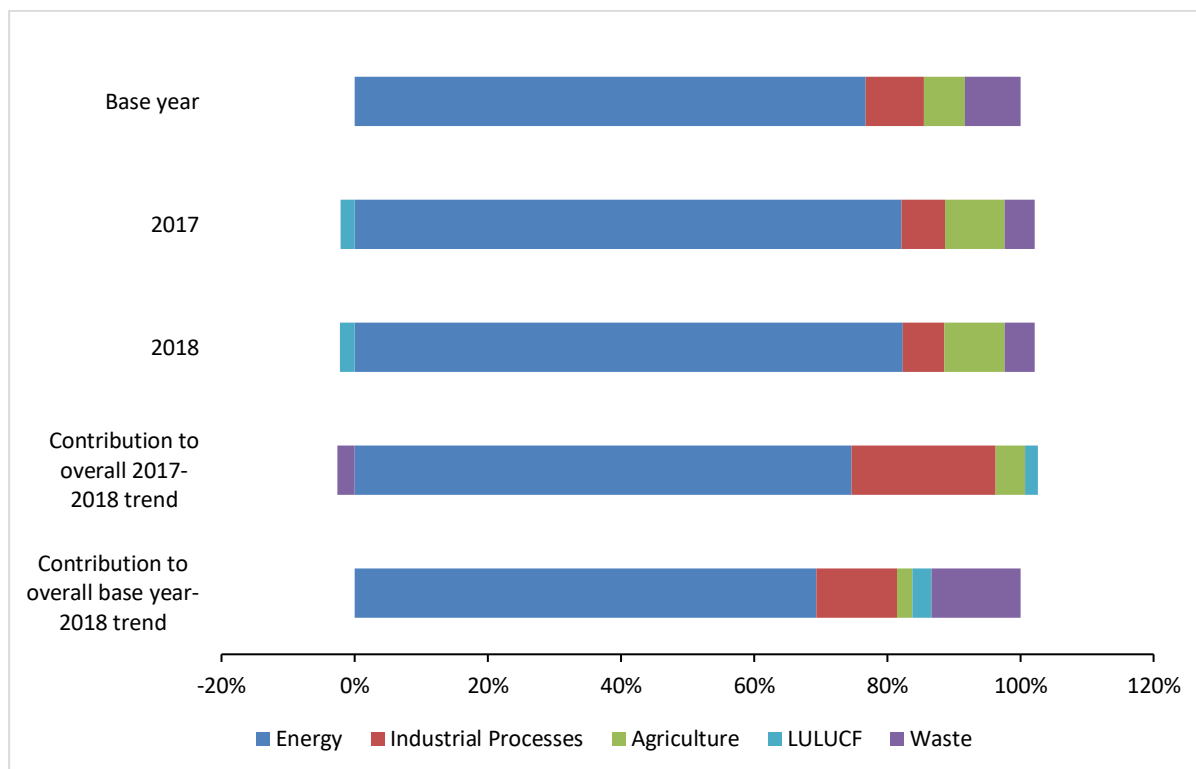
[35] LULUCF omitted from graph as it is a combination of sinks and sources of emissions; this makes it challenging to representatively present in this format.

[36] 'Base year' refers to 1990 for $CO_2$, $CH_4$ and $N_2O$, or 1995 for F-gases.

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As shown in **Figure 2.1** and **Figure 2.2**, total emissions of direct GHGs have decreased since 1990. **Figure 2.3** illustrates that this decline is driven predominantly by a decrease in emissions from the energy sector – particularly from power stations. The decline between 2017 and 2018 is primarily due to a significant switching from coal use to other, less carbon intensive fuels and renewables (see **Section 2.1**). Total emissions are dominated by the energy sector across the time series. Emissions from all sectors have declined, with the largest decline in percentage terms from Land Use, Land-Use Change and Forestry (LULUCF). In addition to being a source of emissions, the LULUCF sector has become a carbon sink of increased magnitude since 1990, i.e. it provides a mechanism by which atmospheric carbon is captured and sequestered. In absolute terms, the largest overall decline is in the energy sector.

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

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

**Figure 2.4**     **GHG emission reductions progress against Kyoto Protocol (KP) Commitment Periods (CP1 and CP2)[37]**
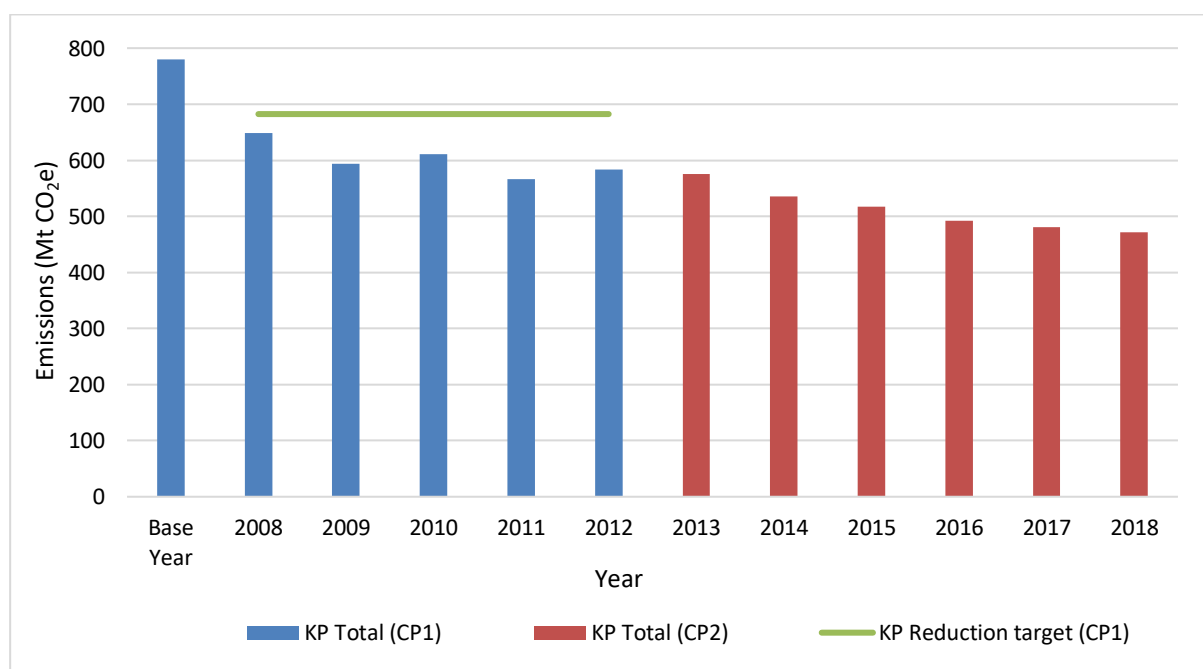


A summary of the contribution of each GHG to the emission trends is provided below. The subsequent sections of this chapter provide an interpretation of emission trends, primarily focusing on the trends by source sector.

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

**Figure 2.5** **Trends in emissions by gas relative to 1990[38]**
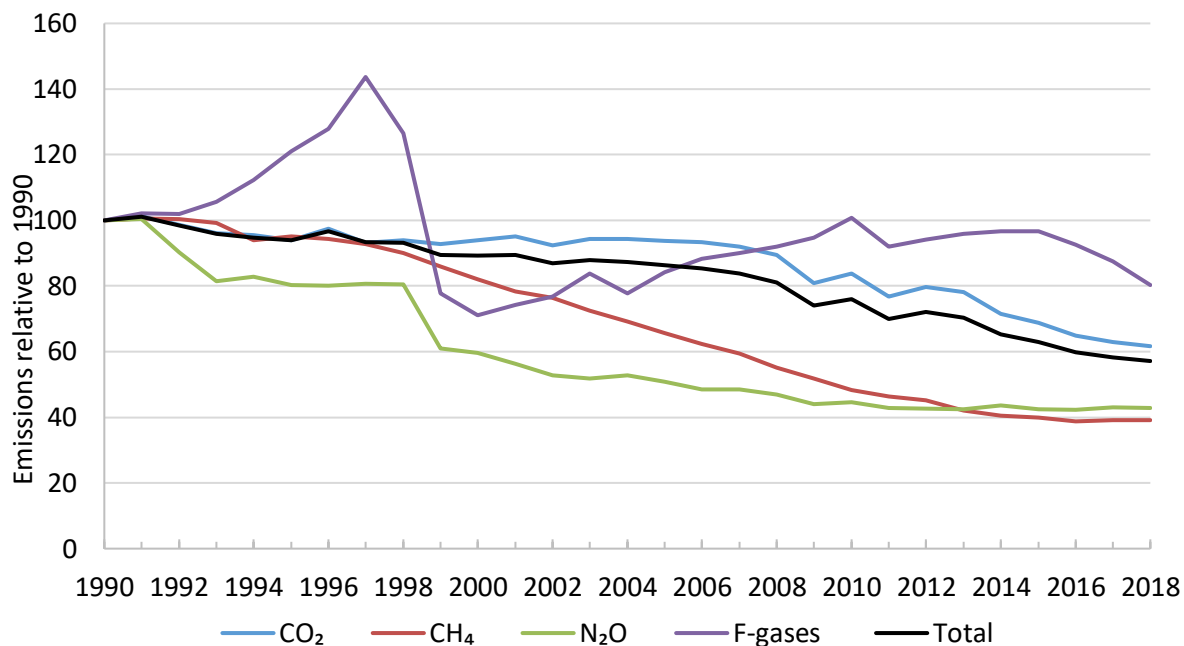


**Figure 2.6** **Contribution to National totals in the selected years and to overall trends between selected years by gas**
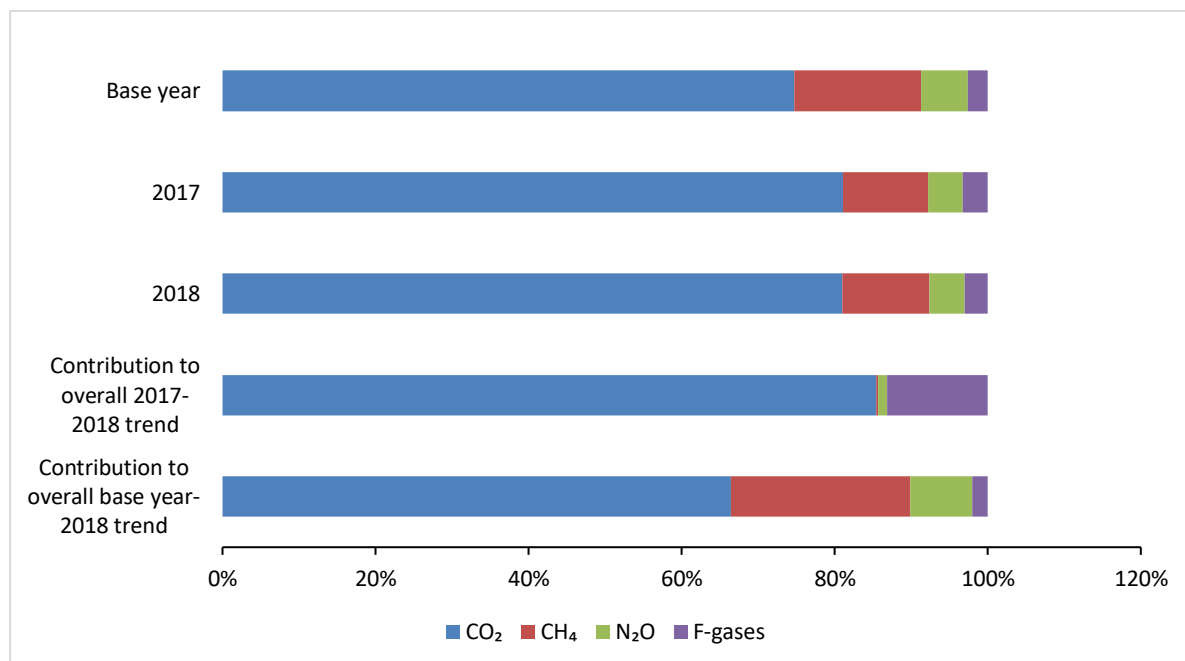


**Figure 2.5** presents the contribution of each GHG to the UK emissions trend:

- 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

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[38] 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).

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 1% 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 2.7** **Total GWP weighted emissions in the energy sector compared to primary energy demand**
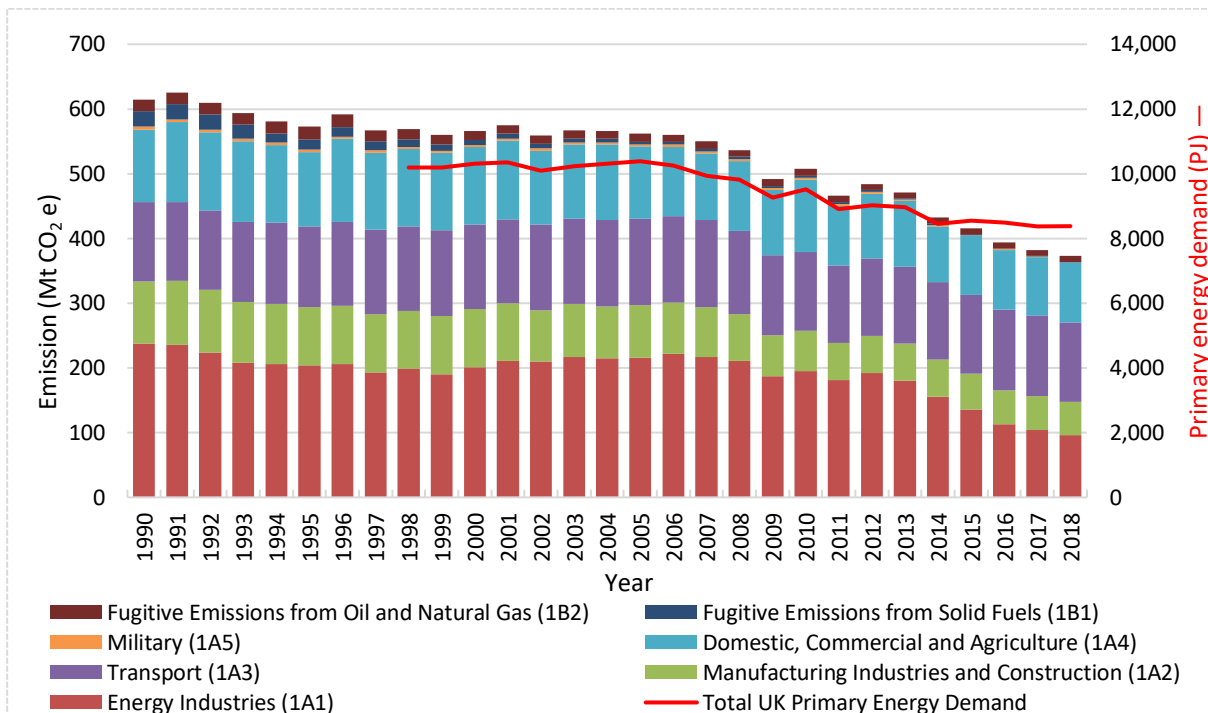


**Figure 2.8** **Trends in Energy emissions by sub-sector relative to 1990**
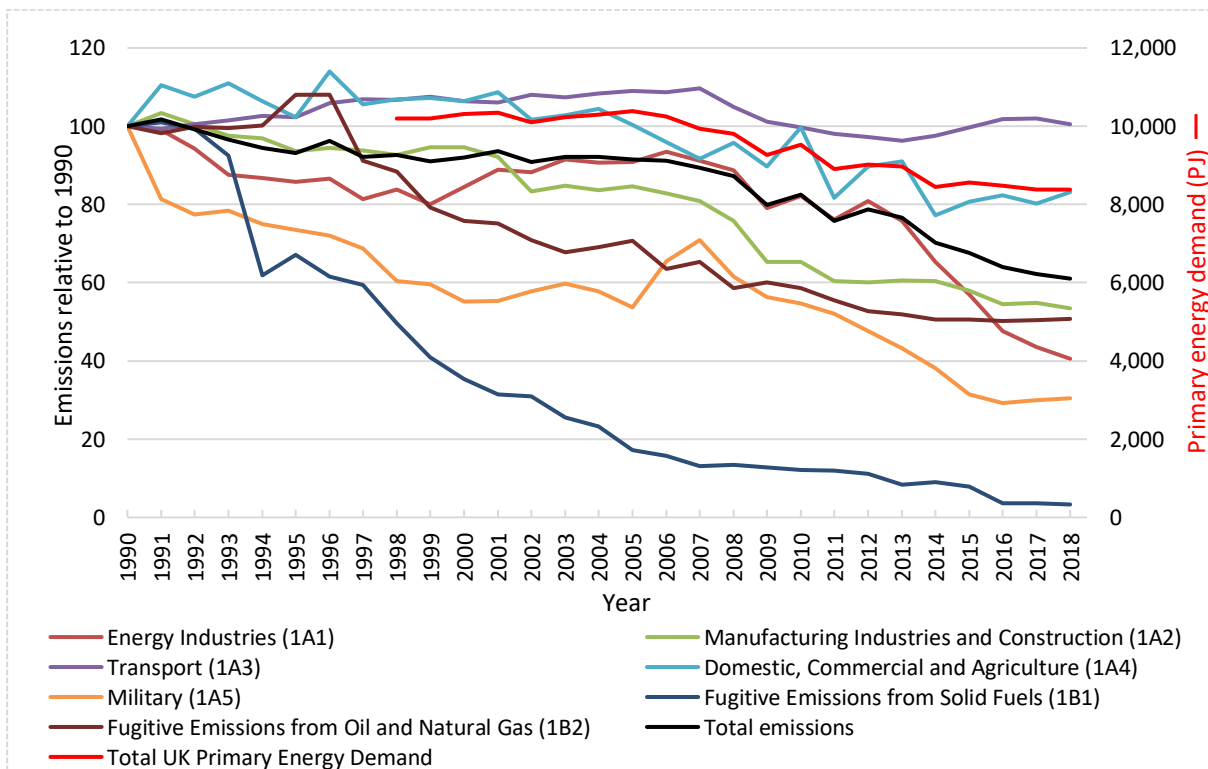
**Figure 2.9** **Contribution to totals in the selected years and to overall sectoral trends between selected years by sub-sector for Energy**
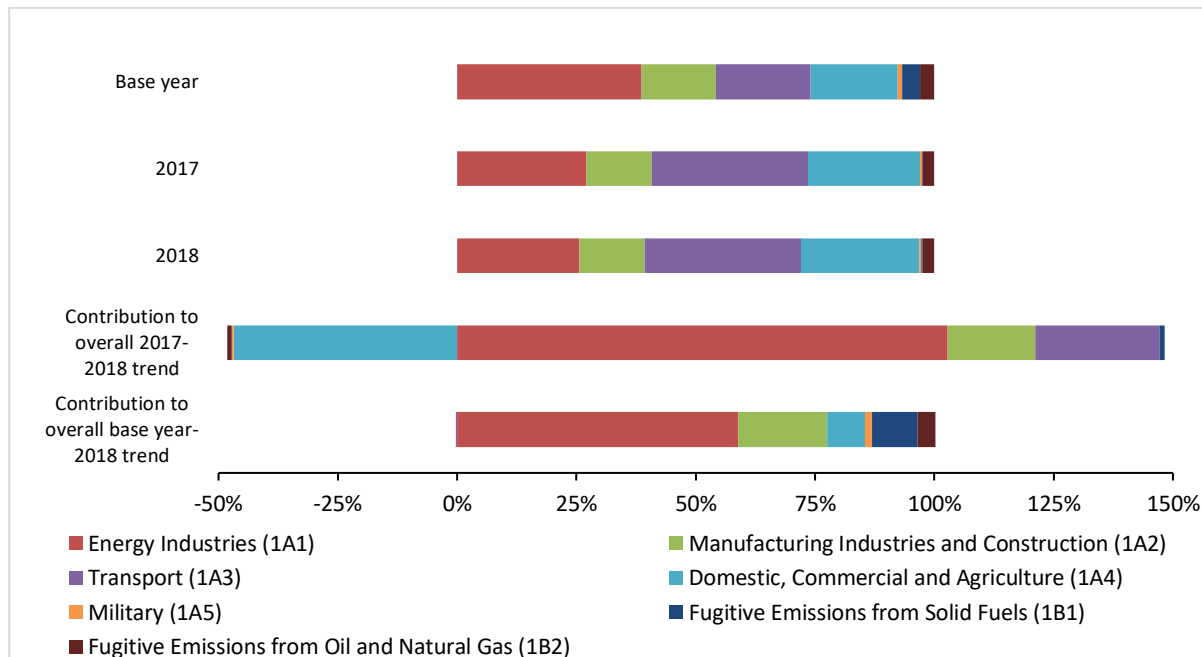


The energy sector GHG emissions are primarily $CO_2$ from fossil fuel combustion in power generation, transport, manufacturing and construction, and other stationary and mobile fuel combustion. The supply of fossil fuels also leads to significant emissions of $CH_4$ from fugitive emission sources, such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

**Figure 2.8** shows that energy sector emissions have declined since 1990. Emission reductions are due primarily to improvements in energy efficiency, and economy-wide fuel-switching from carbon-intensive fossil fuels such as coal, to greater 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 2.10        Fuel mix of energy generation**
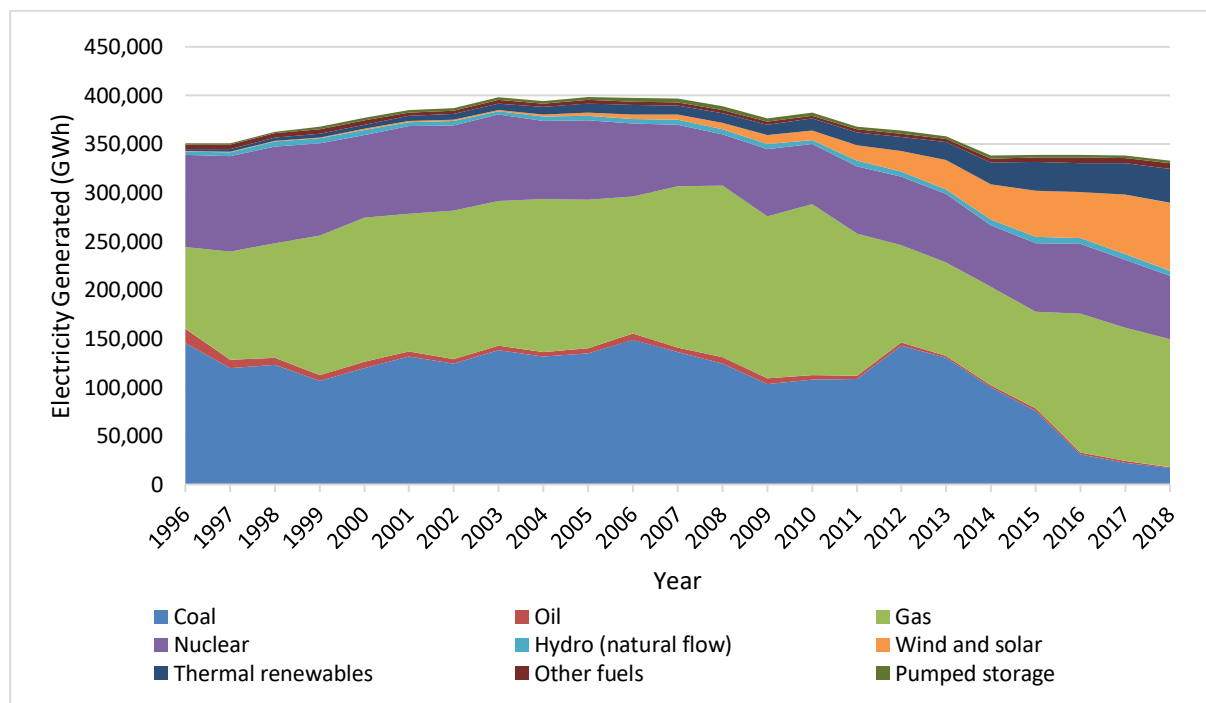


There are several reasons for the decline in emissions from the power generation sector since 1990, including:

- the UK power sector fuel mix has shifted towards use of Combined Cycle Gas Turbine (CCGT) stations rather than conventional steam stations burning coal or oil. CCGT stations operate at a higher thermal efficiency, for example in 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 nearly half since 1990. This is largely a result of reduced consumption of gas oil, fuel oil, coal, and natural gas, partly offset by increases in burning oil and LPG within the sector.

### 2.1.2.3 Transport

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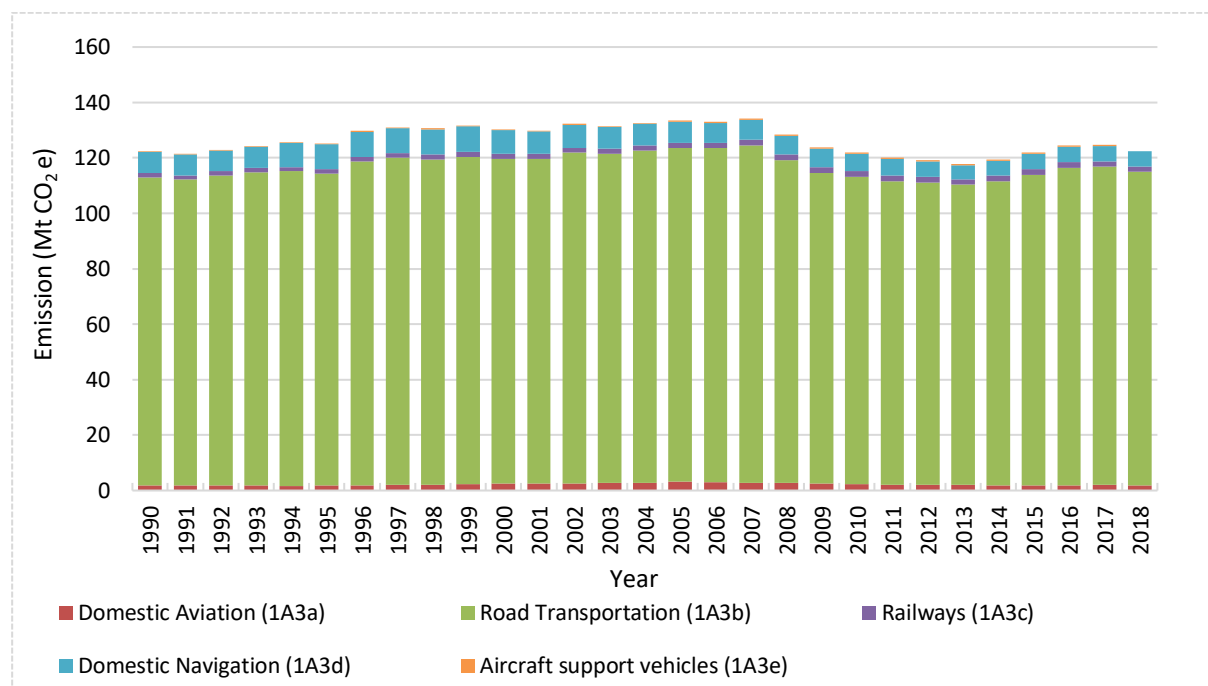


Emissions from the Transport sector are dominated by road transport, which peaked in 2007, but have declined since 2007, and by 2018 are back almost exactly to 1990 levels. This is driven by a number of factors, including:

- Increases in vehicle kilometres in most years, except for a few years after 2007;
- Improvements in the fuel efficiency of engines in the UK fleet;
- Increases in the typical weight of passenger cars, increasing the energy needed to propel them;
- Increase in energy requirement for additional applications, like air conditioning;
- Fuel switching from petrol to diesel, improving fuel efficiency, but in some cases resulting in higher $N_2O$ 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[39].

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

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

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[39] 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**.

#### 2.1.2.4 Domestic, Commercial and Agriculture

Emissions from domestic fuel combustion dominates emissions from the Domestic, Commercial and Agriculture sector. Emissions from this sector changed little between 1990 and 2009 but have declined more recently. The effect of annual temperatures can produce 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 2.12**    **Total GWP weighted emissions in the Industrial Process and Product Use sector**
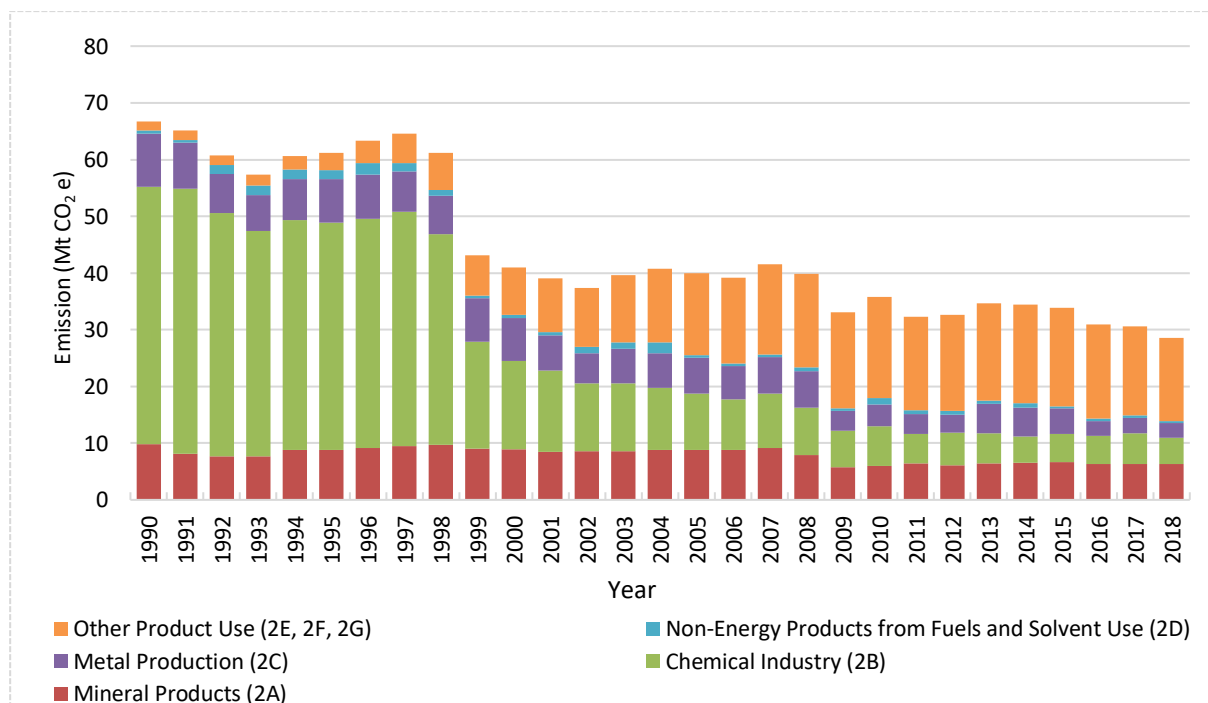
**Figure 2.13**    **Trends in emissions from Industrial Processes and Product Use by sub-sector, relative to 1990[40]**
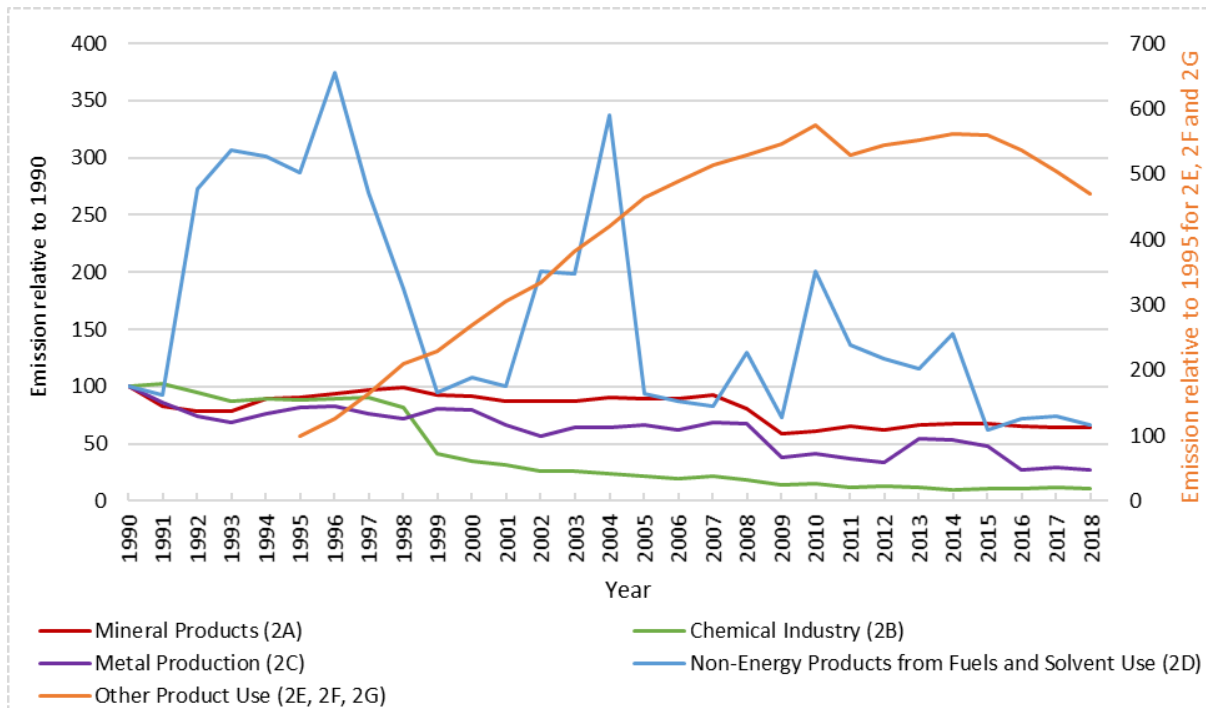


**Figure 2.14**    **Contribution to totals in the selected years and to overall sectoral trends between selected years by sub-sector for Industrial Processes and Product Use**
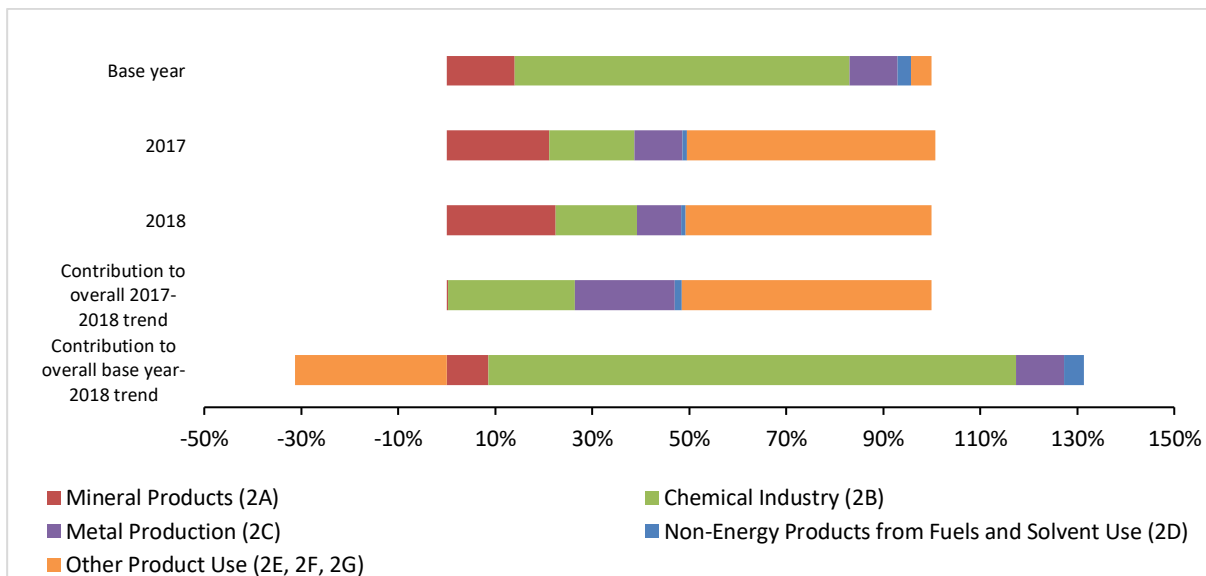


The Industrial Processes and Product Use (IPPU) sector accounts for all GHG emissions from industrial sources[41] and product use including solvents. Just under half of IPPU emissions are now $CO_2$, although this only contributes to small proportion of total $CO_2$ emissions. All F-gas

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

[41] 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

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 2.15** - **Figure 2.17**). The declining trend in IPPU emissions in the UK (see **Figure 2.12**) is partly due to the closure of numerous UK installations, including several integrated steelworks, primary aluminium works, chemical production sites and cement kilns, as well as the installation of abatement equipment, for example at adipic and nitric acid plant and by F-gas manufacturers. The declining trend in emissions is also a reflection of decreasing production of many industrial materials in the UK, most notably in the chemicals and steel sectors. A large number of closures in the period 2007-2009 were due to decreased demand for many products as a result of the general economic situation in the UK and elsewhere, with falling demand for steel, cement, bricks, and aluminium, for example, leading to plant closures. The large step-change in chemical sector emissions in 1998-1999 was due to the fitting of $N_2O$ 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 brought forward the plateaux in HFC emissions and the downturn since 2014.

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

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

### 2.2.2.2 Mineral Industry

**Figure 2.15    Trends in the number of mineral process sites[42]**
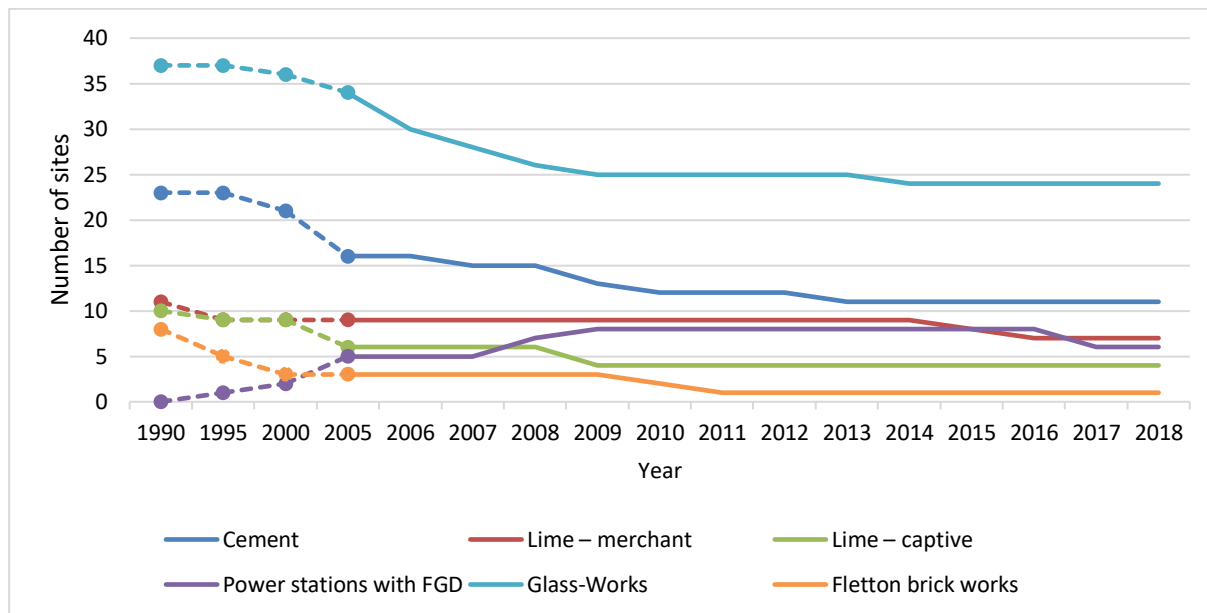


Annual $CO_2$ emissions from cement manufacture comprised 70% of total mineral sector $CO_2$ emissions in 2018, but have fallen by 40% since 1990 due to the closure of many kilns and decreasing UK clinker production. Emissions fell to a low point of 3.7 $MtCO_2$ in 2009 due to the impact of the recession 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 11%; brick manufacturing emissions are down by 49%. Emissions from other product uses of carbonates (including soda ash applications which have been included in the inventory for the first time) have increased by 60% since 1990, this being due to the growth in the use of carbonates for flue gas treatment. However emissions are still only 2% of total mineral sector $CO_2$ emissions in 2018. Chemical Industry

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[42] 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

**Figure 2.16    Trends in the number of chemical process sites**
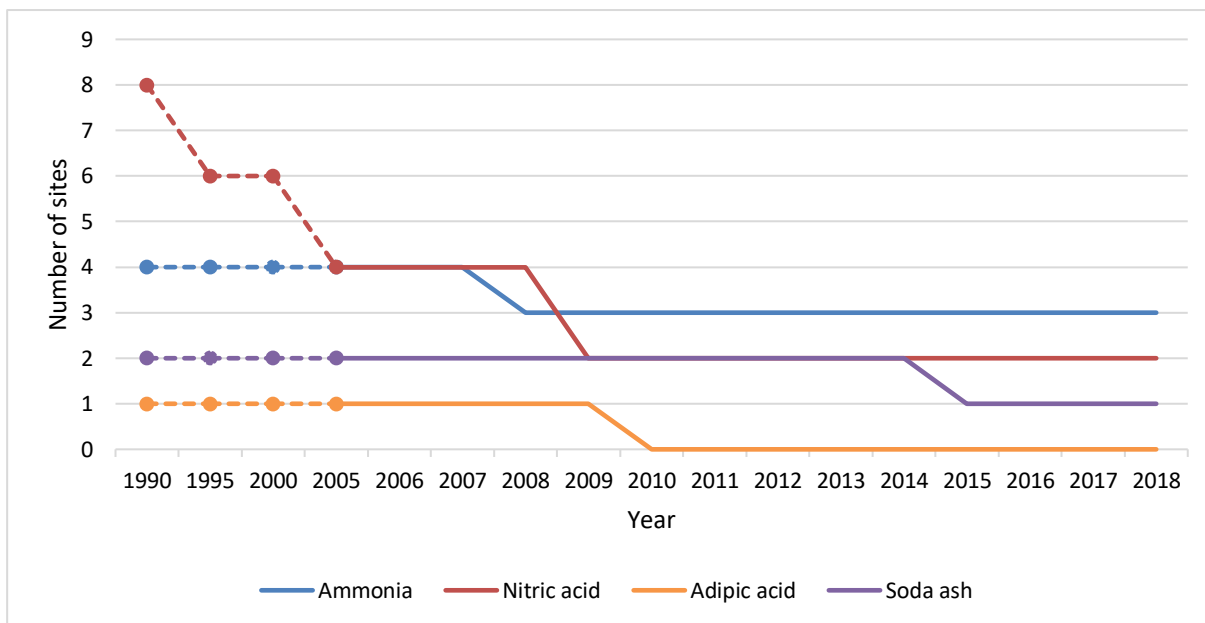


Emissions from adipic acid manufacture were reduced significantly in 1999, approximately half of the total fall in chemical sector emissions in that year, due to the retrofitting of an emissions abatement system to the only adipic acid plant in the UK, which subsequently closed in April 2009.

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

$N_2O$ 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.

### 2.2.2.3 Metal Production

**Figure 2.17 Trends in the number of metal process sites[43]**
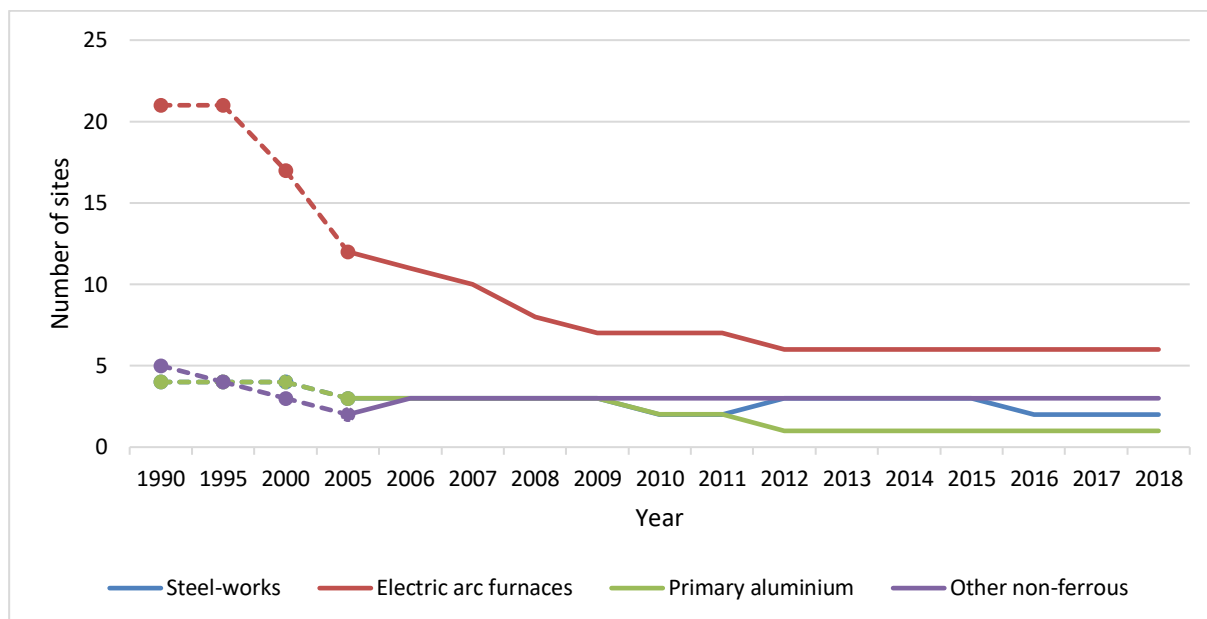


GHG emissions from across the UK metal production sector have fallen by around 73% since 1990, with every sector showing a marked reduction in production levels and emissions over the time series. The largest contributor to the UK trends is the closure of several large integrated steelworks and a decline in UK steel output, leading to Iron & Steel (I&S) sector IPPU $CO_2$ emissions down by 59% (across 2C1a-2C1d), which accounts for 66% 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 46% 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 45% decline in $CO_2$ emissions in 2015-2016, with total IPPU emissions (2c1a-2C1d) thereafter stabilizing at around 2.3 to 2.5 $MtCO_2$.

The production of primary aluminium has also declined significantly across the time series, with $CO_2$ emissions down by 85% 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 over a quarter 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.

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

## 2.3    AGRICULTURE

### 2.3.1  Overview

**Figure 2.18      Total GWP weighted emissions in the Agriculture sector[44]**
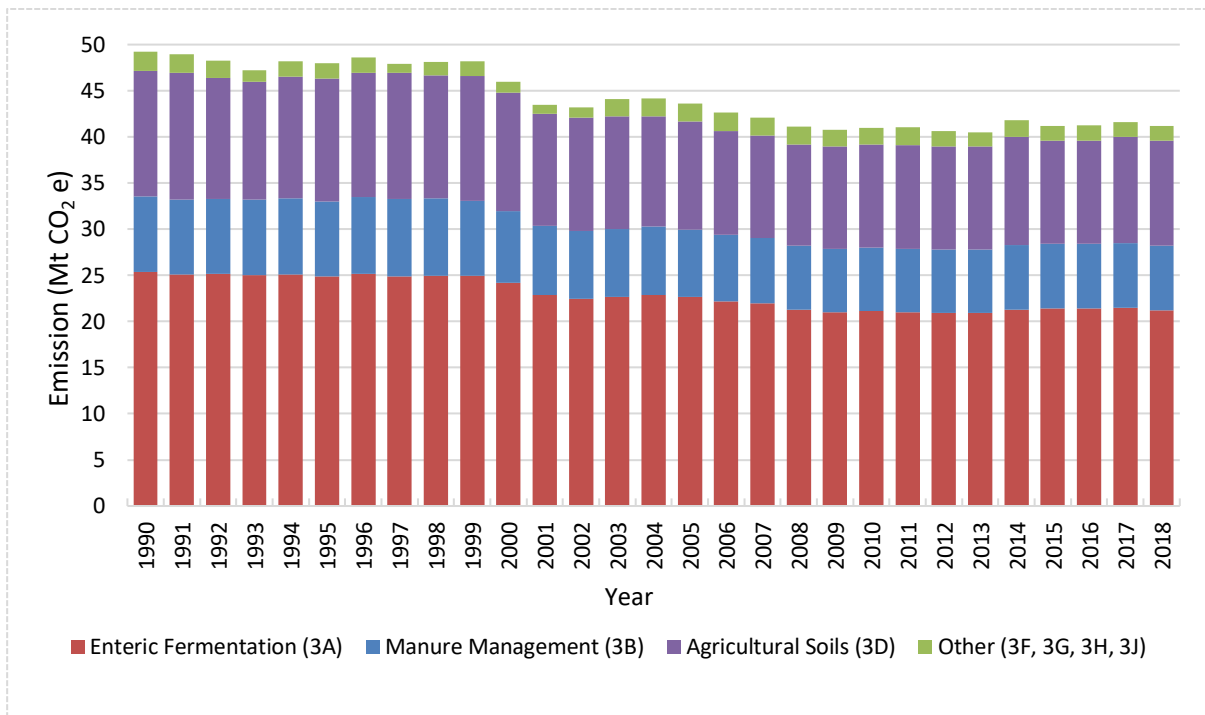


**Figure 2.19      Trends in emissions from Agriculture by sub-sector, relative to 1990[44]**



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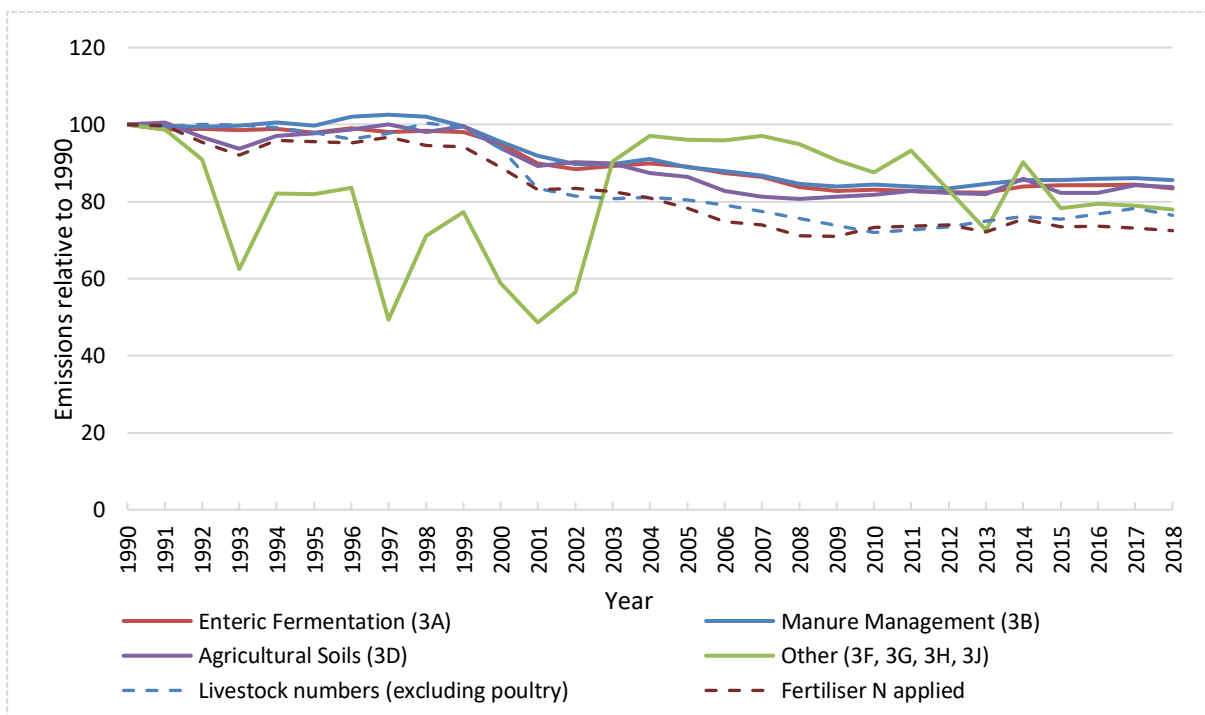
[44] 'Other' refers to the following IPCC sectors: Field Burning of Agricultural Wastes (3F), Liming (3G), Urea Application (3H), and Overseas Territory and Crown Dependency Agriculture Emissions (3J)

**Figure 2.20**    **Contribution to totals in the selected years and to overall sectoral trends between selected years by sub-sector for Agriculture[44]**
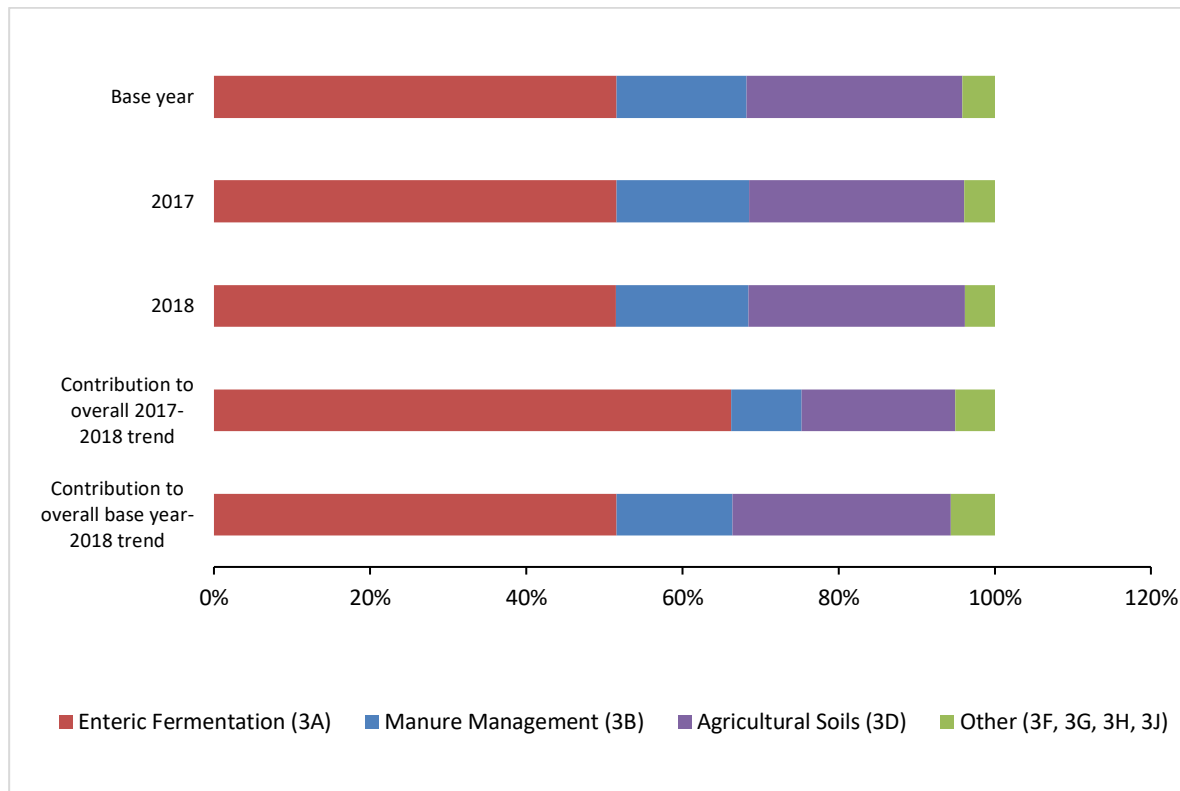


In the UK, the Agriculture sector is dominated by $CH_4$ emissions from livestock generated through enteric fermentation (animal digestion processes), and from $N_2O$ emissions from manure management and fertiliser application. The emissions from this sector have shown an overall decrease since 1990, 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 ($CH_4$) and manure ($N_2O$) from cattle. This is, in turn, due to decreased cattle numbers.

### 2.3.2.2    Agricultural Soils

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

## 2.4    LAND USE, LAND-USE CHANGE AND FORESTRY

### 2.4.1  Overview

**Figure 2.21        Total GWP weighted emissions in the LULUCF sector**
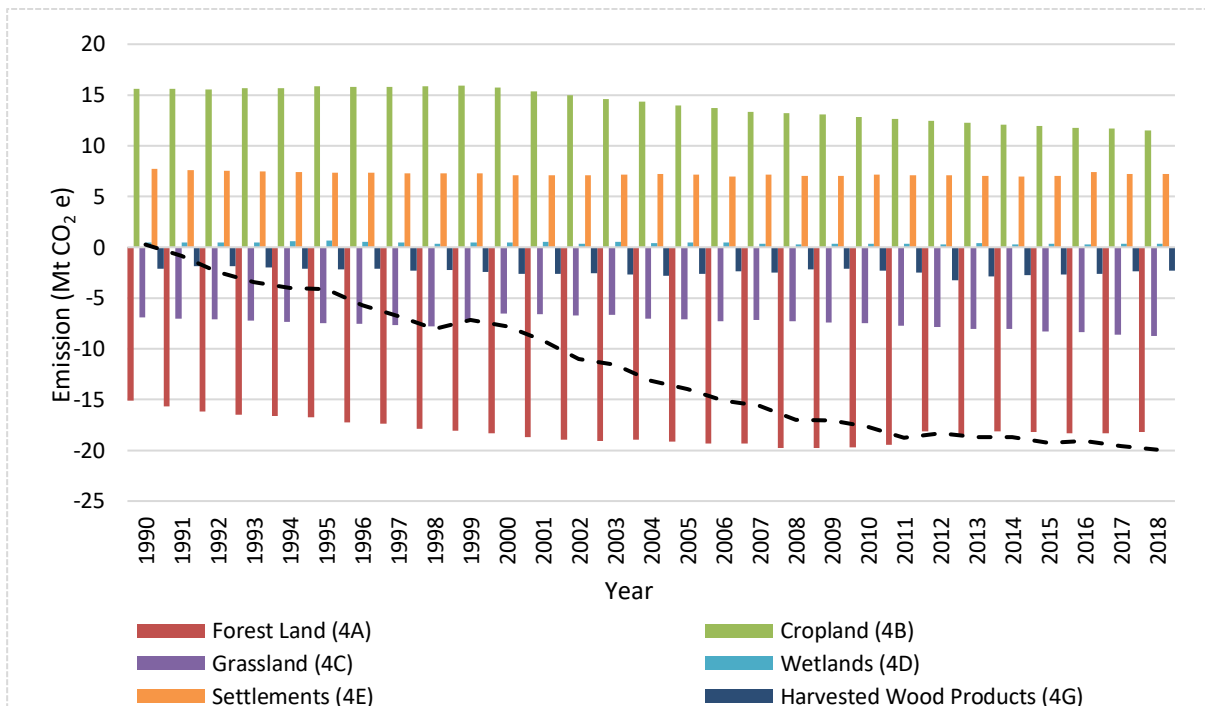


**Figure 2.22        Trends in net emissions/sinks from LULUCF by sub-sector, relative to 1990[45]**



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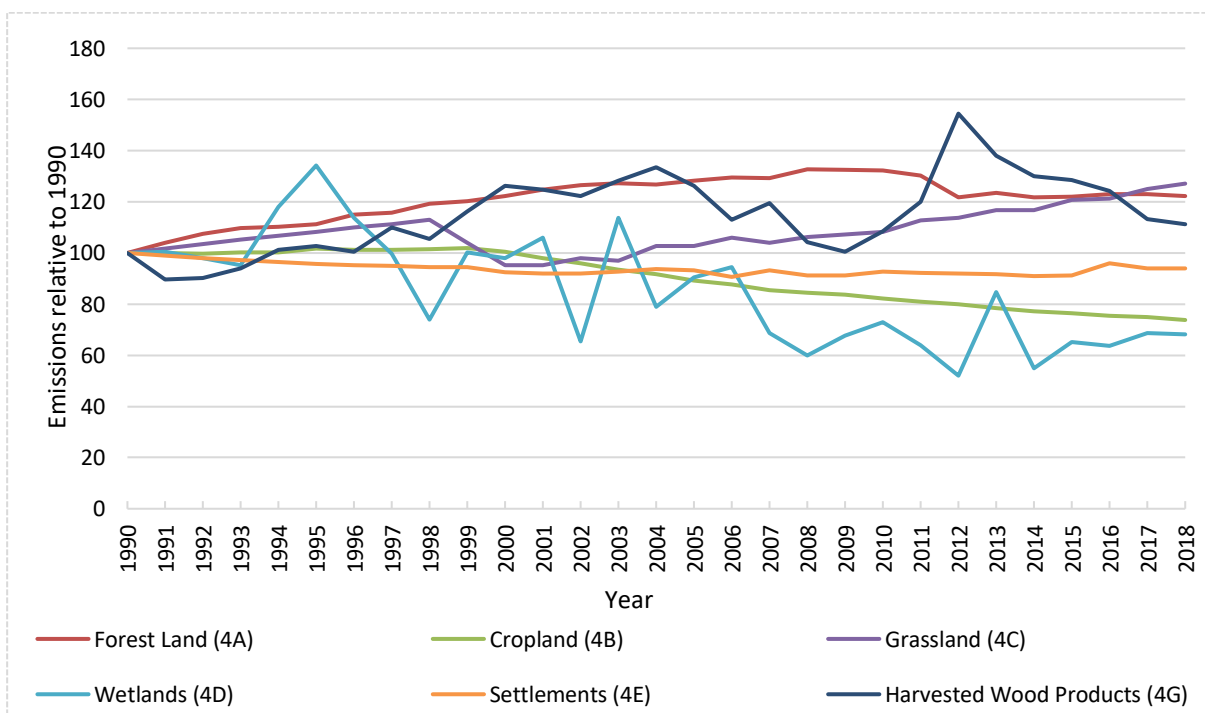
[45] Some of these are trends in the size of the net sink rather than net emissions.

The Land Use, Land-Use Change and Forestry (LULUCF) sector is the only sector within the national GHG inventory to report net removals. The net sink is provided by removals from carbon stock gains in above- and below-ground biomass, soils and harvested wood products exceeding emissions from carbon stock losses and GHG emissions from LULUCF activities. The LULUCF sector is a source of $CH_4$ and $N_2O$, but these are small in relation to carbon fluxes which are accounted for as $CO_2$ equivalent.

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

## 2.4.2 Emission trends in LULUCF sub-sectors

### 2.4.2.1 Forest land

The size of the Forest land sink increased significantly by 30% between 1990 and 2010 but has levelled off to around 20% 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 2010 but these forests are now reaching harvesting age, with associated carbon losses and transfer to the Harvested Wood Products category. Harvested areas are replanted but the replacement young trees have also much lower rates of carbon stock increase. As a result there is a progressively decreasing stock in tree biomass and litter, offset by an increasing carbon stock in soils (BEIS 2019). Afforestation rates have also reduced substantially since 1990.

### 2.4.2.2 Cropland & grassland

Annual emissions from cropland have decreased significantly since 1990 and annual removals from the grassland sink have also increased since 2003. This is due to lower rates of land use conversion since 2000, compared to rates of conversion before 2000 (based on Countryside Surveys in 1990, 1998 and 2007).

### 2.4.2.3 Harvested wood products

Annual removals due to harvested wood products (HWP) are variable over time, but have increased significantly in relative terms since 2009. 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 2.21**). 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 cabon 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 2.23        Total GWP weighted emissions in the Waste sector**
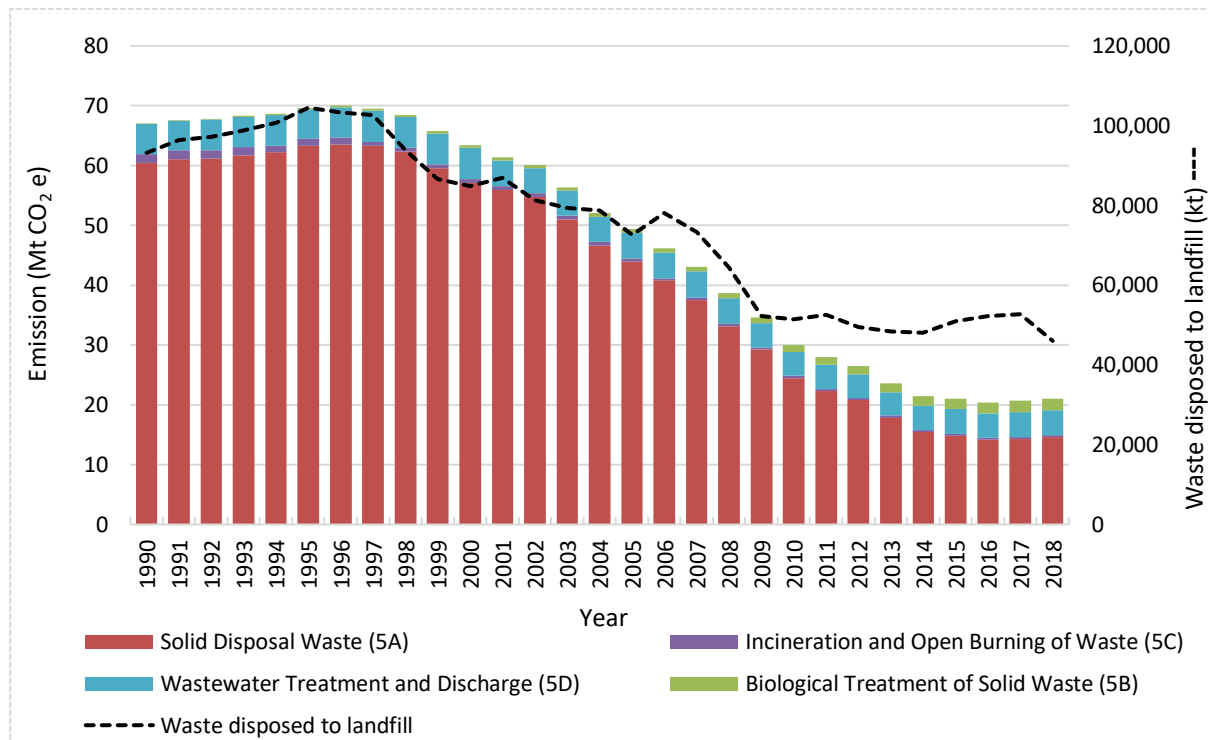


**Figure 2.24        Trends in emissions from Waste by sub-sector, relative to 1990**
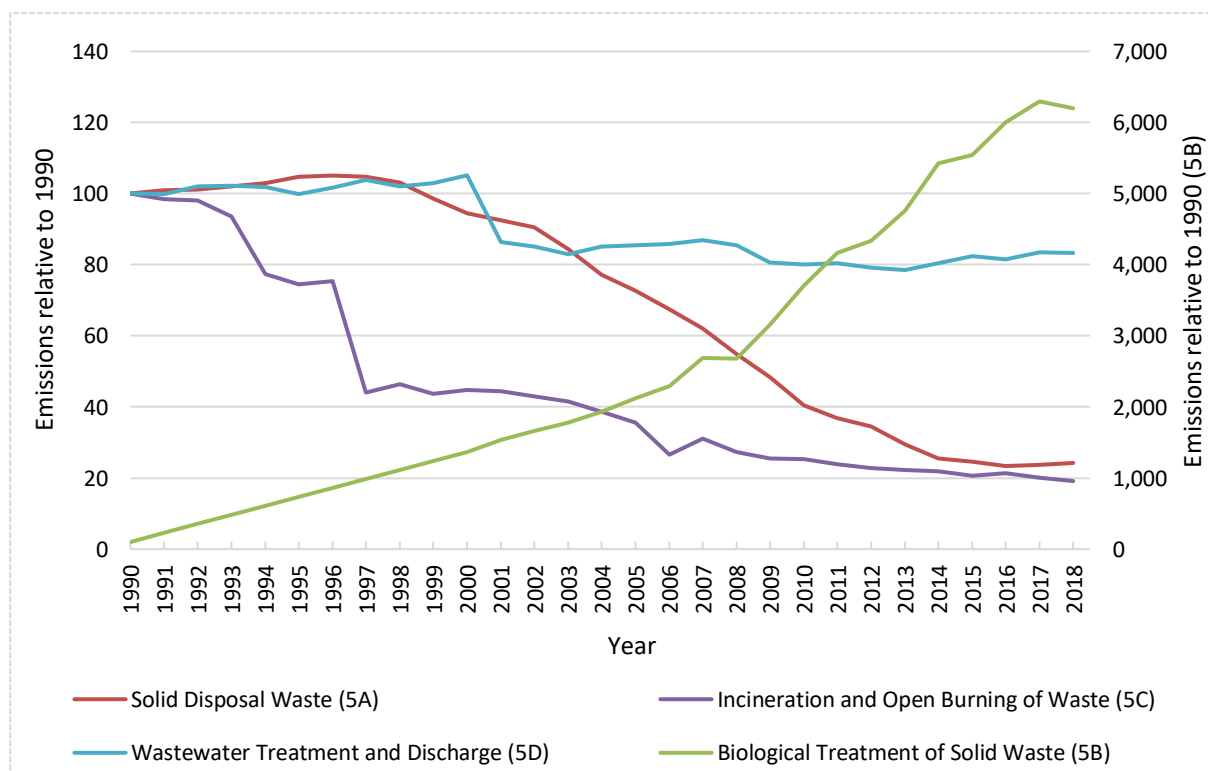
**Figure 2.25** **Contribution to totals in the selected years and to overall sectoral trends between selected years by sub-sector for Waste**
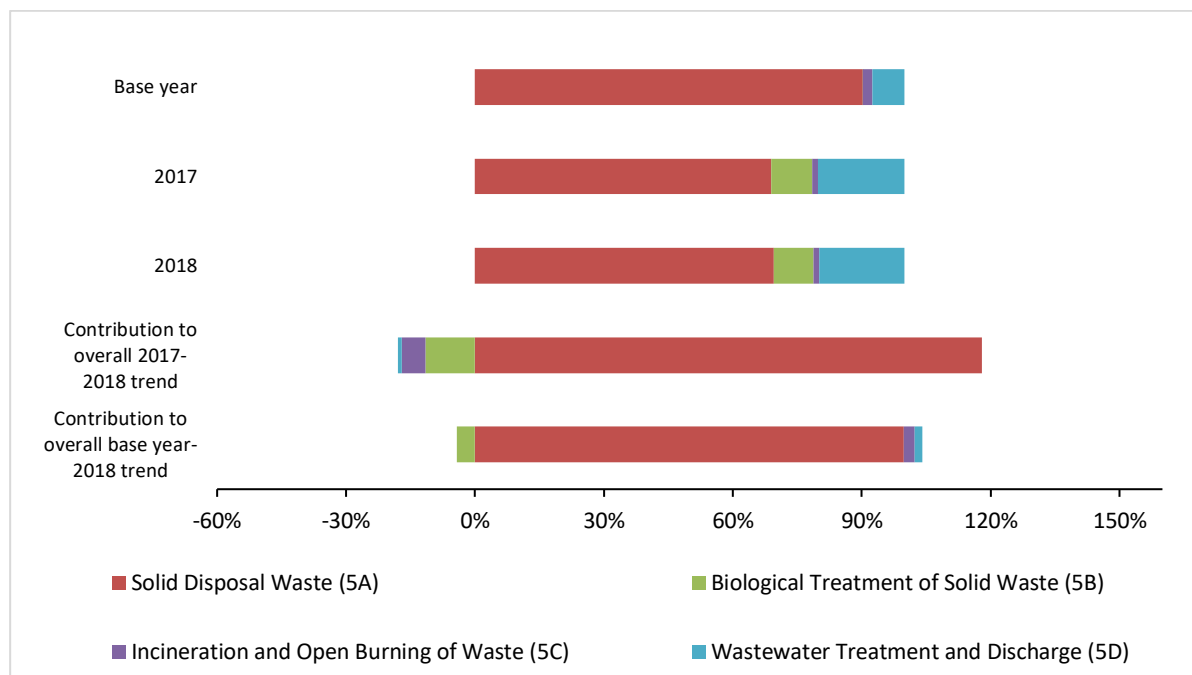


The Waste sector accounts for all emissions generated from waste treatment and disposal. Emissions generated from energy recovery from waste are accounted for in the Energy sector. In the UK, emissions from the waste sector are dominated by $CH_4$ emissions from landfill sites.

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

## 2.5.2 Emission trends in Waste Management sub-sectors

### 2.5.2.1 Solid waste disposal

Almost all of the reduction in UK GHG emissions across the Waste sector is due to a decline in $CH_4$ 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 retro-fitting boilers to raise electricity, and therefore from 1997 onwards all "energy from waste" plant emissions from the incineration of MSW are reported in the power generation sector of the inventory, in 1A1a.

### 2.5.2.4   Biological treatment of solid waste

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

## 2.6   EMISSION TRENDS FOR INDIRECT GREENHOUSE GASES AND 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 2.26**. Significant reductions of all indirect GHGs and SO$_2$ have occurred since 1990.

**Figure 2.26     UK Emissions of Indirect Greenhouse Gases**
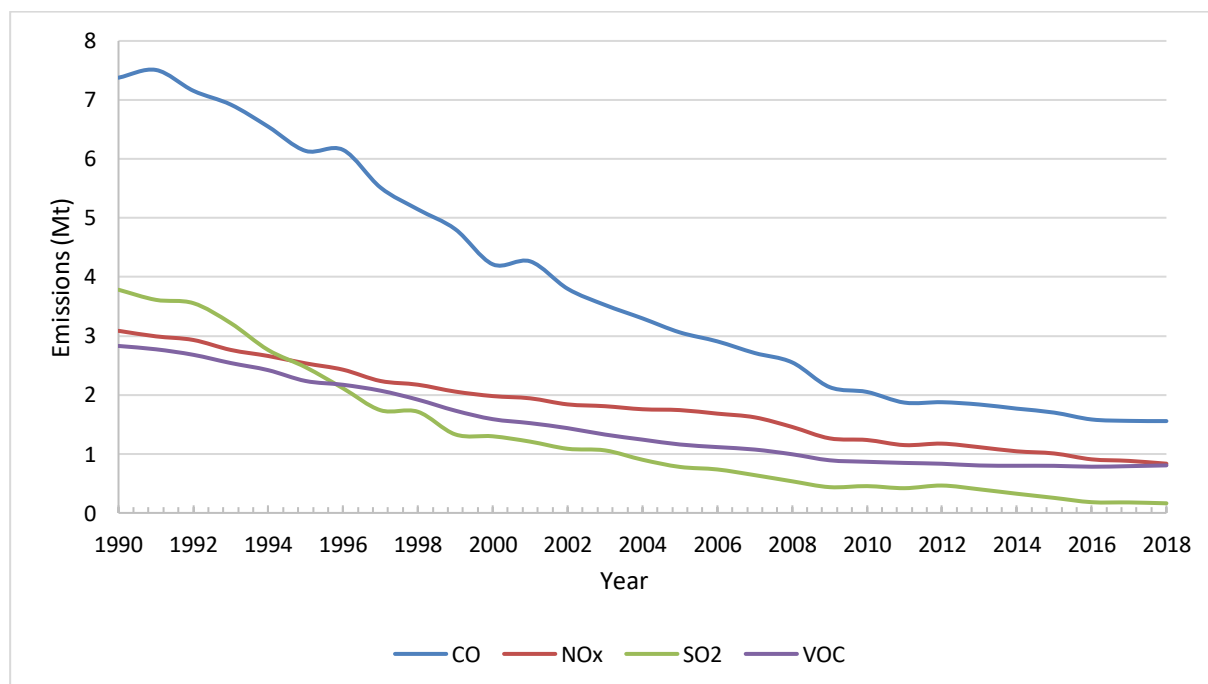
### 2.6.1  Carbon Monoxide

Annual emissions of CO have decreased significantly since 1990. Over three quarters of UK emissions of CO are from the energy sector, with a quarter of the latter from transport in recent years. Since 1990, annual emissions from transport have declined dramatically, which is mainly because of the increased use of three-way catalysts, although a proportion is a consequence of fuel switching in moving from petrol to diesel cars.

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

### 2.6.2  Nitrogen Oxides

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

Emissions from the energy industries contributes to almost a quarter of total $NO_x$ emissions in the UK. Since 1990, annual emissions from this sector have decreased by over three-quarters mainly due to a decrease in emissions from public electricity and heat production. Since 1998 the electricity generators adopted a programme of progressively fitting low $NO_x$ burners to their 500 MWe coal fired units. Since 1990, further changes in the electricity supply industry such as the increased use of nuclear generation and the introduction of CCGT plant have resulted in additional reduction in $NO_x$ emissions.

Emissions from Manufacturing, Industry and Construction have also fallen since 1990. Over this period, the industrial sector has seen a move away from the use of coal, coke and fuel oil towards natural gas and gas oil usage.

### 2.6.3  Non-Methane Volatile Organic Compounds

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

Approximately one third of NMVOC emissions originate from the energy sector. Of these, the largest contribution arises from the fugitive emissions of oil and natural gas. This includes emissions from gas leakage, which comprise around half of the total for the energy sector, the remaining emissions arise from oil transportation, refining, storage and offshore.

### 2.6.4  Sulphur Dioxide

Since 1990, total annual emissions of $SO_2$ have reduced dramatically. Almost all $SO_2$ emissions originate from energy sector, with the greatest contribution from energy industries. Since 1990, emissions from power stations have declined to a fraction of 1990 levels. This decline has been due to the increase in the proportion of electricity generated CCGT stations, other gas fired plants, the increase in the proportion of electricity generated in nuclear plants, and the application of Flue Gas Desulphurisation abatement equipment on several of the largest coal-fired power stations in the UK. CCGTs run on natural gas and are more efficient than conventional coal and oil stations and have negligible $SO_2$ emissions.

Emissions from Manufacturing, Industry and Construction are currently responsible for approximately a fifth of UK $SO_2$ emissions. Since 1990, emissions from this category have declined significantly. This decline is due to the reduction in the use of coal and oil in favour of natural gas, and also some improvement in energy efficiency.

# 3   Energy (CRF Sector 1)

## 3.1   OVERVIEW OF SECTOR

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

Emission trends are presented for 1990-2018 and 2017-2018. A description of the trends and the main drivers behind these can be found in **Chapter 2**.

**Table 3.1        Energy Sector Overview**

| Energy<br><br>GREENHOUSE GAS SOURCE AND SINK CATEGORIES | KCA Rank (UNFCCC) scope | Uncertainty (MC) | Latest year total | 1990-Latest year trend | Last 2 yr trend | Recalculation-: 2017 | Recalculation-: 1990 | Methodology reference (NIR Section) |
|---|---|---|---|---|---|---|---|---|
| **Total Energy** | | | **375** | **-39%** | **-2%** | **0%** | **0%** | |
| **A. Fuel combustion activities (sectoral approach)** | | | **365** | **-36%** | **-2%** | **0%** | **0%** | |
| **1. Energy industries** | | | **96** | **-59%** | **-7%** | **0%** | **0%** | |
| a. Public electricity and heat production | 3, 5, 7, 29 | 3% | 68 | -67% | -8% | 0% | 0% | MS 1 |
| b. Petroleum refining | 3, 5, 7, 29 | 15% | 13 | -27% | -4% | 0% | 0% | MS 1 |
| c. Manufacture of solid fuels and other energy industries | 3, 5, 7, 29 | 3% | 15 | 5% | -4% | -1% | 0% | MS1, MS 2 |
| **2. Manufacturing industries and construction** | | | **51** | **-47%** | **-2%** | **2%** | **0%** | |
| a. Iron and steel | 6, 8, 10 | 9% | 9 | -59% | -6% | 1% | 0% | MS 4 |
| b. Non-ferrous metals | 6, 8, 10 | 5% | 1 | -83% | 2% | -2% | 0% | MS 3 |
| c. Chemicals | 6, 8, 10 | 5% | 5 | -55% | -1% | 2% | 0% | MS 3 |
| d. Pulp, paper and print | 6, 8, 10 | 6% | 1 | -69% | -2% | 3% | 1% | MS 3 |
| e. Food processing, beverages and tobacco | 6, 8, 10 | 5% | 4 | -43% | 5% | 1% | 0% | MS 3 |
| f. Non-metallic minerals | 6, 8, 10 | 12% | 3 | -62% | -1% | 0% | -6% | MS 3 |
| g. Other (*please specify*) | 6, 8, 10 | 5% | 28 | -28% | -3% | 2% | 0% | MS 3, MS 6 |
| **3. Transport** | | | **123** | **0%** | **-1%** | **0%** | **0%** | |
| a. Domestic aviation | 32 | 20% | 2 | -3% | -7% | 3% | 0% | MS 7 |
| b. Road transportation | 1 | 2% | 113 | 2% | -1% | 0% | 0% | MS 8 |
| c. Railways | | 19% | 2 | 20% | -10% | -1% | 1% | MS 9 |
| d. Domestic navigation | 20 | 18% | 5 | -29% | -1% | 0% | 0% | MS 10, MS 11, MS 12 |
| e. Other transportation | | 19% | 1 | 158% | 3% | 0% | 0% | MS 6 |
| **4. Other sectors** | | | **93** | **-17%** | **4%** | **0%** | **0%** | |
| a. Commercial/institutional | 2, 12, 15 | 3% | 20 | -23% | 3% | -1% | 0% | MS 5 |
| b. Residential | 2, 12, 15 | 4% | 68 | -15% | 4% | -1% | 0% | MS 5, MS 6 |
| c. Agriculture/forestry/fishing | 2, 12, 15 | 30% | 5 | -14% | 0% | 2% | -1% | MS 5, MS 6, MS 10, MS 13 |

| Energy<br><br>GREENHOUSE GAS SOURCE AND SINK CATEGORIES | KCA Rank (UNFCCC) scope | Uncertainty (MC) | Latest year total | 1990-Latest year trend | Last 2 yr trend | Recalculation: 2017 | Recalculation: 1990 | Methodology reference (NIR Section) |
|---|---|---|---|---|---|---|---|---|
| **5. Other** *(as specified in table 1.A(a) sheet 4)* | | | **2** | **-70%** | **1%** | **2%** | **0%** | |
| a. Stationary | N/A | N/A | IE | N/A | N/A | N/A | N/A | |
| b. Mobile | 25 | 8% | 2 | -70% | 1% | 2% | 0% | MS 15, MS 16 |
| **B. Fugitive emissions from fuels** | | | **10** | **-76%** | **0%** | **0%** | **0%** | |
| **1. Solid fuels** | | 11% | **1** | **-97%** | **-9%** | **0%** | **0%** | |
| a. Coal mining and handling | 18 | | 0 | -98% | -4% | 0% | 0% | MS 17 |
| b. Solid fuel transformation | 18 | | 0 | -82% | -15% | 0% | 0% | MS 4 |
| c. Other *(as specified in table 1.B.1)* | N/A | N/A | NO | N/A | N/A | N/A | N/A | |
| **2. Oil and natural gas and other emissions from energy production** | | 33% | **9** | **-49%** | **1%** | **0%** | **0%** | |
| a. Oil | 17, 23 | | 0 | -75% | 7% | 0% | 2% | MS 5 |
| b. Natural gas | 17, 23 | | 4 | -65% | -2% | 0% | 0% | MS 5, MS 20 |
| c. Venting and flaring | 17, 23 | | 5 | -12% | 3% | -1% | 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. CO₂ Transport and storage** | **N/A** | **N/A** | **NO** | **N/A** | **N/A** | **N/A** | **N/A** | |
| 1. Transport of CO2 | 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** | **48** | **94%** | **1%** | **3%** | **0%** | |
| **International bunkers** | **N/A** | **N/A** | **48** | **94%** | **1%** | 3% | **0%** | |
| Aviation | N/A | N/A | 37 | 136% | 1% | 4% | 0% | MS 7 |
| Navigation | N/A | N/A | 11 | 21% | 0% | 2% | 0% | MS 14 |
| **Multilateral operations** | **N/A** | **N/A** | **NE** | **N/A** | **N/A** | **N/A** | **N/A** | |
| **CO₂ emissions from biomass** | **N/A** | **N/A** | **82** | **832%** | **12%** | 67% | 116% | MS 1, MS 3, MS 6, MS 8 |
| **CO₂ 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 10 pollutants in accordance with the IPCC reporting format. These UK GHGI emission estimates are based on bottom-up activity data, including:

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

As a verification of the detailed Sectoral Approach inventory estimates, the Inventory Agency also calculates alternative UK emission estimates for carbon dioxide from energy sources in the UK, using the IPCC Reference Approach. This is a top-down inventory compilation method, which calculates emission estimates from National Statistics on production, imports, exports, stock changes and non-energy uses of fossil fuels: crude oil, natural gas and solid fuels.

The Reference Approach inventory method utilises different sections of the UK national energy statistics, combining aggregated data on fuel inputs and outputs from the overall UK economy, using top-level data on oils, gas and solid fuels to assess the UK carbon balance for combustion sources. This more simplistic, non-source-specific methodology provides a very useful quality check against the more rigorous Sectoral Approach.

Differences between the RA and SA arise primarily due to statistical differences between production-side and demand-side fuel estimates within national energy statistics, the exclusion of carbon estimates from specific activities (e.g. some carbon within coke and coal deliveries to the iron and steel and non-ferrous metal industries) and the more aggregated approach to applying emission factors to activity data across fuel types.

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

**3.2.1.1** Discrepancies between the IPCC Reference and Sectoral Approach

The IPCC Reference Approach total can be compared with the IPCC Table 1A total for all fossil fuels, and under the new 2006 GLs approach the Reference Approach (RA) $CO_2$ estimates for the UK typically range between **1.4% lower** to **3.1% lower** than the comparable bottom-up emission totals of the Sectoral Approach (SA).

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

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

### 3.2.1.1.2 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 Treatment of Blast Furnace Gas

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

### 3.2.1.1.5 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.

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

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

**Table 3.2        Summary of RA/Amended RA-SA comparison**

| | Maximum RA/SA ratio | Minimum RA/SA ratio | Average RA/SA ratio | Average RA % deviation from SA[a] | Maximum amended RA/SA ratio | Minimum amended RA/SA ratio | Average amended RA/SA ratio | Average amended RA % deviation |
|---|---|---|---|---|---|---|---|---|
| Liquid Fuels | 1.015 | 0.959 | 0.985 | 1.6% | 1.033 | 0.972 | 1.000 | 0.9% |
| Solid Fuels | 0.952 | 0.807 | 0.909 | 9.1% | 1.029 | 0.973 | 1.008 | 1.4% |
| Gaseous Fuels | 1.027 | 0.997 | 1.008 | 0.9% | 1.001 | 0.988 | 0.997 | 0.4% |
| **Total** | **0.984** | **0.965** | **0.973** | **2.7%** | **1.012** | **0.991** | **1.001** | **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 1.6%[46]) than the sectoral approach; there are some years with larger deviations, the highest being a 4.1% deviation in 1997. In the adjusted RA the values are slightly lower than the SA (on average 0.9%), and the extreme deviations are curtailed so that the greatest deviation is 3.3% in 2000. There are still some stochastic variations from the SA, which are likely linked to statistical difference which is why the average deviation is significantly higher than the average % difference. The most significant differences between the adjusted and non-adjusted RA are our estimate of the impact of the difference in carbon between crude oil and derived petroleum fuels, and the accounting for fuel oil and gas oil consumption in the shipping sector considered additional to DUKES as indicated by the new bottom-up estimates integrated into the inventory for the first time this year.

For solid fuels, the RA is 4.8-19.3% lower than the SA in all years. This difference is primarily due to the fact that we believe that a significant amount of blast furnace gas is used for energy use (and report this in the energy sector), whereas the guidance recommends that blast furnace gas should be excluded from the RA.

From 2000 the RA for gaseous fuels, which is based on supply statistics, is consistently 0.1-0.9% higher than the SA and before then the relationship is less consistent. For gaseous fuels, once the known differences presented in national statistics between total supply and total production are accounted for, as well as known inventory deviations from national statistics, the adjusted RA is on average 0.3% lower than the SA and never deviates by more than 1.2%.

The overall comparison between the Reference Approach (RA) and the Sectoral Approach (SA) indicates that in most years the RA estimates are around 2.7% lower than the SA estimates. However, once the RA is amended for known differences, the comparison is much closer with a range of 1.2% higher (in 1999) to 0.9% lower (in 1996) than the SA; the adjusted RA is on average 0.4% higher than the SA.

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

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

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

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sectoral Approach 1A (Mt $CO_2$) | 566.2 | 576.9 | 561.2 | 547.3 | 541.0 | 530.7 | 551.0 | 529.7 | 535.6 | 529.7 | 538.2 | 548.6 | 533.5 | 543.2 |
| Reference Approach (Mt $CO_2$) | 547.9 | 563.0 | 552.1 | 534.0 | 526.0 | 516.5 | 533.6 | 511.3 | 519.8 | 516.2 | 527.8 | 534.1 | 519.8 | 527.1 |
| Reference Approach (Amended for known differences) (Mt $CO_2$) | 532.5 | 548.2 | 538.9 | 523.6 | 509.9 | 504.4 | 521.2 | 495.1 | 504.1 | 496.4 | 511.8 | 518.0 | 503.8 | 509.3 |
| RA/SA % | -3.2% | -2.4% | -1.6% | -2.4% | -2.8% | -2.7% | -3.2% | -3.5% | -2.9% | -2.6% | -1.9% | -2.6% | -2.6% | -3.0% |
| RA/SA (amended) % | -0.5% | 0.2% | 0.7% | -0.5% | 0.2% | -0.4% | -0.9% | -0.4% | 0.0% | 1.2% | 1.0% | 0.3% | 0.4% | 0.3% |

| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sectoral Approach 1A (Mt $CO_2$) | 543.3 | 540.7 | 540.3 | 530.0 | 518.1 | 473.4 | 489.8 | 448.7 | 467.3 | 455.4 | 416.4 | 400.3 | 379.3 | 367.8 | 360.5 |
| Reference Approach (Mt $CO_2$) | 528.4 | 529.5 | 527.2 | 514.9 | 504.6 | 459.6 | 476.9 | 433.6 | 455.0 | 443.4 | 402.8 | 390.0 | 369.8 | 358.6 | 351.5 |
| Reference Approach (Amended for known differences) (Mt $CO_2$) | 511.2 | 515.1 | 513.2 | 500.2 | 489.3 | 445.7 | 465.9 | 422.2 | 444.3 | 429.0 | 387.7 | 377.0 | 359.1 | 347.3 | 342.2 |
| RA/SA % | -2.7% | -2.1% | -2.4% | -2.9% | -2.6% | -2.9% | -2.6% | -3.4% | -2.6% | -2.6% | -3.3% | -2.6% | -2.5% | -2.5% | -2.5% |
| RA/SA (amended) % | 0.4% | 0.6% | 0.2% | -0.1% | 0.3% | 0.0% | -0.4% | -0.8% | -0.3% | 0.5% | 0.4% | 0.7% | 0.3% | 0.5% | 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 revised Tier 3 method adopted for shipping as described in **MS 13.** The methods for the calculation of international bunker fuels are presented in the relevant method statements.

Each year the Inventory Agency confirms that the UK energy balance is consistent with data submitted to EUROSTAT and IEA and that the total fuel consumption used for the GHG estimates is consistent with the UK energy balance. For marine bunkers, the UK GHG estimates are based on the bottom up analysis from the BEIS shipping inventory (Scarborough et al., 2017). This leads to a different total fuel use allocation for marine fuels from the allocations in the national energy statistics (DUKES) and submissions to IEA/EUROSTAT.

### 3.2.3  Feedstock and Non-Energy Use of Fuels

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

The UK energy statistics (DUKES, 2019) contain an allocation for non-energy use for each fuel in the commodity balance tables. The UK inventory estimates emissions from fuels, including emissions arising from non-energy uses. In some cases, the inventory estimate for non-energy use does not agree with the DUKES allocation, and reallocations are made between energy and non-energy use for inventory reporting, if inventory estimates lead to more conservative emission estimates. In 2013, the Inventory Agency carried out research into non-energy uses of fuels; this was followed up by the DECC (now BEIS as of 2016) energy statistics team during 2014, and a series of revised allocations were introduced in the Digest of UK Energy Statistics 2014 (DECC, 2014), improving consistency between the inventory and the UK energy statistics. The activity data used for the national inventory and any deviations from the UK energy balance are presented and explained in **Annex 4**.

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

- annual reporting by plant operators (e.g. EU ETS returns, which include data on the use of process off-gases in the chemical and petrochemical production sector);
- periodic surveys or research by trade associations / research organisations / environmental regulators, such as to assess the fate of coal tars and benzoles, petroleum coke or waste oils, or the impact of regulations on solvents, waste, product design and use; and,
- information from literature sources on the estimated split of stored to emitted carbon (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.

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

### 3.2.4   Use of UK Energy Statistics in the GHG inventory

The main source of official national statistics and energy balances data used in the UK inventory is the Digest of UK Energy Statistics (BEIS, 2019a), 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 EU Emissions Trading System indicates higher fuel use for several high-emitting industrial sectors which is used in preference to DUKES data.*

- DUKES and other national statistics do not include any data for a given source. *For example, DUKES does not provide any information on secondary fuels such as process off-gases that are derived from petroleum feedstocks and are commonly used as fuels in petrochemical and chemical industries.*

- Where the BEIS DUKES team make improvements to national energy statistics, they typically do not revise the full time series of data; usually, DUKES data are typically retrospectively revised for up to the 5 most recent years. This can lead to step changes in the DUKES time-series that are due to methodological differences rather than reflecting real changes in fuel use. Therefore, to ensure time series consistency of reported emissions, the Inventory Agency works with the BEIS energy statistics team to derive a defensible historic time series back to at least 1990 for use in the UK inventory. *For example, in DUKES 2015 the estimates for residential wood use were significantly revised due to new research into uptake of biomass combustion units. In this case, the data were only revised back to 2008 in the DUKES 2015 statistical*

*publication, therefore new activity data for wood use in 1990-2007 were estimated by the Inventory Agency in consultation with the DUKES team, which are then used in the inventory in place of the published DUKES data.*

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

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

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

Apart from DUKES, the main other data source used for fuel use estimates in the inventory is the installation-level data available for processes covered by the EU Emissions Trading System (BEIS, 2018b), which has been analysed and compared with the data from DUKES. Further details of the analysis of EU ETS and use of the data within the UK GHG inventory are given in **Annex 7**. Further fuel consumption data are taken from the Environmental Emissions Monitoring System (EEMS) data set (BEIS OPRED, 2019) and from data supplied by the UK Mineral Products Association (MPA, 2019), and from the UK solid fuel supply sector (Roberts, 2015). These are used to modify fuel use and emission estimates for 1A1c, 1A2f, and 1A4b respectively, and are described more fully in the sections below that deal with those source categories.

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

### 3.2.5  Biomass

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

Greenhouse gas emissions including $CO_2$ are estimated for these fuels and presented in the relevant sections of the CRF. The $CO_2$ emissions from biomass are, however, not added to the total UK emissions from fuel combustion and are instead recorded as a memo item. The exception to this approach is that there is a fossil-carbon component of some liquid biofuels (e.g. the methyl group in FAME is derived from fossil feedstock), and the $CO_2$ derived from that fossil component of the biofuels is reported in the UK inventory, predominantly in 1A3b where liquid biofuels are used most widely.

Emissions of $N_2O$ and $CH_4$ from biomass combustion are included within the UK inventory totals although in the case of emissions from use of biofuels in road transport, the emissions are not reported separately, and are instead included in the emissions reported for petrol and DERV. The impact of biomass use on carbon stocks in the UK is recorded in the LULUCF sector; biomass imported into the UK will affect the LULUCF sector in the country from which the biomass is imported.

### 3.2.6  Unoxidized Carbon

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

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

**Table 3.4         Levels of unoxidized carbon assumed for the UK GHGI**

| Fuel Type | Fuel sub-type | Source Sector | Years | Assumed unoxidized carbon | |
|---|---|---|---|---|---|
| | | | | **UK GHGI[c]** | **IPCC default** |
| Gaseous | All fuels | All sectors | All | 0% | 0% |
| Liquid | All fuels (incl. petroleum coke) | All sectors | All | 0% | 0% |
| Solid | Coal | 1A1a | 1990-2004 | 2%[a] | 0% |
| | | | 2005 | 1.8%[b] | |
| | | | 2006 | 2.0%[b] | |
| | | | 2007 | 1.7%[b] | |
| | | | 2008 | 2.0%[b] | |
| | | | 2009 | 1.9%[b] | |
| | | | 2010 | 1.9%[b] | |
| | | | 2011 | 1.8%[b] | |
| | | | 2012 | 1.7%[b] | |
| | | | 2013 | 1.8%[b] | |
| | | | 2014 | 1.8%[b] | |
| | | | 2015 | 1.8%[b] | |
| | | | 2016 | 1.8%[b] | |
| | | | 2017 | 1.6%[b] | |
| | | | 2018 | 1.5% [b] | |
| | | 1A2f (cement) | All | 0% | |
| | | 1A4b | All | 0% | |
| | | All others | All | 0% | |
| | Anthracite | 1A4b | All | 0% | |
| | Coke, solid smokeless fuel | 1A4b | All | 0% | |
| | | All others | All | 0% | |

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

[b] Calculated from site-specific EU ETS returns for all UK coal-fired power stations except in 2005 and 2016 where no information is available for one site.

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

## 3.3 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 | 1A1a, 1A1b, 1A1ciii | Power stations, 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, *Memo item* | Aviation, International aviation |
| MS 8 | 1A3b | Road Transport |
| MS 9 | 1A3c | Railways |
| MS 10 | 1A3d, 1A4ciii | Shipping – coastal, and fishing in UK waters |
| MS 11 | 1A3d | Shipping between UK and Gibraltar, and between UK and OTs |
| MS 12 | 1A3d | Inland Waterways |
| MS 13 | *Memo item* | International shipping |
| MS 14 | 1A5b | Naval Shipping |
| MS 15 | 1A5b | Military aircraft |

| MS number | IPCC categories | Source categories |
|---|---|---|
| Fugitive sources *(Except 1B1b – see MS 4)* | | |
| 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.* <br><br> *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 |

## MS 1   Power stations, refineries, and other energy industries

**Relevant Categories, source names**

1A1a: Power stations

1A1b: Refineries

1A1ciii: Collieries, gas production and nuclear fuel production

**Relevant Gases**

$CO_2$, $CH_4$, $N_2O$

**Relevant fuels, activities**

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

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

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

**Background**

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

**Table 3.6** shows the number of power stations in the UK, by the type of fuel burnt. The main fossil fuels used by the UK electricity supply industry are bituminous coal and natural gas. The number of coal stations has decreased markedly across the time series, and the number of gas fired stations peaked in 2012 but has decreased slightly since then. The share of total UK electricity generated in 2018 was 8.3% from coal and 42% from gas. Nuclear stations

generated a further 28%, and almost all the remaining 23% was generated from renewables or non-thermal sources such as wind and hydro (18%).

Biomass is being burnt at an increasing number of power generation sites to help electricity generators meet Government targets for renewable energy production. These sites use poultry litter, straw, or wood as the main fuel, whilst many coal-fired power stations have increased the use of biofuels such as short-rotation coppice to supplement the use of fossil fuels. Electricity is also generated in a large number of engines running on biogas at landfill sites and sewage treatment works. $CO_2$ 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 |
| 2005 | 17 | 3 | 13 | 49 | 20 | 5 | 461 | 13 |
| 2010 | 17 | 3 | 13 | 56 | 24 | 8 | 554 | 10 |
| 2012 | 16 | 2 | 13 | 57 | 26 | 9 | 565 | 10 |
| 2013 | 15 | 2 | 13 | 51 | 28 | 11 | 621 | 10 |
| 2014 | 13 | 1 | 13 | 50 | 34 | 12 | 628 | 10 |
| 2015 | 13 | 1 | 13 | 51 | 34 | 14 | 633 | 9 |
| 2016 | 12 | 0 | 13 | 52 | 39 | 15 | 642 | 9 |
| 2017 | 9 | 0 | 13 | 55 | 40 | 15 | 658 | 9 |
| 2018 | 8 | 1 | 13 | 53 | 44 | 16 | 654 | 9 |

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

**Table 3.7** shows how the numbers of refineries vary over the period covered by the inventory. The UK had 8 operating refineries during 2017, of which 2 were small specialist refineries employing simple processes such as distillation to produce solvents or bitumen only. The remaining 6 complex refineries are much larger and produce a far wider range of products

including refinery gases, petrochemical feedstocks, transport fuels, gas oil, fuel oils, lubricants, and petroleum coke. The crude oils processed, refining techniques, and product mix will differ from one refinery to another, influencing the energy use and emissions from the sector. A seventh large crude oil refinery ceased operation in November 2014, and four other major refineries in operation in 1990 closed between 1997 and 2010.

**Table 3.7        Refineries in the UK by type**

| Year | Crude oil refineries | Specialist refineries |
|------|----------------------|-----------------------|
| 1990-1996 | 11 | 4 |
| 1997-1998 | 10 | 4 |
| 1999 | 9 | 4 |
| 2000-2009 | 9 | 3 |
| 2010-2012 | 8 | 3 |
| 2013 | 7 | 3 |
| 2014 | 7 | 2 |
| 2015-2018 | 6 | 2 |

Some of the crude oil and natural gas input to the refineries comes from a large number of offshore installations in UK waters, together with a small number of onshore production facilities. Emissions estimates from these activities are described in **MS 2** and **MS 18**. Coal is extracted in the UK from deep mines and open-cast sites. The production of coal has been in rapid decline in the UK and levels of UK activity are far lower in recent years than in 1990. The last large UK deep mine closed in 2015 and so production of deep-mined coal was negligible in 2016-2018. Emissions from combustion at UK collieries are covered in this MS. Fugitive emission estimates from these mining and extraction activities are included in **MS 16** and **MS 17.**

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

**Key Data sources**

Activity data:          DUKES (BEIS, 2019), EU ETS (BEIS, 2019)

Emission Factors:   Carbon factors are predominantly derived from EU ETS data (2005 onwards), from refinery sector reporting (UK Petroleum Industry Association, 2019) 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_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references[47]. The justification for use*

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

*of several references, such as EU ETS, the 2004 Carbon Factors Review and Fynes and Sage, are presented in* **Annex 3.1.2***.*

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

**Method approach**

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

UK Emissions = EF x AD

The sources of emission factors and activity data are summarised under "key data sources" above, with a full list of emission factors set out in *"Energy_background_data_uk_2020.xlxs"*. The activity data are taken from DUKES, noting the exceptions set out under Assumptions & observations, below. **Annex 4** describes the energy balance for the UK and how this is used for the inventory, and any deviations from these data.

**Assumptions & observations**

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

- **Coal-fired power stations** – oxidation factors (OF). All UK coal-fired power stations report to EU ETS and present installation-specific data on coal composition (carbon content), and almost all also report the fuel OF. The weighted-average figure is reported in Table 3.4 above. The range of OFs at UK coal-fired stations is typically 95-99%. There are some UK power stations that consistently report a low OF due to the grate design and nature of the coal fired; in 2017 the lowest OF reported is around 96.8%, whereas most stations report 98-99%. The factors presented in *"Energy_background_data_uk_2020.xlxs"* are the factors including consideration of the oxidation factor. The data for recent years is taken from installation-specific analysis through EU ETS, and from the underlying data we can derive the weighted average oxidation factor across UK coal-fired power stations. The data for earlier years 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 EU ETS data. These EU ETS data indicate that 0.98 is a defensible estimate.

- **Power stations – MSW**: The activity data reported in the UK inventory is a combination of non-biodegradable (fossil) and biodegradable wastes and we apply IPCC default carbon factors for each type of waste.

- **Refineries - OPG activity data**: As noted in the recalculation justification & summary of change section below, for OPG, discrepancies in activity data are evident between EU ETS and DUKES. Based on data from EU ETS and the refinery trade association, UKPIA, potential under-reports were identified in the UK energy balance data for the refinery sector from 2004 onwards, although not in all years. The Inventory Agency takes the conservative approach of using the higher fuel consumption data for each year. The estimates for 2004 in the UK GHGI are therefore based on data supplied directly to the Inventory Agency by the UK Petroleum Industry Agency (UKPIA) data, whilst the data for 2006-2011 and 2013-2018 are based on EU ETS data. Data from

DUKES are used for 2005 and 2012. Prior to 2004 the UK GHGI emission estimates based on DUKES energy data are closely consistent with UKPIA sector estimates, and are therefore retained; and,

- **Refineries - Petroleum coke activity data**: Similar to the issue noted above for OPG, comparison of the AD presented in DUKES versus the AD reported via the EU ETS indicates for several years that the DUKES AD are under-reported. The UK GHGI estimates from refinery petroleum coke use are therefore based on the higher value of DUKES or EU ETS and applying the EF for petroleum coke provided by UKPIA; EU ETS data are higher (and therefore used in the GHGI, deviating from DUKES) for all years 2005 to 2010 and again in 2013 and 2015-2018. In 2011, 2012 and 2014, the DUKES data are higher than EU ETS and are therefore retained; we note, however that this is a possible over-report and leads to UK GHGI emission estimates for the sector as a whole being higher than EU ETS totals in 2012. The Inventory Agency retains this approach in order to use EU ETS emission estimates as a de-minimis, and taking a conservative approach to deriving the time series of refinery emissions. Note that the UK GHGI estimates for the refinery sector are also higher than the EU ETS figures for 2005: this is because DUKES reports higher consumption of other fuels (including fuel oil and natural gas) than given in EU ETS, rather than due to differences for OPG and petroleum coke as in 2012.

## Recalculations

Activity data revisions include:

- Revisions to DUKES have been incorporated in addition to minor changes in calorific value conversions, but these have a small impact on emissions.

For emission factors:

- Minor revisions to carbon emission factors for natural gas (revised gross to net conversion) and OPG.

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

## Improvements (completed and planned)

Completed: Recalculations and updates completed as described above.

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

## QA/QC

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

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

The energy AD used in these estimates that come from DUKES are subject to the UK Statistics Authority's *Code of Practice for Statistics[48]*. The EU ETS data, is subject to its own QA process, defined and managed by the competent authority and compliant with EU rules.

**Time series consistency**

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

For some sources and fuels, carbon emission factors are taken from Baggott et al., for the period 1990-2003, and from ETS for 2005 onwards (2004 is interpolated). This makes best use of available data and the time series trend of EFs shows a smooth transition between data sources. We note that the key data providers that informed the 2004 Carbon Factors Review are the same operators of high-emitting plants (i.e. power stations, refineries, cement kilns, iron, and steel works) that subsequently provide data to the EU ETS. Therefore, whilst the EU ETS data provides a larger dataset of more detailed, installation-specific fuel composition and hence carbon emission factors for recent years, the underlying source data available prior to EU ETS comes from the same operators. This means that, despite use of a smaller dataset prior to the availability of EU ETS data, the time series consistency of this approach is good.

**Uncertainties**

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

## MS 2    Upstream oil and gas production – fuel combustion

**Relevant Categories, source names**

1A1cii: Upstream gas production – combustion;

Upstream oil production - combustion;

Upstream oil and gas production – combustion at gas separation plant

**Relevant Gases**

$CO_2$, $CH_4$, $N_2O$

**Relevant fuels, activities**

Gas oil, Natural Gas, LPG, OPG

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

**Background**

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

**Key Data sources**

Activity Data:    Primarily taken from DUKES (BEIS, 2019), with some supplementary data from the EU ETS and EEMS data sets (both from BEIS OPRED, 2019).

Emission Factors:    Carbon factors for natural gas are derived from operator-reporting to EU ETS and EEMS (both from BEIS OPRED, 2019), supplemented by periodic analysis for the earlier years in the time-series (UKOOA, 2005); the carbon factors for LPG and gas oil are derived from the 2004 Carbon Factors Review (Baggott et al, 2004); the carbon factor for OPG used at gas separation plant is taken from the IPCC 2006 Guidelines CEF for ethane. Methane and Nitrous Oxide EFs are based on operator reporting via EEMS from 1998 onwards with earlier data based on industry research (UKOOA, 2005).

*An accompanying spreadsheet "Energy_background_data_uk_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references*[47]. **Table 1.6** *gives additional information for common activity data sources.*

**Method approach**

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

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

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

- From 2003 onwards there are no data in DUKES for LPG/OPG use in oil & gas terminals and therefore EU ETS data are used to provide activity and emission estimates; and
- Prior to 2001 (when BEIS energy data gathering systems were updated) the collection of data on natural gas use at oil and gas facilities was incomplete.

Therefore, the more complete and consistent data available from EEMS has been used to generate new estimates of natural gas use for the upstream sector back to 1990.

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

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

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

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

### Assumptions & observations

Emissions from OTs and CDs are 'Not Estimated' for this source. There is no oil or gas production in any of the OTs and CDs; however, the Inventory Agency is aware of a low level of well drilling and initial exploration activity (i.e. well testing) in waters around the Falklands Islands in 1998, in 2010, 2012 and 2015. There is an ongoing research project to review data and methods for the upstream oil and gas sector, and new estimates for the Falklands may become available for the 2022 submission

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

### Recalculations

The have been no major methodological changes in the 2020 submission. In response to comments from the ERT at the In-Country Review in 2019, a minor correction to the methodology has been made regarding the emissions from gas separation plant at oil terminals. The emissions totals are still aligned with operator-reported emissions, but the allocation between 'OPG' and 'fuel gas' (i.e. natural gas) is now made by applying the correct carbon emission factor on a net energy basis for 'OPG'; previously the allocation of emissions between the two fuels was made using an erroneously high NCV value for OPG. This

correction to the method slightly alters the allocation of emissions between the two fuels, and the reported IEFs for each fuel, but has no impact on emissions totals.

**Improvements (completed and planned)**

Emission factors and activity data remain under review.

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

**QA/QC**

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

- The comparison of the reference/sectoral approach;
- Comparison of EEMS, EU ETS and DUKES activity data for natural gas combustion. The data underpinning DUKES estimates are gathered via the Petroleum Producers Reporting System (PPRS) which presents facility-level activity data that are compared against EEMS and EU ETS to identify and reconcile any data inconsistencies;
- Comparisons between EEMS and EU ETS, to review installation-specific activity data and emissions data (and hence implied IEFs for each site and source) to identify any possible gaps in the EEMS dataset, using EU ETS as a de-minimis. The EU ETS data typically covers a smaller scope of activities on a given installation, but the data quality (AD, EFs) are third-party verified, whereas the EEMS dataset should be a comprehensive record of all combustion activities on upstream oil and gas installations but the data are subject to less rigorous QC.
- Comparisons on total emissions data reported by each onshore oil and gas installation via the Pollution Inventory/Scottish Pollutant Release Inventory/Welsh Emissions Inventory to assess time-series consistency and completeness of reporting, comparing $CO_2$ emissions data against those presented in EU ETS.

The energy AD used in these estimates that come from DUKES are subject to the UK Statistics Authority's *Code of Practice for Statistics*[48]. EU ETS data is subject to its own QA process.

**Time-series consistency**

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

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

is a higher uncertainty associated with the estimates for earlier years, but the inventory method has been developed to minimise that uncertainty despite the data limitations.

**Uncertainties**

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

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

**Relevant Categories, source names**

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

1A2b - Non-Ferrous Metal (combustion), Autogeneration - exported to grid (coal), Autogenerators (coal)

1A2c - Chemicals (combustion)

1A2d - Pulp, Paper and Print (combustion)

1A2e - Food & drink, tobacco (combustion)

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

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

**Relevant Gases**

$CO_2$, $CH_4$, $N_2O$

**Relevant fuels, activities**

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

**Background**

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

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

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

**Key Data sources**

Activity Data:         DUKES (BEIS, 2019), cement sector fuel use estimates (MPA, 2019) and, installation-specific activity data from EU ETS e.g. for lime kilns (EA, SEPA, NRW, NIEA, all 2019).

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

*An accompanying document "Energy_background_data_uk_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references.* **Table 1.6** *gives additional information for common activity data sources.*

**Method approach**

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

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

- Fuel use in cement kilns (1A2f) is collected from process operators, via the Mineral Products Association (MPA). These data are not complete for all of the earlier part of the time series, so some assumptions have to be made to fill these gaps (see assumptions). Reallocations are sometimes made between cement and other subcategories compared with DUKES, to account for known fuel uses;
- Fuel use in lime kilns (1A2f) is estimated based on EU ETS data. All lime kilns are included in the scope of EU ETS from 2008 onwards, so there is a full set of fuel data for 2008-2018, with incomplete data for the years 2005-2007. For the earlier part of the time-series, fuel use is estimated by extrapolation from the EU ETS data using lime production estimates;

- Balancing of energy consumption data between 1A2 and other source categories, to accommodate source-specific AD from other data sources (e.g. operator data, EU ETS) in preference to DUKES data. Key examples of fuel re-allocations in 1A2 are: AD for natural gas for gas network operators (i.e. gas use re-allocation between 1A2 and 1A1c); AD for oils for power stations (i.e. gas and fuel oil re-allocations between 1A2 and 1A1a);
- Analysis of EU ETS indicates that there are 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 EU ETS. This re-allocation increases the overall reporting of petroleum coke as an emissive energy use, deviating from DUKES;
- Analysis of EU ETS data has identified several chemical and petrochemical manufacturers that utilise carbon-containing process off-gases and residues as fuel sources. Consultation with industry and with the BEIS energy statistics team has clarified that in DUKES the delivery of feedstock materials to chemical and petrochemical sites are reported as non-energy use, with no subsequent reporting in DUKES of the use of process off-gases as an energy source in these industries. The EU ETS data are therefore used to derive inventory estimates to account for this use of feedstock-derived process gases, which are reported as "other petroleum gas" use within the inventory, in addition to DUKES allocations to fuel use in these sectors. However, in accordance with the 2006 GLs, these emissions are reported under source category 2B8 (see IPPU chapter) rather than 1A2; and,
- Separation of gas oil used for stationary and mobile machinery is based on data on populations of mobile equipment, or train or ship movements etc. The approach developed for allocating gas oil between different source categories is described in **Annex 4**.

Emission factors for carbon are almost exclusively derived from country specific data. Site-specific data, (including both EU ETS data, and data provided by process operators directly or via industrial trade associations) is aggregated up to generate factors for a small number of sectors. Sector-wide factors are derived in other cases based usually on the methods described in Baggott *et al*, 2004.

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

Emission factors for waste oils are based on the analysis of 8 samples of waste oils collected from UK sites in 2003. The factors for coke and other manufactured fuels are based on carbon balance approaches (see **MS 4** for coke). Emission factors for methane and nitrous oxide are largely IPCC defaults. *An accompanying spreadsheet "Energy_background_data_uk_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references*[47]

**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 2018) 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**

The following summarises the recalculations in 1A2:

- Revision to carbon emission factor for the combustion of fuels within the cement industry (1A2f). In the previous submission carbon emission factors (CEFs), using the methods detailed in Baggott *et al*, 2004. were applied across the time series. In 2005/6, the Inventory Agency received an updated set of CEFs from the British Cement Association (BCA), which indicated that the coal CEFs dating back to 2000 were considerably lower than those presented in the 2004 study. The updated set also provided CEFs back to 1990. In previous submissions the updated set was applied to the later time series, however the earlier time series was not revised to reflect the 2005/6 updated set. These revisions from the updated set have now been applied, resulting in minor recalculations in the early time series.
- Minor recalculations as a result of revisions in DUKES.

**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 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*[48]*.*

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

**Time series consistency**

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

**Uncertainties**

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

## MS 4    Iron and steel, and coke manufacture

**Relevant Categories, source names**

1A1ci: Coke production

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

1B1b:  Coke production

Iron and steel - flaring

2C1a: Basic oxygen furnaces

2C1b: Iron and steel - flaring

2C1d: Sinter production

**Relevant Gases**

$CO_2$, $CH_4$, $N_2O$

**Relevant fuels, activities**

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

**Background**

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

Most UK coke is produced at coke ovens associated with the UK's three integrated steelworks, although one independent coke manufacturer also 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** |
| **2016-2018** | **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 reported under CRF category 1A2. Gases emitted from the top of the blast furnace are collected and emissions should only occur when this gas is subsequently used as fuel. These emissions are allocated to the process using them. However, some blast furnace gas is lost and the carbon content of this gas is reported under CRF category 2C1.
7. Pig iron has a high carbon content derived from the coke used in the blast furnace. A substantial proportion of this must be removed to make steel and this is done in the basic oxygen furnace. Molten pig iron is charged to the furnace and oxygen is blown through the metal to oxidise carbon and other contaminants. As a result, carbon monoxide and carbon dioxide are emitted from the furnace and are collected for use as a fuel. As with blast furnace gases, some losses occur and these losses are reported with blast furnace gas losses under CRF category 2C1. In DUKES, basic oxygen furnace gas is combined with blast furnace gas and so separate figures for production and use of the two gases are not given.
8. The fuels derived in coke ovens and integrated steelworks are used in boilers and in heat treatment or melting furnaces and $CO_2$ emissions from these energy uses are calculated using emission factors derived using the carbon balance.

**Key Data sources**

Activity Data: Main sources of activity data (fuel use, production data) are DUKES (BEIS, 2019), ISSB annual statistics (ISSB, 2019), installation-specific activity data from EU ETS (EA, NRW, both 2019), operator information for integrated steelworks (Tata Steel and SSI Steel, both 2015)

Emission Factors: Input parameters for the carbon balance method are derived from EU ETS data or operators of integrated steelworks (reference as for AD). Other UK CS CEFs are derived from the 2004 Carbon Factors Review

(Baggott et al., 2004). EFs for non-$CO_2$ gases are predominantly IPCC defaults (IPCC 2006), Baggott et al., 2004.

*An accompanying spreadsheet "Energy_background_data_uk_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references[47]. **Table 1.6** gives additional information for common activity data sources.*

**Method approach**

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

**Carbon Flow Description**

coal $\rightarrow$ coke + coke oven gas + benzole & tars + fugitive carbon emission

coke + limestone + iron ore $\rightarrow$ sinter + carbon emission

sinter + coke + other reducing agents $\rightarrow$ pig iron + blast furnace gas

pig iron + scrap + dolomite $\rightarrow$ 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 2018 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 2018[a]**



| Inputs | | |
|---|---|---|
| Coal | Limestone 412 kt $CO_2$ <br> Coal 3225 kt | Dolomite 68 kt $CO_2$ <br> Scrap metal 1 kt $CO_2$ |
| 4694 kt $CO_2$ | 3637 kt $CO_2$ | 69 kt $CO_2$ |

Non Fuel products

183 kt $CO_2$

e.g. coal tars, benzoles

**Processes**

| Coke ovens | Coke, COG 6207 kt $CO_2$ | Sinter / blast furnace | Pig iron 963 kt $CO_2$ | Oxygen furnace | Steel etc. 43 kt $CO_2$ |
|---|---|---|---|---|---|

-2517 kt $CO_2$          3842 kt $CO_2$          921 kt $CO_2$

Fuel products

exported from the steelmaking processes, with emissions occurring elsewhere

**Emissions (direct)**

| kt $CO_2$ | category |
|---|---|
| 805 | 1A1c |
| 16 | 1B1b |

| kt $CO_2$ | category |
|---|---|
| 2853 | 1A2a |
| 925 | 2C1b |
| 1261 | 2C1d |

| kt $CO_2$ | category |
|---|---|
| 68 | 2C1a |

| kt $CO_2$ | category |
|---|---|
| 5,051 | 1A2a |

Plus imports, stock changes, statistical differences etc.

[a] Other adjustments includes statistical differences (-31 kt $CO_2$), imports (-3058 kt $CO_2$), exports (0 kt $CO_2$), stock changes (+275 kt $CO_2$), fugitive emissions from coke ovens reported as methane (16 kt $CO_2$), adjustments for natural gas added to coke oven gas (-34 kt $CO_2$), carbon stored in dusts (+52 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, 2018) and carbon contents from the operators (Tata Steel, SSI Steel, both 2015), and based on their EU ETS reporting (EA, NRW, both 2019).

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[49]) 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 dependent upon the assumptions made about the quantity of carbon in inputs, and in the main

[49] https://uk-air.defra.gov.uk/assets/documents/reports/cat19/1405081135_GHG_Inventory_Research_Report_EU ETSEU ETS_final.pdf

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 2003-2018 is mostly higher than the figures given in DUKES, and the operator data are used in preference. The coal consumption figures for other industrial use are also modified by an equal and opposite amount so that overall coal consumption in the GHGI is the same as in DUKES. DUKES also excludes a small quantity of coke oven gas generated at one steelworks which is then supplied as a fuel to a co-located process, and so we have used operator data on this fuel in the inventory. In this case, it would not be appropriate to maintain consistency with overall UK demand figures in DUKES (since this fuel is missing from DUKES, not classified to a different sector). Finally, some small deviations are made for 2009, where operator data on consumption of coal and coke oven coke in blast furnaces are somewhat higher. The changes to coal are treated as misallocations in DUKES (so UK totals for coal consumption are adhered to), whereas for coke oven coke, it is necessary to increase UK consumption to above the level given in DUKES, since coke consumption by known users exceeds the DUKES figure.

### Recalculations

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

### Improvements (completed and planned)

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

### QA/QC

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

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

The energy AD used in these estimates that come from DUKES are subject to the UK Statistics Authority's *Code of Practice for Statistics*[48]. 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 2015-2018 as well. While this does introduce some additional uncertainty for parts of the time-series, the assumed factors for coking coal and blast furnace coal, and the derived factors for coke oven coke, coke oven gas and blast furnace gas for these years are all within the ranges suggested in the IPCC 2006 Guidelines.

**Uncertainties**

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

# MS 5    Other stationary combustion

### Relevant Categories, source names

1A4ai: Miscellaneous industrial/commercial combustion

> Public sector combustion

> Railways - stationary combustion

1A4bi: Domestic combustion

1A4ci: Agriculture - stationary combustion

> Miscellaneous industrial/commercial combustion

### Relevant Gases

$CO_2$, $CH_4$, $N_2O$

### Relevant fuels, activities

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

### Background

This method statement covers emissions from fuel combustion by non-industrial sectors including commercial, agricultural, public 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, 2019)

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

*An accompanying spreadsheet "Energy_background_data_uk_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references*[47]*. **Table 1.6** 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).

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

**Recalculations**

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

- Any revisions to DUKES and other input data have been incorporated into the inventory, specifically this resulted in less natural gas use in stationary residential combustion than previously estimated;
- Minor revisions to calorific values used in stationary residential combustion (1A4bi) and the calorific value for coal within commercial/institutional combustion.

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

**Improvements (completed and planned)**

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

**QA/QC**

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.3.3**. 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*[48].

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

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

**Background**

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

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

- Domestic house & garden – reported under 1A4b;
- Agricultural power units (includes forestry) – reported under 1A4c;

- Industrial off-road (includes construction and quarrying) – reported under 1A2gvii; and
- Aircraft support machinery – reported under 1A3e.

**Key Data sources**

Activity:                  Netcen, 2004, ONS, UKMY, BEIS Projections (pers. comm.), CAA

Emission factors:   Baggott et al., 2004, EMEP/ EEA Guidebook, EU Non-Road Mobile Machinery Directive.

*An accompanying spreadsheet "Energy_background_data_uk_2020.xlsx" lists all emission factors used in the energy sector, including a full list of references[47]. **Table 1.6** gives additional information for common activity data sources.*

**Method approach**

A Tier 3 methodology is used for calculating emissions from individual types of mobile machinery. Default machinery or engine-specific fuel consumption and emission factors (g/kWh) are taken from EMEP/ EEA Guidebook. For methane, emission factors for more modern machinery based on engine or machinery-specific emission limits for total hydrocarbons established in EU Non-Road Mobile Machinery Directive are also included where available. The measures introduced to reduce total hydrocarbon emissions are assumed to 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. Part of the 2014 Improvement Programme for the air pollutant emissions inventory led to some minor changes in activity data for certain types of construction and airport support machinery, but these had minor effects on GHG emissions.

The population and usage surveys and assessments were only able to provide estimates on activity of off-road machinery for 2004. These are one-off studies requiring intensive resources and are not updated on an annual basis. There are no reliable national statistics on population and usage of off-road machinery nor figures from BEIS on how these fuels, once they are delivered to fuel distribution centres around the country, are ultimately used. Therefore, other activity drivers were used to estimate activity rates for the four main off-road categories from 1990-2003 and 2005 onwards.

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

**Table 3.9**          **Activity drivers used for off-road machinery**

| Category | Driver source | Machinery types |
|---|---|---|
| Domestic house and garden | 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 |
| Airport machinery | Airports data: Air passengers by type and nationality of operator | All types of airside machinery and transport, e.g. terminal tractors |
| Agricultural machinery | DUKES, gas oil consumption in agriculture | All types of agricultural and forestry machinery, e.g. tractors, combines, balers, tillers, fellers, chain saws, shredders |
| Construction | ONS construction statistics. "Output in the Construction Industry.", http://www.ons.gov.uk/businessindustryandtrade/constructionindustry/datasets/outputintheconstructionindustry Table 2b – Value of construction output in Great Britain: non-seasonally adjusted. The value of all new work (i.e. excluding repair and maintenance work) at constant (2010) prices. The seasonally non-adjusted figures were used and scaled to ensure time-series consistency. | generator sets <5 kW |
| | | generator sets 5-100 kW |
| | | asphalt pavers |
| | | tampers /rammers |
| | | plate compactors |
| | | concrete pavers |
| | | rollers |
| | | scrapers |
| | | paving equipment |
| | | surfacing equipment |
| | | trenchers |
| | | concrete /industrial saws |
| | | cement & mortar mixers |
| | | cranes |
| | | graders |
| | | rough terrain forklifts |
| Quarrying | Data on UK production of minerals, taken from UK Minerals Yearbook data, BGS (2017). | bore/drill rigs |
| | | off highway trucks |
| | | crushing/processing equipment |
| Construction and Quarrying | Growth driver based on the combination of the quarrying and construction drivers detailed above. | excavators |
| | | loaders with pneumatic tyres |
| | | bulldozers |
| | | tracked loaders |
| | | tracked bulldozers |
| | | tractors/loaders |
| | | crawler tractors |
| | | off highway tractors |
| | | dumpers /tenders |
| General Industry | Based on an average of growth indices for all industrial sectors, taken from data supplied by BEIS for use in energy and emissions projections. | generator sets 100-1000KW |
| | | pumps |
| | | air compressors |
| | | gas compressors |
| | | welding equipment |
| | | pressure washers |
| | | aerial lifts |
| | | forklifts |
| | | sweepers/ scrubbers |
| | | other general industrial equipment |
| | | other material handling equipment |

Having calculated fuel consumption from a bottom-up method, the figures for diesel engine machinery were allocated between gas oil and road diesel. This was following a survey of fuelling practices of uses of off-road machinery where it was found that, particularly for small,

non-commercial and domestic users who may only occasionally need to refuel, engines are filled with road diesel rather than gas oil.

A simple turnover model is used to characterise the population of each machinery type by age (year of manufacture/sale). For older units, the emission factors used came mostly from EMEP/ EEA (2009) though a few of the more obscure classes were taken from Samaras & Zierock (1993). The load factors were taken from Samaras (1996). Emission factors for garden machinery, such as lawnmowers and chainsaws were updated following a review by Netcen (2004). For the air pollutants and for those equipment whose emissions are regulated by Directive 2002/88/EC or 2004/26/EC, the emission factors for a given unit were taken to be the maximum permitted by the directive at the year of manufacture. The emission regulations are quite complex in terms of how they apply to different machinery types. Each of the 77 different machinery types was mapped to the relevant regulation in terms of implementation date and limit value. The trends in total hydrocarbon (THC) emissions across the emission regulation stages were applied to the trends in methane emissions as it is assumed that measures to control THC emissions will also impact methane emissions.

### Assumptions & observations

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

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

### Recalculations

There have been no changes to the method.

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

Other re-calculations arise from:

- Revision to DUKES gas oil consumed in agriculture used as a driver for the agricultural machinery sector. Revisions to the household numbers statistics used to generate the timeseries for the population of household and garden machinery

### Improvements (completed and planned)

There have been no improvements completed for this submission. Defra have commissioned Ricardo Energy & Environment to gather more up to date information regarding the population of specific machinery types, in addition to information regarding load factors and typical hours of useage. Whilst, at the time of publication, this work is ongoing and subject to further consultation, there is potential for this data to be used in future compilation cycle, to further refine parameters and data within the existing model.

**QA/QC**

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

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

**Time-series consistency**

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

**Uncertainties**

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

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

# MS 7    Aviation

**Relevant Categories, source names**

1A3a: Aviation

International bunkers - Aviation

**Relevant Gases**

$CO_2$, $CH_4$, $N_2O$

**Relevant fuels, activities**

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

**Background**

In accordance with the agreed guidelines, the UK inventory contains estimates for both domestic and international civil aviation. Emissions from international aviation are recorded as a memo item, and are not included in national totals. Emissions from both the Landing and Take-Off (LTO) phase and the Cruise phase (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 (2019a); CAA (2019b); BEIS (2019a); DfT (2019)

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

*An accompanying spreadsheet "Energy_background_data_uk_2020.xlsx" lists all emission factors used in the energy sector, including a full list of references[47]. In addition, Annex 3 includes a table to map all aircraft types evident in UK activity data from the CAA to the EMEP/EEA Guidebook aircraft categories.*

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

### Method approach

Estimates are based on IPCC Tier 3 method, and use the number of aircraft movements broken down by aircraft type at each UK airport together with UK energy statistics.

### *Activity data*

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

- **Aircraft movements and distances travelled**

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

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

   Total inland deliveries of aviation spirit and aviation turbine fuel to air transport are given in DUKES (BEIS, 2019a). This is the best approximation of aviation bunker fuel consumption available and is assumed to cover international, domestic and military use.

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

   These data are supplied by the Ministry of Defence (MoD). Military aviation estimates are included in **MS 15**. The data for total fuel use for military aviation is used in the normalisation to the DUKES total.

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

**Table 3.10     Aircraft Movement Data: LTOs and Cruise distances for Domestic and International Flights from UK Airports, 1990-2018**

| 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 |

| Year | International LTOs (000s) | Domestic LTOs (000s) | International Aircraft, Gm flown | Domestic Aircraft, Gm flown |
|------|--------------------------|----------------------|---------------------------------|-----------------------------|
| 2010 | 734.0 | 393.9 | 1395. | 146.4 |
| 2015 | 821.7 | 356.0 | 1565.8 | 135.0 |
| 2016 | 874.6 | 349.5 | 1675.5 | 133.7 |
| 2017 | 903.2 | 349.3 | 1751.7 | 135.2 |
| 2018 | 910.8 | 340.4 | 1803.6 | 130.8 |

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_2020.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, 2016) provides fuel consumption and emission data for non-GHGs ($NO_x$, HC and CO) for a number of aircraft cruise modes (climb cruise and descent). The data are given for a selection of generic aircraft type and for a number of standard flight distances.

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

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

$$FC\_Cruise_{d,g,p} = m_{g,p} \times d + c_{g,p}$$

Where:

$FC\_Cruise_{d,g,p}$   is the fuel consumption in cruise of pollutant $p$ for generic aircraft type $g$ and flight distance $d$ (kg)

$g$   is the generic aircraft type

$p$   is the pollutant (or fuel consumption)

$m_{g,p}$   is the slope of regression for generic aircraft type $g$ and pollutant $p$ (kg / km)

$c_{g,p}$   is the intercept of regression for generic aircraft type $g$ and pollutant $p$ (kg)

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

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

The estimates of aviation fuels consumed in the commodity balance table in the BEIS publication DUKES are the national statistics on fuel consumption, and IPCC guidance states that national total emissions must be on the basis of fuel sales. Therefore, the estimates of emissions have been re-normalised based on the results of the comparison between the fuel consumption data in DUKES and the estimate of fuel consumed produced from the civil aviation emissions model, having first scaled up the emissions and fuel consumption to account for air-taxi and non-ATMs. The scaling is done separately for each airport to reflect the different fractions of air-taxi and non-ATMs at each airport and the different impacts on

domestic and international emissions. Air-taxi and non-ATM fuel consumption estimates are not documented by Watterson *et al.* (2004), as this revision to methodology occurred after publication of the report. The aviation fuel consumptions presented in BEIS DUKES include the use of both civil and military fuel, and the military fuel use must be subtracted from the DUKES total to provide an estimate of the civil aviation consumption. This estimate of civil aviation fuel consumption has been used in the fuel reconciliation. Emissions from flights originating from the overseas territories have been excluded from the fuel reconciliation process as the fuel associated with these flights is not included in DUKES. Emissions will be re-normalised each time the aircraft movement data are modified or data for another year added.

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

### Assumptions & observations

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

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

### Recalculations

For recalculations, see improvements listed below (for 2020). There have been no method changes.

### Improvements (completed and planned)

A number of improvements have been made to the model over recent years, to include findings from UK specific research. The 2020 inventory submission included minor improvements resulting from revisions to the assignment of aircraft to EMEP/EEA cruise categories resulting from the introduction of cruise categories for the Airbus A350, Boeing 787-800 and Boeing 787-900 and from changes to the assumed APUs fitted to some aircraft types resulting from the introduction of new APU 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. 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). 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, EMEP/EEA 2016 Emission Inventory Guidebook.

*An accompanying spreadsheet "Energy_background_data_uk_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references[47]. **Table 1.6** gives additional information for common activity data sources.*

**Method approach**

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

Petrol and diesel vehicle fuel consumption and emissions are estimated for individual vehicle types from a bottom-up approach using an array of traffic statistics and exhaust emission and fuel consumption factors representing 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 (0.2%) 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 (Emisia, 2018) 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 built-up areas (urban) and non-built-up areas (rural) (DfT, 2018a). DfT provides a consistent time series of vehicle km data by vehicle and road types going back to 1993 for the 2018 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) are used to provide the breakdown in vkm for cars by fuel type.

Vehicle kilometre data for Northern Ireland by vehicle type and road class were provided by the Department for Regional Development, Northern Ireland, Road Services (DRDNI, 2016). This gave a time-series of vehicle km data from 2008 to 2014. To create a time-series of vehicle km data for 1990 to 2007, the vehicle km data from DRDNI (2013) was used. The data was scaled up or down based on the ratio of the data for 2008 between DRDNI (2016) and DRDNI (2013) for the given vehicle type and road type considered. Data from 2015 toand 2018 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 2018 in Great Britain. Motorcycle vehicle km data were not available from the DAERA and so they were derived based on the ratio of motorcycles registered in Northern Ireland relative to Great Britain each year. The ratios were then applied to the motorcycle vehicle km activity data for Great Britain. Information about the petrol/diesel split for cars and LGVs in the traffic flow are based on licensing data for Northern Ireland as provided by DfT (2019).

The Northern Ireland data have been combined with the DfT data for Great Britain to produce a time-series of total UK vehicle kilometres by vehicle and road type from 1970 to 2018. **Table 3.11** shows the time-series of total UK vehicle kilometres by vehicle and road type for select years from 1990 to 2018.

**Table 3.11      UK Vehicle km by Type of Road Vehicle, 1990-2018**

| Billion vkm | | 1990 | 2000 | 2005 | 2010 | 2015 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|
| Petrol cars | urban | 142.2 | 135.1 | 119.9 | 99.4 | 89.3 | 85.2 | 85.4 |
| | rural | 140.9 | 134.1 | 127.2 | 109.0 | 93.5 | 95.5 | 96.8 |
| | m-way | 49.3 | 53.0 | 48.9 | 41.7 | 34.3 | 34.1 | 34.4 |
| Diesel cars | urban | 5.8 | 26.1 | 40.8 | 54.0 | 65.2 | 69.1 | 68.4 |
| | rural | 6.1 | 28.3 | 47.5 | 65.8 | 88.3 | 96.3 | 96.4 |
| | m-way | 2.8 | 14.7 | 25.2 | 33.6 | 46.0 | 47.9 | 47.6 |
| Petrol LGVs | urban | 11.1 | 4.2 | 1.9 | 1.3 | 1.0 | 0.9 | 0.9 |
| | rural | 11.4 | 5.0 | 2.3 | 1.6 | 1.3 | 1.2 | 1.3 |
| | m-way | 3.9 | 2.0 | 0.9 | 0.6 | 0.6 | 0.5 | 0.6 |
| Diesel LGVs | urban | 5.8 | 15.6 | 21.2 | 22.7 | 25.3 | 26.5 | 26.3 |
| | rural | 6.0 | 18.8 | 25.9 | 29.5 | 33.9 | 37.2 | 37.8 |
| | m-way | 2.0 | 7.4 | 10.4 | 11.4 | 14.7 | 16.2 | 16.5 |
| Rigid HGVs | urban | 4.5 | 3.9 | 4.0 | 3.2 | 2.9 | 2.6 | 2.5 |
| | rural | 7.1 | 7.2 | 7.5 | 6.6 | 6.3 | 6.3 | 6.2 |
| | m-way | 3.7 | 4.2 | 4.2 | 4.1 | 3.9 | 4.0 | 4.1 |
| Artic HGVs | urban | 1.1 | 1.1 | 1.1 | 0.8 | 0.9 | 0.9 | 1.0 |
| | rural | 4.4 | 5.2 | 5.4 | 5.1 | 5.3 | 5.7 | 5.8 |
| | m-way | 4.7 | 7.4 | 7.9 | 7.5 | 8.4 | 8.8 | 8.9 |

| Billion vkm | | 1990 | 2000 | 2005 | 2010 | 2015 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|
| Buses | urban | 2.4 | 3.0 | 3.2 | 3.1 | 2.6 | 2.3 | 2.2 |
| | rural | 1.7 | 1.7 | 1.5 | 1.6 | 1.4 | 1.3 | 1.2 |
| | m-way | 0.6 | 0.5 | 0.5 | 0.5 | 0.4 | 0.4 | 0.4 |
| M/cycle | urban | 3.3 | 2.3 | 2.9 | 2.5 | 2.2 | 2.3 | 2.2 |
| | rural | 2.0 | 2.0 | 2.2 | 1.8 | 2.0 | 1.9 | 1.9 |
| | m-way | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| **Total** | | **423.3** | **482.9** | **512.9** | **507.9** | **529.9** | **547.4** | **549.1** |

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

Vehicle kilometre data based on traffic surveys do not distinguish between the type of fuels the vehicles are being run on (petrol and diesel) nor on their age. The inventory uses the Automatic Number Plate Recognition (ANPR) data provided by DfT to define the UK's vehicle fleet composition on the road. The ANPR data has been collected at over 256 sites in the UK on different road types (urban and rural major/minor roads, and motorways) and regions. They cover various vehicle and road characteristics such as fuel type, age of vehicle (which can be associated with its Euro standard), engine size, vehicle weight and road types.

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

- Petrol and diesel mix in the car fleet on different road types (urban, rural and motorway), leading to the vehicle km data for petrol and diesel cars on different road types in the UK shown in **Table 3.11**; and
- Variations in age and Euro standard mix on different road types.

The year-of-first registration of a vehicle determines the type of emission regulation that the vehicle complies with. These have entailed the successive introduction of tighter emission control technologies. Although emission standards do not apply to $CH_4$ and $N_2O$, technologies designed to control the regulated pollutants such as hydrocarbons and $NO_x$ affect these GHG emissions.

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

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

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

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

The inventory also takes account of the early introduction of certain emission standards and additional voluntary measures, such as incentives for HGVs to upgrade engines and retrofit

with particle traps, to reduce emissions from road vehicles in the UK fleet. This was based on advice from officials in DfT.

*Fuel Consumption Factors for Vehicle Types:*

Fuel consumption is calculated for each vehicle type using the fuel consumption-speed relationships given in COPERT 5 and the EMEP/EEA Emissions Inventory Guidebook (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 2005-2018. 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, 2019). The real-world uplift uses empirically-derived equations in the Guidebook that take account of average engine capacity and vehicle mass.

Using the Guidebook factors with fleet composition data and average speeds on different road types, fleet average fuel consumption factors for each main vehicle category are shown in **Table 3.12** for a selection of years between 1990 and 2018.

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

| Source | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|
| Petrol cars | 56.3 | 55.8 | 54.8 | 54.9 | 54.0 | 50.6 | 49.7 | 47.9 |
| Diesel cars | 54.8 | 53.2 | 53.4 | 53.5 | 54.1 | 50.3 | 48.1 | 49.4 |
| LGVs | 77.9 | 78.7 | 77.6 | 74.9 | 74.7 | 72.1 | 69.7 | 70.2 |
| HGVs | 210 | 205 | 194 | 207 | 211 | 216 | 214 | 218 |
| Buses and coaches | 292 | 293 | 268 | 267 | 262 | 255 | 263 | 265 |
| Mopeds and motorcycles | 36.2 | 37.0 | 38.0 | 36.9 | 35.9 | 34.9 | 35.0 | 35.1 |

*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_2020.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. 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 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 3.13** 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 3.13**  **$N_2O$ and $CH_4$ Implied Emission Factors for Road Transport (in mg/km). Includes cold start emissions**

| Gas | Source | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| $CH_4$ | Petrol cars | 124.4 | 93.3 | 59.1 | 34.3 | 18.6 | 15.1 | 13.8 | 13.3 |
| | DERV cars | 20.0 | 13.8 | 7.9 | 2.7 | 1.0 | 0.3 | 0.2 | 0.1 |
| | LGVs | 88.4 | 57.6 | 26.6 | 7.3 | 2.3 | 0.9 | 0.6 | 0.5 |
| | HGVs | 87.3 | 79.1 | 61.5 | 54.5 | 29.0 | 10.8 | 7.1 | 5.8 |
| | Buses and coaches | 151.3 | 157.4 | 118.0 | 95.3 | 52.8 | 22.5 | 12.7 | 9.9 |
| | Mopeds and motor-cycles | 231.0 | 223.7 | 210.7 | 167.1 | 114.0 | 87.1 | 76.9 | 70.1 |
| $N_2O$ | Petrol cars | 9.2 | 15.1 | 12.4 | 7.9 | 2.9 | 1.6 | 1.4 | 1.3 |
| | DERV cars | - | 2.2 | 4.0 | 6.1 | 6.6 | 6.6 | 6.6 | 6.6 |
| | LGVs | 6.0 | 4.6 | 5.4 | 6.3 | 6.4 | 6.5 | 6.4 | 6.4 |
| | HGVs | 35.7 | 27.8 | 14.6 | 8.6 | 18.0 | 39.6 | 45.3 | 46.9 |
| | Buses and coaches | 35.7 | 29.4 | 16.8 | 9.3 | 14.3 | 26.9 | 32.8 | 34.9 |
| | Mopeds and motor-cycles | 2.2 | 2.1 | 2.2 | 2.1 | 2.0 | 2.1 | 2.1 | 2.1 |

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 all years, the bottom-up method tends to underestimate fuel consumption. The maximum deviation from DUKES is 16% (for DERV, in 1990) however the ratio tends towards 1 up to 2009, indicating better agreement with fuel sales data in recent years than in the earlier part of the time-series. In 2018, the bottom-up method underestimates petrol and diesel consumption by 6.8% and 7.0%, respectively.

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

The fuel consumption, normalised to DUKES in the manner described above, is used to calculate $CO_2$ emissions for each vehicle type. For $CH_4$ and $N_2O$, the 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.

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

**Figure 3.2       Ratio of calculated consumption of petrol and diesel fuel**
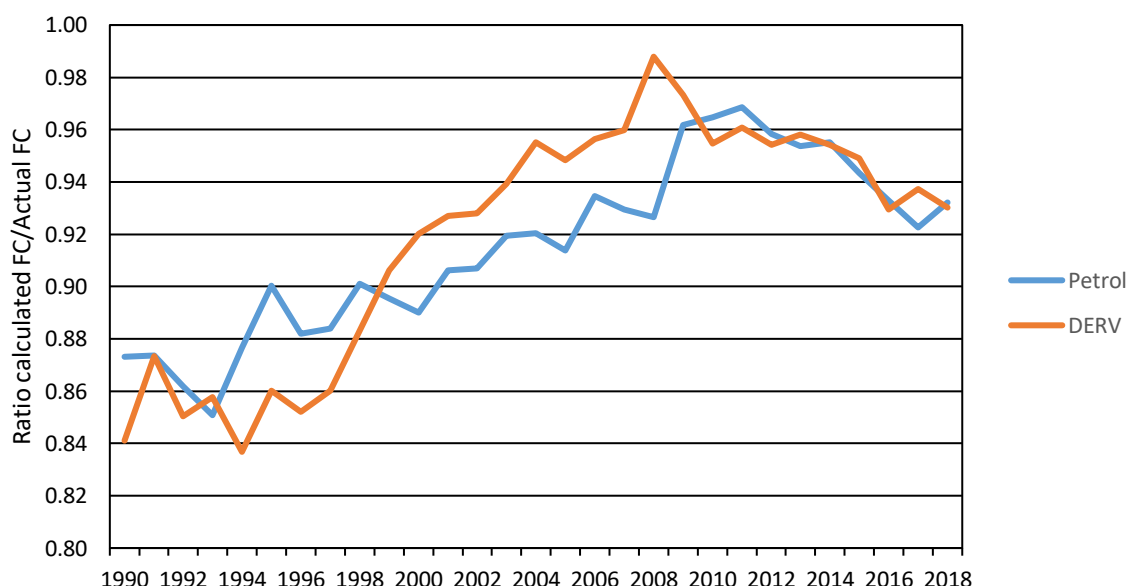


Note: Calculated petrol and diesel fuel consumption are based on traffic movement and fuel consumption factors summed for different vehicle types. DUKES figures for these fuels are based on fuel sales in the UK.

### *Emission factors for $CH_4$ 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_2020.xlsx"*.

Consumption of LPG is relatively small in the UK (0.2% of all road fuels in 2018) and there are no reliable data on the number or types of vehicles running on LPG. Licencing statistics suggests that 0.15% of all light duty vehicles ran on LPG in 2018.

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**

There have been no major recalculations. However, one small recalculation has occurred for the following reason: An update to the percentage of diesel cars in Northern Ireland in 2016 and 2017. This leads to an approximate 1-2% increase in UK emissions from petrol cars and an approximate <1% decrease in UK emissions from diesel cars.Improvements (completed and planned)

No specific improvements are currently planned. A watching brief is kept on developments in emission factors and activity data for all modes of transport.

**QA/QC**

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

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

The traffic data (vkm) and fleet composition data are provided by DfT and have been assessed by the UK Statistics Authority and confirmed as National Statistics. DfT statistics are accompanied by a Statement on Quality Strategy Principles and Processes[50].

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).

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[50] 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

## MS 9    Railways

**Relevant Categories, source names**

1A3c: Rail - coal

Railways: freight – gas oil

Railways: intercity – gas oil

Railways: regional – gas oil

**Relevant Gases**

$CO_2$, $CH_4$, $N_2O$

**Relevant fuels, activities**

Gas oil, coal

**Background**

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

**Key Data sources**

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

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

*An accompanying spreadsheet "Energy_background_data_uk_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references*[47]. **Table 1.6** *gives additional information for common activity data sources.*

**Method approach**

Emissions are calculated based on AD x EF.

Coal consumption data has been obtained from DUKES. Estimates have been made for 2005-2018 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.

Both activity (passenger vehicle kilometres, passenger and freight rolling stock fleet splits) and emission factors (in units of g/km) for intercity, regional and freight were updated for the 2018 NAEI.

Based on recent work for the UK's Rail Safety Standards Board (RSSB) to develop new emission factors (EFs) by engine throttle notch (in units of g/kWh) (which better reflect actual

operation of the diesel engine), better accounting for the non-linear relationships between engine power output and emissions of pollutants has been made possible.

Ultimately these factors can be used with detailed On-Train Monitoring Recorder (OTMR) data to develop detailed emission profiles of individual train journeys. However, these new factors were also used to develop revised emission factors in units of g/km, providing an improvement over the previous factors used in the NAEI for many train and locomotive classes. Essentially, a review of available OTMR data collected as part of the recent RSSB project allows a better understanding of typical drive cycles (the amount of time spent in different engine modes) which can differ from the regulatory drive cycles used to develop the previous NAEI factors.

Output from runs for 2014 and 2018 from the DfT Rail Emissions Model (REM) were used to update the passenger train kilometres diesel/electric split, passenger vehicle kilometres data, and rolling stock fleet distributions. This data allowed assessment of the distribution of different High Speed Train formations (with 5, 7, 8 and 9 passenger vehicles) back to 2009, the introduction of new Intercity Express Train bi-mode trains in 2018 and the introduction of the Class 172 (back to 2010). Revisions based on expert knowledge were also made to introductions of new freight locomotives (and of different Class 66 emission variants).

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. Train kilometre data for freight trains has been estimated from ORR's NRTY and data portal, which provides data on the tonne kilometres travelled. An assumption is then made that the ratio between the tonne kilometres and freight train kilometres is the same as it was in 2004 for all years.

Gas oil consumption by passenger and freight trains is obtained from the 2011 NRTY for the period 2005-2009 and from ORR's data portal for the years 2011-2018. 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. Following finalisation of the 2018 data, a revised fuel consumption dataset for the rail freight sector from 2011 onwards was published by ORR. This has resulted in a reduction in the estimates and these figures will be included in the 2019 inventory.

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).

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 passenger train kilometres have steadily increased from 220 million km in 2000 to almost 260 million km in 2018. This trend is generally reflected in the passenger train fuel consumption data, aside from in 2018 where a reduction in fuel consumption is recorded. The amount of freight moved has declined steadily since 2013 as a result of a substantial decline in the amount of coal hauled. The amount of freight moved in 2018 is around 78% of the amount estimated for 2013.

**Recalculations**

Fuel consumption for 2015, 2016 and 2017 was updated to reflect finalised ORR data. In addition, improvements have been made to the fleet composition and emission factors as outlined above.

**Improvements (completed and planned)**

Various emission related projects are currently being undertaken by the rail industry in the UK which should 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 2010. 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 (2019c), MMO Fishing statistics (MMO, 2018), DUKES (BEIS 2019a), Scarbrough et al. (2017).

Emission factors:    IMO (2015).

*An accompanying spreadsheet "Energy_background_data_uk_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references*[47]. **Table 1.6** *gives additional information for common activity data sources.*

**Method approach**

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

The receivers capture a number of smaller vessels and voyages such as movements to and from off-shore oil and gas rigs, and journeys to/from crown dependencies. The approach also uses a detailed set of port statistics for different vessel categories as proxies for estimating activities in years back to 1990 and forward to 2018 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 2018). In many cases, multiple statistical series need to be used if no complete series is available to cover the entire period to 1990. The specific statistical series used for each vessel category is indicated in Table 3.14. The main DfT statistics used are (DfT, 2019c):

- PORT0102 UK major and minor port freight traffic, international and domestic by direction, annually: 1965 - 2018
- PORT0201 Domestic UK major port freight traffic by cargo type and direction, annually: 2000 – 2018

- PORT0202 UK major and minor ports main freight units, by route, annually: 1970 - 2018

**Table 3.14        Summary of activity indices**

| Vessel category | Activity index used | Separate domestic index? |
|---|---|---|
| Bulk carrier | 2000-2018: Table PORT0201 – 'All dry bulk traffic' [Note 1] | ✓ |
| Chemical tanker | 2000-2018: Table PORT0201 – 'Other liquid bulk products' [Note 1] | ✓ |
| Container | 2000-2018: Table PORT0201 – 'All container traffic' [Note 1] | ✓ |
| General cargo | 2000-2018: Table PORT0201 – 'All other general cargo traffic' [Note 1] | ✓ |
| Liquefied gas tanker | 2000-2018: Table PORT0201 – 'liquefied gas' [Note 1] | ✓ |
| Oil tanker | 2000-2018: Table PORT0201 – 'total of Crude Oil and Oil Products' [Note 1] | ✓ |
| Ferry-pax only | 2003-2018: 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 | 2000-2018: Table PORT0201 – 'Other dry bulk' [Note 1] | ✓ |
| Ro-Ro | 2000-2018: Table PORT0201 – 'Roll-on/roll-off traffic' [Note 1] | ✓ |
| Service - tug | 2000-2018: Table PORT0201 – 'total domestic traffic' [Note 1] | ✓ |
| Miscellaneous - fishing | 2010-2018: 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 | 2000-2018: Table PORT0201 – 'total domestic traffic' [Note 1] | ✓ |
| Miscellaneous - other | 2000-2018: 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 backcasted inventory prior to 2010, any vessels that would have used HFO, save for the at berth requirement of 0.1% S fuel, are assumed prior to 2010 to use HFO.

*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 2018.

*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**

Emissions from fishing vessels have been recalculated as a result of using updated UK Sea Fisheries Annual Statistics data. This leads to a 0.3% decrease in activity in 2016 and a 3.3% decrease in activity in 2017, relative to the previous submission. Minor changes in the DfT port statistics used as timeseries proxies also result in minor revisions in the average emission factors for this sector. These changes in emission factors are all less than 0.3% different to those used in the previous submission.

**Improvements (completed and planned)**

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

**QA/QC**

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

**Time-series consistency**

The time-series for national navigation and fishing is derived from trends in port activity statistics for different vessel types. Some of these show an increase in activities over time, others a decrease in activities over the time-series for different vessel types..

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

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

**Uncertainties**

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

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

Additional uncertainty is introduced through the use of proxy statistics to develop the time-series. The uncertainty in the carbon emission factor is considered low, whereas the uncertainties for non-$CO_2$ 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_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references*[47]. **Table 1.6** *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, 2019d) were able to interrogate their ports database which forms the basis of the less detailed information published in DfT's Maritime Statistics. This included information on freight shipping movements and passenger vessel movements. Additional information on passenger vessel movements were gathered from individual OT port authorities.

**For freight shipping**, the DfT were able to provide the number of trips made between a UK port and an OT port by each unique vessel recorded. The information provided the type of vessel and the departure and arrival port. Figures were provided for all years between 2000 and the latest inventory year.

The information on the type of vessel combined with information from the EMEP Emissions Inventory Guidebook 2016 was used to define:

- the average cruise speed of the vessel;
- the average main engine power (in kW); and
- the specific fuel consumption factor (g/kWh).

DfT were unable to provide the detailed port data for years before 2000. The individual OT port authorities also did not have this information. The trends in fuel consumption calculated for all UK international shipping from 1990 to 2000 (based on less detailed UK port statistics) were used to define the trend in fuel consumption for shipping between the UK and OTs over these years.

**For passenger vessels**, the information held by OT port authorities indicated the only movements were by cruise ships (i.e. not ferries). Data from DfT was used for the years 2013-2017 (DfT, 2018a). Detailed movement data were held by the port authority of Gibraltar listing

all voyages departing to or arriving from the UK from 2003 to 2012[51]. The DfT also held information on the number of UK port arrivals by cruise ships from the OTs, but only between 1999 and 2004. This is unpublished information and was provided via direct communication with DfT officials.

Information held by the other OTs indicated that none had any cruise ship sailings with the UK logged. The data held by DfT showed the majority of sailings were from Gibraltar and the data were consistent with the information provided by the Gibraltar port authority. However, the DfT data also showed a total of 3 arrivals from the Falkland Islands between 1999 and 2004.

No cruise ship information was available before 1999 from either DfT or the individual OT port authorities. Trends in the total number of passengers on cruises beginning or ending at UK ports between 1990 and 1999 published in DfT's Maritime Statistics (from Table 3.1(a) UK international short sea passenger movements, by port and port area: 1950 – 2009) were used to define the trend in fuel consumption by cruise ships between the UK and OTs over these years.

This information was combined to show the total number of cruise ship movements between the UK and OTs from 1999 to 2017. Data upon request from DfT for calendar year 2018. To estimate the fuel consumption for passenger vessels for 2018, the mean fuel consumption of the previous five years (2013 – 2017) by OT was used. DfT are optimistic that they could provide the required data for the 2021 inventory submission.

**Distance travelled:** Distances for each voyage for freight and passenger were taken from http://www.portworld.com/map/. This has a tool to calculate route distance by specifying the departure and arrival ports. Using the distance, average speed, engine power and fuel consumption factor it was possible to calculate the amount of fuel consumed for every voyage made.

### *Emission factors*

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

### *Assumptions & observations*

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

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

### Recalculations

There have been minor recalculations to the emission factors. This is due to revised vessel type splits as a result of updated DfT port activity data.

### Improvements (completed and planned)

This emission source was introduced in response to the UNFCCC ERT in 2012. No improvements to this method are currently planned.

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

**QA/QC**

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. There are no official statistical data sets available to verify the information provided for the calculation of these estimates. They are considered to be the best available data.

**Time-series consistency**

The method approach section above details which years data were available for. Gaps have been filled for the early part of the time-series based on other statistics, to ensure that the inventory is complete for all years.

**Uncertainties**

The uncertainty analysis is set out in **Annex 2**. The uncertainty in this particular source is high although the contribution to the total inventory is low and as such, it does not warrant further research. Estimates are included for completeness, following a recommendation from the ERT.

## MS 12   Inland Waterways

**Relevant Categories, source names**

1A3d Inland goods-carrying vessels

> Motorboats / workboats (e.g. canal boats, dredgers, service boats, tourist boats, river boats)
>
> Personal watercraft e.g. jet ski
>
> Sailing boats with auxiliary engines

**Relevant Gases**

$CO_2$, $CH_4$, $N_2O$

**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_2020.xlsx" lists all emission factors used in the energy sector, including a full list of references[47]. **Table 1.6** gives additional information for common activity data sources.*

**Method approach**

The Guidelines recommend national energy statistics be used to calculate emissions, but if these are unavailable then emissions should be estimated from surveys of fuel suppliers, vessel movement data or equipment (engine) counts and passenger and cargo tonnage counts. The UK has no separate national fuel consumption statistics on the amount of fuel used by inland waterways in DUKES. However, they are included in the overall marine fuel statistics. A Tier 3 bottom-up approach based on estimates of population and usage of different types of inland waterway vessels is used to estimate their emissions. In the UK, all emissions from inland waterways are included in domestic shipping totals.

The methodology applied to derive emissions from the inland waterways sector uses an approach consistent with the 2016 EMEP/EEA Emissions Inventory Guidebooks (EMEP, 2016).

Emissions from individual vessel types are calculated using the following equation:

$$E = \sum_i N \times HRS \times HP \times LF \times EF_i$$

where:

$E$ = mass of emissions of pollutant i or fuel consumed during inventory period,
$N$ = source population (units),
$HRS$ = annual hours of use,
$HP$ = average rated horsepower,
$LF$ = typical load factor,
$EF_i$ = average emissions of pollutant i or fuel consumed per unit of use (e.g. g/kWh).

The method requires:

- a categorisation of the types of vessels and the fuel that they use (petrol, DERV or gas oil);
- numbers for each type of vessel, together with the number of hours that each type of vessel is used;
- data on the average rated engine power for each type of vessel, and the fraction of this (the load factor) that is used on average to propel the boat; and
- g/kWh fuel consumption factors and fuel-based emission factors.

The inland waterways class is divided into four categories and sub-categories (Walker et al, 2011):

- Sailing Boats with auxiliary engines;
- Motorboats / Workboats (e.g. dredgers, canal, service, tourist, river boats);
    - recreational craft operating on inland waterways;
    - recreational craft operating on coastal waterways;
    - workboats;
- Personal watercraft i.e. jet ski; and
- Inland goods carrying vessels.

*Activity data for 2008*

A bottom-up approach was used based on estimates of the population and usage of different types of craft and the amounts of different types of fuels consumed. Estimates of both population and usage were made for the baseline year of 2008 for each type of vessel used on canals, rivers and lakes and small commercial, service and recreational craft operating in estuaries / occasionally going to sea. For this, data were collected from stakeholders, including the British Waterways, DfT, Environment Agency, Maritime and Coastguard Agency (MCGA), and Waterways Ireland.

As it was only possible to estimate population and activities for one year (2008), proxy statistics were used to estimate activities for different groups of vessels for other years in the time-series:

- Private leisure craft – ONS Social Trends 41: Expenditure, Table 1, Volume of household expenditure on "Recreation and culture"[52];. 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)[53];
- Commercial passenger/tourist craft – Visit Britian, Visitor Attraction Trends in England 2018, Full Report: "Total England Attractions"[54]
- 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[55])

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

Within inland waterways, revised data on domestic waterborne freight leads to a 7% increase in the activity for this class of vessels in 2017. There was also a minor (0.2% decrease in

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

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

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

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

2017) in the activity data on household expenditure data from OECD, used for private leisure craft.

### Improvements (completed and planned)

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

### QA/QC

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

### Time-series consistency

The bottom up analysis for this source category was carried out for one year, and the time-series is generated using proxy statistics, as set out in the method approach section, above. Consistent time-series of proxy statistics, where available, have been used to estimate the inland waterways activities time-series. For private water craft, two data sets have been combined. Where the two data sets overlap, there is a correlation in the trend. The combination of these data sets does not introduce any time consistency issues.

### Uncertainties

The uncertainty analysis is set out in **Annex 2**. There are no official statistics for the population of vessels, the total fuel consumption or the annual usage of the vessels. There may also be some overlap in definitions between small coastal shipping and inland waterways.

## MS 13   International shipping

### Relevant Categories, source names

Marine bunkers: Shipping - international IPCC definition

### Relevant Gases

$CO_2$, $CH_4$, $N_2O$

### 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, 2019);

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

*An accompanying spreadsheet "Energy_background_data_uk_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references[47]. **Table 1.6** gives additional information for common activity data sources.*

### Method approach

### *Activity data*

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

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

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

### *Emission factors*

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

## Assumptions & observations

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

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

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

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

## Recalculations

Recalculations in the activity data led to a 1% increase in the 2017 for this MS. There are only minor (<0.1%) recalculations to emission factors due to updated DfT port statistics used to derive the time-series.

Table 3.15 summarises the time-series in gas oil and fuel oil consumption for domestic coastal and military shipping, fishing, inland waterways, international shipping and voyages from the

UK to the OTs since 1990 based on the new approach for all these marine activities. Fuel consumed in the OTs and for voyages from the OTs to the UK are not included in this table.

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

| Year | Gas oil | | | | Fuel oil | | | |
|---|---|---|---|---|---|---|---|---|
| | Domestic coastal and military | Fishing | Inland waterways | International bunkers | Domestic coastal and military | Fishing | Voyages from UK to OTs | International bunkers |
| 1990 | 1.89 | 0.23 | 0.03 | 1.14 | 0.82 | 0.82 | 0.008 | 1.39 |
| 1991 | 1.89 | 0.23 | 0.03 | 1.19 | 0.80 | 0.80 | 0.008 | 1.28 |
| 1992 | 1.86 | 0.24 | 0.03 | 1.24 | 0.78 | 0.78 | 0.008 | 1.30 |
| 1993 | 1.84 | 0.25 | 0.03 | 1.16 | 0.77 | 0.77 | 0.008 | 1.31 |
| 1994 | 2.06 | 0.25 | 0.04 | 1.20 | 0.84 | 0.84 | 0.009 | 1.11 |
| 1995 | 2.13 | 0.26 | 0.04 | 1.11 | 0.89 | 0.89 | 0.009 | 1.35 |
| 1996 | 2.14 | 0.24 | 0.04 | 1.20 | 0.90 | 0.90 | 0.009 | 1.45 |
| 1997 | 2.12 | 0.21 | 0.03 | 1.16 | 0.86 | 0.86 | 0.010 | 1.80 |
| 1998 | 2.06 | 0.20 | 0.03 | 1.40 | 0.88 | 0.88 | 0.010 | 1.67 |
| 1999 | 2.12 | 0.19 | 0.03 | 1.15 | 0.89 | 0.89 | 0.011 | 1.17 |
| 2000 | 1.96 | 0.18 | 0.03 | 1.14 | 0.80 | 0.80 | 0.011 | 0.93 |
| 2001 | 1.84 | 0.18 | 0.03 | 1.43 | 0.76 | 0.76 | 0.011 | 0.83 |
| 2002 | 1.83 | 0.18 | 0.03 | 1.14 | 0.79 | 0.79 | 0.008 | 0.76 |
| 2003 | 1.76 | 0.19 | 0.04 | 0.90 | 0.75 | 0.75 | 0.009 | 0.86 |
| 2004 | 1.73 | 0.19 | 0.03 | 1.07 | 0.75 | 0.75 | 0.010 | 1.00 |
| 2005 | 1.64 | 0.19 | 0.04 | 0.89 | 0.78 | 0.78 | 0.009 | 1.16 |
| 2006 | 1.53 | 0.18 | 0.04 | 1.04 | 0.72 | 0.72 | 0.013 | 1.30 |
| 2007 | 1.54 | 0.18 | 0.04 | 0.90 | 0.74 | 0.74 | 0.019 | 1.45 |
| 2008 | 1.47 | 0.18 | 0.04 | 1.03 | 0.70 | 0.70 | 0.011 | 2.44 |
| 2009 | 1.43 | 0.16 | 0.04 | 1.05 | 0.66 | 0.66 | 0.009 | 2.25 |
| 2010 | 1.41 | 0.17 | 0.04 | 0.96 | 0.57 | 0.57 | 0.011 | 1.83 |
| 2011 | 1.29 | 0.16 | 0.04 | 0.99 | 0.56 | 0.56 | 0.011 | 2.13 |
| 2012 | 1.15 | 0.16 | 0.04 | 1.12 | 0.52 | 0.52 | 0.009 | 1.53 |

| Year | Gas oil | | | | Fuel oil | | | |
|------|---------|---------|---------|---------|---------|---------|---------|---------|
| | Domestic coastal and military | Fishing | Inland waterways | International bunkers | Domestic coastal and military | Fishing | Voyages from UK to OTs | International bunkers |
| 2013 | 1.06 | 0.15 | 0.05 | 1.34 | 0.47 | 0.47 | 0.008 | 1.37 |
| 2014 | 1.04 | 0.17 | 0.05 | 1.68 | 0.49 | 0.49 | 0.010 | 1.14 |
| 2015 | 1.41 | 0.16 | 0.05 | 1.67 | 0.18 | 0.18 | 0.009 | 0.83 |
| 2016 | 1.38 | 0.17 | 0.05 | 1.77 | 0.17 | 0.17 | 0.010 | 0.88 |
| 2017 | 1.35 | 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 |

**Improvements (completed and planned)**

No improvements to this method are currently planned.

**QA/QC**

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

**Time-series consistency**

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

**Uncertainties**

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

# MS 14   Naval shipping

**Relevant Categories, source names**

1A5b: Shipping - naval

**Relevant Gases**

$CO_2$, $CH_4$, $N_2O$

**Relevant fuels, activities**

Gas oil

**Background**

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

**Key Data sources**

Activity:               MoD, 2019

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

*An accompanying spreadsheet "Energy_background_data_uk_2020.xlsx" lists all emission factors used in the energy sector, including a full list of references[47]. **Table 1.6** gives additional information for common activity data sources.*

**Method approach**

Emissions are calculated using a time-series of naval fuel consumption data (naval diesel and marine gas oil) provided directly by the Sustainable Development team of the MoD (MoD, 2019). Data are provided on a financial year basis and are amended to derive figures on a calendar year basis.

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

**Assumptions & observations**

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

**Recalculations**

There are no changes to the activity data. There are only minor (<0.1%) recalculations to emission factors due to updated DfT port statistics used to derive the time-series.

**Improvements (completed and planned)**

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

**QA/QC**

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

**Time-series consistency**

The time-series is generated from consistent data sets for all years, there are no known issues to raise.

**Uncertainties**

The uncertainty in the fuel use estimates is low since these are taken directly from the MoD. The carbon factors of fuel used by naval vessels would be known with low uncertainty, but default factors for $CH_4$ 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, 2019

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

*An accompanying spreadsheet "Energy_background_data_uk_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references24. **Table 1.6** gives additional information for common activity data sources.*

**Method approach**

LTO data are not available for military aircraft movements, so a simple, Tier 1 approach is used to estimate emissions from military aviation. The estimate of military emissions is made using military fuel consumption data (MoD, 2019) and IPCC (1997) and cruise defaults shown in Table 1 of EMEP/EEA (2016). 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, 2019) is subtracted from DUKES to ensure there is no double counting (**see Annex 4**). Fuel use for casual uplift is considered to be outside of DUKES.

The EMEP/EEA (2019) factors used are considered appropriate for military aircraft.

**Recalculations**

There have been no method changes and revised fuel use statistics from the MoD.

**Improvements (completed and planned)**

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

**QA/QC**

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

**Time-series consistency**

The time-series is generated from consistent data sets for all years, there are no known issues to raise.

**Uncertainties**

The uncertainty in the fuel use estimates is low since these are taken from a reliable source. Carbon emission factors are based on country specific data, whereas the non-$CO_2$ 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 2018 there were only eight 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, 2019). None of the remaining 3 mines are large enough to warrant investment in methane drainage and recovery systems used to collect and burn mine gas to raise power; until 2015 there were still operational deep mines in the UK that did capture and utilise methane. A further 10 open-cast coal mines were also operating in the UK in 2018. This is compared with 188 deep mining collieries and 126 open-cast mines operating in 1990[56].

**Key Data sources**

Activity Data: All activity data on coal production at open cast and deep mines is from DUKES (BEIS, 2018), except for production at licensed mines during 1990-1995 (only) which are from an industry reference (Barty, 1995).

Emission Factors: Operator reported data on methane emissions from deep mines are available for many years of the inventory time-series (1998-2014), and are used to derive CS EFs (UK Coal, 2015; Coal Authority, 2015), in conjunction with UK energy statistics from DUKES (BEIS, 2019). 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 2018 UK activity data on coal production in deep mines (BEIS, 2019). Methane EFs from mining operations from

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

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_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references[47]. **Table 1.6** gives additional information for common activity data sources.*

**Method approach**

Emissions are calculated from saleable coal production statistics for open-cast and deep-mined coal, taken from DUKES (BEIS, 2019). For all sources, UK-specific emission factors are applied, which in the early part of the time-series are derived from periodic industry publications, and for later years (1998 onwards) are primarily derived from company-specific or mine-specific reporting of methane emissions by mine operators. Industry-wide colliery methane utilisation data are taken from DUKES (BEIS, 2018).

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

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

***1990-1992*** Bennett et al (1995) was a study on deep mines which produced estimates of emissions for the period 1990-93. This was a period over which significant numbers of mines were being closed, hence the range in emission factors from 10 to 13.1 kg $CH_4$ 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 99% reduction in emissions reported in 1B1a1i since 2015,is fully consistent with the almost complete closure of UK deep-mined coal production. The UK energy statistics publication, DUKES, (BEIS, 2019), states on page 33 that: "*Deep-mined production in the UK has virtually ceased with only 25 thousand tonnes produced in 2018, less than 1 per cent of production, and down from 17 million tonnes in 2000"*

## Recalculations

There were very minor recalculations, (around +0.02%) to methane emissions from 1B1a1i and 1B1a1ii, due to minor revisions in the calorific values for coal in 2016 and 2017 Improvements (completed and planned)

No improvements to this method are currently planned. Emission factors and activity data are kept under review. As the UK deep-mined coal market continues to undergo restructuring and closures due to economic constraints, we anticipate that the number of mines that will remain

operating and reporting may continue to reduce and therefore the data availability and method options may be further impacted.

**QA/QC**

Activity data for coal production in deep-mined and open-cast mines in the UK are quality-checked through comparison of data reported within DUKES and data reported directly by the UK Coal Authority, which provides regional and UK totals of coal production. The information provided directly by colliery operators regarding their methane recovery systems are also checked against the data published by BEIS on coal mine methane projects in the UK (which encompasses both operating and closed / abandoned mines with coal mine methane recovery systems).

**Time-series consistency**

The factors for coal mining are all based on UK industry research. Emission factors from coal storage and transport, licensed mines and from open-cast mines do not vary through the time series; in each case the same factor is applied to the UK activity in every year. For deep-mined coal emissions there is a variable emission factor across the time series, derived from operator reporting and reflecting the changing methane management practices within UK collieries, especially to increase methane capture and oxidation for power-raising in recent years, leading to a gradually declining methane emission factor per unit coal produced since the early 2000s. The variability in the factor also reflects the changes in production from different mines that have different methane management practices, as for some UK collieries the capture and use of methane has not proved cost-effective and therefore the technology is not uniformly implemented. The variability of the time series of emission factors represents changes in UK coal mining, and not time series consistency issues. As described in the methodology section above, 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 and 2017. 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 0.01% of total methane emissions in the UK in 2017, whilst open-cast coal mining only accounts for 0.06% of total UK methane emissions.

## MS 17  Closed coal mines

**Relevant Categories, source names**

1B1a1iii: Closed Coal Mines

**Relevant Gases**

$CH_4$

**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 2020 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_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references*[47]. **Table 1.6** *gives additional information for common activity data sources.*

**Method approach**

The UK model was developed in 2005 (White Young Green, 2005) and revised in 2011 (WSP, 2011). The 2011 study used the same method, updating data for mine closures during 2005-2010.

The model generates both historic and projected methane emission estimates from closed UK coal mines, combining two separate sets of calculations to estimate emissions from:

- coal mines that were closed before 2005 and included in the 2005 update; and
- mines that were not included in the 2005 update, including mines closing or predicted to close between 2004 and 2028.

The model uses a relationship between emissions and the quantity of the underlying methane gas within the abandoned mine workings, including site-specific considerations of the most appropriate decay model for the recently closed mines.

The model calculates methane reserves for all UK coalfields that are not totally flooded from 1990 with projections to 2050. The gas reserves are calculated by totalling all the gas quantities in individual coal seams likely to have been disturbed by mining activity. To enable

calculation of the reserves over time, the rise in water levels in the abandoned mines due to water inflow has been calculated based on industry consultation, with a date estimated for each of the mines to be fully flooded; as mine workings become flooded they cease to release significant amounts of methane to the surface.

The development of the model has drawn on industry monitoring to measure methane emission from vents and more diffuse sources, including measurement of the flow rate and methane concentrations of vented mine gases. The industry knowledge of these methane sources has increased greatly in the UK over the last 10 years as the technology to capture and utilise the methane for power generation has developed alongside new economic incentives to utilise the mine methane in this way. Monitoring of more diffuse sources involves the collection of long-term gas samples to measure any increases in background atmospheric methane level in the locality.

Methane flows measured by both methods showed a general increase with the size of the underlying gas reserve. The data indicate an emission of 0.74% of the reserve per year as a suitable factor to apply to the methane reserve data in order to derive methane emission estimates for abandoned UK coalfields for 1990 to 2050, and this factor is applied within the model to derive the UK emission estimates.

Estimates have been made for both deep-mined and open-cast coal.

### Assumptions & observations

WSP (2011) derived estimates for historic methane emissions from closed coal mines and also generated projections to 2050, based on forecasts for UK coal mining activity and industry information on the quantity of underlying methane gas and expected rates of flooding of each mine following closure. The 2018 emission estimates in this 2020 UK GHGI submission are therefore taken from the projections of emissions within the 2011 WSP report, with the emission profiles through time for all major UK deep mines recently closed (i.e. since the study in 2011) brought forward to the actual date of closure, as all such mines were closed by the end of 2015. Each large deep mine within the model 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 2018.

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

All 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 required 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 2017 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: Upstream Oil Production - Offshore Well Testing

1B2a2: Petroleum processes

      Upstream Oil Production - process emissions

1B2a3: Upstream Oil Production - offshore oil loading

      Upstream Oil Production - onshore oil loading

1B2a4: Upstream Oil Production - oil terminal storage

1B2b1: Upstream Gas Production - offshore well testing

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

1B2b3: Upstream Gas Production - process emissions

1B2b4: Upstream Gas Production - gas terminal storage

1B2c1i: Upstream Oil Production - venting

1B2c1ii: Upstream Gas Production – venting

1B2c1iii: Upstream Combined Production – venting *(reported as IE)*

1B2c2i: Upstream Oil Production - flaring

1B2c2ii: Upstream Gas Production – flaring

1B2c2iii: Upstream Combined Production – flaring *(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 reported emissions from offshore well testing (1B2a1, 1B2b1) also include some emissions from fuel gas combustion, as well as fugitive emissions.

**Background**

This source category covers emissions which occur during the production, transportation, or use of liquid and gaseous fuels. It excludes combustion of those fuels used by the industry during the production, transportation, or use of liquid and gaseous fuels, other than at the well testing phase in offshore production. Fuel combustion emissions associated with upstream oil and gas exploration and production are reported within 1A1cii Oil and Gas Extraction, the method for which is presented in **MS 2**. However, the operator-reported emissions from offshore well testing comprise emissions from both combustion of fuel gas and fugitive releases; due to the limited data resolution in reported emissions, all of these well testing emissions are reported under 1B2a1 and 1B2b1. Emissions from leakage during gas transmission and distribution, and the point of use are included in **MS 19.**

UK upstream oil and gas exploration and production is almost entirely offshore, with a very small number of onshore oil wells. No onshore gas production occurs in the UK. Shale gas reserves have been identified and some preliminary research into prospective shale gas extraction is on-going, but there is no active exploration or production currently in the UK.

Offshore oil and gas is transported to processing plants via pipelines and marine tankers; emissions of $CH_4$ and VOC occur during loading of oil into the ship's tanks (including from the onshore terminal when oil is transferred to tankers for export or transfer to UK refineries), and then subsequently at the unloading stage to onshore storage vessels. Emissions of $CH_4$ and VOC also occur from storage tanks at oil terminals.

**Key Data sources**

Activity data:        EEMS (BEIS, 2019), DUKES (BEIS, 2019), IED/PRTR-reported data (EA, NRW and SEPA, 2019) EU ETS data (BEIS, 2019), UKOOA (2005), UKPIA (2019)

Emission factors:    EEMS (BEIS, 2019), EU ETS (BEIS, 2019), UKOOA (2005)

*An accompanying spreadsheet "Energy_background_data_uk_2020.xlsx" lists all emission factors used in the energy sector, including a full list of references*[47]. ***Table 1.6*** *gives additional information for common activity data sources.*

**Method approach**

An overview of the data sources and methods used to derive estimates for the categories included in this MS is below. Note that in the UK there are different regulatory mechanisms that govern the activities of: (i) offshore oil & gas exploration and production, (ii) onshore conventional oil & gas exploration and production, and (iii) onshore unconventional shale gas exploration (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 two exceptions: (i) there are

no data available currently to estimate emissions from oil & gas well blowouts with the exception of estimates included for the 2012 blow-out at the Elgin platform, discussed below),, and (ii) there are no data available to enable the Inventory Agency to derive estimates for the ten onshore shale gas sites that have been spudded[57] since 2010, with eight well completions. These issues are detailed below.

The key methodology for 1B2 source categories is based around several data sources and studies;

- 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) and developed in conjunction with the trade association Oil & Gas UK. For further details see **Annex 3**. UK GHGI estimates are based on EEMS (activity data and emission factors derived from operator-reported emissions) from 1998 to the latest inventory year for all offshore installations. Industry studies from the trade association **(UKOOA, 2005)** are used to inform estimates prior to the EEMS system, 1990-1997;

- **Well testing** emissions estimates on an installation-specific basis are also included within the EEMS datasets from 1998-2016 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. Extrapolation of these sources from 1990 to 1997 is discussed below. Following a change of reporting systems used by the regulators in 2017, the inventory team noted that emissions from well testing were outliers in comparison to previous years. Clarification was sought from the regulator, and it was determined that reported emissions were an underestimate. Therefore, 2017 and 2018 well testing emissions estimates use 2016 data scaled on interannual trends in UK production of crude oil, condensate, and natural gas as published in the DUKES statistics (BEIS, 2019).

- 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 $N_2O$;

- For 1995 to 2009, all terminals reported source-specific emission estimates to the **EEMS system**. For combustion and flaring sources, the EEMS dataset for this period includes mass-based activity data, and emission estimates for a suite of GHG and air quality pollutants including $CO_2$, $CH_4$ and $N_2O$. However, in 2010 it was agreed with the offshore regulator (then called DECC, now BEIS) that onshore terminals no longer had to report to EEMS, as it was a duplication of regulatory reporting, as onshore terminals are also regulated under the IED/PRTR regulatory system by the EA and SEPA. Since 2010 onshore terminals may report voluntarily to EEMS, but the reporting is incomplete across UK terminals. Therefore from 2010 onwards the EEMS dataset does not provide a comprehensive dataset from which to derive emission estimates for onshore terminals for the UK GHGI, and the IED/PRTR data are used in conjunction

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

with EU ETS data in preference; **together these data provide a complete dataset** for emission sources on terminals and they provide source-specific detail for combustion and flaring sources;

- From 2005-2007, **combustion-only CO$_2$** emissions from upstream oil and gas facilities (both offshore installations and onshore terminals) have been reported under **EU ETS**, and from 2008 onwards **combustion and flaring CO$_2$** emissions from upstream oil and gas facilities has been reported under EU ETS. The scope of source emissions under EU ETS for each installation is not as comprehensive as EEMS or IED/PRTR (e.g. EU ETS does not include emissions from fugitives or venting), but the data are used to check carbon emission factors and to inform a de-minimis emission value for each site. The EU ETS data submissions by operators are also subject to third party verification as part of the requirements for the trading scheme, and therefore the EU ETS data are regarded as high quality data. For oil and gas **terminals** the EU ETS data provides useful additional detail, where facilities may not report to EEMS but do report facility-wide (i.e. aggregated across all sources) emission estimates under IED/PRTR. The EU ETS data provides emission estimates that can be broken down by fuel and between combustion and flaring sources, to augment the IED/PRTR emissions data, enabling more accurate source-specific emission reporting;

- The EEMS data are only comprehensive post-1998, therefore, additional data sets are required to compile a full time-series. To do this the **Petroleum Processing Reporting System (PPRS) is used** to provide data on **gas flaring volumes** at offshore and onshore installations, as well as **oil and gas production data** to extrapolate the activity data back to 1990. PPRS is the mechanism by which upstream oil and gas operators are required to report energy and other activity data to the BEIS Energy Statistics team as part of the wider system of regulation of the oil & gas extraction and production sector, and to inform upstream energy market trends;

- The UK GHG inventory estimates for categories during 1990-1997 inclusive are based on industry estimates provided within periodic reports in the 1990s, with a comprehensive review and update by the trade association provided in 2005 **(UKOOA, 2005).** This 2005 update was based on a UKOOA report from 1998, updated to use latest emission factors and activity data from across the sector. The 1998 UKOOA report presents data from detailed industry studies in 1991 and 1995 to derive emission estimates for 1990 from available operator estimates. Emission estimates for 1991-1994 were then calculated using production-weighted interpolations. Only limited data were available from operators in 1990-1994, and emission totals were only presented in broadly aggregated sectors of: drilling (offshore), production (offshore), loading (offshore) and total emissions onshore. Emission estimates for the more detailed oil & gas processing sources (well testing, fuel combustion, flaring, venting, process and fugitive, oil loading / unloading and oil storage) were then based on applying the fraction of total emissions derived from the 1997 data from EEMS; and

- The Inventory Agency continues to investigate ways in which methane 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 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 included it for the first time in the 2020 submission, to the fugitive emission estimates for the year 2012. The new 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)**[58].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 oil and gas production to date is from conventional oil and gas wells. These installations are all regulated under the IED/PRTR by UK environmental regulators (EA, SEPA) and the operators report on annual methane emissions and these estimates are aggregated and included within the UK GHGI under 1B2a2. However, the Inventory Agency continues to investigate ways in which methane emissions from onshore shale gas exploration activities can be estimated; there are currently no estimates of emissions from this activity in the UK GHGI. To date there has been no production of natural gas from unconventional shale gas resources in the UK, however the Inventory Agency notes that since 2010 there have been ten shale gas wells spudded in the UK, eight of which have been completed. None of these sites are actively producing gas as UK planning applications have yet to be passed on a site-by-site bases. Therefore none of the shale gas sites are yet under IED/PRTR regulation by the EA or SEPA, and there are no annual reported emission estimates by operators from their initial well spudding and completion activities.

- Also, as there has been no production of natural gas at any of these sites, there is no activity data that the Inventory Agency can use to apply a Tier 1 factor as provided in Table 4.2.4 in Section 4.2.2.3 of the Fugitives chapter of the IPCC 2006 Guidelines. We note that any fugitive emissions from these initial well spudding and completion activities are expected to be well below the threshold of significance for UK reporting for sources that are Not Estimated, although we further recognise following discussions with the ERT at the in country review of October 2019, that the source cannot be reported as "NE", as it is a sub-set of the IPCC source category for fugitive methane emissions from well drilling and completions, for which the UK does report emission estimates. We note that using the fugitive EF 0.0023 Gg $CH_4$ per million $m^3$ gas produced, from Table 4.2.4 of the IPCC 2006 Guidelines (the upper value in the table, for onshore gas production) that for the source to exceed the 0.05% value of annual reported UK GHGI emissions from 2010 to 2016 would require an annual production each year of over 4,000 million $m^3$ gas. Annual production each year at these well sites to date is zero. The UK inventory therefore has a very small under-report, but it is not practicable to quantify the under-report for this well spudding activity with the IPCC methods and default EFs currently available.

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

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

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

| Categories and subcategories | | Methodology |
|---|---|---|
| Onshore terminals, Offshore oil and gas platforms & Offshore floating production and storage vessels, well testing rigs | 1B2aii, 1B2bii Oil, Gas Production: Upstream facility process and fugitive releases | 1990-1997 (UKOOA 2005): 1998-Latest year from EEMS (BEIS, 2019): For onshore terminals and wells, missing sites from EEMS are estimated based on IED/PRTR-reported data (EA, NRW and SEPA, 2019). Emissions estimates for 2012 Elgin blowout use Lee *et al.*, (2018). |
| | 1B2aiii Transport: Offshore loading of oil, 1B2avi Other: Onshore loading of oil | 1990-1997 (UKOOA 2005): 1998-Latest year from EEMS (BEIS, 2019): Assumes $CH_4$ IEF from 1998 applies to all years 1990-1997. For onshore terminals and wells, missing sites from EEMS are estimated based on IED/PRTR-reported data (EA, NRW and SEPA, 2019). |
| | 1B2ci,ii Venting at upstream oil, gas facilities | 1990-1997 (UKOOA 2005): 1998-Latest year from EEMS (BEIS, 2019): For onshore terminals and wells, missing sites from EEMS are estimated based on IED/PRTR-reported data (EA, NRW and SEPA, 2019). |
| | 1B2ci,ii Flaring at upstream oil, gas facilities | 1990-1996 (UKOOA 2005): 1997-Latest year from EEMS (BEIS, 2019): Assuming the same oil:gas split as in EEMS 1997, and aggregate oil and gas flaring volumes 1990-Latest year (BEIS, 2019). For onshore terminals and wells, where terminals do not report to EEMS (since 2010) EU ETS data on flaring are used if available. Where no EEMS or EU ETS data are available, an estimate of the total reported emissions in IED/PRTR data are allocated to flaring. |
| | 1B2ai, 1B2bi Oil, Gas Exploration: well testing | 1990-1996 (UKOOA 2005): 1997-Latest year from EEMS (BEIS, 2019): AD estimated assuming $CO_2$ IEF from 1998 is valid for earlier years. |
| Refineries | 1B2aiv Refining / Storage: Petroleum processes, Oil Terminal storage | All years - Fugitive emissions from oil storage and refinery processes are derived from aggregate industry estimates provided by the refinery trade association (UKPIA, 2019). All flaring emissions from refineries are reported aggregated with combustion emissions, in 1A1b. |

**Assumptions & observations**

The EEMS data set allows for emissions to be accurately allocated between oil and gas production between 1998 and the latest year. Prior to 1998, in order to present a plausible trend in overall emissions for the oil and gas sectors back to 1990, a relatively simplistic approach has been adopted to divide the industry estimates between oil and gas back to 1990.

For flaring, gas consumption and well testing emissions, the oil:gas ratio of activity data in 1998 has been used to extrapolate back the activities to 1990, retaining the previous emission factors for the "oil and gas" sources. For process and fugitive sources, oil storage and venting emissions, where the EEMS data are provided as emissions data without any underlying activity and emission factor information, and the UK inventory method is to aggregate those operator-reported data and conduct QC against other reported data to ensure completeness, the estimates for the early part of the time-series are simply based on the oil:gas ratio (for each pollutant) from 1998.

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

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

**Recalculations**

There have been no major methodological changes in the 2020 submission.

Continued detailed QA/QC analysis of the full time-series of EEMS data leads to identification of outliers on an installation-specific basis which are then gap-filled using appropriate interpolation techniques. This means there have been various revisions to the emissions estimates from 2012 onwards, but most significantly for 2017 (for 1.B.2.a.3, 1.B.2.b.3, 1.B.2.c.1.i, 1.B.2.c.1.ii, 1.B.2.c.2.i, and 1.B.2.c.2.ii). DUKES revisions to oil and gas production statistics in 2017 are reflected in recalculations in 2017 for 1.B.2.a.1 and 1.B.2.b.1 also.

Finally, emissions estimates for the 2012 Elgin blowout have been added to the inventory for the first time in the 2020 submission, utilising data published by UK-based researchers (Lee *et al.*, 2018) calculating the flow rate and emissions profile of the plume from the site at that time, leading to recalculations to 1.B.2.a.2 for the year 2012 only.

**Improvements (completed and planned)**

In the 2020 submission the main improvement was the addition of new estimates for the 2012 Elgin blowout, which improves the UK inventory completeness, applying a bespoke country-specific method based on novel sampling and analysis techniques developed by UK researchers.

In late 2019, a new research project was commissioned by BEIS to research data and improve the inventory models for the upstream oil and gas sector. This project is currently in a data gathering and scoping phase. The project is expected to run until mid-2021 and lead to improvements in UK inventory estimates from the 2022 submission onwards, dependent on the outcomes of concurrent research being conducted across the upstream industry in the UK, including by the sector regulator, the Oil and Gas Authority, and also by the trade association, UK Oil and Gas. Emission factors and activity data will be kept under review. The Inventory

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

### QA/QC

The EEMS dataset quality system is managed by the regulatory agency (BEIS OPRED) and developed in conjunction with the trade association (UK Oil & Gas). EEMS uses an online reporting system with controls over data entry, together with guidance notes provided to operators to provide estimation methodology options and emission factors for specific processes. The IED/PRTR system is similar to EEMS, but regulated by the onshore environment agencies (EA, NRW, SEPA); it also has operator guidance on emission estimation and reporting, and a system of annual checks on data submitted by operators, by a Site Inspector / Process Engineer assigned by the regulator to manage the performance and compliance assessments for each installation. The data reported under IED/PRTR however are installation-wide, rather than source-specific.

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

The Inventory Agency combines UK energy statistics, the EEMS data, EU ETS and IED/PRTR data to derive the oil and gas sector estimates. The data reported from the EEMS system must be reconciled with the UK Energy Statistics and integrated into the NAEI without double-counting emissions. Where the EU ETS or IED/PRTR data are inconsistent with the EEMS data, the Inventory Agency works with BEIS OPRED and facility operators to determine the best available data for each source to ensure that the reported data are **complete for each installation**. The Inventory Agency also conducts time-series consistency checks to identify missing sites or sources, and for those sources where the EEMS data includes emissions and activity data the Inventory Agency reviews the time-series of implied emission factors to identify outliers. Any sites or sources where the quality checks identify gaps, outliers or inconsistent reporting between different regulatory systems are resolved in consultation with BEIS OPRED. An example is noted above regarding the 2017 and 2018 EEMS dataset for emissions from well testing, where the outlier data were considered to be potentially incomplete and therefore a more conservative emission estimate for that source was derived through extrapolation of the 2016 data, scaled using the interannual trends in UK production of crude oil, condensate and natural gas.

### Time-series consistency

The emission estimates for the offshore industry are based on the EEMS dataset for 1998-2017, whilst emission estimates for 1990-1997 are based on trade association data (UKOOA, 2005) to update earlier industry studies (UKOOA, 1998) that had used production data as a basis for generating sector-wide estimates from 1990. The EEMS dataset (BEIS, 2018) provides a consistent time-series of emission estimates for many facilities and sources, but since 2010 the reporting by onshore terminals is voluntary. Furthermore, whilst the EEMS data quality appears to be improving over recent years, the completeness of EEMS data for specific facilities and sources is still subject to uncertainty; reporting gaps appear to be systematic for some facilities, such as frequent non-reporting of oil loading / unloading emissions at some terminals. The Inventory Agency continues to work with the regulatory agency, BEIS, in the continued development of emission estimates from this sector.

The time-series of the IEF of $CO_2$ emissions in sector 1.B.2.a.2 (Oil Production) show a significant drop between 2011-2012 and a sharp rise between 2013 and 2015. Whilst oil production activity data is comparatively steady between 2011 and 2015, $CO_2$ emissions from this source are highly variable. This is because $CO_2$ emissions for this source are dominated by one installation which processes sour gas in the UK. This site was offline for most of 2012, 2013, and part of 2014, explaining the large variation in IEF over this period of the time-series.

### Uncertainties

Uncertainties are presented in **Annex 2**. Emissions data taken from the EEMS reporting system 1998 onwards are considered to be high quality, emissions data for other years are subject to greater uncertainties.

## MS 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, 2019) 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_2020.xlxs" lists all emission factors used in the energy sector, including a full list of references[47].*

**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, and (ii) NG records of intentional venting actions on the network. These data have not been available for every year across the time-series, with only two data points in the 1990s, annual data from 2000-2004, and for 2011-2018, 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 Brtian (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, 2019; SGN, 2019; Firmus Energy, 2019),

and the data for 1999 to 2004 have been extrapolated back from the 2005 figure.

*Gas Leakage at the Point of Use*

The third inventory estimation methodology is used to determine estimates of natural gas leakage at the point of use, and these estimates are also reported in 1B2b5. Leakages are estimated for a range of different appliances that use gas, combined with national statistics on natural gas consumption in the domestic and commercial sectors (BEIS, 2018).

*Industrial Heating Boilers*

Methane releases are assumed to be "**Not Occurring**" from these appliances, based on consultation with technical experts that advise the UK Government for the CHP QA scheme (Personal Communication: R Stewart, 2011). Larger boilers typically operate almost permanently once ignited (particularly if used for steam-raising) with little or no cycling from on to off states. Furthermore, releases of un-burnt natural gas are strictly controlled in industrial locations for safety reasons.

*Domestic Heating, Water Heating Boilers and cooking*

Methane emissions from pre-ignition losses of gas appliances domestic properties are based on activity data from Energy Consumption in the UK (BEIS, 2018) which provides a time-series of gas use for heating, water heating and cooking in the domestic sector, using a series of assumptions regarding the size of units, number of units, age of units, gas flow rates, air flow rates, delays to ignition, operation times from used to determine the percentage of gas that is not burned. The estimates of UK appliance stock, by capacity and design and estimated average gas consumption per appliance per day are all derived from Ecodesign studies (energy efficiency analysis) through the UK Government Market Transformation Programme (Ecodesign Lot 22 and Lot 23, 2011). The estimates of appliance cycle operation times and estimated delays to ignition for different appliances are based on expert judgement of UK combustion technology experts (Personal communication, Stewart, 2012).

*Commercial Gas Appliances: Catering and other uses*

Methane emissions from pre-ignition losses of gas appliances used in commercial catering and other uses are based on activity data from ECUK (BEIS, 2018) which provides a time series of gas use for catering and other uses in the commercial sector to 2017. The method then applies a series of assumptions regarding the operational cycles and delays to ignition, to derive a simple percentage non-combusted estimate for each gas appliance type using references and expert judgements as noted above for domestic appliances.

An overview of the time series of gas leak at point of use estimates in the UK, together with overall gas use by economic sector and appliance type is presented in **Annex 3**.

## Assumptions & observations

Assumptions used to estimate the leakage at point of use for domestic heating and water heating boilers are as follows:

- average boiler size in the UK of 30kW;
- a burn chamber size, natural gas flow rate taken from a typical combination boiler;
- estimated delay to ignition: 0.25 seconds for automatic ignition, 2 seconds for manual ignition;
- an air flow rate based on 25% excess oxygen in the combustion chamber when compared to stoichiometric ratio;
- an equation for a mixed reactor $(1-e^x)$ that when integrated will provide an estimate of the concentration of un-burnt air/fuel mixture released; and
- assumptions relating to the boiler yearly operation and cycling frequency, between heating and water heating applications
    - On average in the UK domestic properties have heating systems operating for half of the year and on average the heating is on for 5 hours per day. It is also assumed that during each hour that the boiler providing heating cycles on and off 4 times.
    - All UK domestic properties that have hot water heating systems also have gas heated hot water.
    - Average water heating is on for 4 hours per day every day of the year.
    - During each hour that a boiler is heating water, the boiler cycles on and off 5 times.

The number of boilers across the time series is thought to have increased (ca. 22 million in 2008) due to the increasing use of gas central heating for space heating, and the increase in the number of houses. However, it is assumed that pre-ignition gas loss in boilers installed in houses in 1990 were greater than in the current boilers installed, as technology has improved. Therefore, it is assumed that the proportion of gas leaked (i.e. % of the total gas use) from domestic heating and water heating appliances per annum is steady across the time series,

with the rationale that the sum of greater pre-ignition losses from fewer older-technology boilers in the early part of the time series will be roughly equivalent to the sum of lower pre ignition losses per unit from the greater number of newer-technology boilers in recent years.

Assumptions used to estimate the leakage at point of use for domestic cooking appliances (manual and automatic ignition) and gas fires are as follows:

- gas fires use an estimated 2.5% of total gas used for space heating in the domestic sector, with the remainder used in (automatic ignition) boilers;
- gas use in cooking hobs is estimated to be 73.6% of the total domestic gas use in cooking, with the remainder in gas ovens. This is based on data of average annual gas oven fuel use in kWh/yr and average domestic gas hob fuel use in kWh/yr, combined with data on UK stock of gas ovens and hobs, taken from a series of 2011 European Commission Eco-design studies (Bio IS / ERA Technology, 2011);
- for manual ignition devices, a conservative estimate of the delay prior to ignition of 2 seconds has been assumed (expert judgement), whilst the average operational cycle times for different types of appliance have been estimated at 900 seconds for a domestic hob (expert judgement) and 5400 seconds for a gas fire (EC Eco-design Lot 20 Task 5, gas stove base case, 2011); and
- for automatic ignition appliances, a conservative estimate of the delay prior to ignition of 0.25 seconds has been assumed (expert judgement), whilst the average operational cycle times of domestic ovens has been estimated at 900 seconds (expert judgement).

Assumptions used to estimate the leakage at point of use for commercial gas appliances (catering and other uses) are as follows:

- for commercial catering gas use, a conservative estimate of the delay prior to ignition of 0.5 seconds has been assumed (expert judgement, to reflect a mixture of hobs and oven use), whilst the average operational cycle has been estimated at 900 seconds (expert judgement); and
- for other commercial gas appliances, assumed to be predominantly gas-fired boilers of automatic ignition design, a conservative estimate of the delay prior to ignition of 0.25 seconds has been assumed (expert judgement), whilst the average operational cycle time has been estimated at 1800 seconds (expert judgement).

**Recalculations**

There have been no significant recalculations in the 2020 submission to emissions from this sector.

Minor recalculations have been introduced throughout the time-series for 1.B.2.b.5, largely as a result of improved understanding of the NCV and GCV of the natural gas in the UK's gas network. Previous estimates of the net and gross calorific values for natural gas have been derived by applying assumptions of the typical net-to-gross ratio for gaseous fuels. However, in the 2020 submission, network operator data that provide NCV and GCV data for each LDZ annually have been used to calculate a UK-wide weighted net-to-gross ratio.

In addition, there has been a minor recalculation due to gas suppliers in Northern Ireland providing a more complete estimate of gas leakage estimates from Northern Ireland for recent years, following consultation with the Inventory Agency.

**Improvements (completed and planned)**

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

**QA/QC**

The sector estimates are subject to the same Tier 1 QA/QC routines as all other source categories in the UK GHGI.

Checks on data reported by gas network operators are conducted to check consistency across the time-series and also between operators.

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

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

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

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

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

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

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

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

Therefore, compared to the Tier 1 methods, <u>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</u>.

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.

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# 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 1990-2018 and 2017-2018. A description of the trends and the main drivers behind these can be found in **Chapter 2**.

**Table 4.1** **Industrial Processes and Produce Use Overview**

| Industrial Processes and Product Use GREENHOUSE GAS SOURCE AND SINK CATEGORIES | Key Categories | Uncertainty | Latest year total (Mt CO2e) | BY–Latest year trend | Last 2 yr trend | Recalculation-: 2017 | Recalculation-: BY | Gases included | Methodology reference (NIR Section) | Method | EF | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total industrial processes** | | | 28.51 | -60% | -7% | 1% | 0% | | | | | |
| **A. Mineral industry** | | | 6.28 | -36% | 0% | 1% | 0% | | | | | |
| 1. Cement production | CO2 (L1) | 3% | 4.36 | -40% | -1% | 0% | 0% | CO2 | 4.2 | T2 | CS | |
| 2. Lime production | | 5% | 1.09 | -18% | 3% | 0% | -9% | CO2 | 4.3 | T1 (1990-1993) T3 (1994 – latest year) | D | |
| 3. Glass production | | 5% | 0.36 | -11% | -2% | 0% | 0% | CO2 | 4.4 | T2 | CS | |
| 4. Other process uses of carbonates | | 4% | 0.47 | -38% | 2% | 9% | 13% | CO2, CH4 | 4.5 | CS | CS (bricks), D (FGD) | CH4 from this source reported under 2H3i in the CRF tables. |
| **B. Chemical industry** | CO2, N2O, HFCs (L2, T2) | | 4.71 | -90% | -14% | 5% | 0% | | | | | |
| 1. Ammonia production | | 2% | 1.38 | -34% | -24% | 0% | 1% | CO2, CH4, N2O | 4.6 | T3 (CO2), T1 (CH4, N2O) | CS (CO2), D (CH4, N2O) | |
| 2. Nitric acid production | N2O (T1) | 10% | 0.02 | -99% | -34% | 0% | 0% | N2O | 4.7 | T2 | CS | |
| 3. Adipic acid production | N2O (L1, T1) | N/A | 0.00 | -100% | N/A | N/A | 0% | N2O | 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 | |

| Industrial Processes and Product Use<br><br>GREENHOUSE GAS SOURCE AND SINK CATEGORIES | Key Categories | Uncertainty | Latest year total (Mt CO2e) | BY-Latest year trend | Last 2 yr trend | Recalculation-: 2017 | Recalculation-: BY | Gases included | Methodology reference (NIR Section) | Method | EF | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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% | 0.18 | 74% | 1% | 0% | 0% | CO2 | 4.11 | CS | CS | |
| 7. Soda ash production | | 6% | 0.13 | -42% | -5% | 0% | 0% | CO2 | 4.12 | CS | CS | |
| 8. Petrochemical and carbon black production | CO2 (L1) | 30% | 2.95 | -38% | -2% | 6% | 5% | CO2, CH4, N2O | 4.13 | CS, T1 | CS, D | N2O from this source reported under 2B10 in the CRF tables |
| 9. Fluorochemical production | HFCs, PFCs, SF6 and NF3 (L1, T1) | 10% | 0.05 | -100% | -84% | 68 % | 0% | HFCs, PFCs | 4.14 | T2 | PS | |
| 10. Other (as specified in table 2(I).A-H) | | 25% | 0.04 | -82% | -32% | 5% | 9% | CH4 | 4.15 | CS | CS | |
| **C. Metal industry** | | 5% | 2.54 | -69% | -6% | 0% | 0% | | | | | |
| 1. Iron and steel production | CO2 (L1) | | 2.30 | -59% | -9% | 0% | 0% | CO2, CH4, N2O | 4.16 | T2 (CO2), T1, T3 (CH4) | CS (CO2), CR, CD, D (CH4) | N2O 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 | | | 0.08 | -90% | -9% | 0% | 0% | CO2, PFCs | 4.18 | T1 (CO2), T2 (PFCs) | CS (CO2), PS (PFCs) | |
| 4. Magnesium production | | | 0.16 | -59% | 42% | 0% | 0% | HFCs, SF6 | 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% | CO2 | 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 | N2O from iron and steel production reported here in the CRF tables |
| **D. Non-energy products from fuels and solvent use** | | 49% | 0.37 | -34% | -11% | -21 % | 0% | | | | | |
| 1. Lubricant use | | | 0.23 | -55% | -10% | -2% | 0% | CO2 | 4.22 | T1 | CS | |
| 2. Paraffin wax use | | | 0.02 | -28% | -2% | 0% | 0% | CO2 | 4.23 | T1 | D | |
| 3. Other | | | 0.11 | N/A | -13% | -45 % | N/A | CO2 | 4.24 | T2 (non energy use of petroleum | D (non energy use of petroleum | |

| Industrial Processes and Product Use / GREENHOUSE GAS SOURCE AND SINK CATEGORIES | Key Categories | Uncertainty | Latest year total (Mt CO2e) | BY-Latest year trend | Last 2 yr trend | Recalculation-: 2017 | Recalculation-: BY | Gases included | Methodology reference (NIR Section) | Method | EF | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | coke), T3 (urea use) | coke), CR (urea use) | |
| **E. Electronics industry** | | 45% | 0.02 | 150% | 10% | 0% | 0% | | | | | |
| 1. Integrated circuit or semiconductor | | | 0.02 | 150% | 10% | 0% | 0% | HFCs, NF3 | 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) | 9% | 13.11 | 825% | -7% | 0% | 0% | | | | | |
| 1. Refrigeration and air conditioning | HFCs, PFCs, SF6 and NF3 (L1, T1) | | 10.74 | 1921% | -8% | 0% | 0% | HFCs, PFCs | 4.29 | T2 | CS | |
| 2. Foam blowing agents | | | 0.46 | 151% | 3% | 0% | 0% | HFCs | 4.30, 4.31 | T2 | CS | |
| 3. Fire protection | | | 0.32 | 22669% | -1% | 0% | 0% | HFCs, PFCs | 4.32 | T2 | CS | |
| 4. Aerosols | HFCs, PFCs, SF6 and NF3 (T1) | | 1.51 | 128% | -9% | 0% | 0% | HFCs | 4.33 | T2 | CS | |
| 5. Solvents | | | 0.02 | N/A | -3% | -11% | N/A | HFCs | 4.34 | T1a | OTH | |
| 6. Other applications | | | 0.06 | 56% | -7% | 1% | 0% | HFCs | 4.35 | CS | CS | |
| **G. Other product manufacture and use** | N2O (L2, T2) | 65% | 1.47 | -12% | 0% | 2% | 1% | | | | | |
| 1. Electrical equipment | | | 0.25 | -68% | -4% | -6% | 1% | SF6 | 4.36 | T3 | CS | |
| 2. SF6 and PFCs from other product use | | | 0.34 | 20% | 6% | 0% | 0% | PFCs, SF6 | 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) | |

| Industrial Processes and Product Use GREENHOUSE GAS SOURCE AND SINK CATEGORIES | Key Categories | Uncertainty | Latest year total (Mt CO2e) | BY-Latest year trend | Last 2 yr trend | Recalculation-: 2017 | Recalculation-: BY | Gases included | Methodology reference (NIR Section) | Method | EF | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. N$_2$O from product uses | | | 0.65 | N/A | N/A | 1% | 0% | N2O | 4.40, 4.41 | OTH (Medical), CS (propellants) | CS (Medical), OTH (Propellants) | |
| 4. Other | | | 0.23 | N/A | N/A | 18 % | 34 % | CO2, N2O | 4.42 | CS | CS | |
| **H. Other (as specified in tables 2(I).A-H and 2(II))[(3)]** | | | 0.00 | N/A | N/A | N/A | N/A | | | CS | CS | CH4 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$_2$O emissions from 2B8 are reported under 2B10 in the CRF tables

\*\*\*N$_2$O emissions from 2C1 are reported under 2C7 in the CRF tables

The industrial processes and other product use sector (IPCC Sector 2) contributes 6.5% to total greenhouse gas emissions. Emissions from this sector include non-energy related emissions from mineral products, chemical industry and metal production and product use, including emissions of F-gases. Since 1990, this category has seen a 54% decline in emissions, mostly due to changes in the emissions from the chemical production and halocarbon and 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 2.15** - **Figure 2.17** show that the numbers of industrial processes in the UK have been declining since 1990. While this is partly due to the closure of some smaller sites, perhaps with growth in capacity at remaining sites, it is predominantly a reflection of decreasing production of many industrial materials in the UK. A large number of closures in the period 2007-2009 were due to decreased demand for many products as a result of the general economic situation in the UK and elsewhere, with falling demand for steel, cement, bricks and aluminium, for example, leading to plant closures.

**Figure 4.1** **Breakdown of total GHG emissions in Industrial Processes sector for the latest inventory year**



- 2A = 21.9%
- 2B = 16.6%
- 2C = 8.9%
- 2D = 1.3%
- 2E = 0.1%
- 2F = 46%
- 2G = 5.2%
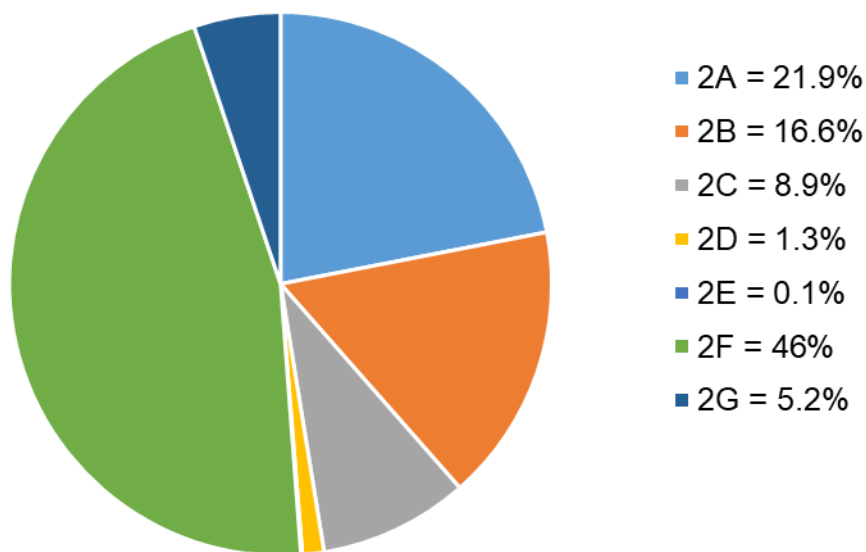
**Figure 4.2** **Trend in total GHG emissions in Industrial Processes sector**
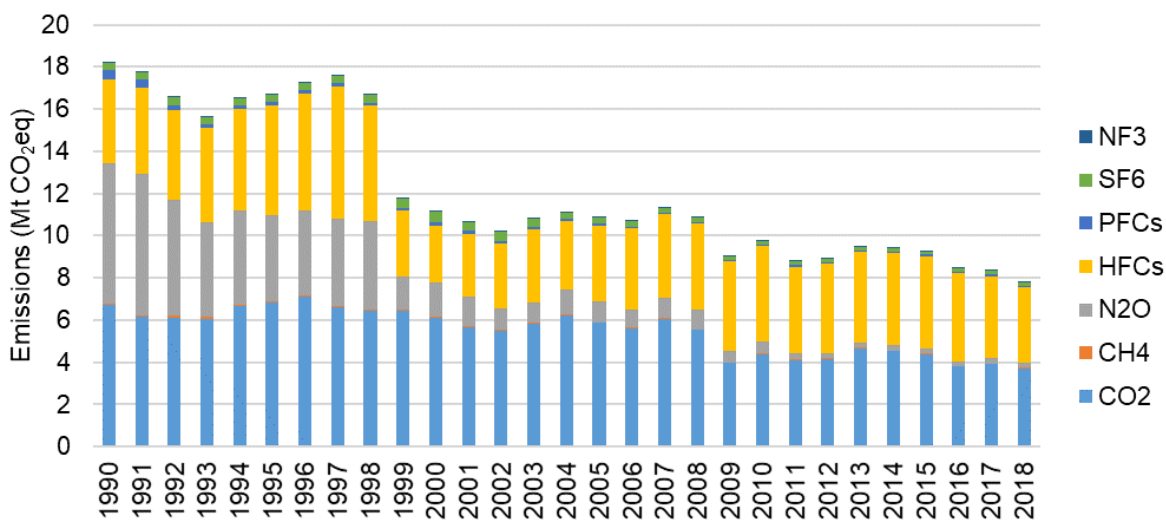


## 4.2 SOURCE CATEGORY 2A1 – CEMENT PRODUCTION

### 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 2005-2018 are available from the annual UK production of clinker and emission factors provided by the Mineral Products Association (MPA, 2019), 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 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 0.09%. In each year, the inventory estimates are based on the higher of the two figures, i.e. MPA data for 2005-2007, 2010 & 2015-2017, and EU ETS for 2008-2009, 2011-2014 and 2018. The EU ETS and MPA/BCA data all include emissions associated with cement kiln dust.

EU ETS and MPA data are available for 2005 to 2018 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 | 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 | | Factor derived from site-specific EU ETS returns for all UK sites (since higher than MPA-based CEF for that year). | |

## 4.2.3  Uncertainties and Time Series Consistency

The time-series consistency of the activity data used in the UK GHGI emission calculations is very good across all years, as the Inventory Agency has a complete, consistent dataset from the UK trade association (BCA then MPA) from 2001 onwards, and routine statistical datasets for the earlier years from BGS. Furthermore, since 2005 there is a comprehensive sector-wide dataset for emissions and the EFs applied for carbonisation emissions. Cross-checks with EU ETS data received directly from UK regulators indicate only very small differences. The extrapolation of the EF from 2005 back to 1990 is the best available data to use for the UK cement sector, but does lead to higher uncertainties for the emissions total in the base year.

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

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

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

**Table 4.3** summarises activity data and implied emission factors over the time series. The activity data for 2001 onwards are for Great Britain only. The $CO_2$ 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 - 2018.**

| 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 |

| Year | Cement Clinker production (kt)[a] | CO$_2$ emitted (kt) | CO$_2$ emission factor, (t / t clinker) |
|---|---|---|---|
| 2018 | *7,734* | 4,364 | 0.564 |

[a] Figures in italics exclude production in Northern Ireland

A large drop in clinker production after 1990 can be explained by a sharp drop in construction activity. This initial drop and a less pronounced downward trend in production over the period 1994-2007 may, in part, also be due to increased use of slag cement, production of which is likely to have risen sharply over the same period; the Inventory Agency estimates that capacity for slag cement production increased from 0.75 Mtonnes in 1990 to 2 Mtonnes by 2007. A sharp decrease in clinker production between 2007 and 2009 is linked to the recession, which caused a decline in construction and therefore demand for cement. A number of kilns were closed or mothballed during those years, and none have subsequently been re-opened. However, there has been a slow increase in clinker production since 2009, and production in Great Britian in 2016 was at the highest level since 2008.

The UK-specific emission factor for cement clinker production is constant for 1990-2000 because no year-specific data are available, and a UK factor from the EU ETS reporting period is extrapolated back to UK production data. Factors presented above for the period 2005-2015 are all higher than the factor for 1990-2000, because of the change in the activity data from UK to GB in 2001, as explained above. Since the later activity data exclude a small number of sites in Northern Ireland, the activity data are lower, and the implied emission factors for CO$_2$ are therefore higher. The emission factors in the period 2001-2018 do vary from year to year, from a minimum value of 0.563 t CO$_2$ / t in 2015 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 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 by coal, coke or gas. The calcination results in the evolution of carbon dioxide. However it is necessary to distinguish between merchant lime processes where the purpose is to produce lime for use off-site and where carbon dioxide is an unwanted by-product emitted to atmosphere, and those captive lime processes where lime is produced so that both the carbon dioxide and lime can be used on-site in the process. In these latter processes, which include sugar refining, none of the carbon dioxide is emitted to atmosphere,

apart from the exception listed in the next section. Emissions from lime kilns used in the manufacture of sodium carbonate are, in line with IPCC Guidelines, reported in 2B7.

## 4.3.2  Methodological Issues

The UK method uses EU ETS data to determine emissions from 2005 onwards, Pollution Inventory (PI) data from 1994 to 2004 and British Geological Survey (BGS) data from 1990 to 1993. The EU ETS data consist of $CO_2$ 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 EU 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.

Prior to 2005 there are no EU ETS data at all, and data are incomplete for 2005-2006 because of UK exemptions from the EU ETS for some sites in those years. Therefore, between 1994 and 2004, $CO_2$ emission estimates for lime production are based on emissions data published for each site in the Pollution Inventory (PI). The PI data are mostly for total $CO_2$ i.e. include emissions from both decarbonisation and fuel combustion on a site, but estimates of the $CO_2$ from decarbonisation only are made using EU ETS data and PI data for 2006-2008, both of which give fuel combustion emissions separately from decarbonisation. For the period 1994-1997, there is less reporting of $CO_2$ in the PI and so site-specific $CO_2$ emissions are estimated based on other site-specific data such as emissions data for particulate matter from those sites in the relevant years. The PI data are assumed to cover the same scope as the later EU ETS data i.e. to include emissions from lime kiln dust as well as lime product. 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 $CO_2$ |
| 2005-2006 | (back-calculated) | 121.5 | EU ETS & PI $CO_2$ |
| 2007-2018 | (back-calculated) | 121.5 | EU ETS |

The calculated emissions and activity data exclude carbonates calcined in the chemical industry since this is all used in the Solvay process, for which emissions are reported in 2B7.

The EU ETS data for UK sugar producers do not include any emissions from calcination, and consultation with the industry in the past confirmed that the industry considers there to be no $CO_2$ 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 to calcium carbonate, 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 ETS provides a full dataset for UK facilities from 2008 onwards, and the uncertainties associated with these verified data are low. EU ETS data for 2005-2007 provide partial coverage of the sector and are used in conjunction with other data sources to derive inventory estimates, and hence these estimates are also regarded as subject to low uncertainty. Uncertainty is higher for the estimates before 2005, because of the need for assumptions to be made in deriving the estimates (for example, assumptions regarding the split between combustion and process emissions in the PI data used between 1994 and 2004). Estimates for the years 1990 to 1993 are the most uncertain, because no reported $CO_2$ 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

A couple of inconsistencies within activity data calculations were corrected for this submission. One has a very minor impact across the time-series (reducing activity by less than 0.1%), while the other correction reduces activity data for 1990 only, by 9%.

### 4.3.6  Source Specific Planned Improvements

Emission factors and activity data will be kept under review. In response to the ERT recommendation (2017 ARR, item I.14) to collect lime production data to enable the UK to derive and report a production-based IEF, the UK Inventory Agency has consulted with the Office of National Statistics (ONS) to seek any data that are available from the industry on production of lime, via the Prodcom surveys and database. The Inventory Agency research has found that there is no complete, consistent time series of annual production data from UK producers from ONS. This is due to the nature of the periodic surveys conducted by ONS, the combination of production data from several mineral sectors (e.g. cement with lime aggregated) and the commercial sensitivity of reported production data. The Inventory Agency notes that the EU ETS emissions reporting is known to cover all existing UK lime works and therefore is complete and accurate for recent years, and that to gather any further activity data from the industry is not practicable given the competing priorities for inventory improvement resources.

## 4.4    SOURCE CATEGORY 2A3 – GLASS PRODUCTION

### 4.4.1  Source Category Description

Emissions from glass manufacture include emissions of carbon dioxide resulting from the use of limestone, dolomite and soda ash as sources of $CaO$, $MgO$ and $Na_2O$ 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 2018, 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 2018. Special and non-lead domestic glasses are no longer manufactured in the UK, and production of lead glass is only on a very small scale. The last producer of frits closed in 2014. It is assumed that limestone and dolomite are used in the production of container, flat, and special glass, and in glass and stone wool. Any use of carbonates in frits and lead glass is assumed to be trivial because of the small-scale production of these in the UK (together, both sectors account for about 0.1% of UK glass production). EU ETS data for the sole UK site making ceramic fibres indicate that this process does not involve the use of the three carbonate minerals. The ballotini processes are not covered by EU ETS but are based almost exclusively on the use of recycled glass (cullet) and so carbonates are not used in significant quantities. Since the production of ballotini is a trivial fraction of UK glass production and the use of carbonates for ballotini is also trivial, emissions are not estimated.

Due to the very small number of sites involved, and the confidential nature of the EU ETS data used to generate the emissions data, reporting the stone wool sector separately would be problematic. The UK therefore combines the data with emissions for other glass industry sites.

Process emissions of $N_2O$ 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 Emissions Trading System (EU ETS) from 2008 onwards.

In the case of the survey of raw material usage, data are available on the quantities of each type of carbonate used by each sub-sector of the industry during 2006. Emissions must be estimated, and this is done based on the stoichiometric relationship between carbon and the related carbonate, and assumes all of the carbon is released to atmosphere i.e.

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

The EU ETS data are for $CO_2$ 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 2008-2018 for all sites manufacturing flat glass, container glass, continuous filament glass fibre, glass wool and stone wool. Carbonate use is back-calculated using the stoichiometric relationships given above. Since ETS data are available on a site by site basis, the emissions data and the derived activity data can be agglomerated to give estimates for each sub-sector of the glass industry. The EU ETS data also includes extremely small $CO_2$ emissions (<1 tonne) occurring due to use of barium or potassium carbonate by the glass sector, but these have been ignored from the UK inventory due to their trivial nature.

The two data sources can be used to derive estimates of carbonate use / $CO_2$ emissions for each sub-sector of the glass industry as follows:

2008-2018: flat, container, glass fibre, glass wool, stone wool;
2006: flat, container, glass fibre/glass wool (combined in the survey).

These data indicate some changes over time in rates of carbonate use for flat, container and glass wool, and partial EU ETS data for 2005-2007 also support this. Therefore the 2006 survey, rather than the later EU ETS data, is assumed to be more reliable as a guide to the rates of carbonate usage in the three sectors in the years 1990-2005 and usage for that period is therefore extrapolated from the 2006 figures on the basis of production in each sub-sector in each year. For stone wool, data are only available from the EU ETS for 2008-2018, 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, 2019), 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 | 2018 production, kt | Estimates included for emissions from use of: | | |
|---|---|---|---|---|---|
| | | | Limestone | Dolomite | Soda Ash |
| Container | a | a | Yes | Yes | Yes |
| Flat | a | a | Yes | Yes | Yes |
| Special | 226 | - | Yes | Yes | Yes |
| Domestic, including lead | 76 | 0.3 | Yes | Yes | Yes |
| Continuous filament glass fibre | 82 | 37 | Yes | Yes | Yes |
| Glass wool | 104 | 328 | Yes | Yes | Yes |
| Stone wool | 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

## 4.4.3  Uncertainties and Time Series Consistency

For the years 2008-2018, the methodology is based on the use of highly accurate emissions data reported under the EU ETS for all significant UK glass producers.

The emission estimates for 2006 are based on activity data given in a detailed industry study. These emission estimates should be assumed to be slightly more uncertain than the EU ETS data of 2008-2018 since the source gives carbonate usage figures only, and emissions have to be calculated assuming that these figures refer to pure carbonates and that all carbon in the minerals is released to atmosphere. While the emissions data are therefore conservative, the uncertainty is still considered to be low since fairly pure carbonate minerals are readily available.

For the remaining years in the time-series, the methodology relies upon the extrapolation of highly accurate activity/emissions data for one year to all other years based on glass production. The glass production data are, however, a mixture of actual production data from

the glass industry, and Ricardo Energy & Environment estimates, which are far more uncertain. The emission estimates for 2A3 are therefore subject to far greater uncertainty for the earlier part of the time-series than for recent years, because of the greater reliance on extrapolation, and the lower quality of the glass production estimates for these years.

### 4.4.4  Source Specific QA/QC and Verification

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

### 4.4.5  Source Specific Recalculations

There have been no significant changes to this category.

### 4.4.6  Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

## 4.5    SOURCE CATEGORY 2A4 – OTHER PROCESS USES OF CARBONATES

### 4.5.1  Source Category Description

The UK has a large number of sites involved in the production of heavy clay goods such as bricks, 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 EU ETS reporting purposes, all UK brick makers use a figure of 50% oxidation. Although 2A4 explicitly covers use of carbonates, the UK inventory estimates include carbon emissions from the use of colourants in bricks here as well, in the absence of anywhere more appropriate to report them.

The 2006 GLs draws attention to other sources of $CO_2$ 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 has previously included $CO_2$ 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. This submission also includes, for the first time, emission estimates for the use of soda ash in applications other than glass production, and these emissions are reported in 2A4. 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. The methodology for sodium bicarbonate is, for convenience, described here but these emissions are reported in 2G4.

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 and Eggborough closed in September 2018. Various small, predominantly waste and/or biomass-fired stations also report $CO_2$ emissions from limestone scrubbing in the EU ETS. In all of these processes, limestone reacts with the $SO_2$ present in flue gases, being converted to gypsum, with $CO_2$ being evolved. Uskmouth B has a dry lime-injection system, so there is no potential for $CO_2$ emissions at this site. Seawater scrubbing systems are used at Aberthaw, Kilroot, and Longannet power stations but $CO_2$ emission estimates are not included in the GHGI for this type of FGD system: there is no estimation method for this process. Some MSW incinerators are believed to use the dry lime injection process to remove $SO_2$ emissions: as with Uskmouth B, there will be no $CO_2$ emissions from this type of FGD technology.

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

## 4.5.2  Methodological Issues

$CO_2$ emissions from production of bricks and tiles are based on data reported in the EU ETS. EU ETS provides site by site emissions, broken down by source (e.g. from clays, fuels, colourants etc.) and begins in 2005, although the data are only representative of the sector from 2008 onwards, when all significant manufacturing sites were included in EU ETS. The data can easily be divided into emissions from fuels and emissions from non-fuels (i.e. process emissions). It is more difficult to divide the non-fuel data into sub-types such as emissions from clays, colourants, or 'pure' carbonates like limestone, dolomite and barium carbonate, since some of the information on the source of the $CO_2$ is ambiguous. So although it is possible to make a crude split, the process emissions are reported as a group. Note that this does mean that emissions from the colourant (coke oven or petroleum coke) are included here, but this is justified both because of the slight ambiguity in some of the ETS data, but also because there is no other category which would be more appropriate.

The ETS data are calculated by each brick and tile producer using site-specific activity data, and industry-wide emission factors, compiled by the industry trade association each year (British Ceramic Confederation, 2014). These factors include factors for simple carbonates based on the stoichiometric relationship of carbon to the carbonate, as well as measured emission factors for different types of clay e.g. Keuper Marl, Weald Clay, and Lower Oxford Clay. The industry factors also include an estimate for colourants which is based on the assumption that 50% of carbon in the colourant is oxidised during firing.

Consultation with the brick industry indicates that the ETS data for 2008-2012 covered 93% of sector production. A single further site joined EU ETS in 2013, bringing coverage to 95%. The EU ETS emissions data for 2008-2018 are therefore increased using these figures to reflect non-reporting brickworks, assuming that emission rates at non-reporting sites will be the same as on average at reporting sites. With the exception of the large site that joined in 2013, the non-reporting sites over the period 2008-2018 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, August 2019, available from www.gov.uk) to extrapolate back from the ETS data. These data are for total numbers of bricks produced, and it is necessary to consider what proportion of these bricks are of the fletton type, since this type of brick is associated with higher process emissions. Fletton bricks have had a declining share of the UK brick market for many years and are no longer used in the construction of new buildings. Information on the market share is however limited: Ove Arup (1990) puts it at 25%, Blythe (1995) states it is 20%, and by 2011, following the announcement that the last but one fletton brickworks was being closed, local media reports all stated that fletton bricks now accounted for less than 10% of the UK market. The inventory method therefore assumes a 25% share in 1990, falling to 20% in 1995, then falling to 10% by 2010. EU ETS data for the fletton works suggest production has fallen further since 2010 and so is used to estimate the trend for fletton bricks since 2010. Using these data and assumptions, it is possible to then generate estimates of the numbers of fletton bricks and non-fletton bricks produced each year. For 2018, 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 EU 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 coal only as a fuel so by the end of 1999, 3 works remain: Stewartby burns coal, the other two (Saxon/Kings Dyke), both in the same area in England, now burn natural gas only. Approximately 100 non-fletton brickworks in early 2000s. | Annual emissions of $CO_2$ and methane available in the Pollution Inventory for each fletton site until 2004, when emissions for the two gas-burning sites, which are located about 1.5 km apart start to be reported as combined totals. Reported emissions have to be split between energy- and process-related emissions. Estimates for non-fletton bricks have to be generated using emission factors from later EU ETS data

Annual production (numbers) of all bricks available: fletton and non-fletton brick production estimated. |

| Years | Number of sites and fuels | Availability of data |
|---|---|---|
| 2008 | Closure of coal-burning fletton works at end of 2008, leaving only the 2 gas-burning works remaining.<br><br>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.<br><br>EU ETS data for the same two fletton brickmaking units, and also for non-fletton brickworks. These data are detailed, allowing fuel-related and process-related emissions to be separated. Emission estimates can be based directly on EU ETS data. |
| 2009-2018 | Saxon works closed in 2011, leaving only the Kings Dyke fletton brickworks in operation.<br><br>Many closures of non-fletton brickworks, with 49 reporting in EU ETS by 2011. In 2013, final large site joins EU ETS, with total of 46 non-fletton sites then reporting. | Annual emission of $CO_2$ and methane available in the Pollution Inventory for the Saxon/Kings Dyke works.<br><br>EU ETS data for all significant fletton and non-fletton works for all years except for one site that joins ETS in 2013. Emission estimates can be based directly on EU ETS data. |

Other types of ceramics are manufactured in the UK, including wall and floor tiles, refractories, sanitary ware, household ceramics etc. There are no national data on either the levels of production or suitable emission factors for these types of ceramic goods, so no emission estimates can be made. However, the following simple calculations have been made, which indicate that emissions can be considered insignificant in the UK inventory context.

The UK Minerals Yearbook (BGS, 2014) gives production, imports and exports for 4 types of clay (ball clay, china clay, fireclay, other clays & shales). This reference also gives a breakdown of the uses to which the 'other clays & shales' are put – mostly bricks, cement production, and construction, with very little used for other ceramics. Fireclay is assumed to be used solely for ceramics, and the EU ETS data shows that fireclay is used by many brick makers. It will also likely be used for refractories and sanitary ware and, in the absence of any data, a 50/50 split of fireclay usage between bricks and other ceramics is assumed. The Kaolin and Ball Clay Association (KABCA) give estimates of the markets for both ball clay and china clay on their website[59]. Neither type of clay will be used in any significant quantity in bricks but KABCA indicate figures of 22% of china clay and 'over 80%' of ball clay used in ceramics. Based on BGS figures for 2008, 2009, 2011, and 2012 (data not available for 2010), approximate figures for clays used in bricks and in other ceramics can be derived, as follows:

**Table 4.7     Consumption of Clays in Brickmaking and Other Ceramics Manufacture (Mtonnes)**

| Product | | 2008 | 2009 | 2011 | 2012 | Average |
|---|---|---|---|---|---|---|
| Bricks | Ball clay | 0 | 0 | 0 | 0 | |
| | China clay | 0 | 0 | 0 | 0 | |

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[59] See http://www.kabca.org/what-is-kaolin.php and http://www.kabca.org/what-is-ball-clay-.php

| Product | | 2008 | 2009 | 2011 | 2012 | Average |
|---|---|---|---|---|---|---|
| | Fire clay | 0.092 | 0.066 | 0.082 | 0.049 | |
| | Other clay & shales | 4.993 | 2.839 | 4.022 | 3.591 | |
| | Total | 5.085 | 2.904 | 4.104 | 3.640 | 3.933 |
| Other ceramics | Ball clay | 0.224 | 0.196 | 0.199 | 0.161 | |
| | China clay | 0.052 | 0.053 | 0.051 | 0.044 | |
| | Fire clay | 0.092 | 0.066 | 0.082 | 0.049 | |
| | Other clay & shales | 0.160 | 0.120 | 0.137 | 0.023 | |
| | Total | 0.527 | 0.434 | 0.470 | 0.277 | 0.427 |

The consumption of clays for other ceramics is therefore estimated as approximately a tenth (11%) of the consumption of clays in bricks. The carbon content of fire clay and other clays and shales could be obtained from EU ETS data for bricks, and the carbon content of ball clay is known to be very low since the British Ceramics Confederation produce carbon emission factors for ball clay in their guidance for EU ETS reporting. No data are available for china clay in order to generate a full time-series of activity data. For the purposes of determining the significance of the source, a time-series can be derived based on 11% of the clay usage in bricks, and to assume the same average carbon content in clay for ceramics as in the common clays used in brickmaking (noting that this is a worst case due to the very low carbon content of ball clay), to yield emission estimates that are well below 0.05% of the national total (0.0064% in 1990 and 0.0037% in 2013) and therefore insignificant.

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 4.8. 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.

**Table 4.8** **Non-glass uses of soda ash and sodium bicarbonate**

| Sector | Uses | % Emissive |
|---|---|---|
| Soda ash: chemicals | Used in production of various chemicals or chemical processes:<br><br>• Sodium tripolyphosphate<br>• Sodium chromate<br>• Ultramarine Blue<br>• Sodium silicates<br>• Sodium percarbonate<br>• Metal carbonates<br>• Brine purification<br>• Sodium bicarbonate | 100%<br>100%<br>100%<br>100%<br>0%<br>0%<br>0%<br>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 4.8. 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 $CO_2$:

$$Na_2CO_3 + CO_2 \rightarrow 2\ NaHCO_3$$
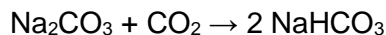
So it follows that for any emissive uses of sodium bicarbonate, an emission factor of 0.8302 kt $CO_2$ / kt soda ash is appropriate i.e. double that of soda ash used for other applications. Further detailed discussion of the methodology are included in the report by Passant et al (2019).

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 EU ETS, and so a composite series of emissions data is used with BGS activity data and the emission factor used for 1994-2004, and EU ETS emissions data for 2005-2018. Four small biomass-fired power stations were no longer in EU 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.

## 4.5.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

In the case of FGD plant there is a change in methodology between 2004 and 2005. However, BGS and EU ETS-based emission estimates for 2005 are very close, and for 2006-2014 are within 6% of each other (with the EU ETS numbers usually higher). No data are available from BGS for 2015-2017 and so no comparison can be made with the EU ETS based figures.

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.
- 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 2008-2018 where EU ETS data are available for almost all sites. For earlier years, the emission estimates rely upon extrapolation of the 2008 emissions data using brick production estimates and this will introduce uncertainty within the earlier part of the time series. Emission estimates for methane from fletton brickworks are, similarly, based on reported data in later years and extrapolation using brick production for the early part of the time-series, so the uncertainty will again be greatest in the earlier part of the time series.

### 4.5.4   Source Specific QA/QC and Verification

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

### 4.5.5   Source Specific Recalculations

The main recalculation is the addition of emission estimates for (non-glass industry) use of soda ash for the first time. This adds 83 ktonnes $CO_2$ to the UK inventory for 1990 and 35 ktonnes $CO_2$ to the 2017 figures.

There have been trivial revisions to data used to calculate emissions from brickmaking and FGD. The largest revision is for 2017 where $CO_2$ emissions are now 2 ktonnes higher than in the previous submission.

### 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.

## 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:

$$CH_4 + H_2O \Leftrightarrow CO + 3H_2$$

$$CO + H_2O \Leftrightarrow CO_2 + H_2$$
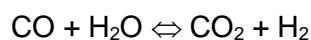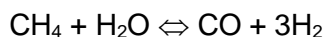
The hydrogen is then reacted with nitrogen to form ammonia.

$$N_2 + 3H_2 \Leftrightarrow 2NH_3$$
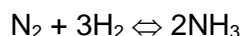
If the by-products CO and $CO_2$ are not captured and used, then these are emitted to atmosphere. Ammonia plants can be integrated with methanol manufacture for greater efficiency, since the carbon oxides can be used to manufacture methanol:

$$CO + 2H_2 \Leftrightarrow CH_3OH$$

$$CO_2 + 3H_2 \Leftrightarrow CH_3OH + H_2O$$
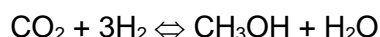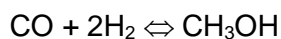
Over the time period covered by the UK greenhouse gas inventory, ammonia has been manufactured at four locations in the UK. $CO_2$ emissions are reported from three of those sites: at the remaining site (Hull), the ammonia is produced with hydrogen supplied as a by-product from another chemical process 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.

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 4.9** summarises the details of the UK ammonia plants and **Table 4.10** gives details of production and emissions etc. by the sector.

**Table 4.9        Details of UK ammonia plants**

| Plant | Feedstock | Carbon emissions | Notes |
|-------|-----------|------------------|-------|
| Billingham | Natural gas | Yes | Some production of methanol using by-product carbon until 2001 |
| Severnside | Natural gas | Yes | Closed in 2007 |
| Ince | Natural gas | Yes | |
| Hull | Hydrogen | No | |

**Table 4.10       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 |

| Year | Ammonia production (kt) | $CO_2$ emitted (kt) | $CO_2$ emission factor, (t / t $NH_3$) (all UK production plant)* |
|------|------|------|------|
| 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 |

*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 1.84 tonnes $CO_2$ / tonne $NH_3$ for production across the whole 1990-2018 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.

### 4.6.3  Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type. The uncertainty associated with this source is low, since the carbon content of natural gas is well known and plant specific data are received from the operators annually.

A consistent time series of activity data has been reported from the manufacturers of ammonia, and this results in good time series consistency of emissions.

### 4.6.4  Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the inventory in **Section  1.6** and the source emissions data from plant operators is subject to the QA/QC procedures of the Environment Agency's Pollution Inventory.

### 4.6.5  Source Specific Recalculations

There have been no significant recalculations to this category, although we have revised the assumed calorific values for natural gas used by the sector, leading to changes in the activity data which are back-calculated from the emissions data provided by operators. This has no impact on the emissions reported in 2B1 and only a trivial impact elsewhere since it results in a very minor re-allocation in gas use within the UK inventory.

### 4.6.6  Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

## 4.7     SOURCE CATEGORY 2B2 – NITRIC ACID PRODUCTION

### 4.7.1  Source Category Description

| Emissions sources | Sources included | Method | Emission Factors |
|---|---|---|---|
| | 2B2: Nitric Acid Production | T3, T2 | CS |
| Gases Reported | $N_2O$, $NO_x$ | | |
| Key Categories | 2B2: Nitric acid production - $N_2O$ (L1, L2, T1, T2) | | |
| Key Categories (Qualitative) | None identified | | |
| Overseas Territories and Crown Dependencies Reporting | Not occurring | | |
| Completeness | No known omissions.<br>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:

$$4NH_3 + 5O_2 \Rightarrow 4NO + 6H_2O$$

$$2NO + O_2 \Leftrightarrow 2NO_2$$

$$3NO_2 + H_2O \Leftrightarrow 2HNO_3 + NO$$
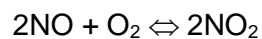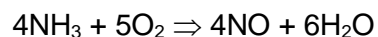
Nitrous oxide is also formed by oxidation of ammonia:

$$4NH_3 + 3O_2 \Rightarrow 2N_2O + 6H_2O$$
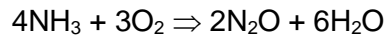
Nitrous oxide is emitted from the process, as well as a small percentage of the $NO_x$ that cannot be recovered for conversion into nitric acid. At the end of 2018, nitric acid was being manufactured at 2 UK sites with a total of 4 production plants. At one site, the nitric acid production plant has had $NO_x/N_2O$ abatement fitted to all units since commissioning (pre-1990), whilst at the other UK production site, all three production lines have had nitrous oxide abatement retrospectively fitted during 2011 Quarter 1. This has led to a notable reduction in the UK IEF for nitrous oxide emissions from nitric acid production in the UK between 2010 and 2011 (see **Table 4.12** below).

## 4.7.2   **Methodological Issues**

Across the 1990-2018 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 4.11** 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 EU ETS Permit. MCERTS (Monitoring Certification Scheme) was set up by the Environment Agency to ensure good quality environmental measurements. The scheme is based on international standards and provides for the product certification of instruments, the competency certification of personnel and the accreditation of laboratories. The European Standard EN14181 covers quality assurance for automated measuring systems. The details of monitoring at the closed sites are not known, but it is assumed to have been the same as the sites that remain in operation i.e. periodic prior to 2010. The closed sites were shut before the fitting of continuous monitoring devices was

required for EU ETS reporting purposes; the $N_2O$ monitoring systems at these sites comply with the requirements of EU ETS reporting, and are subject to low uncertainty (5-10%). Therefore, the emissions data reported by operators are associated with low uncertainty, and are representative of the technology and abatement in the UK installations.

**Table 4.11    Methods used to estimate emissions from this category (figures are numbers of sites)**

| Period | Site specific production data | | Site Specific emissions data, kt $N_2O$ | | | |
| | | | Reported by operator | | Estimated by Inventory Agency | |
| | Estimated | Operator data | Based on emission factors | Based on monitoring | Site-specific EF | IPCC EF |
| --- | --- | --- | --- | --- | --- | --- |
| 1990-1993 | 7 | 1 | | | 5 | 3 |
| 1994 | 5 | 1 | | | 6 | |
| 1995-1997 | 4 | 2 | | | 6 | |
| 1998-1999 | | 6 | 4 | 1 | 1 | |
| 2000 | 1 | 5 | 4 | 1 | 1 | |
| 2001 | | 5 | 3 | 1 | 1 | |
| 2002-2004 | | 4 | 3 | 1 | | |
| 2005 | | 4 | 2 | 2 | | |
| 2006-2007 | | 4 | 1 | 3 | | |
| 2008 | | 4 | 2[a] | 2 | | |
| 2009-2018 | | 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 4.12    Summary of Nitric Acid Production in the UK, 1990-2018**

| 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 | 0.115 |
| 2013 | 2 | 1.01 | 0.142 |
| 2014 | 2 | 1.10 | 0.124 |
| 2015 | 2 | 1.13 | 0. 087 |
| 2016 | 2 | 1.17 | 0.071 |
| 2017 | 2 | 1.22 | 0.103 |
| 2018 | 2 | 1.08 | 0.076 |

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)[60]. 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 $N_2O$ 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 (2009-2018) on continuous monitoring, and therefore will be subject to low uncertainty. The monitoring systems used at the 2 sites currently in operation are subject to an uncertainty of 5-10%.

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

### 4.7.4   Source Specific QA/QC and Verification

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

### 4.7.5   Source Specific Recalculations

Emissions data were revised for 2012 for one site, leading to a 6% reduction in sectoral emissions for that year. Emission estimates for other years are unchanged.

### 4.7.6   Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

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[60] 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.

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

From these data it is possible to obtain the emissions from the chemical process for some years: 2006-2008 (using the PI data for chemical $CO_2$ emissions), and 2013-2018 (from the detailed EU 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 EU ETS and PI data, even if not relating to input materials as required by the Tier 2 method in the GLs, ensures that emissions data are quite certain for the period from 1998 onwards. Estimates for 1990-1997 are more uncertain due to the need to extrapolate 1998 data backwards in the absence of any specific information on production, materials usage or emissions in those years.

## 4.11.4 Source Specific QA/QC and Verification

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

## 4.11.5 Source Specific Recalculations

There have been no significant recalculations in this category.

## 4.11.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

## 4.12    SOURCE CATEGORY 2B7 – SODA ASH PRODUCTION

## 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 in 2G. EU 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 are reported in 2A4. Emissions from the use of soda ash converted to sodium bicarbonate are currently reported in 2G.

## 4.12.2 Methodological Issues

The 2006 GLs suggests that emissions should be based "on an overall balance of $CO_2$ around the whole chemical process". In the UK, soda ash has been produced at two sites and both began to report under the EU ETS in 2013, although one is now closed. The EU ETS emissions data for the two sites is calculated using a carbon balance approach with inputs in coke and limestone balanced against soda ash and waste products. The 2013-2017 EU ETS data therefore meets the requirements for the method suggested in the GLs.

Prior to 2013, no data for the UK plant were reported in EU ETS, but $CO_2$ emissions have been reported in the PI from 1998 onwards. Comparison of the PI and EU ETS data for 2013-2017 shows that EU ETS data were 38% higher than emissions in the PI in 2013 and, on average, 73% higher in the years from 2014-2018. 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 1.38 to give estimates of emissions in those years. The difference in 2014-2018 was consistently higher and so a more conservative approach would be to use a factor based on data for all years after 2013 (1.67). However, the Winnington plant was closed in early 2014 and so the years from 2014 onwards are atypical compared with the 1990-2013 period of full operation of both processes. For 1990-1997, no data of any type are available, but since the same two sites have been in operation in the UK across the entire time-series, emissions in 1990-1997 are assumed to be at the same level as in later years.

## 4.12.3 Uncertainties and Time Series Consistency

The method used is regarded as the best available given the lack of any production activity data, or a time-series of coke consumption. The use of site-specific EU ETS data for 2013-2018 should ensure that the emission estimates for those years are quite certain. The poor agreement between the PI and EU ETS data in 2013-2018 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 2014-2018 than in 2013, however both sites only operated fully throughout 2013, Winnington having closed in February 2014. We have therefore treated the 2013 EU ETS/PI ratio of 1.38 (based on both plant operating throughout the year) as a more reliable guide to the potential underestimation in the PI data in earlier years. Estimates for 1990-1997 are more uncertain still due to the need to extrapolate 1998

data backwards in the absence of any specific information on production, materials usage or emissions in those years.

### 4.12.4 Source Specific QA/QC and Verification

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

### 4.12.5 Source Specific Recalculations

There have been no significant recalculations in this category.

### 4.12.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

## 4.13    SOURCE CATEGORY 2B8 – PETROCHEMICAL AND CARBON BLACK PRODUCTION

### 4.13.1 Source Category Description

This category includes emissions from the following sources: 2B8a Methanol, 2B8b Ethylene, 2B8c Ethylene Dichloride, 2B8d Ethylene Oxide, 2B8e Acrylonitrile, 2B8f Carbon Black and 2B8g Other. The UK has a large petrochemical industry, with manufacture of all of the chemicals explicitly mentioned in the 2006 IPCC Guidelines for at least part of the period 1990-2017, although a series of site closures in recent years has reduced the number of products manufactured.

Methanol was manufactured in the UK until 2001 in a process which was integrated with ammonia production. Ethylene was produced at five sites in 1990, although the closure of the two works in 1993 and 2010 reduced this to three at the end of 2018. The UK ethylene crackers use either naphtha or natural gas liquids as feedstocks, and off-gases from the ethylene crackers are used as fuels on-site. Ethylene dichloride (EDC) has been produced at 4 sites over the period covered by the GHGI, although only 1 is still in operation, and only 2 of those processes used the oxychlorination route that causes process emissions of $CO_2$. Ethylene oxide (EO) was produced at a single UK plant between 1990 and closure in January 2010. There is also a single site producing acrylonitrile (ACN): this has operated since 1990 and is still in operation. Two sites produced carbon black, until their closure at the very start, and in the middle of 2009 respectively. Most of the production was of furnace black.

A number of other chemical sites also emit $CO_2$ due to the use of off-gases as fuels. Emissions of $CO_2$ at these sites are very small relative to the emissions from ethylene production. All emissions of $CO_2$ from use of off-gases as fuels is reported under 2B8g, including the emissions from ethylene production.

Many chemical processes emit small quantities of methane, either as a result of fugitive releases from equipment, or as a component of tail gases released from vents. The inventory includes separate emissions data for production of ethylene, methanol, ACN, EO, and carbon black. Emissions of methane from other chemical processes are reported under 2B10.

### 4.13.2 Methodological Issues

Details of the methodologies used for petrochemical and related processes are shown in **Table 4.13**.

**Table 4.13    Methodologies for petrochemical and related processes**

| Chemical product | Reporting for | | Methodology |
|---|---|---|---|
| | $CO_2$ | $CH_4$ | |
| Ethylene | 2B8g | 2B8a | Site specific emissions data from EU ETS ($CO_2$ only), PI and from process operators. Where no emissions data are available, these are estimated by extrapolation from data available for later years, taking into account changes in plant capacity. |
| Methanol | 2B8b | 2B8b | See below for $CO_2$ methodology. Emission estimates for methane are based on operator-reported data from the PI. |
| Ethylene Dichloride | 2B8c | - | Emissions estimated using IPCC Tier 1 emission factor for process $CO_2$ assuming production is 500,000 tonnes per year[a]. |
| Ethylene Oxide | 2B8d | 2B8d | $CO_2$ emission estimates for 1995-2009 from the PI, emissions in 1990-1994 assumed same as in 1995. $CH_4$ estimates for 2004-2009 from the PI. No emissions data are available for 1990-2003, so the Tier 1 IPCC default is used, combined with estimates of EO production at the plant derived from the $CO_2$ emitted, and assuming a $CO_2$ emission factor of 0.663 t $CO_2$ / t EO (IPCC default for oxygen process, default catalyst sensitivity). |
| Acrylonitrile | 2B8g | 2B8e | $CO_2$ emission estimates for 2008-2018 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 is taken from EU ETS ($CO_2$ only), and the PI (English/Welsh sites) or SPRI (Scottish sites). For those years where operator-reported emissions data are not available, then emissions are assumed to be the same as for later years where data are available. There are no petrochemical processes located in Northern Ireland which would emit GHGs |

a – production is not known but capacity of two plant in 1987 was 500,000 tonnes and one subsequently closed so 500,000 tonnes is considered a conservative estimate.

Methanol production, like ammonia, requires hydrocarbon fuels both as a source of raw materials and as a fuel. The UK methanol process used natural gas. Whereas in ammonia processes, natural gas is reformed to produce hydrogen for the process and carbon dioxide as a waste by-product, in the methanol process reforming of natural gas generates carbon dioxide for the process with hydrogen as the waste product. The UK's only methanol plant was integrated with one of the ammonia plants, so that carbon dioxide produced by the ammonia plant could be exported and used to synthesise methanol. This $CO_2$, 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 4.14** summarises the data for methanol production.

**Table 4.14          Estimates for methanol production**

| Year | Estimated methanol production (kt) | $CO_2$ emitted (kt) | $CO_2$ stored (kt) |
|---|---|---|---|
| 1990 | 488 | 498 | 671 |
| 1995 | 488 | 498 | 671 |
| 1996 | 488 | 498 | 671 |
| 1997 | 488 | 498 | 671 |
| 1998 | 232 | 237 | 319 |
| 1999 | 215 | 219 | 295 |
| 2000 | 257 | 262 | 353 |
| 2001 | 130 | 133 | 179 |
| 2002 onwards | 0 | 0 | 0 |

The methodology for $CO_2$ emissions from 2B8g was developed through an inventory improvement research project in 2013-14 (Ricardo-AEA, 2014b), with a review conducted of available data on industrial use of process off-gases and waste residues as fuels, including consultation with operators of several of the installations that were known to use process off-gases as a fuel. The research included a review of data within the EU ETS. In addition, installation-specific (but anonymised) data from the chemical industry Climate Change Agreement (CCA) data reported for 2008 and 2010 were also reviewed. CCA data was used primarily to quality check the number of sites in the chemicals sector that reported the use of waste-derived fuels, and this dataset confirmed that there were a very small number of sites reporting waste-derived fuel use. It is not possible with the current data available to distinguish between feedstock-derived off-gases that are used directly as a fuel and those used in other process-related activities that result in emissions, such as flaring, and therefore the total emissions reported for those sites are allocated to 2B8g.

## 4.13.3 Uncertainties and Time Series Consistency

For the use of waste residues and process off-gases as fuel in the chemical industry, the emissions estimates are somewhat uncertain as the level of completeness of the data over

the whole time-series is hard to verify; the 2014 inventory improvement study, however, has confirmed that the inventory covers all high-emitting sites in the UK that have been in operation in recent years, and therefore the overall uncertainty on the UK inventory estimates, at least for the period covered by EU ETS data, is not regarded as significant. Energy and environmental experts within the UK trade association for the chemical sector, the Chemical Industries Association, also confirmed that they were not aware of any other sites in the UK that used process off-gases, over and above the sites identified included in the UK GHGI (Personal communication, Chemical Industries Association, 2014). These are dominated by the four ethylene production sites and a handful of other sites producing organic chemicals, typically co-located with refineries.

Emission estimates for other sources are mostly based on a mixture of PI and/or EU ETS data with estimates for earlier years then based on the assumption that emissions are as in later years. Tier 1 IPCC default emission factors are used for the minor sources 2B8c (for $CO_2$), 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 1.8**.

## 4.13.5 Source Specific Recalculations

Estimates for $CO_2$ from 2B8g have been revised upwards following review of the available EU ETS and other data. New figures for 2B8g are about 5-6% higher across the time-series compared with the previous submission.

## 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

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

### 4.14.6 Source Specific Planned Improvements

There are currently no planned improvements for this sector, however data sources will be kept under review.

## 4.15    SOURCE CATEGORY 2B10 – OTHER

### 4.15.1 Source Category Description

The UK has a large chemical manufacturing sector and emissions of methane are reported elsewhere in 2B for emissions from specific chemical processes, but also reported in 2B10 in the case of emissions from other, general petrochemical processes. Methane emissions from ammonia production sites are included in 2B10, rather than being reported separately in 2B1.

### 4.15.2 Methodological Issues

Site-specific emissions data for chemical processes located in England and Wales are available in the Pollution Inventory (Environment Agency, 2018) and Welsh Emission Inventory (NRW, 2018) respectively. Reporting generally started in 1994 or 1995, and few data exist for the years prior to 1994. Site specific emissions data for processes in Scotland have been obtained from the Scottish Pollutant Release Inventory (SEPA, 2018).

All of the data available are in the form of emission estimates generated by the process operators and based on measurements or calculated based on process chemistry. Emission factors and activity data are not available, but emission factors are estimated using the best available 'surrogate' activity data that are available across the time series; this approach then enables estimates of emissions to be made for the years prior to operator-reported emission estimates (typically pre-1994). For most commodities, the extrapolation is linked to changes in the level of output from the chemicals manufacturing sector as measured by the 'index of output' figures published by the Office for National Statistics (2018).

### 4.15.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

Estimates for 1994 onwards are mostly based on data reported by process operators through the regulatory agency data management and checking systems that govern UK industrial emissions data within the PI, WEI, SPRI and NIPI. The dataset is evidently incomplete in some years, due to the variations through time in the reporting thresholds for different pollutants. The Inventory Agency has used good practice techniques to address these reporting inconsistencies, and therefore the completeness of the data is good through the time series.

Unfortunately, UK production data are not readily available for chemicals and other products from the sites reported under 2B8. This inhibits the Inventory Agency's ability to conduct data validation tests on the reported emissions data against a reliable time-series of production estimates. Emission estimates for the period prior to 1994 are also more uncertain due to the need for extrapolation of emissions data for 1994 or some other year backwards, using general indicators of chemical industry output.

### 4.15.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the inventory in **Section 1.6**. Emissions data taken from the Pollution Inventory are subject to additional QA/QC by the Environment Agency before being used in the inventory.

### 4.15.5 Source Specific Recalculations

We have made some changes to the way in which we generate emission estimates from the available data from regulators. The regulators' emissions data will not necessarily cover all sites in operation – for example, some sites may not need to report emissions if those are considered below reporting thresholds. So UK estimates require a degree of extrapolation in order to address gaps in the data. We have introduced procedures to try to make the gap-filling process more complete and more consistent. The new procedures also make it easier to ensure that the UK estimates include all relevant regulator data – previously, it is likely that a very small proportion of data were omitted in error. These revisions to procedures do not result in any large revisions to UK totals for methane: estimates are mostly slightly lower: 6% lower in 1990 (11 ktonnes $CO_2$ eq) and 2% lower in 2016 (1 ktonne $CO_2$ eq). As well as the more consistent use of the regulator data, the revisions also result from the removal of a double-count since one chemical process had previously been included in both the estimates for 2B8d and 2B10, and is now only included in 2B8d.

### 4.15.6 Source Specific Planned Improvements

Minor revisions to emission estimates may be required periodically in order to deal with changes in the data available e.g. revisions to emissions reported to UK regulators. The Inventory Agency will continue to review the available operator-reported data and seek to derive a consistent time series of emissions.

## 4.16    SOURCE CATEGORY 2C1 – IRON AND STEEL PRODUCTION

### 4.16.1 Source Category Description

| Emissions sources | Sources included | Method | Emission Factors |
|---|---|---|---|
| | 2C1:  Sinter plant – coke | T1, T2 | CS |
| |      Iron & steel flaring (BFG) | T1, T2 | D, CS |
| |      Electric arc furnaces | T1, T2 | CR, CS |
| |      Ladle arc furnaces | T2 | CS |
| |      Sinter plant – limestone | T2 | CS |
| |      Sinter plant - dolomite | T2 | CS |
| |      Basic oxygen furnaces - dolomite | T2 | CS |
| | | | |
| | Following for indirect gases only: | | |
| | Blast furnaces | T2 | CS |
| | Basic oxygen furnaces | T2 | CS |
| | Iron and Steel (other) | T2 | CS |
| | Rolling Mills (Hot & Cold Rolling) | T2 | CS |

Iron and steel production may be divided into integrated steelworks, electric arc steelworks, downstream processes such as continuous casting, and iron & steel foundries.

Integrated steelworks convert iron ores into steel using the three processes of sintering, pig iron production in blast furnaces and conversion of pig iron to steel in basic oxygen furnaces. For the purposes of the inventory, emissions from integrated steelworks are estimated for these three processes, as well as other minor processes such as slag processing.

Sintering agglomerates the raw materials for the production of pig iron by mixing these materials with fine coke (coke breeze) and placing it on a travelling grate where it is ignited. The heat produced fuses the raw materials together into a porous material called sinter.

Blast furnaces are used to reduce the iron oxides in ore to iron. They are continuously charged with a mixture of sinter, fluxing agents such as limestone, and reducing agents such as coke. Hot air is blown into the lower part of the furnace and reacts with the coke, producing carbon monoxide, which reduces the iron ore to iron. Gas leaving the top of the furnace has a high heat value because of the residual CO content, and is used as a fuel in the steelworks. Molten iron and liquid slag are withdrawn from the base of the furnace. The most significant greenhouse gas emissions to occur directly from the blast furnace process are the combustion gases from the 'hot stoves' used to heat the blast air. These generally use blast furnace gas (BFG), together with coke oven gas and/or natural gas as fuels. Emissions are reported in CRF category 1A2a. Gases emitted from the top of the blast furnace are collected and emissions occur when this BFG is subsequently used as fuel. Emissions from BFG combustion are reported according to the process using them, rather than being reported in 2C1. However some BFG is lost and the carbon content of this gas is reported in 2C1.

Pig iron has a high carbon content derived from the coke used in the blast furnace. A substantial proportion of this must be removed to make steel and this is done in the basic oxygen furnace. Molten pig iron is charged to the furnace and oxygen is blown through the metal to oxidise carbon and other contaminants. As a result, carbon monoxide and carbon dioxide are emitted from the furnace and are collected for use as a fuel. As with blast furnace gases, some losses occur and these losses are reported with blast furnace gas losses in 2C1.

Limestone and dolomite are used in steelmaking, typically being added to sinter where they are calcined, releasing $CO_2$ 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 2018, 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 (2019). 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 2007-2018. These data show close consistency across the time series and therefore the 2007 value has been extrapolated back to 1990.

Carbon emissions from electrodes in electric arc and ladle arc furnaces are calculated using emission factors provided by Corus (2005). Emissions from the addition of petroleum coke to electric arc furnaces at one steelworks are based on EU ETS data for the period 2005-2018, with estimates for the period 1990-2004 being extrapolated from the 2005 data on the basis of our estimates of steel production at that site. Emissions from the use of coke oven coke in foundries and other iron & steel industry processes are included in category 1A2a but any other process emissions from foundries of direct GHGs are likely to be very small and are not estimated. **Table 4.15** summarises the methods used for emissions reported under 2C1.

**Table 4.15**     **Summary of Emission Estimation Methods for Source Categories in CRF Category 2C1**

| Source Category | Method | Activity Data | Emission Factors |
|---|---|---|---|
| Sintering – coke breeze | AD x EF | BEIS energy statistics | Carbon: UK-specific factor from carbon balance<br>$CH_4$: UK-specific based on reported emissions<br>$N_2O$: 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<br>$CH_4$, $N_2O$: IPCC (2006) |
| Electric arc furnaces | AD x EF | ISSB | Carbon: UK-specific factor<br>$CH_4$, $N_2O$: 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

There have been a few relatively trivial updates due to revisions to calorific values used in calculating the emission estimates UK energy statistics affecting the carbon balance calculations. For information on the magnitude of recalculations, see **Section 10**.

## 4.16.6 Source Specific planned Improvements

It is noted that this sector has been identified as a key category, and that not all of the estimates within this sector use a tier 2 or higher approach. The UK uses what is believed to be the best currently available data, and that tier 1 methods are only used for very limited parts of this sector. The UK will review this position should further information come to light. Emission factors and activity data will be kept under review. Where appropriate, fuel characterisation data from verified EU ETS datasets will be considered in future GHGI cycles.

## 4.17    SOURCE CATEGORY 2C2 – FERROALLOYS PRODUCTION

The term ferroalloy covers a wide range of products, manufactured by various means, only some of which lead to industrial process emissions of greenhouse gases. Potential sources of $CO_2$ 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[61] estimated UK production in 1993 as 55 ktonnes out of a European total production of 2,620 ktonnes while the updated version of that document, published in 2017, does not identify any production of ferroalloys at all in the UK in the period 2005-2012.

Other than the estimate for 1993 given in the BREF note, the inventory agency has not found any data on UK production of ferroalloys. The absence of the UK as a European producer in the recent update of the BREF note suggests that UK production is either zero or insignificant; through consultation with trade associations and industry statistics experts (ISSB) the Inventory Agency has only been able to identify a few small-scale manufacturers of specialist ferroalloys such as ferro-molybdenum and ferro-vanadium. The production data for 1993 lists 45,000 tonnes of ferromanganese production in a blast furnace (where emissions would arise from use of reductants), and 10,000 tonnes of other ferroalloys in electric furnaces. The ferroalloy producers identified as in operation in recent years either carry out exothermic processes only (for ferro-molybdenum alloys) or use electric induction furnaces for melting. None of the processes report any $CO_2$ emissions in the Pollution Inventory, or are included in the EU ETS; the Inventory Agency has not identified any process currently in operation that would cause any industrial process emissions 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

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[61] downloadable from http://eippcb.jrc.ec.europa.eu/reference/

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 (BGS, 2019) 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 year between 2013 and2017, 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 4.16**.

**Table 4.16**     **Emission Estimation Methods for Primary Aluminium Production, CRF Category 2C3**

| Source Category, Gas | Method | Activity Data | Emission Factors |
|---|---|---|---|
| Primary aluminium, $CO_2$ | AD x EF | UK Minerals Yearbook (BGS, 2018); $\Sigma$ operator production data (Anglesey Aluminium, to 2010; RioTintoAlcan, 2019) | Technology-specific default EFs for Soderberg and pre-bake processes |
| Primary aluminium, PFCs | $\Sigma$ 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 4.17** below. Note that the PFC EFs presented here are essentially back-calculated IEFs for the UK industry as a whole, derived from the reported production data and sum of operator-reported emissions.

**Table 4.17**     **Activity Data and Emission Factors: UK Aluminium Production 1990-2018**

| Year | Activity data | Emission factors - kt/Mt | | |
|---|---|---|---|---|
| | Mt Al Produced | Carbon | $CF_4$ | $C_2F_6$ |
| 1990 | 0.290 | 423.8 | 0.601 | 0.075 |
| 1995 | 0.238 | 423.2 | 0.158 | 0.019 |
| 2000 | 0.305 | 420.0 | 0.110 | 0.014 |
| 2005 | 0.370 | 420.0 | 0.035 | 0.004 |
| 2008 | 0.327 | 420.0 | 0.046 | 0.006 |
| 2009 | 0.254 | 420.0 | 0.032 | 0.004 |
| 2010 | 0.186 | 420.0 | 0.079 | 0.010 |
| 2011 | 0.214 | 420.0 | 0.099 | 0.013 |
| 2012 | 0.060 | 420.0 | 0.031 | 0.004 |
| 2013 | 0.044 | 420.0 | 0.018 | 0.002 |
| 2014 | 0.042 | 420.0 | 0.115 | 0.014 |
| 2015 | 0.048 | 420.0 | 0.027 | 0.003 |
| 2016 | 0.048 | 420.0 | 0.034 | 0.004 |
| 2017 | 0.047 | 420.0 | 0.037 | 0.004 |
| 2018 | 0.044 | 420.0 | 0.027 | 0.003 |

**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 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. It is estimated that 95% of $SF_6$

(Gluckman, 2013) used in this way is released to the atmosphere unless capture/recycle technologies are employed. $SF_6$ is non-flammable and non-toxic, and is therefore a safe gas to use. In the UK, $SF_6$ has been used as an alternative cover gas to $SO_2$ in magnesium alloy production and sand and die-casting since the early 1990s. Since 2006, EU magnesium producers have looked for alternatives to $SF_6$ in response to bans in the EU F-Gas regulation. Some die casters have gone back to using $SO_2$. Others have used HFC-134a and a fluoro-ketone (FK 5-1-12) with the trade name Novec 612.

The UK magnesium casting industry is very small. There are three significant manufacturers (one alloy producer, one die-caster and one sand-caster) plus two very small operations (both sand-casters). Alloy production involves the use of primary magnesium ingots, recycled scrap material and second-generation magnesium materials (i.e. material already made into alloys) for the production of different alloys. Both die and sand casters use these magnesium alloys to produce specific components for a wide range of industries. For the casting industry, $SF_6$ is used for casting specific magnesium alloys where other cover gases, such as HFC-134a, are currently considered not suitable.

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 Environment Agency Pollution Inventory (EA, 2015), whilst emissions prior to 1998 are estimated based on consultations with the plant operators.

From 2004, one of the main industry users of $SF_6$ as a cover gas has implemented a cover gas system using HFC-134a for some of its production capacity. There has not been a complete switch to HFC-134a, although the operator is considering this on an ongoing basis depending on suitability for the different alloys produced. In addition to having a significantly lower GWP than $SF_6$ (and thus reducing emissions on a $CO_2$ equivalent basis), use of HFC-134a is further advantageous in that a significant fraction of it is destroyed by the high process temperatures (80%) thus reducing the fraction of gas emitted as a fugitive emission.

From 2008, emissions of HFCs have been reported in the Pollution Inventory, and therefore the reported data are used directly.

As part of a 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.

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 110 kt $CO_2$ equivalent in 2017. HFC-134a emissions were zero until 2008 and are 2 kt $CO_2$ equivalent in 2017.

### 4.19.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. Emissions data taken from the Pollution Inventory are subject to additional QA/QC from the Inventory Agency.

### 4.19.5 Source Specific Recalculations

For information on the magnitude of recalculations to this Source Category, see **Section 10**.

### 4.19.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

## 4.20   SOURCE CATEGORY 2C5 – LEAD PRODUCTION

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 lead 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, 2019), 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, 2019), '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

There have been no significant recalculations in this category.

## 4.21.6 Source Specific Planned Improvements

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

## 4.22   SOURCE CATEGORY 2D1 – LUBRICANT USE

## 4.22.1 Source Category Description

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

Emissions of $CO_2$, $CH_4$ 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, 2018) includes some limited data breakdown on sector-specific lubricant use (e.g. use by industry, agricultural sector, shipping) in addition to the total lubricant demand time-series. Lubricant consumption in road vehicle engines is estimated using the COPERT method from the EMEP/EEA Emissions Inventory Guidebook (2016). Lubricant use in the remaining sectors is then calculated from the difference between the UK demand figure in DUKES & the COPERT-based road transport lubricant figures.

The consumption estimates are used to calculate $CO_2$ 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 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

DUKES gives a full time series of lubricant consumption data so consistency of the emission estimates is good. The use of a Tier 1 methodology means that estimates are quite uncertain.

## 4.22.4 Source Specific QA/QC and Verification

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

## 4.22.5 Source Specific Recalculations

There have been some very minor revisions to UK energy statistics, such that 2017 emissions of $CO_2$ are now 5 ktonne lower than in the previous submission.

## 4.22.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

## 4.23   SOURCE CATEGORY 2D2 – PARAFFIN WAX USE

## 4.23.1 Source Category Description

This category includes $CO_2$ 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: Cartwright, 2018) on the same basis as the earlier data, as they comprise part of other long-term energy data reporting outputs, e.g. to EUROSTAT.

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 significant recalculations.

## 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 EU ETS and other data. For most years, there is more petroleum coke listed in the UK energy statistics than can be accounted for by these known users. In other years, the known users require more petroleum coke than is available in the energy statistics. But since there is excess petroleum coke for most years (21 out of 29) between 1990 and 2018, 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 IVV and VI standards. These came into effect from 2006. The EMEP/EEA Emissions Inventory Guidebook (2016) provides the means for estimating urea consumption as a proportion of fuel consumed by these specific types of vehicles. Fuel consumption by Euro IV, V and VI HGVs and buses was estimated using a bottom-up method described in **Chapter 3**. The estimations involve the use of vehicle km activity and fleet composition data from DfT and g/km fuel consumption factors, with total fuel consumption calculated for road transport by this method normalised to national fuel sales in DUKES.

Following figures given in the EMEP/EEA Guidebook for estimating other pollutant emissions, an assumption was made that 75% of Euro V HGVs and buses are equipped with SCR – the catalyst system that uses urea. The same assumption was also applied to Euro IV vehicles and it is assumed that 100% of Euro VI vehicles are equipped with SCR. Fuel consumption was calculated for these types of vehicles using SCR technology. Following the EMEP/EEA Guidebook, urea consumption is assumed to be 4% of fuel consumption for a Euro IV HGV or bus, 6% for Euro V and 3.5% for Euro VI. Independent assessment in the UK from suppliers of urea and vehicle manufacturers supports these assumptions. These assumptions allowed the time-series for consumption of urea by UK road transport to be estimated. No urea was consumed before 2006.

A constant emission factor of 0.238 $kgCO_2$/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 eight years where zero emissions are reported due to the UK Inventory Agency estimates for known uses for petroleum coke exceeding the UK demand figure for petroleum coke in the UK energy statistics.

### 4.24.4 Source Specific QA/QC and Verification

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

### 4.24.5 Source Specific Recalculations

The estimate of urea emissions is dependent on the fraction of specific HDVs' fuel use; therefore, the revision to the fuel consumption factors and fuel normalisation methodologies in 1A3b means that there are small recalculations to 2D3 emissions from urea use in this submission, of around 0.8 $ktCO_2$ in 2016

There have been revisions to the estimates of petroleum coke used in other sectors (such as within 2A and 2C), and these recalculations have an impact on the estimates of petroleum coke used in 2D3, as the 2D3 activity data is the residual once known uses of petroleum coke in other source categories are subtracted from the total UK petroleum coke demand. The changes are small for some years, but much larger in other years, for example $CO_2$ emissions in 2017 are now 104 ktonnes lower than in the previous submission.

For information on the magnitude of recalculations, see **Section 10**.

### 4.24.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

## 4.25   SOURCE CATEGORY 2E1 – INTEGRATED CIRCUIT OR SEMICONDUCTOR

Emissions of $SF_6$ from semiconductor manufacturing are combined with emissions from training shoes and electrical insulation in source category 2G2e for reasons of commercial confidentiality. This source category is described in **Section 4.39**.

## 4.26   SOURCE CATEGORY 2E2 – TFT FLAT PANEL DISPLAY

### 4.26.1 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[62] for the UK in 2003-5. When using this activity data and the default methodology the resulting

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[62] Table 6.7 of Volume 3 of the IPCC 2006 Guidelines

emission was well below the threshold to be considered insignificant, so is reported by the UK as 'NE' for years before 2014.

### 4.26.2 Source Specific Planned Improvements

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

## 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[63] for the UK in 2003. When using this activity data and the default methodology the resulting emission was well below the threshold to be considered insignificant, so is reported by the UK as 'NE' for years before 2014.

### 4.27.2 Source Specific Planned Improvements

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

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

### 4.28.1 Source Category Description

PFCs are used as heat transfer fluids (HTFs) in commercial and consumer electronic applications. The various applications of PFC as HTFs use much smaller volumes of liquid PFCs than electronics manufacturing. Some examples of consumer applications include cooling kits for desktop computers and commercial applications include cooling supercomputers, telecommunication, and radar systems, as well as drive units on high-speed trains.

### 4.28.2 Methodological Issues

Market analysis by Ricardo (2016) confirmed that there are no UK emissions from this sector. Discussions were held with the only 2 companies that supply the relevant PFC to the EU market ($C_6H_{14}$), 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

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[63] Table 6.8 of Volume 3 of the IPCC 2006 Guidelines

are sold exclusively for hermetically sealed applications and products that are sold on to be used outside the UK.

## 4.28.3 Source Specific Planned Improvements

Any emergence of volume manufacturing capacity of heat transfer applications using F-gases is kept under review.

## 4.29  SOURCE CATEGORY 2F1 – REFRIGERATION AND AIR CONDITIONING EQUIPMENT

## 4.29.1 Source Category Description

HFCs and HFC blends have been widely used as replacement refrigerants for ozone depleting substances across virtually all refrigeration end-uses. They generally share many of the properties of CFC and HCFC refrigerants, namely low toxicity, zero and/or low flammability and acceptable materials compatibility. Emissions of HFCs can occur at various stages of the refrigeration/air-conditioning product life-cycle:

- During the refrigeration equipment manufacturing process;
- Over the operational lifetime of the refrigeration or air-conditioning unit; and
- At disposal of the refrigeration or air-conditioning unit.

This emission category contains aggregated emission estimates from the end-uses summarized in the table below. As shown, the UK inventory uses a code (RAC-1 to RAC-13) to refer to these sector sub-divisions.

**Table 4.18        Model End-Uses and Definitions**

| End-Use | | Description |
|---|---|---|
| RAC-1 | Domestic Refrigeration | Refrigerated appliances including refrigerators, chest freezers, upright freezers, and fridge freezers. |
| RAC-2 | Small Commercial Stand-Alone Refrigeration Units | Small, hermetic, stand-alone refrigeration units including ice cream cabinets and drinking water coolers. These systems are commonly used in retail food stores but are also found in pubs, restaurants, and other hospitality and catering outlets such as hotels, hospitals, and schools. |
| RAC-3 | Condensing Units for commercial refrigeration applications | Refrigeration systems composed of one (or two) compressor(s) and one condenser, assembled into a unit, which is located external to the sales area. The condensing unit is connected by refrigerant pipework to an evaporator located in the retail sales area (e.g. in a chilled retail display). These units are typically installed in small shops, beer cellars and small walk-in cold rooms and have refrigeration capacities ranging from 1 kW to 20 kW. |
| RAC-4 | Centralised Refrigeration Systems for commercial refrigeration applications | Refrigeration systems that are comprised of racks of compressors installed in a machinery room. These systems are commonly used in supermarket applications, with many refrigerated displays connected to a central system. Each system typically has a cooling capacity in the 30 kW to 150 kW range. |
| RAC-5 | Industrial Systems | Refrigeration systems including industrial process refrigeration and cold storage. Industrial refrigeration systems vary widely in cooling capacity. Many industrial systems are above 1,000 |

| End-Use | | Description |
|---|---|---|
| | | kW. However, the majority that use HFC refrigerants are relatively small, in the 50 kW to 200 kW range. |
| RAC-6 | Small Stationary Air Conditioning | Includes small self-contained air-conditioning (including window units) and non-ducted single split air-conditioning. Units are used primarily in commercial applications, but there is some use in the residential sector. System cooling capacities typically range from 3 to 12 kW. The majority of modern systems are reversible – they can operate either as an air-conditioning unit or an air-source heat pump. |
| RAC-7 | Medium Stationary Air Conditioning | Includes non-ducted multi-split, variable refrigerant flow (VRF) non-ducted split, ducted split, and packaged air-conditioning. Units are used in the commercial UK sector. System cooling capacities typically range from 12 to 200 kW. |
| RAC-8 | Large Stationary Air Conditioning (Chillers) | Large water chillers used for commercial comfort air conditioning. Cooling capacity is typically in the range 100 kW to 500 kW. |
| RAC-9 | Heat Pumps | Residential and small commercial heating only heat pumps, including air-source heat pumps (ASHP) (air-to-air and air-to-water systems) and ground-source heat pumps (GSHP). |
| RAC-10 | Land Transport Refrigeration | Refrigerated road vehicles (i.e., light commercial vehicles, trucks, trailers) and intermodal containers. |
| RAC-11 | Marine Transport Refrigeration | Refrigerated general cargo ships, container ships and fishing vessels (1,000 GT and above). |
| RAC-12 | Light Duty Mobile Air Conditioning | Air-conditioning systems for passenger cars and light commercial vehicles (up to 3.5 tonnes). Both of these vehicle types are covered under Directive 2006/40/EC (the MAC Directive). |
| RAC-13 | Other Mobile Air Conditioning | Air-conditioning systems for trucks (over 3.5 tonnes), buses/coaches, semi-trailers, trailers, and railcars. |

## 4.29.2 Methodological Issues

A refrigeration/air conditioning inventory model developed by ICF International in 2011, based on revised industry input and a Tier 2a modelling approach. Specifically, the model comprises 13 end-use sub-sectors (as described in **Table 4.18**), for which detailed assumptions were developed to utilise a fully bottom-up approach. The model makes use of a bottom up approach with assumptions made about emission factors and stock levels. The model is verified by comparing the predicted HFC consumption for the whole RAC sector with top-down data for the sales of HFCs in the UK. In 2015 the ICF model was reviewed (Gluckman, 2015). A key aspect of the review was to revise input assumptions due to the impact of the revised EU F-Gas Regulation (517/2014), including bans of some higher HFCs for some applications and a general phased down of HFC consumption. The model is reviewed on a regular basis.

For each of the 13 end-use sub-sectors, market data and other country-specific information were considered in the development of assumptions on equipment stocks, market growth, equipment lifetimes, refrigerant market penetrations, charge sizes, manufacturing loss rates, operational loss rates, and disposal loss rates across the 1990-2050 time-series. An extensive literature review was conducted and key industry stakeholders were contacted. Priority industry stakeholders were selected across all end-uses and initially contacted to fill data gaps and corroborate information found in the literature. Following the development of preliminary

assumptions for all end-uses, draft assumptions were then shared with a broader range of stakeholders to solicit additional industry input and vet assumptions.

In developing modelling input assumptions by end-use, expert judgment was applied to select appropriate values when more than one estimate was provided by literature and/or stakeholders. In general, more weight was given to estimates that are UK- or region specific and/or more recent. In cases of equal data quality where numerous data points were available, values were selected based on the mid-point of the data range. Where no UK- or EU-specific information was available, the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines default assumptions were relied on to estimate emissions.

The various input assumptions used by the model can be varied on an annual basis. This allows changes in response to market growth or regulatory constraint to be reflected in the bottom-up estimates of HFC emissions made by the model. For example, the 2006 EU F-Gas Regulation has led to significant reductions in the levels of leakage from some RAC sub-sectors and improvements in the level of refrigerant recovery during servicing and at end-of-life. This is reflected in the model by changes to the annual operating emission factors and end-of-life recovery factors.

In the process of finalising the input assumptions, an analysis was conducted to compare estimated refrigerant consumption (calculated as the amount of refrigerant used to manufacture new equipment produced in the UK plus the amount used to service leaking equipment) with annual refrigerant sales data from the British Refrigeration Association (BRA). A summary table of the 2015 input assumptions is provided below. A full description of the methodology, sources, and input assumptions used to update emission estimates by end-use is contained in ICF (2011) and Gluckman (2015).

A key input assumption is the split of different refrigerants used in new and existing equipment in each of the 13 sub-sectors. The accuracy of the input assumptions is checked by comparisons with top-down BRA data for the whole RAC market. The model then generates a detailed speciated split of total emissions. This is available split either by the type of refrigerant used (e.g. a blend such as R-404A) or by the individual HFC components within such blends (e.g. R-404A is a mixture of HFC-143a, HFC-125 and HFC-134a).

**Table 4.19** **Summary of 2017 Input Assumptions by End-Use[b]**

| Application | | 2016 Parameters[b] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CRF Sector | UK Category | Total Stock (units)[a] | Total Sales (units)[a] | Lifetime (years) | Charge (kg)[a] | Refrigerants in New Equipment | Manufacturing Loss Rate | Operational Loss Rate | Disposal Loss Rate |
| Domestic Refrigeration | Domestic Refrigeration | 43,046,902 | 3,116,386 | 15 | 0.10 | HCs | 0.6% | 0.3% | 28%[b] |
| Commercial Refrigeration | Small Hermetic Stand-Alone Refrigeration Units | 2,951,697 | 351,225 | 10 | 0.5 | HFC-134a, R-404A, R-407C, HCs, HFO-1234yf, R-744 | 1% | 1.2% | 28%[b] |
| | Condensing Units | 665,907 | 47,666 | 14 | 6 | HFC-134a, R-404A, R-407A, R-407F, R-410A, R-744 | 2% | 6% | 12%[b] |
| | Centralised Supermarket Refrigeration Systems | 12,465,659 (m$^2$) | 990,374 (m$^2$) | 18[b] | 0.55 (kg/m$^2$) | HFC-134a, R-407A, R-407C, HCs, R-744 | 2% | 9% | 5%[b] |
| Transport Refrigeration | Land Transport Refrigeration | 97,252 | 11,322 | 7 | 3.3 | HFC-134a, R-404A, R-407F, HFO-1234yf, R-744 | 0.2% | 9%[b] | 12%[b] |
| | Marine Transport Refrigeration | 527 | 16 | 25[b] | 1,500[b] | HFC-134a, R-407F, R-717 | 1% | 13% | 12%[b] |
| Industrial Refrigeration | Industrial Systems | 45,947 | 1,915 | 25 | 99 | HFC-134a, R-407F, HCs, R-717, R-744 | 1% | 9% | 8% |
| Stationary Air-Conditioning | Small Stationary Air Conditioning | 6,643,972 | 516,757 | 13 | 1.8 | R-410A, HFC-32, HCs | 0.5% | 4% | 23% |
| | Medium Stationary Air Conditioning | 346,245 | 22,296 | 15 | 15 | HFC-134a, HFC-32, R-410A | 1% | 5% | 17%[b] |
| | Large Stationary Air Conditioning (Chillers) | 45,051 | 2,809 | 18 | 180 | HFC-134a, HFC-32, R-410A, R-717, HCs, HFO-1234yf | 0.5% | 3% | 7% |
| | Heat Pumps | 188,246 | 43,441 | 15 | 3.5 | R-410A, R-717, HCs, HFO-1234yf, HFC-32 | 1% | 6%[b] | 25%[b] |
| Mobile Air-Conditioning | Light Duty Mobile Air Conditioning | 29,020,205 | 2,271,374 | 15 | 0.7 | HFC-134a, HFO-1234yf | 0.5% | 8%[b] | 25%[b] |
| | Other Mobile Air Conditioning | 543,171 | 50,706 | 10 | 4[b] | HFC-134a, HFC-32, R-410A, R-717, HFO-1234yf | 0.5% | 9%[b] | 18%[b] |

[a] Except where otherwise noted.

[b] Estimates fall outside of the IPCC (2006) range but are in line with UK- and/or EU-specific estimates provided by industry or in the published literature.

Speciated emissions are reported for the OTs and CDs under 2F1. Emission estimates from the UK GHGI were scaled by a territory-specific indicator. The indicators for each activity were chosen based on expert judgement and are as follows:

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

### 4.29.3 Uncertainties and Time-Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

### 4.29.4 Source Specific QA/QC and Verification

End-use input assumptions used to generate the refrigeration and air conditioning emissions were developed based on industry consultation and were peer-reviewed. Further, to verify the emissions estimates generated by the revised model, the results were compared with the sales data provided by BRA. The results of the comparison reveal that the data sets align closely, with the 2015 revised model output for UK refrigerant consumption being within 1% of the collective annual BRA data for HFCs from 2006-2010.

Historic emissions estimates generated by the revised model were also compared with concentration observations captured by the dispersion model NAME (Numerical Atmospheric dispersion Modelling Environment). More information relating to atmospheric measurements and verification of UK emissions estimates is provided in **Annex 6**.

A list of industry stakeholders consulted on the input assumptions, as well as detailed results from the BRA and emission observation comparisons are discussed in more detail in ICF (2011).

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 overhaul of the RACHP model will lead to changes in the data presented for this sector, it is likely that the revised model will present a similar trend. 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**; when looking at key refrigerant components like HFC-134a, HFC-125 and HFC-143a the UK model is consistently higher than the verification approach for earlier years, but for recent years the verification shows a similar declining trend in emissions, but a year or two behind when the trend is predicted in the model. 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 2020.

## 4.29.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10**.

## 4.29.6 Source Specific Planned Improvements

The UK is in the process of developing a new model to estimate RACHP emissions that will be available for use in 2020. This will review all input assumptions and AD used in the old model to ensure that the model is a realistic best estimate of UK emissions from 2.F.1. The bottom-up model of HFC consumption is being cross-checked against top-down data for HFC sales in the UK and the bottom-up model of emissions is being cross-checked against detailed atmospheric HFC concentration measurements taken by the UK Meteorological Office, together with analysis by experts from Bristol University

## 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[64].

## 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.

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[64] 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.

The model provides insight to the manufacturing and trade aspects of each product type in order to determine the amount of product placed on the market in the UK each year. This adds to the existing bank of blowing agent contained in installed products. In parallel, the blowing agent lost from product through annual emission and the decommissioning of product at end-of-life are subtracted from the bank.

The waste stream (not to be confused with decommissioning) is considered as a source of emission in its own right on the basis that a bank of blowing agent is established following decommissioning; while this source is mentioned in the 2006 IPCC guidelines, a method for estimating this source is not given. Although this reduces annual emissions when compared with the previous default assumption of full emission on decommissioning, the impact is mitigated by the long lifecycles of most products being considered. In practice, there is only limited product decommissioning taking place involving HFC-based foams in the period until 2035. Emissions from this source are estimated using a similar approach to product lifetime emissions, i.e. estimated HFCs remaining in the product after decommissioning is added to a bank of gas expected to be in landfill, and a fraction of this is emitted annually. The main difference between this stage and the product lifetime stage is that gas can only escape the bank via emissions, so eventually all of the bank is assumed to be emitted.

The species used for foam blowing are given below.

**Table 4.20      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 4.21** *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 4.22***.*

**Table 4.21        Significant Deviations from 2006 IPCC GL default parameters[a]**

| Application | EF Source | Product Lifetime (years) | Manufacturing Factor | Product Lifetime Factor | Notes |
|---|---|---|---|---|---|
| Domestic Refrigerators | IPCC 2006 GLs | | 4% | | All HFC-containing units imported |
| | UK GHGI Model | | 0% | | |
| Other Appliances | IPCC 2006 GLs | | 4% | 0.5% | Wider range of products included, but lower in use losses because of better designs and thicker foams |
| | UK GHGI Model | | 6% | 0.25% | |
| PU Boardstock | IPCC 2006 GLs | 25 | | | IPCC uses global figure influenced by timber-framed housing |
| | UK GHGI Model | 50 | | | |
| PU Cont. Panel | IPCC 2006 GLs | 50 | | | Information from major panel manufacturers suggests 30 years is a better figure although some guarantee for 40 years |
| | UK GHGI Model | 30 | | | |
| PU Disc Panel | IPCC 2006 GLs | 50 | 12% | | Better manufacturing practices. Information from major panel manufacturers suggests 30 years is a better figure although some guarantee for 40 years |
| | UK GHGI Model | 30 | 6% | | |
| PU Spray | IPCC 2006 GLs | | 15% | | Recognises pre-2006 status of industry and improvements made |
| | UK GHGI Model | | 15-25% | | |
| PF Block Pipe | IPCC 2006 GLs | | 45% | | Recognises new process introduction |
| | UK GHGI Model | | 45%/7.5% | | |
| PU/PF Block Slab | IPCC 2006 GLs | 15 | 20% | 1% | Recognises better foam structure and fabrication processes. Most slab now used for panel purposes so lifetime should be aligned. |
| | UK GHGI Model | 30 | 15% | 0.75% | |
| XPS Board | IPCC 2006 GLs | | 25% | 0.75% | 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 4.22        Parameters used in the foams model**

| Application | Product Lifetime (years) | Manufacture | Product Lifetime Factor | Decommissioning | Waste |
|---|---|---|---|---|---|
| Dom. Refr-Freezers | 15 | 0.00% | 0.25% | 2.50% | 0.00% |
| Other Appliances | 15 | 6.00% | 0.25% | 5.00% | 0.00% |
| PU Reefers-Marine | 15 | 6.00% | 0.50% | 10.00% | 1.00% |
| PU Boardstock | 50 | 6.00% | 1.00% | 7.50% | 2.00% |
| PU Continuous Panel | 30 | 5.00% | 0.50% | 5.00% | 0.75% |
| PU Disc. Panel | 30 | 6.00% | 0.50% | 5.00% | 0.75% |
| PU Spray | 50 | 15-25%[a] | 1.50% | 10.00% | 2.00% |
| PU Pipe-in-Pipe | 30 | 6.00% | 0.25% | 2.00% | 0.50% |
| PU Block-Pipe | 15 | 45.00% | 0.75% | 2.50% | 1.50% |
| PU Block-Slab | 30 | 15.00% | 0.75% | 2.50% | 1.50% |
| XPS - Board | 50 | 12-25%[a] | 2.50% | 7.50% | 4.00% |
| PF - Boardstock | 50 | 6.00% | 1.00% | 7.50% | 2.00% |
| PF - Panels | 30 | 10.00% | 0.50% | 5.00% | 0.75% |
| PF - Pipe | 15 | 7.5-45%[a] | 0.75% | 2.50% | 1.50% |
| PF - Block Slab | 30 | 15.00% | 0.75% | 2.50% | 1.50% |

[a] The factor varies depending on the year to reflect the impact of regulation and UK industry practice

Speciated emissions for the OTs and CDs are reported under 2F2. Emission estimates from the UK GHGI were scaled using the GDP of each territory.

## 4.30.3 Uncertainties and Time-Series Consistency

There are a number of parameters that feed into the modelled estimate of emissions and hence the uncertainty. Between data on foam manufacturing capacity/utilisation, the blowing agent consumption and the overall tracking of thermal insulation demand through publications such as IAL studies we can have a fairly high level of confidence in the estimate. This is despite some high uncertainties in some of the individual assumptions in the model; manufacturers were cautious in providing comment on the HFC market penetration which is the assumption that has greatest cause for uncertainty. Regulatory pressures to label products containing HFCs may help in future to hone the estimates and reduce uncertainties in activity data.

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

## 4.30.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. Details of verification of emissions are given in **Annex 6**.

## 4.30.5 Source Specific Recalculations

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

For information on the magnitude of recalculations, see **Section 10**.

## 4.30.6 Source Specific Planned improvements

This source has recently been updated so there are no immediate plans for improvement. However, we will be recommending that this sector is revisited when we have a few years' data on the impact of recent F-gas regulations.

## 4.31 SOURCE CATEGORY 2F2B – OPEN CELLS (ONE COMPONENT FOAMS)

## 4.31.1 Source Category Description

One Component Foams (OCFs) are used by building tradesmen (and in the DIY home improvement sector, to a lesser extent) to mount doors and windows and to insulate different types of open joints and gaps. When used as an OCF propellant, HFC (134a, 152a) is blended with various flammable gases. HFC escapes from the foam on application, leaving small residues, which remain in the hardened foam for up to a year. These products are not manufactured in the UK, although they are imported. The use of HFCs of GWP 150 or greater in OCFs has been banned under the EC Regulation on fluorinated greenhouse gases (EC 842/2006) from July 4th 2008, except for where their use is safety critical. This was maintained in the 2014 F-gas regulations (EC 517/2014).

## 4.31.2 Methodological Issues

The method of calculation is an IPCC Tier 2 method.

UK estimates of emissions from this source were based on a European evaluation of emissions from this sector (Harnisch and Schwarz, 2003), subsequently disaggregated by GDP to provide a top-down UK estimate.

It has been very difficult to establish the exact size of the UK import market and, therefore, hard to generate an accurate estimate of emissions from the use of this product.

Harnisch and Schwarz (2003) estimated EU emissions from OCFs as follows:

- 1996: 4,000 kt $CO_2$ equivalent per annum (3100 tonnes of HFC-134a); and
- 2000: 1,700 kt $CO_2$ equivalent per annum (1200 tonnes of HFC-134a; 1000 tonnes of HFC-152a)

Emissions in tonnes of $CO_2$ equivalent have reduced between 1996 and 2000 due to the use of HFCs with lower GWP values, and the manufacture of cans containing less HFC. In 2000, 23 million OCF cans that contained HFCs were sold in Germany while 7 million where sold to the rest of the EU market. Research indicated that Germany accounted for 77% of the total EU emission, and that out of the remaining 23%, the UK accounts for 24%, based on a percentage of total EU GDP (excluding Germany). This is equivalent to 1.68 million cans (AEA, 2008).

The estimates of HFCs assume that the ban on F-gas use in one component foams (banned from July 2008 under the F-Gas regulations) has been successful, and this success has been confirmed with the UK Defra F-Gas Regulation team. Therefore, no emissions occur from 2009 onwards.

### 4.31.3 Uncertainties and Time-Series Consistency

Estimates of the uncertainties associated with time-series data for this sector were made in AEA (2004), based on an understanding of the uncertainties within the sector and from discussion with industry. 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[65] 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."

### 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.

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[65] https://www.firesafe.org.uk/phase-out-of-halon-in-portable-extinguishers/

ICF reviewed available literature to confirm/update key assumptions—notably, EEA (2014, 2016)—and then refined and finalized the estimates based on consultation with ASSURE (European Association for Responsible Use of HFCs in Fire Fighting) and the UK Fire Industry Association (FIA).

### 4.32.2.1 Stock

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

The equipment stock in years beyond 2007 is estimated based on EEA (2017) estimates for net supply of F-gases in the fire protection sector from 2007-2012 (metric tonnes) in the EU, 85% of which is HFC-227ea, and scaled to the UK using a time-dependent GDP ratio. This annual net supply was assumed to equal annual UK consumption of fire protection agent in new and existing systems. The methodology and resulting stock estimates were reviewed and approved by ASSURE (2013) and FIA (2013). ASSURE confirmed that the estimates looked reasonable; FIA noted that the estimates looked reasonable for recent years, but that the 2000 estimates are slightly high. Additional information to refine these historical estimates was not available but this is a conservative bias as it will slightly overestimate emissions.

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

### 4.32.2.2 Chemicals in use

According to FIA (2013) and ASSURE (2013), HFC-227ea accounts for virtually 100% of F-gas consumption in this sector in the UK; consumption of other HFCs (e.g., HFC-23, HFC-125, and HFC-236fa) in the UK are statistically insignificant. Therefore, 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 4.23        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[66] | 1.0 |
| % released during recovery (disposal) | 0.1 | | |

Speciated emissions for the OTs and CDs are reported under 2F3. Emission estimates from the UK GHGI were scaled by the relative GDP of each territory.

## 4.32.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

## 4.32.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. Details of verification of emissions are given in **Annex 6**.

## 4.32.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10**.

## 4.32.6 Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

## 4.33    SOURCE CATEGORY 2F4 – AEROSOLS

## 4.33.1 Source Category Description

Most aerosols use hydrocarbon propellants, with a relatively small proportion of the market favouring other volatile liquids including dimethyl ether (DME) and HFCs. Compressed gases are used in very few aerosols since they suffer from a number of disadvantages compared with liquefied gas propellants such as DME and hydrocarbons. HFCs are used only in a few applications where the use of a more expensive propellant is required to provide a non-flammable material. The most important industrial applications in volume terms are air dusters and pipe freezing products; other applications include specialised lubricants and surface treatments, and specialised insecticides. The use of HFCs for novelty applications, such as 'silly string' was banned from July 2009, under the EC Regulation on fluorinated greenhouse gases (EC 842/2006).

Metered dose inhalers (MDIs) are used to deliver certain pharmaceutical products as an aerosol. For patients with respiratory illnesses, such as asthma and chronic obstructive pulmonary disease (COPD), medication needs to be delivered directly to the lungs. MDIs are one of the preferred means of delivering inhaled medication to patients with these illnesses. MDIs originally used CFC propellants but, as with industrial aerosols, concern over ozone destruction led to replacement of CFCs with HFCs. Note that HFC use in MDIs are exempted from the 2014 EU F-gas regulation phase down of HFC consumption.

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[66] Interpolated between 2000 and 2005

## 4.33.2 Methodological Issues

### 4.33.2.1 Aerosols

The methodology used to estimate emissions corresponds to an IPCC Tier 2 method. Aerosol HFC emission estimates have been derived on the basis of fluid consumption data provided by the British Aerosol Manufacturers' Association (BAMA) up to 2012. BAMA discontinued collecting data for 2013 onwards, so for these years we have projected estimates of HFC consumption using knowledge of the regulatory landscape and industry insight of the market from a contact at BAMA. An average product lifetime of one year for all aerosols containing HFC has been assumed, based on discussions with BAMA, although this may be shorter or longer depending on the specific aerosol application. It is estimated that 1% of HFC emissions from aerosols occur during manufacture. The majority is released during the product lifetime (97%), with end of life emissions accounting for the other 2%. The lifetime and end of life emissions are calculated after import and exports have been taken into account.

### 4.33.2.2 Metered Dose Inhalers (MDIs)

The methodology used to estimate emissions corresponds to an IPCC Tier 2 method. The current approach is essentially a "UK consumption model". The number of MDIs used each year in the UK is derived from the UK National Health Service (NHS) prescription data. HFC emissions have been calculated with estimates of the species and volumes of HFCs used as MDI propellants. Detailed data from the UK NHS are used for estimates between 1998 and 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 (4%) have been formulated using HFC-227ea. The table shows the estimated number of MDIs consumed each year in the UK, together with the $CO_2$ emissions for this level of MDI consumption (assuming 96% HFC-134a and 4% HFC-227ea).

**Table 4.24        Key assumptions used to estimate HFC emissions from MDIs**

| Year | MDI Number (thousands) | Average Propellant (g per MDI) | Emissions (kt $CO_2e$) |
|------|------------------------|--------------------------------|------------------------|
| 2006 | 40,146 | 14 | 844 |
| 2007 | 41,874 | 13 | 817 |
| 2008 | 45,353 | 12 | 817 |
| 2009 | 48,413 | 12 | 872 |
| 2010 | 50,190 | 12 | 904 |
| 2011 | 50,644 | 12 | 913 |
| 2012 | 52,009 | 12 | 937 |
| 2013 | 51,518 | 12 | 928 |

| Year | MDI Number (thousands) | Average Propellant (g per MDI) | Emissions (kt CO$_2$e) |
|---|---|---|---|
| 2014 | 53,317 | 12 | 961 |
| 2015 | 53,612 | 12 | 966 |
| 2016 | 54,174 | 12 | 976 |
| 2017 | 53,452 | 12 | 963 |
| 2018 | 53,155 | 12 | 958 |

Speciated emissions for the OTs and CDs are reported under 2F4. Emission estimates from the UK GHGI were scaled by the population of each territory.

### 4.33.3 Uncertainties and Time Series Consistency

Uncertainty data from this study have been used in the uncertainty analysis presented in **Annex 2**.

### 4.33.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. Details of verification of emissions are given in **Annex 6**.

### 4.33.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10.**

### 4.33.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

## 4.34    SOURCE CATEGORY 2F5 – SOLVENTS

### 4.34.1 Source Category Description

HFCs can be used as solvents in a range of applications such as precision cleaning to replace CFCs, HCFCs or 1,1,1-trichloroethane. HFCs have been developed that are used for precision cleaning in sectors such as aerospace and electronics.

### 4.34.2 Methodological Issues

Emissions from solvent applications are considered to be prompt emissions because 100% of the chemical is typically emitted within two years of initial use (IPCC 2006). To calculate HFC emissions from the solvent sector using a Tier 1a method, the 2006 IPCC Guidelines specify that activity data should be the quantity of solvent sold in a given year. Therefore, obtaining annual sales of solvents in the UK is required. Using sales data, emissions of HFCs from solvent use in year t are calculated using the following equation, as provided in the 2006 GLs:

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

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 (2017) data on HFC-43-10mee supply data in the EU was used to estimate HFC consumption from 2007 onwards.

To estimate the amount of HFCs placed on the market in the UK, the EU estimates from EEA (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%[67] was applied in this analysis using the IPCC (2006) equation above. Recovery and recycling is not considered in emission estimates, per the 2006 IPCC GLs.

## 4.34.3 Uncertainties and Time Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

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

## 4.34.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. Details of verification of emissions are given in **Annex 6**.

## 4.34.5 Source Specific Recalculations

There have been no recalculations to emissions from this sector.

## 4.34.6 Source Specific Planned Improvements

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

## 4.35    SOURCE CATEGORY 2F6 – OTHER (INCLUDING TRANSPORT OF REFRIGERANTS)

## 4.35.1 Source Category Description

| Emissions sources | Sources included | Method | Emission Factors |
|---|---|---|---|
| | 2F6b: Refrigerant Containers<br>　　　Refrigerant handling | CS<br>CS | CS<br>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.<br>A general assessment of completeness for the inventory is included in **Section 1.8**. | | |
| Major improvements since last submission | No major improvements | | |

## 4.35.2 Methodological Issues

Under the 2006 GLs, a new term in the IPCC Tier 2a method emissions equation for the Refrigeration and Air Conditioning sector includes emissions from the management of refrigerant containers used to service existing refrigeration/air-conditioning equipment, including refrigerant cylinders used by professional service technicians and small cans used by Do-It-Yourselfers (DIYers). No Tier 1 methodology is provided for this source.

Emissions from refrigerant containers occur when refrigerant is transferred from bulk containers (e.g. 20-tonne isotanks) to smaller capacity containers, typically ranging from approximately 300-500 grams (small cans) to 60 - 70 kg (cylinders). Emissions also occur at time of cylinder reprocessing (for reusable cylinders) or cylinder disposal (for non-returnable cylinders) if the refrigerant "heel" is not fully recovered. IPCC 2006 GLs require that emissions from each type of refrigerant container be calculated separately for refrigerant sold in small cans and in cylinders, including both disposables and reusables. The IPCC 2006 GLs default disposal emissions factors are 20% for small cans and 2% for disposable cylinders. Although

the GLs do not specify a default emission rate for losses during the transfer of refrigerant into smaller containers, they do specify a default loss rate of 0.5% during the charging of refrigeration/air-conditioning equipment.

ICF (2014) provides a review of available literature to develop key assumptions on stock and emission factors—notably, Enviros Consulting Limited (2008), Defra (2008), and BRA (2010). ICF also contacted the five largest refrigerant Fillers & Packers in the UK that reported sales data to BRA in order to confirm/refine the estimates. Further work was carried out and is reported in Ricardo (2016) to refine a refrigerant containers model that is now used for the UK emissions estimate.

### 4.35.2.1 Package Sizes and Types

Refrigerants are used by four different types of end users who each use different sizes of refrigerant packaging:

a) Original equipment manufacturers that manufacture pre-charged RACHP equipment. They purchase the majority of refrigerant in large volumes e.g. 20 tonne iso-containers or 1 tonne drums.

b) RACHP system installers that charge new systems after construction at an end user site. For larger sized systems (e.g. supermarket refrigeration systems or air-conditioning water chillers) the majority of refrigerant is supplied in large cylinders (e.g. 60 kg). For small systems (e.g. split air-conditioning) small cylinders (e.g. 15 kg) may also be used.

c) RACHP maintenance companies that carry out regular maintenance of equipment. The majority of refrigerant used for maintenance is supplied in small cylinders.

d) DIY activities for mobile air-conditioning – refrigerant is supplied in small cans (e.g. 0.3 to 0.5 kg) for use in the DIY market.

All large package sizes (e.g. 20 tonne iso-containers, 1 tonne drums, and 60 kg cylinders) have been sold as re-usable containers since before 1990.

A small proportion of smaller cylinders (e.g. 15 kg) were sold as non-returnable containers from 1990 to 2008. From 2008 the supply of non-returnable cylinders was banned under the 2006 EU F-Gas Regulation.

The majority of small cans for mobile air-conditioning were sold as non-returnable containers from 1990 to 2008. From 2008 the supply of non-returnable small cans was banned under the 2006 EU F-Gas Regulation.

### 4.35.2.2 Sources of emission from refrigerant containers

The refrigerant containers emissions model takes into account 4 sources of HFC emission:

a) During package filling at a specialist company that transfers refrigerant from bulk storage into the package sizes described above.

b) During the re-processing of re-usable packages, at the specialist packer-filler companies

c) From non-returnable cylinders in the waste stream (only until 2008 when they were banned)

d) From the use of cylinders in the field by installers and maintenance companies.

All emissions are assumed to occur when cylinders are connected or disconnected to other equipment. There are small losses each time a cylinder is filled, used in the field or reprocessed. The emissions are on a "per event" basis. For example each time a cylinder is

filled there is a small emission – the filling emission is the same for filling a large 60 kg cylinder as for filling a small 15 kg cylinder. There are no emissions from cylinders in storage.

### 4.35.2.3 Number of cylinders filled, used and reprocessed

Annual estimates of cylinder use were developed using data on the sales of refrigerant into the UK market consistent with the UK RACHP model. The total quantity of refrigerant sold is available for each of the main refrigerant types (e.g. R-404A, HFC-134a etc.). The split of cylinder sizes for each refrigerant type was estimated through discussions with packer-fillers as summarised in the table below.

**Table 4.25        Estimated split of UK refrigerant sales by cylinder size**

|  | Bulk (1 tonne / 15 tonne) | Large cylinder (60 kg) | Small cylinder (13 kg) |
|---|---|---|---|
| R-134a | 15% | 25% | 60% |
| R-404A / R-507 | 5% | 25% | 70% |
| R-407A / R-407C / R-407F | 5% | 25% | 70% |
| R-410A | 5% | 5% | 90% |
| Other HFC blends | 10% | 10% | 80% |

### 4.35.2.4 Emission Factors

Emission factors for each type of emission have been assessed in discussion with industry experts.

#### 4.35.2.4.1  Cylinder filling

Emissions during cylinder filling are very low. Packer-fillers use sophisticated automatic filling equipment and have taken steps to minimise losses of refrigerant when a cylinder is connected or disconnected to filling equipment, including use of "gas drawback" systems to suck gas out of connecting pipework before they disconnect a cylinder after it has been filled. Packer-fillers estimate that the loss per charging operation is under 1 gram of gas in the most sophisticated facilities. Prior to 2006 it is likely that the emission rates were higher. An emissions factor of 10 grams per charging operation has been used in the period 1990 to 2000, tapering to 2 grams after 2008 (a conservatively high estimate).

#### 4.35.2.4.2  Returned cylinder re-processing

All used cylinders have a heel of gas left in them. This is usually a small amount (e.g. well under 5% of full cylinder quantity) although in a few cases partially filled cylinders are returned with over 50% of the original quantity. Packer-fillers treat returned cylinders with great care, partly for environmental reasons and also because of the potential value of the returned gas. Packer-fillers use one of two methods to re-process returned cylinders:

a)  They "de-heel" each cylinder by transferring any remaining refrigerant into a large storage drum. When this drum is full it is tested for quality and then added to the main refrigerant bulk tank for use in filling new cylinders

b)  They "top-fill" a cylinder with the appropriate refrigerant, filling to the required total weight.

Packer-fillers indicate negligible losses from these processes (e.g. for top fill there is no emission other than that for cylinder filling). Conservatively the model uses 10 grams per de-heeling operation in the period 1990 to 2000, tapering to 2 grams after 2008.

### 4.35.2.4.3 Non-returnable cylinders

Any heel left in a non-returnable cylinder will be emitted e.g. from a landfill site or a waste metal reprocessing site. There is no data on the average heel size for non-returnable cylinders or small cans. Only a small proportion of UK refrigerant was sold in non-returnable packages in the period 1990 to 2008 and none after that date (due to the ban in the 2006 EU F-Gas Regulation). The model assumes a 2% heel in small cylinders (approx. 0.25 kg) and a 10% heel in small cans (approx. 30 grams).

### 4.35.2.4.4 Cylinder use in the field

There are losses each time a cylinder is connected / disconnected to RACHP equipment during field installation or maintenance. The loss will depend on the care taken by the technician carrying out the filling operation. Refrigerant is lost from the connection hoses when a cylinder is disconnected. Technicians are trained how to use cylinders correctly (it is part of the mandatory F-Gas handling training specified in the 2006 EU F-Gas Regulation and part of the training specified by the EU Ozone Regulation). With best practice the losses are estimated to be in the range of 0.5 to 3 grams of refrigerant per filling event, assuming only refrigerant vapour is emitted. However, with poor practice some liquid refrigerant could be emitted – this could result in an emission of 50 to 100 grams per event. Discussion with experts has established that an average loss of 10 grams per event is reasonable for properly trained technicians (allowing for one in ten filling events to be poor practice). Prior to the introduction of mandatory training loss rates were higher – the model assumes 40 grams per filling event prior to 2001, tapering to 10 grams in 2008.

Some cylinders are used multiple times in the field e.g. a 15 kg cylinder could be used to add, say 5 kg to plant A, 1 kg to plant B etc. There is no detailed data available on average cylinder use patterns. Based on discussion with experts the model assumes 5 filling events per cylinder.

The emissions estimates from refrigerant containers are summarised in the **Figure 4.3** below. A high proportion of the emissions are from cylinder use in the field. The drop of field emissions in the period 2000 to 2008 is due to the introduction of better training. The drop in filling / disposal emissions in 2008 is due to the ban on non-returnable cylinders and cans.

**Figure 4.3** **Trends in refrigerant container emissions**
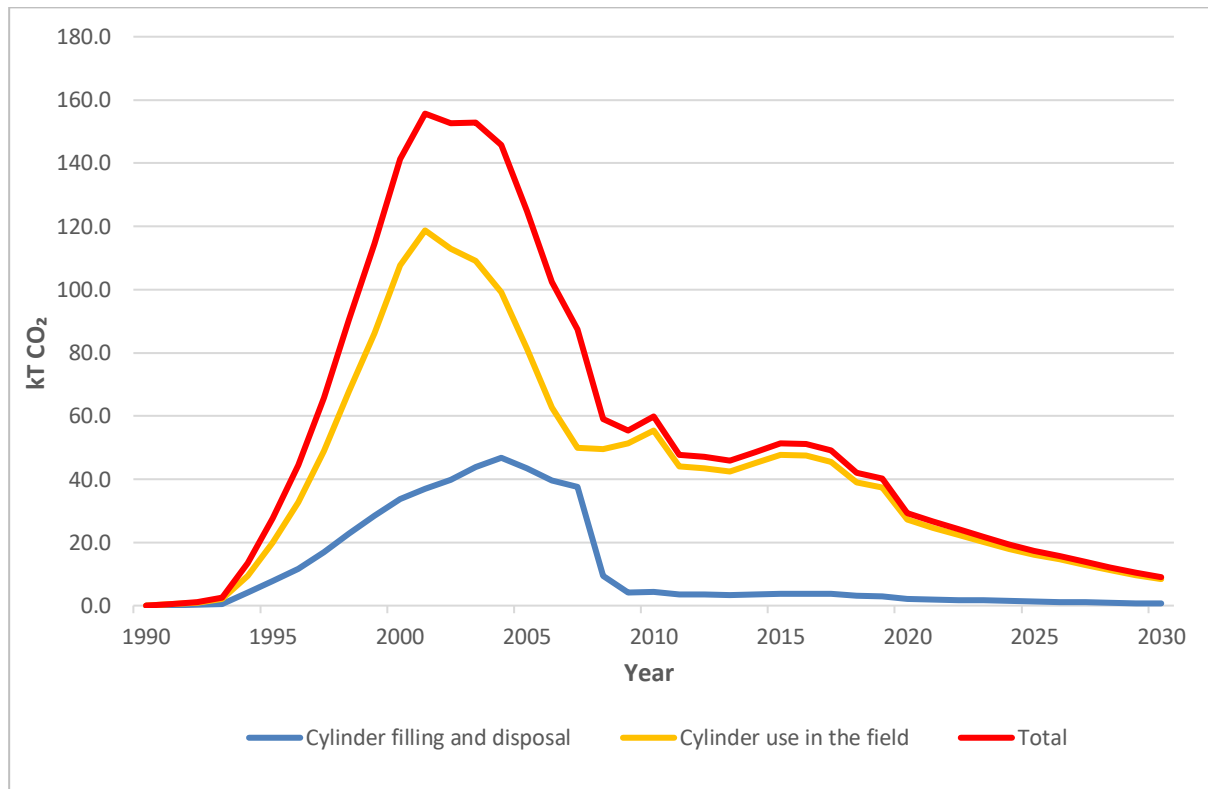


**4.35.2.5 Refrigerant handling by other organisations**

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

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

## 4.35.3 Uncertainties and Time Series Consistency

As discussed above, emissions in the field dominate the total. From 2009 the emissions from filling and disposal of cylinders are well under 10% of the total. There is a high confidence in the estimates for filling and disposal post-2009. Prior to 2008 the filling and disposal estimates have a lower confidence because of uncertainties regarding the quantity of refrigerant left in non-returnable cylinders/cans on disposal. There are significant uncertainties regarding cylinder use in the field. In particular there is no data on the proportion of "poor practice" filling events or on the average number of filling events per cylinder.

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

## 4.35.4 QA/QC and Verification

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

## 4.35.5 Source Specific Recalculations

No recalculations have been made to this category.

## 4.35.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

## 4.36 SOURCE CATEGORY 2G1 – ELECTRICAL EQUIPMENT

### 4.36.1 Source Category Description

Sulphur hexafluoride has been used in high and medium voltage switch gear and transformers since the mid-1960s. The physical properties of the gas make it 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. Currently, there are no mature alternative technologies to using $SF_6$ although some new insulating fluids are being tested and may become commercially viable during the next few years.

### 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 2018). Since the introduction of the EU F-Gas Regulation in 2006, the UK electricity industry has made significant efforts to monitor and reduce consumption of $SF_6$.

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**.

### 4.36.5 Source Specific Recalculations

There have been no recalculations to emissions from this sector.

### 4.36.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

## 4.37 SOURCE CATEGORY 2G2A – MILITARY APPLICATIONS – AWACS

### 4.37.1 Source Category Description

Military applications include Airborne Warning and Control System (AWACS), which are military reconnaissance planes. In AWACS, the $SF_6$ is used as an insulating gas in the radar system.

### 4.37.2 Methodological Issues

A Tier 1 method, country specific activity data, and an IPCC default emission factor of 740 kg $SF_6$ per plane per year is used to estimate emissions.

The method uses the total number of planes carrying AWACS as the activity data. ICF's research of the UK Royal Air Force (RAF) website confirmed that the RAF carries the same number of AWACS (seven) in 2012 as reported in the 2006 GLs (RAF, 2013). ICF further confirmed that RAF has had seven AWACS since 1990. Indeed, AWACS are a part of the Number 8 squadron of the RAF and they were acquired in 1985 (8 Squadron 2012). However, of the seven AWACS present in UK Fleet, not all are designated as forward available fleets. During times of low activity, some AWACS are placed as depth fleet, i.e., not operational, and therefore do not contribute to emissions. In 2012, only four AWACs were classified as forward available fields (MOD, 2012), as we do not have data on how many are in the forward fleet at any one date (with the exception of 2012) all 7 are conservatively assumed to be active in all years.

### 4.37.3 Uncertainties and Time Series Consistency

The Tier 1 method relies on a constant emission factor, but actual emissions will vary based on the number of sorties (missions), with emissions higher during periods of high military operations and lower during times of low military operations.

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

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type.

### 4.37.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. Details of verification of emissions are given in **Annex 6**.

### 4.37.5 Source Specific Recalculations

There have been no recalculations to emissions from this sector.

### 4.37.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

## 4.38 SOURCE CATEGORY 2G2B – PARTICLE ACCELERATORS

### 4.38.1 Source Category Description

Particle accelerators are used for research purposes (at universities and research institutions), for industrial applications (in cross-linking polymers for cable insulation and for rubber parts and hoses), and in medical (radiotherapy) applications.

Estimates of emissions in the UK are confined to those from research and university accelerators particle accelerators.

### 4.38.2 Methodological Issues

The emissions from industrial particle accelerators are a result of leakage during operation and repair. Research and industrial high voltage systems usually need to be opened more frequently than industrial low voltage accelerators. Hence the emission factor of low voltage industrial accelerators is comparably lower. In the case of radiotherapy applications, industrially pre-set particle accelerators with hollow conductors filled with $SF_6$ 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 4.26** below.

**Table 4.26          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 recalculations to emissions from this sector.

## 4.38.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review.

## 4.39 SOURCE CATEGORY 2G2E – $SF_6$ AND PFCS FROM OTHER PRODUCT USE

## 4.39.1 Source Category Description

Emissions of PFCs and $SF_6$ from the production of semiconductors, the use of $SF_6$ as a tracer gas, and PFCs and $SF_6$ from sporting goods (training shoes) have been combined in order to preserve the confidentiality of estimates of emissions of $SF_6$ and PFCs used in training shoes.

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

- Cleaning of chambers used for chemical vapour deposition (CVD) processes;
- Dry plasma etching;
- Vapour phase soldering and vapour phase blanketing;
- Leak testing of hermetically sealed components; and
- Cooling liquids, e.g. in supercomputers or radar systems.

In addition, $SF_6$ is used in etching processes for polysilicon and nitrite surfaces, and there is some usage of $CHF_3$ and $NF_3$.

In the electronics manufacturing process, the fluorinated gases (PFCs, $SF_6$,HFCs and $NF_3$) are mainlky 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 2006 GLs Tier 1 method estimates emissions based on the amount of substrate processed, in units of $m^2$.

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

Emissions for $E_i = (1-h)*FC_i*(1-U_i)*(1-a_i*d_i)$

Where:

*i* = *F-gas species*

$E_i$ = emissions of gas$_i$, kg

*h* = fraction of gas i remaining in container (heel)

$FC_i$ = consumption of gas$_i$, kg

$U_i$ = use rate of gas$_i$

$a_i$ = abatement rate of gas$_i$

$d_i$ = fraction of gas$_i$ destroyed by the abatement

The Tier 2a method also estimates by-product emissions of $CF_4$, $C_2F_6$, $C_3F_8$ and $CHF_3$. The Tier 2a equation used for by-product emissions is:

By-Product Emissions of gas j $(BPE_{j,i}) = (1-h)*B_j,i*FC_i*(1-a_i*d_j)$

Where:

$BPE_{j,i}$ = by-product emissions of gas *j* from the gas *i* used, kg

$B_{j,i}$ = emission factor, kg gas *j* created/kg gas *i* used

$d_j$ = fraction of gas *j* by-product destroyed by the abatement

*j* = $CF_4$, $C_2F_6$, $CHF_3$ and $C_3F_8$

### 4.39.2.1.1  Activity Data

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

The $NF_3$ 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 (IPCC 2006). In situ chamber cleans are chemical vapour deposition chamber cleaning processes, which may use $NF_3$ or other F-gases to generate F-atoms in the chambers whose walls are being cleaned. $NF_3$ may also be used to etch patterns (i.e., circuits) on semiconductors. The use of $NF_3$ remote clean is assumed to start in 2003 and growing increasingly over time. As no data on the UK's use of $NF_3$ remote clean processes was made

available from NMI, the US semiconductor market was used as a proxy to estimate the use of $NF_3$ in remote clean processes relative to all other processes.

Specifically, the share of $NF_3$ remote clean versus other uses was estimated based on industry-reported $NF_3$ usage data from US semiconductor manufacturers for the years 2009 and 2010 (US EPA, 2011). This US data was readily available and is believed to be a good proxy for the UK given that semiconductor processes do not typically vary by world region. The ratio of $NF_3$ remote to other uses was interpolated for years between 2003 and 2009, assuming 0.0 (nil) in the year 2003. This was done as 2006 GLs provide emission factors for the $NF_3$ use in remote clean and $NF_3$ in-situ and etch use.

*4.39.2.1.2 Emission factors and other default factors*

The emission factors used in the updated inventory were taken from 2006 GLs. A summary of the emission factors for the 2006 GL Tier 2a method is provided in the table below.

**Table 4.27     Summary of 2006 GL Tier 2a emission factors for the semiconductor manufacture sector**

| Process Gas (i)[a] | $CF_4$ | $C_2F_6$ | $CHF_3$ | $CH_2F_2$ | $C_3F_8$ | c-$C_4F_8$ | $NF_3$ Remote | $NF_3$ | $SF_6$ |
|---|---|---|---|---|---|---|---|---|---|
| Emission Factor (1-Ui)[b] | 0.9 | 0.6 | 0.4 | 0.1 | 0.4 | 0.1 | 0.02 | 0.2 | 0.2 |
| $BCF_4$ | NA | 0.2 | 0.07 | 0.08 | 0.1 | 0.1 | 0.02[c] | 0.09 | NA |
| $BC_2F_6$ | NA | NA | NA | NA | NA | 0.1 | NA | NA | NA |
| $BC_3F_8$ | NA | NA | NA | NA | NA | NA | NA | NA | NA |

NA = no data available based on information available during time of publication.

[a] Bx = X is a by-product from the usage of another gas (in row headings).

[b] Ui = Utilization rate of gas i.

[c] Estimate reflects presence of low-k, carbide and multi-gas etch processes that may contain C-containing FC additive.

The default value used for the fraction of gas remaining in the shipping container (heel) is 0.10. The assumptions regarding destruction efficiencies for emission control technologies are based on the 2006 GLs.

**Table 4.28     Key assumptions used to estimate emissions from semiconductor manufacture**

| Gas | Destruction efficiency[68] | Fraction fed to abatement | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1990 | 1995 | 2000 | 2005 | 2010 | 2012 onwards |
| $CF_4$ | 0.9 | 0% | 0% | 0% | 15% | 40% | 45% |
| $C_2F_6$ | 0.9 | 0% | 0% | 0% | 15% | 40% | 45% |
| $C_3F_8$ | 0.9 | 0% | 0% | 0% | 15% | 40% | 45% |
| $C_4F_8$ | 0.9 | 0% | 0% | 0% | 15% | 40% | 45% |
| $CHF_3$ | 0.9 | 0% | 0% | 0% | 15% | 40% | 45% |
| $SF_6$ | 0.9 | 0% | 0% | 0% | 15% | 40% | 45% |
| $NF_3$ | 0.95 | 90% | 90% | 90% | 100% | 100% | 100% |

**4.39.2.2 Use of $SF_6$ as a tracer gas in scientific research:**

$SF_6$ is used in a number of applications in the UK

- Tracer gas to certify fume hoods; and
- UK studies of greenhouse gas emissions

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[68] Destruction Efficiency: Source: IPCC 2006 Guidelines, Chapter 6, Table 6.6

ICF investigated the use of tracer gas to certify fume hoods.

The use of $SF_6$ as a tracer gas to certify fume hoods is a practice established by ASHRAE in the test procedure ASHRAE-110, "Method of Testing Performance of Laboratory Fume Hoods" (ASHRAE, 1995). $SF_6$ is emitted in the fume hood and the concentration of the gas is measured after some time has passed. This is to ensure that the gases created under the fumes, toxic or otherwise, are properly ventilated. The amount of gas used per test is dependent on the tester. All of the $SF_6$ used in tracer tests is lost in the atmosphere and so the emissions are treated as prompt emissions—i.e., each test results in direct emissions of $SF_6$ (IPCC 2006). $SF_6$ is also used for tracer testing of nuclear power plant control room emergency ventilation systems (CARB, 2009).

Due to data limitations, $SF_6$ emissions were estimated using a slightly modified Equation 8.23 of Volume 3 of the 2006 GLs. The $SF_6$ emission is calculated on a per-use basis as opposed to the amount purchased/sold as provided in the equation. This modified method relies on the number of tracer tests conducted annually as the activity data, which when multiplied by the emissions per test as the emission factor, gives the total $SF_6$ emissions from this sector. This method is represented in the following equation:

Total emissions = emissions per test x number of tests

Additional emissions may also occur from bottling, leakage, and piping; however, such emissions cannot be estimated without activity data and are believed to be de minimis.

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 4.29         Quantities of $SF_6$ used in scientific research**

| Year | kg $SF_6$ |
|---|---|
| 2011 | 1.224 |
| 2012 | 1.433 |
| 2013 | 0.270 |
| 2014 | 0.273 |
| **Total** | **3.200** |

More details of the work can be found at www.ghgplatform.org.uk. This research project ended in 2014, so emissions from this source do not occur in 2015 onwards.

**4.39.2.3 Use and disposal of training shoes:**

Estimates of emissions from sports-shoes were based on a bottom-up Tier 2 estimate, using activity data supplied in confidence by the manufacturer.

A full description of the emissions and associated methodology used is contained in AEA (2004) and AEA (2008).

Speciated emissions for OTs and CDs are reported in this category. Emission estimates from the UK GHGI were scaled by population of each territory as appropriate.

## 4.39.3 Uncertainties and Time-Series Consistency

Estimates of emissions in some categories of this sector are based on very limited and uncertain data, and are therefore uncertain.

More information on uncertainty data used in the uncertainty analysis is presented in **Annex 2**.

## 4.39.4 Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in **Section 1.6**. Details of verification of emissions are given in **Annex 6**.

## 4.39.5 Source Specific Recalculations

For information on the magnitude of recalculations, see **Section 10**.

## 4.39.6 Source Specific Planned Improvements

Activity data and emission factors will be kept under review. We note that the ERT has specifically requested that the UK improves estimates for semiconductor manufacture, and this remains on the improvement programme for consideration.

## 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[69]. 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**.

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[69] http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2013

### 4.40.6 Source Specific Planned Improvements

The inventory team will continue to search for data relating to the sales of $N_2O$ for anaesthetic use, and will make improvements to the methodology when this information is available.

## 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, 2019).

Activity data on the number of adults using new psychoactive substances in the UK is available from 2012 in the Home Office Drug Misuse tables (Home Office, 2019), whilst frequency of use is available only for 2017 onwards. It is therefore assumed that;

- The average frequency of use implied by the 2017 statistics is appropriate for earlier 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". The frequency of use per adult is determined using the most recent Home Office Drug Misuse dataset (Home Office, 2019). Since no data is available for earlier years of the time-series, the 2017 frequency of use is extrapolated to all estimated previous years.

### 4.41.3 Source Specific QA/QC and Verification

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

## 4.41.4 Source Specific Recalculations

Small revisions to estimates due to revisions in the latest statistics. Estimates for recreational use of $N_2O$ were uplifted to account for the entirety of the UK, as the statistics are for England and Wales only; the approach was also reviewed to make the best use of available data.

## 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 19years of reported data, $N_2O$ emissions have been reported in at least one year for 19 sites which can be described as chemical sites. For most of those sites, $N_2O$ is reported for only one or two years out of the time-series and we think it is likely that the reported $N_2O$ is an error (operators do occasionally confuse $N_2O$ and $NO_X$ on their reporting submissions) and in a few other cases it is likely that the $N_2O$ occurs from the substantial combustion processes that constitute part of the reporting installation. In three cases however $N_2O$ is reported in multiple years, from processes which are either known to emit the gas, or thought to be the most likely source:

- A process to manufacture nitrous oxide, and to transfer it into gas cylinders for sale. This process was commissioned in 2004;
- A further process manufacturing industrial gases, which probably also supplied nitrous oxide in cylinders and which closed in 2008;
- A catalyst manufacturing process which involves dissolving metals in nitric acid, leading to emissions of oxides of nitrogen (including both $NO_X$ and $N_2O$). This process has been in operation since the 1940s.

Emission estimates are based on the data reported by the process operators to the Environment Agency for inclusion in the Pollution Inventory (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 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 but unlikely that other sites that report $N_2O$ emit the gas from chemical manufacturing processes but if this were the case, these emissions would be much smaller than those from the three sites currently included.

### 4.42.4 Source Specific QA/QC and Verification

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

### 4.42.5 Source Specific Recalculations

No significant recalculations have been made for this category.

### 4.42.6 Source Specific Planned Improvements

The estimates will be kept under review, and additional sites added if appropriate.

## 4.43   SOURCE CATEGORY 2H1 – PULP AND PAPER INDUSTRY

### 4.43.1 Source Category Description

The UK paper industry is mainly confined to the production of pulp from recycled material and the production of papers using imported virgin pulp, recycled pulp or a combination of the two. Production of virgin pulp is limited to a few processes producing mechanical or neutral sulphite semi-chemical pulp. Emissions from UK paper processes consist largely of emissions from the associated combustion processes and these are reported under CRF category 1A2d. Other emissions of GHGs from UK paper and pulp processes will be minor and are not estimated.

## 4.44   SOURCE CATEGORY 2H2 – FOOD AND BEVERAGES INDUSTRY

### 4.44.1 Source Category Description

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

# 5    Agriculture (CRF sector 3)

## 5.1    OVERVIEW OF SECTOR

| IPCC Categories Included | 3A: Enteric Fermentation<br>3B: Manure Management<br>3D: Agricultural Soils<br>3F: Field Burning of Agricultural Residues<br>3G: Liming<br>3H: Urea application<br>3J: Overseas Territory and Crown Dependency emissions |
|---|---|
| Gases Reported | $CO_2$, $CH_4$, $N_2O$, $NO_x$, CO, NMVOC, $SO_2$ |
| Key Categories ('T' or 'L' indicates whether it has been identified in the trend or level assessment respectively and the number indicates which KCA approach it was identified in) | 3A: Enteric Fermentation – $CH_4$ – (L2, T2)<br>3A1: Enteric fermentation from cattle – $CH_4$ (L1, T1)<br>3A2: Enteric fermentation from sheep – $CH_4$ (L1, T1)<br>3B1: Manure management from cattle – $CH_4$ (L1, T1)<br>3B2: Manure management from sheet – $N_2O$ (L1)<br>3D: Agricultural soils – $N_2O$ (L1, T1, L2) |
| Key Categories (Qualitative) | None identified |
| Overseas Territories and Crown Dependencies Reporting | Emissions for OTs and CDs are included for enteric fermentation, animal wastes and agricultural soils. |
| Completeness | A general assessment of completeness for the inventory is included in **Section 1.8**. |
| Major improvements since last submission | No major method changes in the 2020 submission. |

In source sector 3, the United Kingdom reports emissions from the following categories: enteric fermentation ($CH_4$) (Table 3A), manure management ($CH_4$, $N_2O$) (Table 3B), agricultural soils direct and indirect ($N_2O$, including synthetic fertiliser, manures applied to soils, urine and dung deposition, sewage sludge, mineralisation, crop residues, histosols) (Table 3D); urea application ($CO_2$) (Table 3H); liming ($CO_2$) (Table 3G).

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

Emissions of other pollutants included $NO_x$, NMVOCs, PM

The agriculture sector has the second largest contribution to total GHG emissions in the UK, after the energy sector. It contributed approximately 9.0% to total emissions in 2018. The emissions from this sector have shown an overall decrease of 16% since 1990, reflecting trends in livestock numbers and emissions from fertiliser application.

**Figure 5.1**    **Breakdown of total GHG emissions in the Agriculture sector in the latest inventory year[70]**



- 3A = 51.4%
- 3B = 17%
- 3D = 27.7%
- 3G = 2.3%
- 3H = 0.8%
- 3J = 0.8%
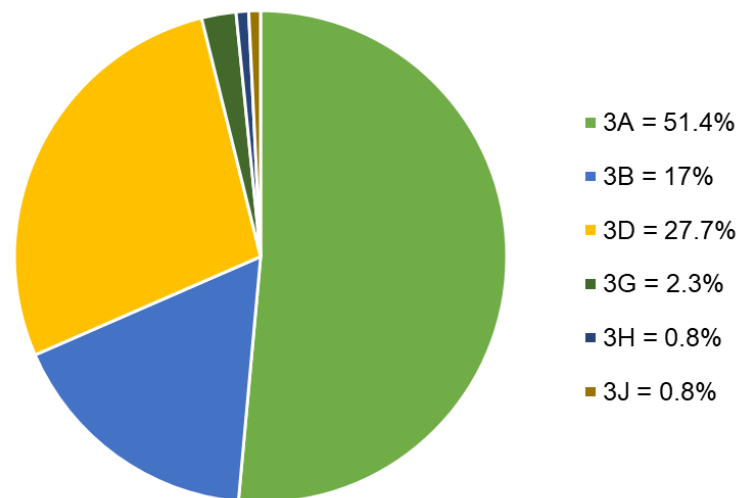
**Figure 5.2**        **Trend in total GHG emissions in the Agriculture sector**
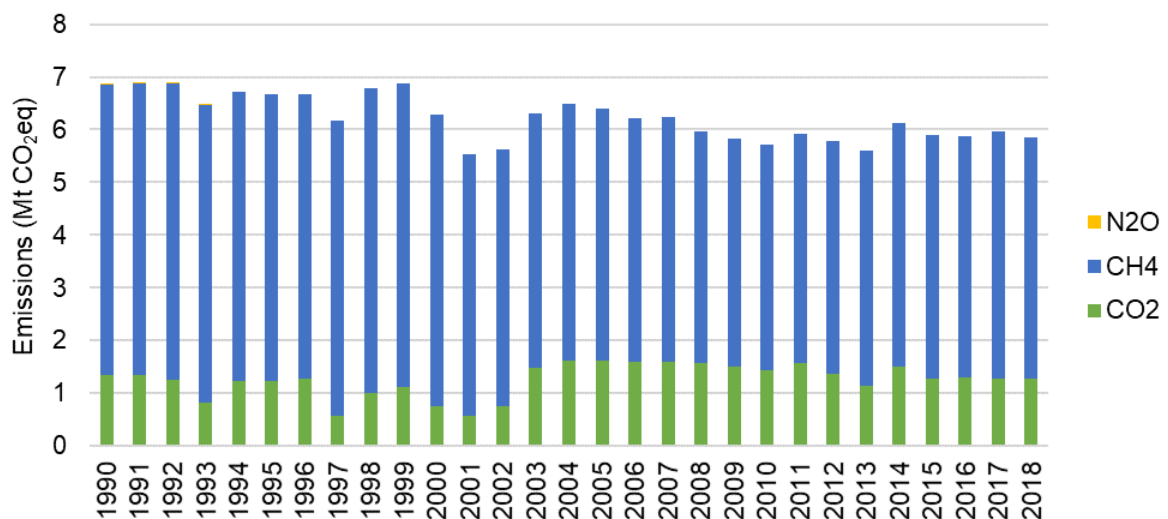


## 5.1.1  The UK greenhouse gas Inventory model for the Agriculture sector

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

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[70] The Agriculture sectors are explained in the IPCC categories section.

#### 5.1.1.1   Model description

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

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

## 5.1.2   General sector characteristics

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

#### 5.1.2.1   Soil and climate

Soil properties, notably field capacity, plant available water and percent clay and organic carbon content are used as input to inventory calculations of grass growth and nitrogen leaching following application of fertilisers, managed manures and excreta returns. The improved inventory uses the RB209 (MAFF, 2000) soils classification, based on soil texture and depth to rock, with seven soil types (light sandy, shallow, medium, deep clay, deep fertile silty, organic, peaty). For each country, soil scientists from the James Hutton Institute (Scotland), National Soils Resources Institute University (England and Wales) and the Agri-Food and Biosciences Institute (Northern Ireland) applied the RB209 soil typology to national digital soils datasets. The resulting United Kingdom map of RB209 soil types was spatially intersected with the reference 10 by 10 km grid to provide a statistical summary of the percent of the agricultural land area located on each of the RB209 soil types. The same national digital soils datasets were also used to calculate the percent of the soil area within each grid cell (excluding peaty soils) that is alkaline, based on top soil measurements of pH (>= 7), which is used in calculations of ammonia emissions from manufactured fertilisers.

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

### 5.1.2.2  Farm types

Farm types may be associated with specific structures and practices (from survey data stratified by Farm Type) which can be used to provide better representation in the emission calculations. The classification of agricultural holdings by Farm Type as used in the UK inventory is based on the method described in the EC typology book[71]. It is based on the type of farming and economic size, determined on the basis of Standard Output (SO) coefficients and structural information (area of crops and number of heads of livestock) of the various types of agricultural production. Ten robust farm types (RFT) are applied at Devolved Administration level (England, Wales, Scotland and Northern Ireland): (1) cereals; (2) general cropping; (3) horticulture; (4) specialist pig; (5) specialist poultry; (6) dairy; (7) Grazing livestock (LFA); (8) Grazing livestock (Lowland); (9) mixed; (10) other.

### 5.1.2.3  Livestock types and numbers

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

### 5.1.2.3.1 Dairy cattle

Dairy cattle are disaggregated into three production/breed types (large, medium, small), associated with different average milk yields for each year (high, medium, low) and into four sub-categories by age and physiological status (dairy calf < 1 year, dairy replacement > 1 year not in calf, dairy replacement in calf, dairy cow). Data are derived from the Cattle Tracing Scheme (CTS) at a monthly resolution for England, Wales and Scotland since 2005. Each animal is categorised by breed, gender, age and parity (if relevant) and associated with a holding. Breed is associated with a role (dairy, beef, dual purpose). All dairy females are included in the dairy sector; bulls used in the dairy sector and replacements for adult bulls are not included because of the difficulties of differentiating them from the beef sector. This does not affect reporting of total emissions from UK agriculture, as all bulls are accounted for in the beef sector. Dual purpose animals are assigned as dairy or beef according to the majority cattle type on the specific holding. Each breed type is associated to the inventory categories of large, medium or small annual average milk yields. For years prior to the introduction of the CTS in England, Scotland and Wales (1990-2004) and for Northern Ireland for 1990-2015 annual data are derived from the JAS at holding level. Monthly cattle numbers for these years are assumed to be equal to the annual JAS total. Dairy industry data were used to characterise the proportion of dairy cattle associated with each production system for pre-CTS years.

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

*5.1.2.3.2 Beef cattle*

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

*5.1.2.3.3 Sheep*

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

*5.1.2.3.4 Swine*

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

*5.1.2.3.5 Poultry*

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

*5.1.2.3.6 Goats, deer and horses*

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

#### 5.1.2.4   Crop types and crop areas

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

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

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

#### 5.1.2.5   Crop residues

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

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

Details of values used are in the supplementary material.

#### 5.1.2.6   Fertiliser types and application rates

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

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

### 5.1.2.7  Calculation of Emission Factors for $N_2O$ emissions from soils

Sources leading to $N_2O$ emissions include slurry, farm yard manure (FYM), fertiliser, and dung and urine applied to the land, where the latter is simulating conditions leading to the emissions from grazed lands. Water filled pore space (wfps) was identified as a key driver of $N_2O$ emissions (Conen et al., 2000), and is affected by both soil clay content and rainfall. The clay content of the soils (NRSI Cranfield, JHI and Ireland) is available at a 1km grid square while the weather data (MORECS) is available at a 40 km grid square. Detailed information on some of the individual experiments that provided the data for the analysis can be found in reports (AC0114, AC0116) and journal articles (e.g. Bell et al., 2016a; Bell et al., 2016b; Bell et al., 2015; Smith et al. 2012; Sylvester-Bradley et al., 2015). Following the guidelines of the IPCC (2006) for the derivation of $N_2O$ EFs, all the data from the experiments were collected over a 12-month period. The static chamber methodology was used to collect all the data, which is consistent with the Global Research Alliance guidelines (de Klein and Harvey, 2012). Data were collected by N-source: surface-spread and broadcast slurry, farm yard manure, dung and urine, and ammonium-based and urea-based fertilisers. In all experiments a control treatment, which received no organic or inorganic fertiliser was included. In all cases, as well as the emissions and the nitrogen application rates, data on the soil characteristics, and the total rainfall (RainYr, mm) and the average daily temperature for the 365 days associated with the experimental period were collated. The analysis was carried out by using REML regression using Genstat 17th Edition Release 17.1 VSN International Ltd., Oxford. With the exception of the Other N to grassland, the EFs for fertiliser application, FYM, broadcast slurry and grazing were lower than the IPCC default value of 1%.

The resulting models for urea and ammonium nitrate application to estimate yearly emission values was are described in section 5.4.2.1:

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

## 5.2   SOURCE CATEGORY 3A – ENTERIC FERMENTATION

## 5.2.1   Source category description

| Emissions sources | Source included | Method | Emission Factors |
|---|---|---|---|
| | 3A1: Dairy Cows Enteric | T3 | CS |
| |      Beef Cows enteric | T3 | CS |
| |      Other Cattle Enteric | T3 | CS |
| | 3A2: Sheep Enteric | T3 | CS |
| | 3A3: Swine Enteric | T1 | D |
| | 3A4: Goats Enteric | T1 | D |
| | 3A4: Horses Enteric | T1 | D |
| | 3A4: Deer Enteric | T1 | D |
| Gases Reported | $CH_4$ | | |
| Key Categories | 3A: Enteric Fermentation - $CH_4$ (L2, T2)<br>3A1: Enteric fermentation from Cattle - $CH_4$ (L1, T3)<br>3A2: Enteric fermentation from Sheep - $CH_4$ (L1, T3) | | |
| Key Categories (Qualitative) | None identified | | |
| Overseas Territories and Crown Dependencies Reporting | A separate category for all OTs and CDs livestock is used in the CRF (3A4). UK implied EFs are applied to animal numbers in the CDs, and 2006 IPCC default EFs are applied to animal numbers in the OTs.<br>Tables of animal numbers used in calculations can be found in **Annex 3.3.** | | |
| Completeness | No known omissions.<br>A general assessment of completeness for the inventory is included in **Section 1.8**. | | |
| Major improvements since last submission | No major improvements have been made since the last submission | | |

Methane is produced in herbivores as a by-product of enteric fermentation. Enteric fermentation is a digestive process whereby carbohydrates are broken down by micro-organisms into simple molecules. Both ruminant animals (e.g. cattle and sheep), and non-ruminant animals (e.g. pigs and horses) produce $CH_4$, although ruminants are the largest source per unit of feed intake.

## 5.2.2   Methodological issues

### 5.2.2.1   Dairy cows

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

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

Where:

$CH_{4\_enteric\_dc}$ is the enteric methane emission per dairy cow, g d$^{-1}$;

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

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

### 5.2.2.1.1 Feed intake

Dry matter intake by dairy cows is determined using UK-specific energy balance equations as published in Feed into Milk (Thomas, 2004), based on metabolisable energy (ME). The daily ME intake by the animal is assumed to correspond with the requirement for live weight gain, activity, milk and gestation. Average milk yield per cow is derived from national statistics provided by each country and this is disaggregated to breed type (large, medium, small) based on industry data regarding yields for specific breeds[72].

### 5.2.2.1.2 Live weight (LW)

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

### 5.2.2.1.3 Diet

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

### 5.2.2.1.4 Housing and grazing period

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

## 5.2.2.2  Other cattle

Enteric methane emissions from other cattle, including dairy sector replacements and calves, and all beef sector cattle, are estimated using the same approach as for dairy cows but with different relationships between enteric emission and dry matter intake for lactating and non-lactating cattle. For lactating cattle (i.e. beef suckler cows) the same equation as for dairy cows (presented above in **5.2.2.1**) is used. For all non-lactating cattle, the relationship as developed under Defra-funded projects AC0115 (Defra AC0115) and AC0114 (Defra AC0114) is:

$$CH_{4\_enteric\_oc} = (17.5653 \times DMI) + 45.8688$$

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[72] www.nbdc.uk

Where:

$CH_{4\_enteric\_oc}$ is the enteric methane emission per other cattle, g $d^{-1}$;

DMI is feed dry matter intake, kg $d^{-1}$; and standard error values for the slope and intercept are 2.4112 and 16.1505, respectively. As for dairy cows, dry matter intake for other cattle categories is determined using UK-specific energy balance equations, derived for non-lactating cattle from AFRC (1993) combined with cattle category- and system-specific production and diet characteristics at a monthly resolution as described for dairy cows (and further detail given in **Annex 3.3**).

*5.2.2.2.1 Feed intake*

The AFRC (1993) recommendations on the energy allowances for cattle are used to estimate the metabolisable energy (ME) needs of cattle (based on liveweight, growth rate, gestation and lactation). The ME coupled with activity data from a Defra Farm Business Survey module (Parsons and Williams 2015) is used to derive diets, composition of ME (MJ/d), gross energy (GE) and crude protein (CP) in each diet. DMI (kg/d), GE and CP intakes are derived from the ME needs (MJ/d) and the ME density in feed (MJ/[kg DMI]).

*5.2.2.2.2 Cattle live weights (LW)*

Cattle live weights are based on a Michaelis-Menten type growth model (López et al., 2000). The model requires mature LW, calf LW and two fitted parameters. Mature LW data are obtained from the established time series of slaughter weights that are collected at national level[73] and supplemented with a very large sample of data from which separate populations are derived of the breed types and age bands used in the model (Wall and Pritchard, 2017). Calf weights are calculated from an established equation in AFRC (1993). Parameters were fitted from a variety of industry and literature sources (Williams and Sandars, 2017).

The fractions of cattle lactating and/or gestating are derived from industry performance data and an analysis of the CTS dataset. The fractions of cattle lactating and/or gestating are applied uniformly over the population throughout the year. The ME needs for maintenance, growth, lactation and gestation are calculated for every age band and cattle type to estimate the DM intake and intakes of CP and GE, which are used to calculate enteric methane emissions, volatile solids (VS) excretion and N excretion.

*5.2.2.2.3 Diets*

There are 11 standard diets assumed for cattle, three corresponding to different types of grass and two corresponding to suckled calves at grazing with mixed nutrition from milk and grass. Data for feeds used (by material) are from the FBS (Parsons and Williams, 2015) and nutritional properties of each material in the diets are derived mainly from the Feed Composition Tables (MAFF, 1992), with some from Ewing (1998).

*5.2.2.2.4 Housing and grazing period*

Data came from a Farm Business Survey module (Parsons, Williams, 2015) and other farm practices surveys[74] 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 ages bands were more aggregated than the CTS-based age bands. Farm practices survey data is used to quantify the housing systems and manure management regimes used as follows: (1) housed all year; (2) Housed in the winter, out in the summer; (3) Outside all year; (4) Housed all year + yards; (5) Housed winter, out summer + yards. The housing management regimes

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[73] https://www.gov.uk/government/statistics/cattle-sheep-and-pig-slaughter

[74] e.g. https://www.gov.uk/government/collections/farm-practices-survey

were used to define cattle locations by month, i.e. grazing, in resting areas and in feeding yards. Each of these has its own emission factors for ammonia and $N_2O$.

### 5.2.2.3  Sheep

The same approach to estimating enteric emissions for cattle is taken with sheep, but using a UK-measurement derived relationship between enteric emission and dry matter intake specific to sheep:

$$CH_{4\_enteric\_sheep} = (12.3894 \times DMI) + 5.1595$$

Where:

$CH_{4\_enteric\_sheep}$ is the enteric methane emission per sheep, g $d^{-1}$;

DMI is feed dry matter intake, kg $d^{-1}$; and standard error values for the slope and intercept are 1.483 and 0.8301, respectively.

### 5.2.2.3.1 Feed intake

Feed intake is calculated using the energy balance model according to requirements to meet the metabolisable energy needs of the animal. It is applied to a description of the live-weight gain of the animal from birth to slaughter. Each type of ewe and lamb has separate growth-curves, access to housing and handling yards, and different access to forage, concentrate and conserved feeds that determine its feed intake.

### 5.2.2.3.2 Sheep live weights (LW)

The inventory uses country- and system-specific values for the LW of the adult ewe and lamb, and for the rate of weight gain. The annual average weight of ewes and slaughter weight of lambs are calculated separately for each country based on average carcase weights and a fixed killing-out percentage of 46 and 44% respectively, derived from national slaughter house statistics (Defra, DARD-NI, Welsh Government, Scottish Government, 1990 to 2016). The relative ewe weights for the hill, upland and lowland systems within each country are estimated based on an analysis of breed lists and expected mature weights, and are centred on the country average.

### 5.2.2.3.3 Diets

Fresh grass is the most significant component of feed, with an metabolisable energy content of 11.1 MJ $kg^{-1}$ DMI and a crude protein content that varies spatially in response to the clover content and level of manufactured fertiliser nitrogen applied to pasture. Ewe and rams are fed a supplement of conserved silage and hay for 120 days over-winter, and store lambs are fed silage, hay and roots for 100 days. The metabolisable energy contents are 10.6 MJ $kg^{-1}$ dm for silage, 9.4 MJ $kg^{-1}$ DMI for hay, and 9.2 MJ $kg^{-1}$ DMI for roots. The crude protein contents are 130 g $kg^{-1}$ DMI for silage, 111 g $kg^{-1}$ DMI for hay, and 192 g $kg^{-1}$ DMI for roots. Lambs are provided with an average creep feed ration of c. 0.150 kg $day^{-1}$ DMI for 42 days prior to weaning, and ewes are provided with a concentrate ration of c. 0.130 kg $day^{-1}$ DMI in the 56 days before and after lambing. The metabolisable energy and crude protein content of concentrate are 160 g $kg^{-1}$ DMI and 12.5 MJ $kg^{-1}$ DMI for the ewe and 180 g $kg^{-1}$ DMI and 12.6 MJ $kg^{-1}$ DMI for the lamb.

### 5.2.2.3.4 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.

#### 5.2.2.4   Other livestock

Enteric emissions for pigs, goats, horses and deer are estimated using IPCC (2006) Tier 1 methodology by combining the Tier 1 default EF with the UK-specific activity data on animal numbers.

#### 5.2.2.5   Overseas Territories and Crown Dependencies

Emission estimates were compiled by Aether-UK using animal numbers sourced from the territories directly and can be found in **Annex 3.6**. In the case of OTs, IPCC default emission factors were applied to animal numbers. For CDs, UK implied emission factors were applied.

### 5.2.3   Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category.

Note that, due to time constraints, the uncertainty analysis has not been updated to fully reflect the differences to uncertainty due to the adoption of new methods and data for estimating emissions from agriculture this year. These parameters will be reviewed for the next inventory cycle. It is likely uncertainties will be lower than the current assessment, as the new methodology makes use of data and methodologies which we have higher confidence in than previously, but would be of a similar order of magnitude

Emissions are calculated from animal population data and appropriate emission factors. The animal population data are collected in the June Agricultural Census, published annually by the devolved administrations (i.e. England, Wales, Scotland and Northern Ireland). These are long running publications and the compilers of the activity data strive to use consistent methods to produce the activity data. The time-series consistency of these activity data is very good due to the continuity in data provided.

Control measures introduced in response to the BSE outbreak in the UK introduced an inconsistency in the slaughter weight statistics and the derived dairy cow live weights for the years 1997 to 2005. To correct for the artefacts introduced by these control measures in the data time-series, data for this period were interpolated using the linear trend of increasing lives weight with time for the years immediately prior to and following this period.

### 5.2.4   Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.8.6**.

### 5.2.5   Source-specific recalculations

There have been no recalculations since the previous inventory submission.

### 5.2.6   Source-specific planned improvements

Revise the parameters for the energy balance equations for sheep and non-lactating cattle based on recent and ongoing research (AFBI).

## 5.3 SOURCE CATEGORY 3B – MANURE MANAGEMENT

### 5.3.1 Source category description

| Emissions sources | Source included | Method | Emission Factors |
|---|---|---|---|
| | 3B11: Dairy Cattle Wastes | T3 | CS, D |
| |      Other Cattle Wastes | T3 | CS, D |
| | 3B12: Sheep Wastes | T3 | CS, D |
| | 3B13: Swine Wastes | T2 | CS, D |
| | 3B14: Goats Wastes | T2 | CS, D |
| | 3B14: Horses Wastes | T2 | CS, D |
| | 3B14: Broilers Wastes | T2 | CS, D |
| |      Laying Hens Wastes | T2 | CS, D |
| |      Other Poultry Wastes | T2 | CS, D |
| | 3B14: Deer Wastes | T1 | D |
| | 3B21: Dairy Cattle Wastes | T2 | CS, D |
| | Other Cattle Wastes | T2 | CS, D |
| | 3B22: Sheep Wastes | T2 | CS, D |
| | 3B23: Swine Wastes | T2 | CS, D |
| | 3B24: Goats Wastes | T2 | CS, D |
| | 3B24: Horses Wastes | T2 | D |
| | 3B24: Poultry Wastes | T2 | CS, D |
| Gases Reported | $CH_4$, $N_2O$ | | |
| Key Categories | 3B1: Manure management from Cattle - $CH_4$ (L1, T1, T3)<br>3B2: Manure Management - $N_2O$ (L2, T2) | | |
| Key Categories (Qualitative) | None identified | | |
| Overseas Territories and Crown Dependencies Reporting | All estimated emissions for Overseas Territories and Crown Dependencies are included in category 3J. In the OTs, Estimates for both $CH_4$ and $N_2O$ emissions are calculated using 2006 IPCC default EFs. In the CDs, estimates are calculated using UK GHGI EFs. This distinction is based on the knowledge of local agricultural practices and climatic conditions. A time series of UK EFs are applied to animal numbers. Animal numbers can be found in **Annex 3.6**. | | |
| Completeness | No known omissions.<br>A general assessment of completeness for the inventory is included in **Section 1.8**. | | |
| Major improvements since last submission | None | | |

### 5.3.2 Methodological issues

#### 5.3.2.1 Methane emissions from animal manures

Methane is produced from the decomposition of manure under anaerobic conditions. When manure is stored or treated as a liquid in a lagoon, pond or tank it tends to decompose anaerobically and produce a significant quantity of methane. When manure is handled as a solid or when it is deposited on pastures, it tends to decompose aerobically and little or no methane is produced. Hence the system of manure management used affects emission rates.

The emission factors for manure management are calculated following IPCC Tier 2 methodology for cattle, sheep, pigs and poultry, according to IPCC (2006) Equation 10.23. For cattle and sheep, country-specific values for volatile solids (VS) excretion are derived by animal sub-category and production system using the UK-specific ME balance equations (as described in Section 5.2.2) and an estimate of GE intake (based on estimated dry matter intake and feed energy content) according to a variation of IPCC (2006) Equation 10.24:

$$VS_{ex} = \left( GE_i \times \left( 1 - \left( Me_{req}/GE_i \right) \right) \right) \times ((1 - ASH)/(GE_i/DMI))$$

Where:

$VS_{ex}$ is the volatile solids excretion, kg d$^{-1}$

$GE_i$ is the gross energy intake, MJ d$^{-1}$

ASH is the ash content of the manure as a fraction of the dry matter feed intake

DMI is the dry matter intake, kg d$^{-1}$

UK-specific data on the methane producing potential ($B_o$) of cattle excreta were not significantly different from IPCC (2006) default values (Defra AC0115), so the default values are retained. For pigs and poultry, IPCC (2006) default values for VS and $B_o$ are used.

Default IPCC (2006) MCF values (IPCC Table 10.17) are applied, with the exception of liquid/slurry systems with a natural crust cover, where no reduction in the MCF value is assumed in accordance with literature evidence (e.g. Petersen et al., 2013). These data are combined with country-specific data for the proportion of manure from each livestock type managed according to the different animal waste management systems (AWMS). The emission factors are listed in **Table A 3.3.2** in **Annex 3**. **Table A 3.3.3** in **Annex 3** shows the methane conversion factors assumed for the different systems.

For goats, deer and horses, IPCC (2006) Tier 1 default emission factors were used (IPCC Tables 10.15).

### 5.3.2.2  Nitrous Oxide emissions from Animal Waste Management Systems

Animals are assumed not to give rise to nitrous oxide emissions directly, but emissions will arise from N excreted by livestock. Emissions from manures during storage are calculated for different animal waste management systems (AWMS) defined by IPCC. Emissions from the following AWMS are reported under the Manure Management IPCC category (it is assumed that uncovered anaerobic lagoons are not present in the UK):

- Liquid/slurry;
- Solid storage/deep litter/poultry manure

According to IPCC (2006), the following AWMS are reported in the Agricultural Soils category:

- All animal manures and slurries applied to soils; and
- Pasture range and paddock

Nitrous oxide emissions from manure management are estimated following IPCC (2006) (equation 10.25) for each livestock category and subcategory, using country-specific data for N excretion by the different livestock types and for the proportion of manure managed according to the different AWMS, and a combination of default and country-specific emission factors for the different AWMS. The UK has implemented a detailed N-flow model describing the flow of N from livestock excretion through the manure management chain (based on Webb and Misselbrook, 2004), accounting for all N losses (via $NH_3$, $N_2O$, NO, $N_2$ and N leaching) and transformations (immobilisation, mineralisation) at each manure management stage.

For cattle and sheep, N excretion is estimated based as the balance of N intake and N retained in live weight gain, milk, wool and developing foetus, specific to livestock sub-category,

production system and diet. N intake is estimated from the calculation of dry matter intake, based on energy requirement and feed characteristics (Section 5.2.2), and the crude protein content of the feed. For cattle, N excreta are partitioned to urine N and dung N, is dynamic in response to protein in the diet (Reed et al., 2015). The urine N is assumed to rapidly convert to ammoniacal N whereas the dung N remains as organic N; these different N forms have important implications for subsequent N losses and transformations through the manure management chain (Webb and Misselbrook, 2004). For sheep, 60% of excreta N is assumed to be excreted as urine and 40% as dung and only 85% of N in urine is TAN, and 15% of N in dung. There is not a direct correspondence between urine N and TAN. For other livestock types, country-specific values for N excretion were derived from the report of Defra project WT0715NVZ (Cottrill and Smith, 2007) with interpretation by Cottrill and Smith (ADAS)**Table A 3.3.4** in **Annex 3**. For pigs and poultry, 70% of excreta is assumed to rapidly become ammoniacal N with 30% remaining as organic N. For goats, horses and deer, the respective excretal proportions are assumed to be 60 and 40%.

The conversion of excreted N into $N_2O$ emissions is determined by the type of manure management system used. The distribution of AWMS is given in **Table A 3.3.5** in **Annex 3**. For manure types with bedding addition, the N content of the added bedding is included in the manure N content. Default emission factors (IPCC, 2006; Table 10.21) are assumed except for cattle, pig, sheep, goat, deer and horse deep litter systems where a UK-specific EF of 2.0 is used and for poultry manure where a UK-specific EF of 0.5 is used (**Table A 3.3.6** in **Annex 3**). The sheep sector uses and $N_2O$ EF of 0.5% for stored manure.

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 3% of manure N for $Frac_{LEACH}$ is used, based on Nicholson et al. (2011) and applied only to solid manure heaps stored in fields. For manure heaps stored on concrete pads, the leachate is assumed to be collected and is subsequently included in the N content of liquid/slurry managed manure. Indirect emissions from manure management due to volatilisation and leaching are then calculated according to IPCC (2006) equations 10.27 and 10.29, respectively, applying IPCC (2006) default values for $EF_4$ and $EF_5$.

### 5.3.2.3  Emissions in the Overseas Territories and Crown Dependencies

Animal numbers are sourced from the territories directly and can be found in **Annex 3.6**. In the case of OTs, IPCC default emissions factors were applied to the data on animal numbers and manure management practices. Where available, data on manure management specific to each OT was used, otherwise default IPCC practices for the appropriate geographic region were assumed. For CDs, UK implied emission factors were applied to the animal numbers data (i.e. manure management practices assumed to be the same as for the rest of the UK), both for $CH_4$ and $N_2O$. These different approaches are used for OTs and CDs to ensure accurate representation of local agricultural practices, and the differing climatic conditions in these locations around the world.

## 5.3.3  Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category.

The estimates of uncertainties in emissions were calculated using Approach 2 (Monte Carlo simulation) described by the IPCC using the new Tier 3 models derived for the UK greenhouse gas inventory. We note that uncertainties related to emissions from goats, deer and horses are not currently included. The uncertainties in the estimates of livestock data were provided by the devolved administrations.

Emissions are calculated from livestock population data and appropriate emission factors. The livestock population data are collected in the June Agricultural Census, published annually by the devolved administrations (i.e. England, Wales, Scotland and Northern Ireland). These are long running publications and the compilers of the activity data strive to use consistent methods to produce the activity data. The time-series consistency of these activity data is very good due to the continuity in data provided.

### 5.3.4  Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.8.6**.

### 5.3.5  Source-specific recalculations

There have been no recalculations since the previous inventory submission.

### 5.3.6  Source-specific planned improvements

Emission factors and activity data will continue to be reviewed including the use of more detailed emission factors and activity data to improve emission estimates and allow estimation of the effect of future mitigation policies.

## 5.4    SOURCE CATEGORY 3D – AGRICULTURAL SOILS

### 5.4.1  Source category description

| Emissions sources | Source included | Method | Emission Factors |
|---|---|---|---|
| | 3D1: Direct $N_2O$ Emissions From Managed Soils | T2, T1 | D, CS |
| | 3D2: Indirect $N_2O$ Emissions From Managed Soil | T2,T1,CS | D, CS |
| Gases Reported | $N_2O$ | | |
| Key Categories | 3D: Agricultural soils - $N_2O$ (L1, T1, L2, T2) | | |
| Key Categories (Qualitative) | None identified | | |
| Overseas Territories and Crown Dependencies Reporting | Emissions included under 3J in the CRF. These estimates use tier 1 methodology and 2006 IPCC default EFs. | | |
| Completeness | A general assessment of completeness for the inventory is included in **Section 1.8**. | | |
| Major improvements since last submission | Spatial disaggregation of the country-specific value of $EF_1$ for inorganic N fertiliser applications, with EF calculated on a 10 km grid basis according to fertiliser type, application rate and annual rainfall amount.<br><br>Full implementation of the N-flow model (Webb and Misselbrook, 2004) in the combined ammonia and GHG inventory model for UK agriculture, accounting for all N losses and transformations through the manure management chain and thus influencing the N remaining for land application. | | |

Direct emissions of nitrous oxide from agricultural soils are estimated using IPCC (2006) Tier 2 methodology (IPCC Equation 11.2), implementing UK-specific EF and parameters where available.

The IPCC (2006) method involves estimating direct emissions from:

(i)    The use of inorganic fertiliser
(ii)   Application of livestock manures to land
(iii)  Application of sewage sludge and compost to land
(iv)   Urine and dung deposited by grazing animals in the field
(v)    Crop residues returned to soils
(vi)   Mineralisation
(vii)  Cultivation of histosols (organic soils)

Indirect $N_2O$ 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)).

Further details on activity data and EF are given in **Annex 3.3**.

**Figure 5.3        Simplified nitrogen cycle highlighting the steps involved in the production of $N_2O$ from agriculture.**
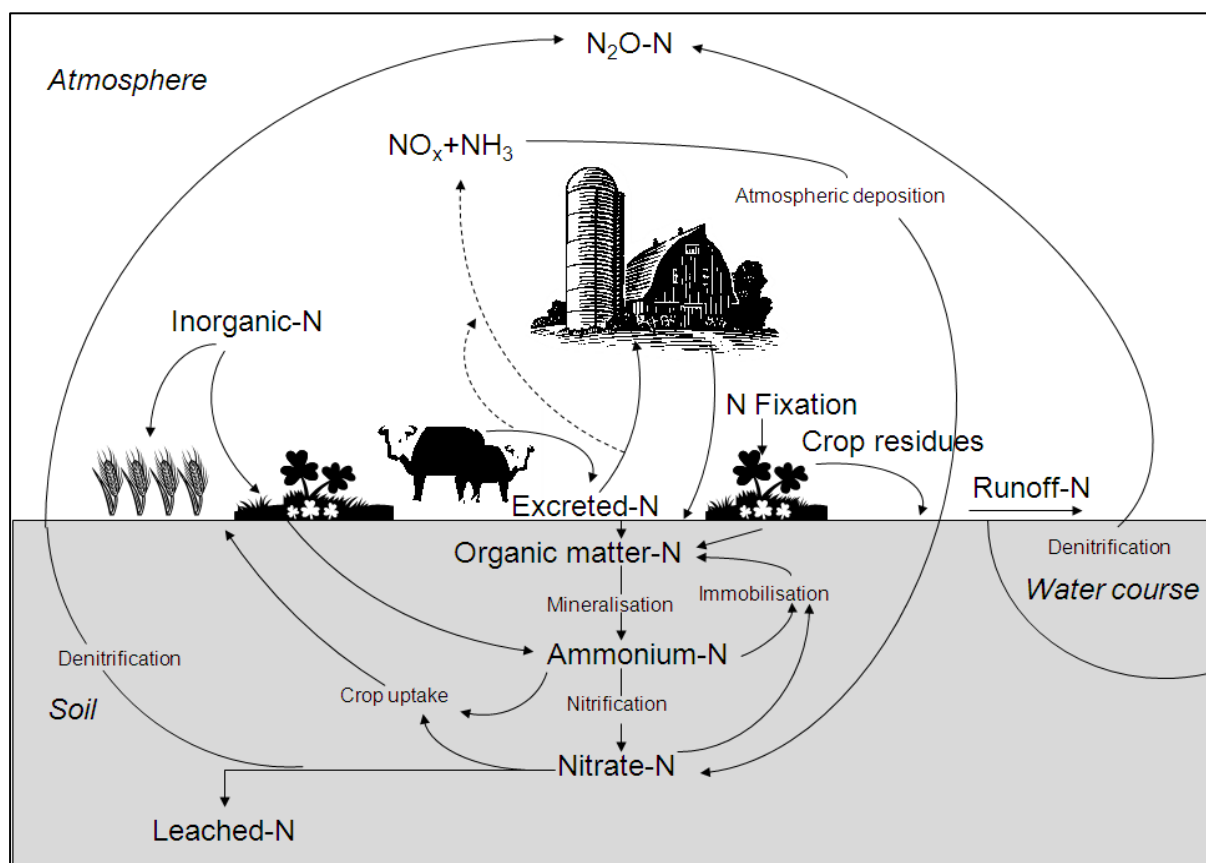


## 5.4.2  Methodological issues

### 5.4.2.1  Inorganic Fertiliser

Direct $N_2O$ emissions from fertiliser N applications are calculated using values of EF1 derived from UK-specific measurements (Topp et al., 2016). 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 2. For all other fertiliser types, the calculation involves fertiliser rate applied and average annual rainfall (equation 1).

Total $N_2O$ emissions (kg $N_2O$-N) in the year following application of ammonium nitrate fertiliser are calculated according to:

$Ln (N_2O+1) = 0.1616 (\pm0.13526) + 0.00006093 (\pm0.000240365) * N + 0.0005187 (\pm0.00016259) * R + 0.00000354 (\pm0.0000002785) * N * R$ (eq. 1)

Total $N_2O$ emissions (kg $N_2O$-N) in the year following application of urea fertiliser are calculated according to:

$Ln (N_2O+1) = 0.494 (\pm0.10008) + 0.002035 (\pm0.0001542) * N$ (eq. 2)

Where N is the annual total fertiliser application (kg N ha$^{-1}$ y$^{-1}$); R is the long-term average annual rainfall (mm y$^{-1}$) at the application site. Values in brackets are the standard errors of the model parameters. Bias correctors of 1.074 for the ammonium nitrate model and 1.104 for the urea model are also applied to correct for fitting the regression model to log-transformed data. Note that rainfall values are capped at 1300 mm. Model predictions are made with and without fertiliser nitrogen and the emission factor is obtained by difference.

### 5.4.2.2   Application of livestock manures to land

Emissions are calculated following IPCC methodology (2006, equation 11.1). Proportions of managed manure N applied to GB cropland are derived from Smith et al. (2015) until 2004. The nature of manure management differs between farms types such that more is retained on the farms with grazing livestock than for pig and poultry farms and also more is spread on grassland than arable crops. In general, slurries are less likely to be transported long distances than solid manures. The fate of manure is calculated by considering spatial disaggregation as in the BSFP; for livestock is calculated according to Smith et al. (2015). On broiler and turkey farms a proportion is deducted to allow for that amount going to biomass power stations and the remainder is assumed to be applied to land in the neighbourhood. Proportions of land types are used for each manure type and are determined within an economically viable 'distribution radius'. It is then assumed that manure is uniformly applied to the soils in those cells.

### 5.4.2.3   Application of sewage sludge to land

Emissions from sewage sludge application to land are calculated following IPCC methodology (2006, equation 11.1). The calculation involves estimating the amount of N contained per dry matter unit of sludge that is applied to land. Activity data are provided by Ricardo Energy & Environment from a combination of Environment Agencies and water companies. The data are disaggregated at the most at DA level, with the proportions on arable and grassland being derived from the BSFP from 2005. Uniform application rates across land from the DAs are assumed. Non-agricultural materials applied to agricultural land in GB was addressed according to Hulin et al. (2015). These included: Digested liquid sewage sludge, composted green manure, digested sludge cake, thermally dried sludge cake, lime-stabilised sludge and biosolids.

### 5.4.2.4   Urine and dung deposited by grazing animals in the field

Emissions are calculated following 2006 IPCC methodology, equation 11.1). Estimates of the proportions of dry matter (DM) that were given to stock were made by Parsons and Williams (2015) in a module of the FBS in England. We assumed that all excretion from grazing livestock is deposited on grassland. N excretion for cattle is partitioned to urine and dung N as described in Section 5.3.2.2 (dynamic in response to protein in the diet), and the separate UK-specific values for EF$_3$ for urine and dung are applied accordingly (**Annex 3.3, Table A3.3.7**). The default IPCC (2006) EF$_3$ for sheep is lower than that for cattle. The UK do not

have any experimental data specifically for sheep grazing, but as the weighted average (across dung and urine) UK-specific $EF_3$ for cattle is lower than the IPCC (2006) default $EF_3$ for sheep, the UK assumes the same value for sheep as for cattle (and for goats, horses and deer), rather than create an anomaly by having a higher $EF_3$ value for sheep than for cattle. For swine and poultry, where behaviour of outdoor animals is quite different to that of cattle and sheep, the default IPCC (2006) $EF_3$ is used.

### 5.4.2.5 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 3.3, Tables A 3.3.10** and **A 3.3.11**). More specifically, the IPCC calculation involves the ratio of crop yield (DM) to total above-ground dry weight (DM harvest index, HI DM. The harvest index can also be defined with respect to nitrogen (N) as nitrogen harvest index (NHI).

The DM harvest index is the ratio of the primary crop DM yield of crop T over the sum of the primary crop DM yield ($Crop_T$) and the above ground biomass DM (eq. 4). The N harvest (HIN) index is shown in eq. 5 and with data for the DM harvest index, AG DM(T) can be calculated by rearranging eq.5 to obtain the above ground residue per unit area ($AG_{DM(T)}$) (eq.6 and 7).

$$HI_{DM} = Crop_T / Crop_T Crop_T + AG_{DM(T)} \qquad \text{(eq.4)}$$

$$HI_N = \left(Crop_T * Crop_{N(T)}\right) / \left(Crop_T * Crop_{N(T)} + AG_{DM(T)} * N_{AG(T)}\right) \qquad \text{(eq.5)}$$

$Crop_{N(T)}$ = fraction of N in the DM of $crop_T$.

$$AG_{DM(T)} = Crop_T - \left(Crop_T * HI_{DM}\right) HI_{DM} / HI_{DM} \qquad \text{(eq.6)}$$

$$AG_{DM(T)} = \left(1 - HI_{DM}\right) * Crop_T / HI_{DM} \qquad \text{(eq.7)}$$

Estimates of the N in cover crops were made from the NDICEA crop simulation model (van der Burgt et al., 2006), which was calibrated and tested in UK conditions by Smith et al. (2015).

### 5.4.2.6 Mineralisation

$N_2O$ emissions from mineralisation of soil organic matter on land converted to Cropland more than 20 years ago are included in the Agricultural inventory (emissions from more recent land-use change are included in the LULUCF inventory). The emissions are estimated using the areas of Forest land and Grassland converted to Cropland from the land-use change matrices. The land-use change matrices are calculated from the Monitoring Landscape Change (MLC) data from 1947 & 1980 (MLC 1986) and the Countryside Surveys (CS) of 1984, 1990, 1998 (Haines-Young et al. 2000) and 2007 (Smart et al. 2009) for Great Britain. For Northern Ireland, the data comes from the Northern Ireland Countryside Surveys of 1990, 1998 (Cooper and McCann 2002) and 2007 (Cooper, McCann and Rogers 2009).

$N_2O$ emissions from mineralisation of soil organic matter as a result of Cropland Management activities are estimated from the change in soil carbon stocks due to Cropland Management using a Tier 1 approach. The methodology used to assess change in soil carbon stocks due to Cropland Management is described in **Section 6.3.4** and **Annex A3.4.7**.

### 5.4.2.7 Cultivation of histosols (organic soils)

Direct $N_2O$ emissions from the cultivation of histosols are estimated following IPCC (2006, equation 11.2) using the default value for $EF_2$ and UK-specific data for the area of cultivated histosols.

### 5.4.2.8 Atmospheric deposition of $NO_X$ and $NH_3$

Indirect emissions of $N_2O$ from the atmospheric deposition of ammonia and $NO_x$ are estimated according to IPCC (2006, equation 11.9) using the default value for EF4 and country-specific

values for the fraction of N that is volatilised as $NH_3$ and NO from inorganic fertiliser and organic (livestock manure, sewage sludge, digestate, grazing returns) N applications to land (FracGASF and FracGASM, respectively) derived directly from the combined ammonia and greenhouse gas inventory model for UK agriculture, using an N-flow approach (Webb and Misselbrook, 2004). UK-specific $NH_3$ EF are used for inorganic fertiliser and organic manure applications to land, as detailed in the UK Informative Inventory Report. Emissions of NO from fertiliser, organic manure applications and grazing returns are assumed to be a factor of 0.1 of the $N_2O$ emissions estimated for each source. The method used corrects for the N content of manures used as fuel (poultry litter incineration) and therefore not applied to land. For sheep we have updated the NO equivalency for organic manure applications to 0.6 (Stehfest and Bouwman, 2006).

### 5.4.2.9   Leaching and runoff

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, animal manures and sewage sludge applied to soils, excretal grazing returns (dung and urine), crop residues and mineralisation. A country-specific value for the proportion of N applied that is leached (FracLEACH) is used for both inorganic fertiliser and manure application to grassland and excretal returns from grazing livestock. For crops, FracLEACH is the IPCC constant 30%, but for fertiliser and excreta losses from grass values are modelled using the UPCYCLE model and is sensitive to soil, climate, fertiliser rate, clover inclusion. First year losses from managed manure to grass are also modelled using the MINNER model (a simplification of MANNER). For mineralisation, the default IPCC (2006) value is also used. The method used corrects for the N content of manures used as fuel (poultry litter incineration) which are not applied to land.

### 5.4.2.10  Overseas Territories and Crown Dependencies

For the CDs, estimates of emissions from agricultural soils were made by applying UK GHGI implied EFs to animal numbers (for livestock manure-related activities) and land areas of cropland and grassland (for non-manure fertilisers and emission related to loss of soil carbon). For OTs, the Tier 1 methodology from the IPCC Guidelines was applied to calculate emissions from agricultural soils. Livestock numbers, mineral fertiliser application and crop production data were provided from each of the OTs, or sourced from FAO; these data can be found in **Annex 3.6**. Emission factors taken from the 2006 IPCC guidelines were applied to all activity data from OTs. These different approaches are used for OTs and CDs to ensure accurate representation of local agricultural practices, and the differing climatic conditions in these locations around the world.

In the Falklands, despite there being a very large area of grassland histosols, $N_2O$ 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.

## 5.4.3   Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category.

The estimates of uncertainties in emissions were calculated using Approach 2 (Monte Carlo simulation) described by the IPCC. The uncertainties in the estimates of crop areas were provided by the devolved administrations, and the uncertainties in estimates of fertilizer application rates to crops were calculated from the British Survey of Fertilizer Practice (BSFP). Together these give estimates of fertilizer use. Estimates of the uncertainty in the amount of sewage applied to the land were omitted but will be included in further developments of the

model. The uncertainties in the new UK specific emission factors and model parameters were calculated from the data used to derive the emission factors.

Emissions are calculated from a range of activity data and appropriate emission factors (see **Annex 3**). Emissions of $N_2O$ from the use of fertilisers are important in this source category. The annual consumption of synthetic fertiliser is estimated based on crop areas (crop area data reported annually by the Devolved Administrations) and fertiliser application rates (reported annually in the British Survey of Fertiliser Practice). These are both long running datasets and the compilers of the activity data strive to use consistent methods to produce the activity data. The time-series consistency of these activity data is very good due to the continuity in data provided.

## 5.4.4  Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.8.6**.

## 5.4.5  Source-specific recalculations

Details of and justifications for recalculations to activity data are given in **Table 5.1**. For information on the magnitude of recalculations to Source Category 3D, see **Section 10**.

**Table 5.1**        **3D Source specific recalculations to activity data since previous submission**

| IPCC Category | Source Name | 2019 submission | | 2020 submission | | Units | Comment/Justification |
|---|---|---|---|---|---|---|---|
| | | **1990** | **2017** | **1990** | **2017** | | |
| 3.D.1.2.b | N$_2$O Emissions From Sewage Sludge Applied to Soils | 0.29 | 0.81 | 0.29 | 0.84 | kt | Sewage sludge data for 2017 updated (previously the 2016 values were rolled over for the 2018 submission due to the data not being available in time). |
| 3.D.1.5 | Mineralisation/Immobilization Associated with Loss/Gain of Soil Organic Matter | 0.62 | 1.39 | 0.62 | 1.40 | kt | Mineralisation data for 2017 updated (previously the 2016 values were rolled over for the 2018 submission due to the data not being available in time). |
| 3.D.2.1 | Indirect N$_2$O Emissions From Managed Soils – Atmospheric Deposition | 2.112 | 1.709 | 2.112 | 1.711 | kt | Sewage sludge and mineralisation data for 2017 updated (previously the 2016 values were rolled over for the 2018 submission due to the data not being available in time). |
| 3.D.2.2 | Indirect N$_2$O Emissions From Managed Soils - Nitrogen Leaching and Run-off | 6.022 | 5.796 | 6.022 | 5.803 | kt | Sewage sludge and mineralisation data for 2017 updated (previously the 2016 values were rolled over for the 2018 submission due to the data not being available in time). |

## 5.4.6 Source-specific planned improvements

Emission factors and activity data will continue to be reviewed including the use of more detailed emission factors and activity data to improve emission estimates and allow estimation of the effect of future mitigation policies

## 5.5 SOURCE CATEGORY 3E – PRESCRIBED BURNING OF SAVANNAS

This source is not relevant in the UK.

## 5.6 SOURCE CATEGORY 3F – FIELD BURNING OF AGRICULTURAL RESIDUES

### 5.6.1 Source category description

| Emissions sources | Source included | Method | Emission Factors |
|---|---|---|---|
| | 3F11: Wheat | T1 | D |
| | 3F12: Barley | T1 | D |
| Gases Reported | $CH_4$, $N_2O$, $NO_x$, CO, NMVOC, $SO_2$ | | |
| Key Categories | None identified | | |
| Key Categories (Qualitative) | None identified | | |
| Overseas Territories and Crown Dependencies Reporting | Emissions reported for Isle of Man, Guernsey and Jersey (1990-1993) based on UK implied emission factors. No data is available in the case of Overseas Territories, so no emissions are reported | | |
| Completeness | No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**. | | |
| Major improvements since last submission | Implementation of the harvest index approach and use of country-specific data where available in estimating quantities of crop residues burned. | | |

### 5.6.2 Methodological issues

The GHGI reports emissions from field burning under the category agricultural incineration. The estimates are derived from emission factors calculated according to IPCC (1997) and from USEPA (1997).

The estimates of the masses of residue burnt of barley, oats, wheat and linseed are based on crop production data (Lindsay Holmes, DEFRA (England & Wales), Nicola Kerr, The Scottish Government and Alison Lambert, Conor McCormack, DAERA), a UK-specific harvest index approach to derive residue amounts (Williams and Goglio, 2017) and data on the fraction of crop residues burnt (MAFF, 1995; ADAS, 1995). Field burning ceased in 1993 in England and

Wales. Burning in Scotland and Northern Ireland is considered negligible, so no estimates are reported from 1993 onwards. The carbon dioxide emissions are not estimated because these are part of the annual carbon cycle.

### 5.6.2.1 Overseas Territories and Crown Dependencies

For CDs, estimates of emissions from field burning are made by applying UK GHGI implied EFs to cropland and grassland land areas. As such, estimates are zero from 1994 onwards.

No quantitative data is available from any OT, so emissions from field burning are not currently estimated. Efforts to improve data collection for this category are planned; however, it is thought that these would be insignificant relative to total UK emissions. This improvement will be considered for future submissions as part of the prioritised inventory improvements, taking into account available resources.

## 5.6.3 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category.

Field burning ceased in 1994 and emissions are reported as NO after this date.

## 5.6.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.8.6**.

## 5.6.5 Source-specific recalculations

There have been no recalculations since the previous inventory submission**.**

## 5.6.6 Source-specific planned improvements

No improvements are planned.

## 5.7    SOURCE CATEGORY 3G - LIMING

## 5.7.1 Source category description

| Emissions sources | Source included | Method | Emission Factors |
|---|---|---|---|
| | 3G1: Limestone $CaCO_3$ | T1 | D |
| | 3G2: Dolomite $CaMg(CO_3)_2$ | T1 | D |
| Gases Reported | $CO_2$ | | |
| Key Categories | None identified | | |
| Key Categories (Qualitative) | None identified | | |
| Overseas Territories and Crown Dependencies Reporting | Emissions from 3G1 have been estimated for CDs. Emissions for OTs do not occur or have not been estimated. | | |

| Completeness | A general assessment of completeness for the inventory is included in **Section 1.8**. |
|---|---|
| Major improvements since last submission | Revision of the historical time series for activity data based on a new data provider. |

## 5.7.2  Methodological issues

$CO_2$ 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 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 British Survey of Fertiliser Practice (BSFP; Table EW1.4 for England & Wales and Table SC1.4 for Scotland) from 1992 onwards; activity for 1990 and 1991 were assumed to be the same as for 1992. The % area limed and application rate of lime in Northern Ireland was assumed to be the same as that for Scotland by land use type. For each of the liming types in BSFP ( i) Ground limestone, ii) Ground chalk, iii) Magnesian limestone, iv) Sugar beet lime, iv) Other), the application rate and % area limed were multiplied by the area of 'all tillage', 'grass under 5 years old' and 'grass 5 years and over' to derive the total limestone and dolomite applied for each Devolved Administration.

The 'Other' category in BSFP is made up of Ag slag, Calcified pelleted limestone, Calicfert, Granules, Humistar, Lime slag, Screed lime  (personal communication Alison Wray, Defra); the majority of these are CaCO3 based limes and thus were included in the activity data for limestone.

Sugar beet lime (Limex) is assumed to have 46% $CaCO_3$ content (British Sugar, Chemical Safety Data; Median of LimeX45 (45%) and LimeX70 (52%) $CaCO_3$ content).

### 5.7.2.1  Overseas Territories and Crown Dependencies

Emission estimates are provided for  Isle of Man, Jersey and Guernsey, and are calculated by the Centre for Ecology and Hydrology (UKCEH). These emissions are thought to include both Limestone and Dolomite, but data characteristics mean that emissions from either rocky type cannot be resolved. As the IPCC 2006 default emission factor in this case refers to Limestone, these emissions have been allocated accordingly.

No quantitative data on liming is available for OTs, but local expert input suggests that liming does not occur in the Falklands or Cayman Islands. In Bermuda, this category has not been estimated as no expert judgement is available. Efforts to improve data collection for this category are planned; however, it is thought that these would be insignificant relative to total UK emissions. This improvement will be considered for future submissions as part of the prioritised inventory improvements, taking into account available resources.

## 5.7.3  Uncertainties and time-series consistency

Uncertainty in both the activity data and emission factor are judged to be low. The main source of uncertainty in the estimates is caused by non-publication of some activity data due to commercial restrictions although these are not judged to be very significant.

There is good time series consistency as there has been continuity in the published data sources.

### 5.7.4  Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.8.6**.

### 5.7.5  Source-specific recalculations

There have been no recalculations since the previous inventory submission.

### 5.7.6  Source-specific planned improvements

Emission factors and activity data will continue to be reviewed when new data are available.

## 5.8  SOURCE CATEGORY 3H - UREA APPLICATION

### 5.8.1  Source category description

| Emissions sources | Source included | Method | Emission Factors |
|---|---|---|---|
| | 3H: Urea Application | T1 | D |
| Gases Reported | $CO_2$ | | |
| Key Categories | None identified | | |
| Key Categories (Qualitative) | None identified | | |
| Overseas Territories and Crown Dependencies Reporting | Emissions from 3H have been estimated for all OTs and CDs, excluding the Falkland Islands and Bermuda. | | |
| Completeness | A general assessment of completeness for the inventory is included in **Section 1.8**. | | |
| Major improvements since last submission | Revision to the historical time series of urea use | | |

$CO_2$ emissions due to the application of urea and related compounds are estimated using the Tier 1 methodology from the IPCC 2006 Guidelines.

### 5.8.2  Methodological issues

The annual amount of fertiliser as urea (alone or as part of urea ammonium nitrate, UAN) used in ktN was estimated from the British Survey of Fertiliser Practice (for England, Wales and Scotland) and the Northern Ireland Fertiliser Supply statistics. Both fertilisers are applied to grassland and cropland in the UK. It was assumed that 35% of UAN was urea. The EF used was the IPCC (2006) default value of 0.2 tonne of C tonnes of urea$^{-1}$, and emission estimates were made using IPCC Tier 1 (2006, equation 11.13).

#### 5.8.2.1  Overseas Territories and Crown Dependencies

For all Crown Dependencies, emissions have been estimated by applying UK GHGI implied EFs for urea application per hectare, to cropland and grassland land area data. This reflects the fact that local agricultural practices and climatic conditions are similar to the UK.

For the Cayman Islands, the amount of urea applied was available from official statistics, and the IPCC default value applied. Emissions for the Falklands Islands and Bermuda were not estimated, due to lack of data availability. However, local expert judgement suggests that urea application in the Falkland islands is minimal, if not zero. Efforts to improve data collection for

this category are planned; however, it is thought that these would be insignificant relative to total UK emissions. This improvement will be considered for future submissions as part of the prioritised inventory improvements, taking into account available resources.

### 5.8.3   Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category. The same data source is used for the entire time series to ensure consistency.

### 5.8.4   Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 5.8.6**

### 5.8.5   Source-specific recalculations

There have been no recalculations since the previous inventory submission.

### 5.8.6   Source-specific planned improvements

Emission factors and activity data will continue to be reviewed when new data are available.

## 5.9   GENERAL COMMENTS ON QA/QC

The UK Agriculture Inventory has a documented QA/QC plan covering the annual compilation of the inventory by the contracted consortium (led by Rothamsted Research) addressing governance, data management, quality control (procedures and checks) and quality assurance activities. The organisational roles and responsibilities of the delivery team and government stakeholders are described. The inventory compilation, reporting, review and improvement cycle for an annual submission to UNFCCC and UNECE is outlined with an overview of the key QC and QA activities at different stages in the cycle, including the timings for the annual compilation cycle and details of source-specific quality checks to be performed on the incoming data, the calculation models and the data validation checks on model outputs. The Agriculture inventory data quality objectives are based on the inventory quality objectives of Transparency, Accuracy, Consistency, Comparability and Completeness (TACCC) as set out in the IPCC national inventory reporting guidelines and clear statements are provided as to how these are to be met. Security, scope and timeliness of data supply are addressed, with Data Supply Agreements being developed with suppliers of key input data. Procedures are in place for the management of confidential data (e.g. farm holding level data) and for data storage, back-up and archiving. During the finalisation of the agriculture "master" dataset and the integration of these data into the wider UK inventory data for onwards submission to the UNFCCC and UNECE, there are iterative quality checks performed by the Inventory Agency (under contract to BEIS) to highlight any data anomalies, recalculations and inventory trends compared against previous inventory submissions. There is then a period of dialogue and clarification of the agriculture data and supporting information is provided to the Inventory Agency where applicable. Peer and bilateral reviews of the Agriculture inventory have been conducted, and the revised methodological approaches introduced in the 2018 submission through the Defra GHG improvement programme were reviewed by an international Research Expert Group (including several IPCC Inventory Review Experts) as part of the programme. The QA/QC plan is subject to annual review. Furthermore, the UK underwent an In Country Review in 2019 and recommendations for improving the NIR have been taken into account in this submission.

# 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 all submissions. .

**Table 6.1**          **LULUCF Sector Overview**

| LULUCF Greenhouse Gas Source and Sink Categories | KCA Rank[1] (gas) | Uncertainty[2] | 1990 emissions total (Mt $CO_2$e) | 2017 emissions total (Mt $CO_2$e) | 2018 emissions total (Mt $CO_2$e) | Recalculations 1990[3] (Mt $CO_2$e) | Recalculations 2017[3] (Mt $CO_2$e) |
|---|---|---|---|---|---|---|---|
| Total LULUCF | - | - | -0.3 | -10.0 | -10.2 | -0.1 | 0.1 |
| A.   Forest Land | 4 ($CO_2$) | 35% | -15.1 | -18.3 | -18.2 | -0.3 | -0.2 |
| B.   Cropland | 2 ($CO_2$) | 44% | 15.6 | 11.7 | 11.5 | 0.3 | 0.3 |
| C.   Grassland | 3 ($CO_2$) | 50% | -6.9 | -8.6 | -8.8 | 0.2 | 0.2 |
| D.   Wetlands | - | 72% | 0.5 | 0.3 | 0.3 | 0.0 | 0.0 |
| E.   Settlements | 5 ($CO_2$) | 38% | 7.7 | 7.2 | 7.2 | 0.1 | 0.2 |
| G.  Harvested Wood Products | 27 ($CO_2$) | 25% | -2.1 | -2.4 | -2.3 | -0.5 | -0.4 |
| Indirect                 $N_2O$ emissions | - | 101% | 0.4 | 0.2 | 0.2 | 0.0 | 0.0 |

[1]These values are the rank for each category using the Approach 2 Level assessment for the latest year, showing that many LULUCF categories are among the primary contributors to the overall uncertainty of the inventory.

[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 2017 emissions/removals from the data reported in the previous UK GHGI submission.

The summary analysis of the trends in greenhouse gas emissions from the LULUCF sector is provided in **Section 2.** The methodological differences since the previous UK GHGI submission are explained in this chapter. 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 eight categories, of which Forest Land (4A), Grassland (4C) and Harvested Wood Products (4G) are net sinks, and Cropland (4B), Wetlands (4D), and Settlements (4E) are net sources (**Figure 6.1**) as well as indirect $N_2O$ emissions. The UK does not report any emissions or removals from the Other Land (4F) and Other (4H) categories.

The LULUCF sector is the only sector within the national greenhouse gas inventory to report net removals. The net sink is provided by removals from carbon stock gains in above-ground and below-ground biomass, soils and harvested wood products exceeding emissions from carbon stock losses and GHG emissions from LULUCF activities. The LULUCF sector is a

source of methane and nitrous oxide, but these emissions are small in relation to carbon fluxes.

**Figure 6.1        LULUCF emissions and removals from the UK 1990-2018 by category**
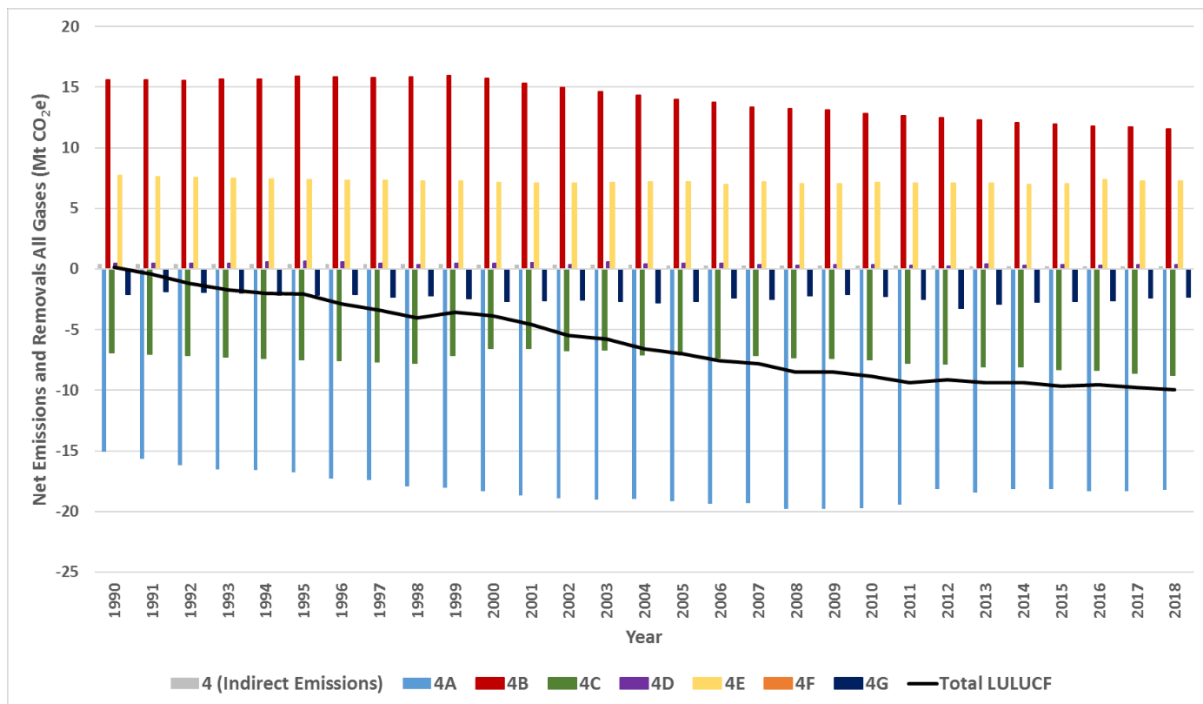


## 6.1    THE LAND USE TRANSITION MATRIX

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) 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 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 is used for land reclaimation since 2009.

The UK uses Approach 2 (IPCC 2006) for the representation of land use areas in the inventory, and compiles several different data sources into a non-spatially-explicit land use conversion matrix. The data sources are available at the individual country level (England, Scotland, Wales and Northern Ireland) and results are combined to give UK totals.

The land use transition matrices have been updated in this submission to take account of the most recently published data and maintain consistency in both the annual matrices (Table 4.1 for each year in the CRF Reporter) and the CRF carbon stock reporting tables. It is assumed for the UK that:

o The total areas of land use categories from recent reports (baseline date of 2015, see **Table 6.2**) are the most reliable;
o 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 | NFI main dataset (woods >0.5 ha) <br><br> Tree cover outside woodland (0.1-0.5 ha) | 3,573[2] |
| Cropland | UK Agricultural Census (Defra, DAERA, Scottish Government, Welsh Government) | Arable land <br><br> Orchards and perennial crops <br><br> Fallow and set-aside land | 4,892 |
| Grassland | ONS Standard Area Measurement land area – area of other categories[3] | NA | 13,619 |
| Wetlands | ONS Standard Area Measurement (water bodies >1km$^2$) <br><br> UK Directory of Mines and Quarries and Google Earth imagery (peat extraction sites) | Natural water bodies > 1km$^2$ <br><br> Reservoirs >1 km$^2$ <br><br> Peat extraction sites | 169 |
| Settlements | Land Cover Map 2015 | Urban land cover class <br><br> Suburban land cover class | 1,765 |
| Other Land | Land Cover Map 2015 | Inland rock, supra-littoral rock, supra-littoral sediment and freshwater classes, adjusted for area of inland water included in Wetlands category | 421 |

[1] Forestry Commission (2017) "Tree cover outside woodland in Great Britain report"

[2] Adjusted from 2016 value for afforestation gains and deforestation losses

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 6.7 for details) to calculate the initial land use areas in 2014 and area of each category that does not undergo any change. This approach is used to calculate the initial and final land use areas back in time to 1990, and forward in time from 2015.

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**.

Annual land use-change matrices for the GBE submission are shown in Table 6.3. 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 GBK and GBR submissions are shown in **Table 6.4** and **Table 6.5**. 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. A pilot study on methodological development has been undertaken to improve the estimation of land-use change using Bayesian assimilation of multiple land use datasets (Levy *et al.* 2018). The

implementation of this method is awaiting sign-off and resourcing by the National Inventory Steering Committee .A BEIS-funded project was also undertaken in 2017 to assess the potential of earth observation datasets at different scales to provide land use/land cover data suitable for LULUCF modelling and reporting. A method to improve the tracking of land-use change will be implemented after agreement on the approach at the NISC.

**Table 6.3**  **Annual land-use change matrices for the GBE submission, kha (Total land area is 24 439.2 kha). (GBE - UK, and Gibraltar)**

| Year | 4A Forest Land | | | | 4B Cropland | | | | 4C Grassland | | | | | 4D Wetland | | 4E Settlements | | | | 4F Other land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Forest area at start of year | Forest Land converted to Cropland | Forest land converted to Grassland | Forest Land converted to Settlement | Cropland area at start of year | Cropland converted to Forest Land | Cropland converted to Grassland | 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 | Wetland converted to Grassland | 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 | 3079.1 | 0.0 | 0.3 | 0.7 | 5529.1 | 5.2 | 83.4 | 2.5 | 13413.5 | 36.0 | 95.9 | 0.0 | 13.5 | 174.4 | 0.5 | 1575.4 | 2.9 | 0.9 | 4.7 | 420.9 |
| 1991 | 3122.3 | 0.0 | 0.3 | 0.6 | 5537.3 | 2.8 | 83.4 | 2.5 | 13371.3 | 21.0 | 95.9 | 0.8 | 13.5 | 173.9 | 0.5 | 1585.0 | 1.5 | 0.9 | 4.7 | 420.9 |
| 1992 | 3146.6 | 0.0 | 0.3 | 0.6 | 5545.4 | 2.9 | 83.4 | 2.5 | 13330.0 | 20.8 | 95.9 | 0.0 | 13.5 | 174.2 | 0.5 | 1594.3 | 1.6 | 0.9 | 4.7 | 420.9 |
| 1993 | 3171.0 | 0.0 | 0.3 | 0.6 | 5553.1 | 3.3 | 83.4 | 2.5 | 13288.5 | 21.0 | 95.9 | 0.0 | 13.5 | 173.7 | 0.5 | 1603.4 | 1.9 | 0.9 | 4.7 | 420.9 |
| 1994 | 3196.2 | 0.0 | 0.3 | 0.6 | 5561.0 | 3.2 | 83.4 | 2.5 | 13245.0 | 23.1 | 95.9 | 0.0 | 13.5 | 173.1 | 0.5 | 1612.6 | 1.7 | 0.9 | 4.7 | 420.9 |
| 1995 | 3223.4 | 0.0 | 0.3 | 0.5 | 5569.1 | 2.8 | 83.4 | 2.5 | 13204.2 | 20.1 | 95.9 | 0.3 | 13.5 | 172.6 | 0.5 | 1621.9 | 1.5 | 0.9 | 4.7 | 420.9 |
| 1996 | 3246.9 | 0.0 | 0.3 | 0.6 | 5577.5 | 2.7 | 83.4 | 2.5 | 13164.2 | 19.6 | 95.9 | 0.0 | 13.5 | 172.4 | 0.5 | 1631.3 | 1.5 | 0.9 | 4.7 | 420.9 |
| 1997 | 3269.5 | 0.0 | 0.4 | 0.6 | 5585.8 | 2.6 | 83.4 | 2.5 | 13124.5 | 19.2 | 95.9 | 0.0 | 13.5 | 171.8 | 0.5 | 1640.8 | 1.4 | 0.9 | 4.7 | 420.9 |
| 1998 | 3291.7 | 0.0 | 0.3 | 0.6 | 5594.2 | 2.7 | 83.4 | 2.5 | 13085.2 | 19.0 | 95.9 | 0.0 | 13.5 | 171.3 | 0.5 | 1650.3 | 1.5 | 0.9 | 4.7 | 420.9 |
| 1999 | 3313.8 | 0.0 | 0.3 | 0.8 | 5602.2 | 2.9 | 83.4 | 2.5 | 13045.5 | 19.2 | 95.9 | 0.0 | 13.5 | 170.8 | 0.5 | 1659.6 | 1.7 | 0.9 | 4.7 | 420.9 |
| 2000 | 3334.3 | 0.0 | 3.1 | 0.2 | 5591.9 | 3.0 | 99.0 | 5.3 | 13053.6 | 18.6 | 52.1 | 0.0 | 10.2 | 170.2 | 0.5 | 1665.7 | 2.8 | 0.1 | 7.7 | 420.9 |
| 2001 | 3355.0 | 0.0 | 3.5 | 0.2 | 5537.6 | 2.3 | 99.0 | 5.3 | 13084.1 | 17.5 | 52.1 | 0.0 | 10.2 | 169.7 | 0.5 | 1671.0 | 2.6 | 0.1 | 7.7 | 420.9 |
| 2002 | 3373.9 | 0.0 | 3.1 | 0.3 | 5483.3 | 2.3 | 99.0 | 5.3 | 13116.1 | 16.5 | 52.1 | 0.0 | 10.2 | 169.2 | 0.5 | 1676.3 | 2.4 | 0.1 | 7.7 | 420.9 |
| 2003 | 3391.0 | 0.0 | 3.5 | 0.6 | 5429.3 | 1.9 | 99.0 | 5.3 | 13148.9 | 15.0 | 52.1 | 0.2 | 10.2 | 169.2 | 0.0 | 1682.0 | 2.2 | 0.1 | 7.7 | 420.9 |
| 2004 | 3406.6 | 0.0 | 2.6 | 1.0 | 5375.2 | 2.1 | 99.0 | 5.3 | 13179.5 | 17.2 | 52.1 | 0.2 | 10.2 | 169.3 | 0.0 | 1687.7 | 2.5 | 0.1 | 7.7 | 420.9 |
| 2005 | 3424.6 | 0.0 | 2.9 | 0.8 | 5321.4 | 1.8 | 99.0 | 5.3 | 13211.2 | 15.1 | 52.1 | 0.2 | 10.2 | 169.5 | 0.0 | 1694.2 | 2.1 | 0.1 | 7.7 | 420.9 |
| 2006 | 3441.1 | 0.0 | 2.4 | 0.2 | 5267.5 | 1.8 | 99.0 | 5.3 | 13242.3 | 16.2 | 52.1 | 0.0 | 10.2 | 169.5 | 0.3 | 1700.3 | 2.3 | 0.1 | 7.7 | 420.9 |
| 2007 | 3458.1 | 0.0 | 2.9 | 0.4 | 5214.0 | 1.5 | 99.0 | 5.3 | 13275.8 | 13.6 | 52.1 | 0.0 | 10.2 | 169.2 | 0.3 | 1706.1 | 1.9 | 0.1 | 7.7 | 420.9 |
| 2008 | 3472.1 | 0.0 | 2.7 | 0.4 | 5160.7 | 1.3 | 99.0 | 5.3 | 13311.7 | 11.6 | 52.1 | 0.2 | 10.2 | 169.0 | 0.3 | 1712.4 | 1.7 | 0.1 | 7.7 | 420.9 |
| 2009 | 3483.6 | 0.0 | 2.8 | 0.4 | 5107.5 | 1.2 | 99.0 | 5.3 | 13348.1 | 11.0 | 52.1 | 0.0 | 10.2 | 168.9 | 0.3 | 1718.8 | 1.6 | 0.1 | 7.7 | 420.9 |
| 2010 | 3493.7 | 0.0 | 2.8 | 0.8 | 5054.0 | 1.4 | 99.0 | 5.3 | 13381.5 | 14.0 | 52.1 | 0.0 | 10.2 | 168.6 | 0.3 | 1724.7 | 2.0 | 0.1 | 7.7 | 420.9 |
| 2011 | 3508.3 | 0.0 | 2.1 | 0.7 | 5000.2 | 1.8 | 99.0 | 5.3 | 13409.9 | 19.1 | 52.1 | 0.0 | 10.2 | 168.6 | 0.0 | 1730.4 | 2.7 | 0.1 | 7.7 | 420.9 |
| 2012 | 3529.1 | 0.0 | 2.1 | 0.7 | 4946.8 | 1.3 | 99.0 | 5.3 | 13442.4 | 13.4 | 52.1 | 0.7 | 10.2 | 168.6 | 0.0 | 1736.8 | 1.9 | 0.1 | 7.7 | 420.9 |
| 2013 | 3543.2 | 0.0 | 1.9 | 0.6 | 4893.3 | 1.5 | 99.0 | 5.3 | 13475.3 | 13.7 | 52.1 | 0.0 | 10.2 | 169.3 | 0.0 | 1743.1 | 2.0 | 0.1 | 7.7 | 420.9 |
| 2014 | 3557.5 | 0.0 | 2.3 | 0.5 | 4840.0 | 1.3 | 99.0 | 5.3 | 13509.7 | 12.0 | 52.1 | 0.0 | 10.2 | 169.2 | 0.0 | 1749.6 | 1.8 | 0.1 | 7.7 | 420.9 |
| 2015 | 3570.1 | 0.0 | 1.9 | 0.6 | 4787.4 | 0.6 | 99.0 | 5.3 | 13551.0 | 5.5 | 52.1 | 0.0 | 10.2 | 169.2 | 0.0 | 1756.8 | 0.8 | 0.1 | 7.7 | 420.9 |
| 2016 | 3573.2 | 0.0 | 2.0 | 1.7 | 4734.8 | 0.5 | 99.0 | 5.3 | 13592.2 | 5.1 | 52.1 | 0.0 | 10.2 | 169.0 | 0.2 | 1764.3 | 0.7 | 0.1 | 7.7 | 420.9 |

| Year | 4A Forest Land | | | | 4B Cropland | | | | 4C Grassland | | | | | 4D Wetland | | 4E Settlements | | | | 4F Other land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Forest area at start of year | Forest Land converted to Cropland | Forest land converted to Grassland | Forest Land converted to Settlement | Cropland area at start of year | Cropland converted to Forest Land | Cropland converted to Grassland | 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 | Wetland converted to Grassland | 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 |
| 2017 | 3576.8 | 0.0 | 1.5 | 1.2 | 4682.1 | 0.7 | 99.0 | 5.3 | 13631.9 | 6.9 | 52.1 | 0.1 | 10.2 | 169.0 | 0.0 | 1772.6 | 1.0 | 0.1 | 7.7 | 420.9 |
| 2018 | 3582.6 | 0.0 | 1.5 | 1.2 | 4629.1 | 0.9 | 99.0 | 5.3 | 13667.8 | 10.1 | 52.1 | 0.0 | 10.2 | 166.6 | 2.5 | 1779.9 | 1.5 | 0.1 | 7.7 | 420.9 |

**Note:** Total areas in each year summed across all LULUCF categories may not equal the UK total land area in some years because of small rounding errors.

**Table 6.4    Annual land-use change matrices for the GBK submission, kha (Total land area is 25 758.4 kha). (GBK - UK, 3 CDs, 3 OTs)**

| Year | 4A Forest Land | | | | | 4B Cropland | | | | 4C Grassland | | | | | 4D Wetland | | | 4E Settlements | | | | 4F Other land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Forest aerea at start of year | Forest Land converted to Cropland | Forest land converted to Grassland | Forest land to Wetland | Forest Land converted to Settlement | Cropland aerea at start of year | Cropland converted to Forest Land | Cropland converted to Grassland | Cropland converted to Settlement | Grassland aerea at start of year | Grassland converted to Forest Land | Grassland converted to Cropland | Grassland converted to Wetland | Grassland converted to Settlement | Wetland aerea at start of year | Wetland converted to Grassland | Wetland to Settlement | Settlement aerea at start of year | Settlement converted to Forest Land | Settlement converted to Cropland | Settlement converted to Grassland | Other land aerea at start of year |
| 1990 | 3096.3 | 0.0 | 0.3 | 0.0 | 0.7 | 5542.0 | 5.2 | 83.6 | 2.5 | 14681.4 | 36.1 | 95.9 | 0.0 | 13.5 | 175.9 | 0.5 | 0.0 | 1594.8 | 2.9 | 0.9 | 4.7 | 421.0 |
| 1991 | 3139.5 | 0.0 | 0.3 | 0.0 | 0.7 | 5550.2 | 2.8 | 83.5 | 2.5 | 14639.3 | 21.0 | 96.0 | 0.8 | 13.5 | 175.3 | 0.5 | 0.0 | 1604.4 | 1.5 | 0.9 | 4.7 | 421.0 |
| 1992 | 3163.7 | 0.0 | 0.3 | 0.0 | 0.6 | 5558.3 | 2.9 | 83.5 | 2.5 | 14598.0 | 20.8 | 95.9 | 0.0 | 13.5 | 175.6 | 0.5 | 0.0 | 1613.9 | 1.6 | 0.9 | 4.7 | 421.0 |
| 1993 | 3188.1 | 0.0 | 0.3 | 0.0 | 0.6 | 5565.9 | 3.3 | 83.5 | 2.5 | 14556.5 | 21.0 | 95.9 | 0.0 | 13.6 | 175.1 | 0.5 | 0.0 | 1623.0 | 1.9 | 0.9 | 4.7 | 421.0 |
| 1994 | 3213.3 | 0.0 | 0.3 | 0.0 | 0.6 | 5573.6 | 3.2 | 83.5 | 2.5 | 14513.0 | 23.1 | 95.9 | 0.0 | 13.5 | 174.6 | 0.5 | 0.0 | 1632.4 | 1.7 | 0.9 | 4.7 | 421.0 |
| 1995 | 3240.4 | 0.0 | 0.3 | 0.0 | 0.6 | 5581.8 | 2.8 | 83.5 | 2.5 | 14472.1 | 20.1 | 96.1 | 0.3 | 13.5 | 174.0 | 0.5 | 0.0 | 1641.8 | 1.5 | 0.9 | 4.7 | 421.0 |
| 1996 | 3263.9 | 0.0 | 0.3 | 0.0 | 0.6 | 5590.2 | 2.7 | 83.4 | 2.5 | 14432.0 | 19.6 | 96.0 | 0.0 | 13.5 | 173.8 | 0.5 | 0.0 | 1651.3 | 1.5 | 0.9 | 4.7 | 421.0 |
| 1997 | 3286.5 | 0.0 | 0.4 | 0.0 | 0.7 | 5598.6 | 2.6 | 83.4 | 2.5 | 14392.3 | 19.2 | 96.0 | 0.0 | 13.5 | 173.2 | 0.5 | 0.0 | 1660.8 | 1.4 | 0.9 | 4.7 | 421.0 |
| 1998 | 3308.7 | 0.0 | 0.3 | 0.0 | 0.7 | 5606.9 | 2.7 | 83.4 | 2.5 | 14352.8 | 19.0 | 96.0 | 0.0 | 13.5 | 172.7 | 0.5 | 0.0 | 1670.4 | 1.5 | 0.9 | 4.7 | 421.0 |
| 1999 | 3330.7 | 0.0 | 0.3 | 0.0 | 0.8 | 5614.8 | 2.9 | 83.6 | 2.5 | 14313.1 | 19.2 | 95.9 | 0.0 | 13.5 | 172.2 | 0.5 | 0.0 | 1679.9 | 1.7 | 0.9 | 4.7 | 421.0 |

| Year | 4A Forest Land | | | | | 4B Cropland | | | | 4C Grassland | | | | | 4D Wetland | | | 4E Settlements | | | | 4F Other land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Forest area at start of year | Forest Land converted to Cropland | Forest land converted to Grassland | Forest land 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 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 | Wetland converted to Grassland | Wetland to Settlement | 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 |
| 2000 | 3351.2 | 0.0 | 3.1 | 0.0 | 0.3 | 5604.1 | 3.0 | 99.3 | 5.3 | 14321.1 | 18.6 | 52.2 | 0.0 | 10.3 | 171.6 | 0.5 | 0.0 | 1686.2 | 2.8 | 0.1 | 7.7 | 421.0 |
| 2001 | 3371.9 | 0.0 | 3.5 | 0.0 | 0.2 | 5549.5 | 2.3 | 99.3 | 5.3 | 14351.8 | 17.5 | 52.2 | 0.0 | 10.3 | 171.1 | 0.5 | 0.0 | 1691.7 | 2.6 | 0.1 | 7.7 | 421.0 |
| 2002 | 3390.8 | 0.0 | 3.1 | 0.0 | 0.3 | 5495.0 | 2.3 | 99.2 | 5.3 | 14383.9 | 16.5 | 52.2 | 0.0 | 10.3 | 170.6 | 0.5 | 0.0 | 1697.2 | 2.4 | 0.1 | 7.7 | 421.0 |
| 2003 | 3407.9 | 0.0 | 3.5 | 0.0 | 0.6 | 5440.9 | 1.9 | 99.2 | 5.3 | 14416.7 | 15.0 | 52.2 | 0.2 | 10.3 | 170.6 | 0.0 | 0.0 | 1703.1 | 2.2 | 0.1 | 7.7 | 421.0 |
| 2004 | 3423.5 | 0.0 | 2.6 | 0.0 | 1.0 | 5386.7 | 2.1 | 99.1 | 5.3 | 14447.2 | 17.2 | 52.3 | 0.2 | 10.3 | 170.8 | 0.0 | 0.0 | 1709.0 | 2.5 | 0.1 | 7.7 | 421.0 |
| 2005 | 3441.5 | 0.0 | 2.9 | 0.0 | 0.8 | 5332.8 | 1.8 | 99.2 | 5.3 | 14478.7 | 15.1 | 52.2 | 0.2 | 10.3 | 170.9 | 0.0 | 0.0 | 1715.5 | 2.1 | 0.1 | 7.7 | 421.0 |
| 2006 | 3458.0 | 0.0 | 2.4 | 0.0 | 0.2 | 5279.0 | 1.8 | 99.0 | 5.3 | 14509.5 | 16.2 | 52.5 | 0.0 | 10.3 | 170.9 | 0.3 | 0.0 | 1721.8 | 2.3 | 0.1 | 7.7 | 421.0 |
| 2007 | 3474.4 | 0.0 | 3.2 | 0.1 | 0.6 | 5225.7 | 1.5 | 99.1 | 5.3 | 14542.5 | 13.6 | 52.4 | 0.0 | 10.3 | 170.6 | 0.3 | 0.0 | 1727.9 | 1.9 | 0.1 | 7.7 | 421.0 |
| 2008 | 3488.0 | 0.0 | 3.0 | 0.1 | 0.4 | 5172.6 | 1.3 | 99.1 | 5.3 | 14578.3 | 11.6 | 52.4 | 0.2 | 10.3 | 170.5 | 0.3 | 0.0 | 1734.7 | 1.7 | 0.1 | 7.7 | 421.0 |
| 2009 | 3499.0 | 0.0 | 3.0 | 0.1 | 0.4 | 5119.1 | 1.2 | 99.7 | 5.3 | 14614.7 | 11.0 | 52.3 | 0.0 | 10.3 | 170.5 | 0.3 | 0.0 | 1741.3 | 1.6 | 0.1 | 7.7 | 421.0 |
| 2010 | 3508.7 | 0.0 | 3.1 | 0.1 | 0.8 | 5065.9 | 1.4 | 99.0 | 5.3 | 14648.5 | 14.0 | 52.4 | 0.0 | 10.3 | 170.4 | 0.3 | 0.0 | 1747.3 | 2.0 | 0.1 | 7.7 | 421.0 |
| 2011 | 3522.9 | 0.0 | 2.4 | 0.1 | 0.8 | 5012.2 | 1.8 | 99.2 | 5.3 | 14677.1 | 19.1 | 52.2 | 0.0 | 10.2 | 170.5 | 0.0 | 0.0 | 1753.1 | 2.7 | 0.1 | 7.7 | 421.0 |
| 2012 | 3543.3 | 0.0 | 2.4 | 0.1 | 0.7 | 4957.8 | 1.3 | 100.1 | 5.3 | 14709.9 | 13.4 | 52.2 | 0.7 | 10.2 | 170.6 | 0.0 | 0.0 | 1759.6 | 1.9 | 0.1 | 7.7 | 421.0 |
| 2013 | 3557.0 | 0.0 | 2.2 | 0.1 | 0.7 | 4904.2 | 1.5 | 99.2 | 5.3 | 14743.7 | 13.7 | 52.5 | 0.0 | 10.2 | 171.4 | 0.0 | 0.0 | 1766.0 | 2.0 | 0.1 | 7.7 | 421.0 |
| 2014 | 3571.3 | 0.0 | 2.4 | 0.0 | 0.5 | 4850.1 | 1.3 | 100.2 | 5.3 | 14778.4 | 12.0 | 52.2 | 0.0 | 10.2 | 171.5 | 0.0 | 0.0 | 1772.5 | 1.8 | 0.1 | 7.7 | 421.0 |
| 2015 | 3583.8 | 0.0 | 1.9 | 0.0 | 0.6 | 4797.2 | 0.6 | 99.3 | 5.3 | 14819.8 | 5.5 | 53.1 | 0.0 | 10.2 | 171.5 | 0.0 | 0.0 | 1779.9 | 0.8 | 0.1 | 7.7 | 421.0 |
| 2016 | 3587.0 | 0.0 | 2.0 | 0.0 | 1.7 | 4745.2 | 0.5 | 99.6 | 5.3 | 14861.1 | 5.1 | 52.2 | 0.0 | 10.2 | 171.2 | 0.2 | 0.0 | 1787.4 | 0.7 | 0.1 | 7.7 | 421.0 |
| 2017 | 3590.6 | 0.0 | 1.6 | 0.0 | 1.3 | 4692.4 | 0.7 | 99.1 | 5.3 | 14901.2 | 6.9 | 52.2 | 0.1 | 10.2 | 171.2 | 0.0 | 0.0 | 1795.8 | 1.0 | 0.1 | 7.7 | 421.0 |
| 2018 | 3596.4 | 0.0 | 1.6 | 0.0 | 1.3 | 4639.3 | 0.9 | 99.2 | 5.3 | 14937.1 | 10.2 | 52.2 | 0.0 | 10.2 | 168.8 | 2.5 | 0.0 | 1803.2 | 1.5 | 0.1 | 7.7 | 421.0 |

**Table 6.5** **Annual land-use change matrices for the GBR submission, kha (Total land area is 25 763.8 kha ) (GBR - UK, 3 CDs, 4 OTs)**

| Year | 4A Forest Land | | | | | 4B Cropland | | | | 4C Grassland | | | | | 4D Wetland | | | 4E Settlements | | | | 4F Other Land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Forest aerea at start of year | Forest Land converted to Cropland | Forest land converted to Grassland | Forest land to Wetland | Forest Land converted to Settlement | Cropland aerea at start of year | Cropland converted to Forest Land | Cropland converted to Grassland | Cropland converted to Settlement | Grassland aerea at start of year | Grassland converted to Forest Land | Grassland converted to Cropland | Grassland converted to Wetland | Grassland converted to Settlement | Wetland aerea at start of year | Wetland converted to Grassland | Wetland to Settlement | Settlement aerea at start of year | Settlement converted to Forest Land | Settlement converted to Cropland | Settlement converted to Grassland | Other land aerea at start of year |
| 1990 | 3096.9 | 0.0 | 0.3 | 0.0 | 0.7 | 5542.4 | 5.2 | 83.6 | 2.5 | 14681.4 | 36.1 | 95.9 | 0.0 | 13.5 | 175.9 | 0.5 | 0.0 | 1598.9 | 2.9 | 0.9 | 4.7 | 421.3 |
| 1991 | 3140.1 | 0.0 | 0.3 | 0.0 | 0.7 | 5550.5 | 2.8 | 83.5 | 2.5 | 14639.3 | 21.0 | 96.0 | 0.8 | 13.5 | 175.4 | 0.5 | 0.0 | 1608.5 | 1.5 | 0.9 | 4.7 | 421.3 |
| 1992 | 3164.4 | 0.0 | 0.3 | 0.0 | 0.6 | 5558.6 | 2.9 | 83.5 | 2.5 | 14598.0 | 20.8 | 95.9 | 0.0 | 13.5 | 175.7 | 0.5 | 0.0 | 1618.0 | 1.6 | 0.9 | 4.7 | 421.3 |
| 1993 | 3188.7 | 0.0 | 0.3 | 0.0 | 0.6 | 5566.2 | 3.3 | 83.5 | 2.5 | 14556.5 | 21.0 | 95.9 | 0.0 | 13.6 | 175.2 | 0.5 | 0.0 | 1627.1 | 1.9 | 0.9 | 4.7 | 421.3 |
| 1994 | 3213.9 | 0.0 | 0.3 | 0.0 | 0.6 | 5574.0 | 3.2 | 83.5 | 2.5 | 14513.0 | 23.1 | 95.9 | 0.0 | 13.5 | 174.6 | 0.5 | 0.0 | 1636.5 | 1.7 | 0.9 | 4.7 | 421.3 |
| 1995 | 3241.0 | 0.0 | 0.3 | 0.0 | 0.6 | 5582.1 | 2.8 | 83.5 | 2.5 | 14472.1 | 20.1 | 96.1 | 0.3 | 13.5 | 174.1 | 0.5 | 0.0 | 1645.9 | 1.5 | 0.9 | 4.7 | 421.3 |
| 1996 | 3264.5 | 0.0 | 0.3 | 0.0 | 0.6 | 5590.5 | 2.7 | 83.4 | 2.5 | 14432.0 | 19.6 | 96.0 | 0.0 | 13.5 | 173.9 | 0.5 | 0.0 | 1655.4 | 1.5 | 0.9 | 4.7 | 421.3 |
| 1997 | 3287.1 | 0.0 | 0.4 | 0.0 | 0.7 | 5599.0 | 2.6 | 83.4 | 2.5 | 14392.3 | 19.2 | 96.0 | 0.0 | 13.5 | 173.3 | 0.5 | 0.0 | 1665.0 | 1.4 | 0.9 | 4.7 | 421.3 |
| 1998 | 3309.3 | 0.0 | 0.3 | 0.0 | 0.7 | 5607.2 | 2.7 | 83.4 | 2.6 | 14352.8 | 19.0 | 96.0 | 0.0 | 13.5 | 172.8 | 0.5 | 0.0 | 1674.6 | 1.5 | 0.9 | 4.7 | 421.3 |
| 1999 | 3331.3 | 0.0 | 0.3 | 0.0 | 0.8 | 5615.1 | 2.9 | 83.6 | 2.6 | 14313.1 | 19.2 | 95.9 | 0.0 | 13.5 | 172.2 | 0.5 | 0.0 | 1684.1 | 1.7 | 0.9 | 4.7 | 421.3 |
| 2000 | 3351.7 | 0.0 | 3.1 | 0.0 | 0.3 | 5604.4 | 3.0 | 99.3 | 5.3 | 14321.1 | 18.6 | 52.2 | 0.0 | 10.3 | 171.7 | 0.5 | 0.0 | 1690.4 | 2.8 | 0.1 | 7.7 | 421.3 |
| 2001 | 3372.4 | 0.0 | 3.5 | 0.0 | 0.2 | 5549.8 | 2.3 | 99.3 | 5.3 | 14351.8 | 17.5 | 52.2 | 0.0 | 10.3 | 171.2 | 0.5 | 0.0 | 1695.8 | 2.6 | 0.1 | 7.7 | 421.3 |
| 2002 | 3391.3 | 0.0 | 3.1 | 0.0 | 0.3 | 5495.3 | 2.3 | 99.2 | 5.3 | 14383.9 | 16.5 | 52.2 | 0.0 | 10.3 | 170.6 | 0.5 | 0.0 | 1701.4 | 2.4 | 0.1 | 7.7 | 421.3 |
| 2003 | 3408.4 | 0.0 | 3.5 | 0.0 | 0.6 | 5441.2 | 1.9 | 99.2 | 5.3 | 14416.7 | 15.0 | 52.2 | 0.2 | 10.3 | 170.6 | 0.0 | 0.0 | 1707.3 | 2.2 | 0.1 | 7.7 | 421.3 |
| 2004 | 3424.0 | 0.0 | 2.6 | 0.0 | 1.0 | 5387.0 | 2.1 | 99.1 | 5.3 | 14447.2 | 17.2 | 52.3 | 0.2 | 10.3 | 170.8 | 0.0 | 0.0 | 1713.2 | 2.5 | 0.1 | 7.7 | 421.3 |
| 2005 | 3442.0 | 0.0 | 2.9 | 0.0 | 0.9 | 5333.1 | 1.8 | 99.2 | 5.3 | 14478.7 | 15.1 | 52.2 | 0.2 | 10.3 | 171.0 | 0.0 | 0.0 | 1719.8 | 2.1 | 0.1 | 7.7 | 421.3 |
| 2006 | 3458.5 | 0.0 | 2.4 | 0.0 | 0.2 | 5279.3 | 1.8 | 99.0 | 5.3 | 14509.5 | 16.2 | 52.5 | 0.0 | 10.3 | 171.0 | 0.3 | 0.0 | 1726.1 | 2.3 | 0.1 | 7.7 | 421.3 |
| 2007 | 3474.9 | 0.0 | 3.2 | 0.1 | 0.6 | 5226.0 | 1.5 | 99.1 | 5.3 | 14542.5 | 13.6 | 52.4 | 0.0 | 10.3 | 170.7 | 0.3 | 0.0 | 1732.1 | 1.9 | 0.1 | 7.7 | 421.3 |
| 2008 | 3488.4 | 0.0 | 3.0 | 0.1 | 0.4 | 5172.9 | 1.3 | 99.1 | 5.3 | 14578.3 | 11.6 | 52.4 | 0.2 | 10.3 | 170.5 | 0.3 | 0.0 | 1738.9 | 1.7 | 0.1 | 7.7 | 421.3 |
| 2009 | 3499.5 | 0.0 | 3.0 | 0.1 | 0.4 | 5119.4 | 1.2 | 99.7 | 5.3 | 14614.7 | 11.0 | 52.3 | 0.0 | 10.3 | 170.6 | 0.3 | 0.0 | 1745.5 | 1.6 | 0.1 | 7.7 | 421.3 |
| 2010 | 3509.2 | 0.0 | 3.1 | 0.1 | 0.8 | 5066.2 | 1.4 | 99.0 | 5.3 | 14648.5 | 14.0 | 52.4 | 0.0 | 10.3 | 170.4 | 0.3 | 0.0 | 1751.6 | 2.0 | 0.1 | 7.7 | 421.3 |
| 2011 | 3523.3 | 0.0 | 2.4 | 0.1 | 0.8 | 5012.5 | 1.8 | 99.2 | 5.3 | 14677.1 | 19.1 | 52.2 | 0.0 | 10.2 | 170.5 | 0.0 | 0.0 | 1757.4 | 2.7 | 0.1 | 7.7 | 421.3 |
| 2012 | 3543.8 | 0.0 | 2.4 | 0.1 | 0.7 | 4958.1 | 1.3 | 100.1 | 5.3 | 14709.9 | 13.4 | 52.2 | 0.7 | 10.2 | 170.6 | 0.0 | 0.0 | 1763.9 | 1.9 | 0.1 | 7.7 | 421.3 |
| 2013 | 3557.5 | 0.0 | 2.2 | 0.1 | 0.7 | 4904.5 | 1.5 | 99.2 | 5.3 | 14743.7 | 13.7 | 52.5 | 0.0 | 10.2 | 171.4 | 0.0 | 0.0 | 1770.3 | 2.0 | 0.1 | 7.7 | 421.3 |
| 2014 | 3571.7 | 0.0 | 2.4 | 0.0 | 0.5 | 4850.3 | 1.3 | 100.2 | 5.3 | 14778.4 | 12.0 | 52.2 | 0.0 | 10.2 | 171.5 | 0.0 | 0.0 | 1776.8 | 1.8 | 0.1 | 7.7 | 421.3 |
| 2015 | 3584.3 | 0.0 | 1.9 | 0.0 | 0.6 | 4797.5 | 0.6 | 99.3 | 5.3 | 14819.8 | 5.5 | 53.1 | 0.0 | 10.2 | 171.5 | 0.0 | 0.0 | 1784.2 | 0.8 | 0.1 | 7.7 | 421.3 |
| 2016 | 3587.4 | 0.0 | 2.0 | 0.0 | 1.7 | 4745.5 | 0.5 | 99.6 | 5.3 | 14861.1 | 5.1 | 52.2 | 0.0 | 10.2 | 171.3 | 0.2 | 0.0 | 1791.7 | 0.7 | 0.1 | 7.7 | 421.3 |

| Year | 4A Forest Land | | | | | 4B Cropland | | | | 4C Grassland | | | | | 4D Wetland | | | 4E Settlements | | | | 4F Other Land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Forest aerea at start of year | Forest Land converted to Cropland | Forest land converted to Grassland | Forest land to Wetland | Forest Land converted to Settlement | Cropland aerea at start of year | Cropland converted to Forest Land | Cropland converted to Grassland | Cropland converted to Settlement | Grassland aerea at start of year | Grassland converted to Forest Land | Grassland converted to Cropland | Grassland converted to Wetland | Grassland converted to Settlement | Wetland aerea at start of year | Wetland converted to Grassland | Wetland to Settlement | Settlement aerea at start of year | Settlement converted to Forest Land | Settlement converted to Cropland | Settlement converted to Grassland | Other land aerea at start of year |
| 2017 | 3591.0 | 0.0 | 1.6 | 0.0 | 1.3 | 4692.7 | 0.7 | 99.1 | 5.3 | 14901.2 | 6.9 | 52.2 | 0.1 | 10.2 | 171.3 | 0.0 | 0.0 | 1800.1 | 1.0 | 0.1 | 7.7 | 421.3 |
| 2018 | 3596.8 | 0.0 | 1.6 | 0.0 | 1.3 | 4639.6 | 0.9 | 99.2 | 5.3 | 14937.1 | 10.2 | 52.2 | 0.0 | 10.2 | 168.9 | 2.5 | 0.0 | 1807.6 | 1.5 | 0.1 | 7.7 | 421.3 |

## 6.2 CATEGORY 4A – FOREST LAND

### 6.2.1 Description

| Emissions sources | 4A Forest Land: carbon stock change<br>4(I) Direct nitrous oxide ($N_2O$) emissions from nitrogen (N) inputs to managed soils<br>4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils<br>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<br>4(V) Biomass burning |
|---|---|
| Gases Reported | $CO_2$, $CH_4$, $N_2O$ |
| Methods | T3 for carbon stock changes, T1 for other emissions |
| Emission Factors | Country-specific for T3 methods |
| Key Categories | 4A: Forest land - $CO_2$ (L1, L2) |
| Key Categories (Qualitative) | None identified |
| Completeness | Methane emissions from drained forest soils are not estimated due to insufficient information.<br>GHG emissions from rewetted forest soils are not estimated due to insufficient information. |
| Major improvements since last submission | Reconciliation of harvest volume and forest age data: Wood production in the years 1961-1975 was estimated using data from the Food and Agriculture Organization (FAO), which in turn improved consistency of predicted wood production later in the time series. Improvement to the soil model describing soil acidity. |

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 6.9.

Forest Land includes carbon stock gains and losses and GHG emissions from forest management and overall is the biggest net sink in the UK. All UK forests are temperate and about 72% of these have been planted since 1921 on land that had not been forested for many decades.

The UK reports carbon stock changes in all forests. Forest surveys have been intermittent in the UK and to date there has been no network of permanent sample plots suitable for constructing a GHG inventory. Consequently, estimates of carbon stock gains and losses for biomass and soils are modelled based on planting history, productivity (yield class) data and assumptions over approaches to forest management. Forest carbon stock changes and fluxes are modelled by CARBINE, the Forest Research forest carbon stock model (described in **Annex 3.4.1**). CARBINE takes account of the effects of forest management on carbon stocks, and also calculates the carbon stocks in the Harvested Wood Products pool.

Carbon stock changes resulting from afforestation on Cropland, Grassland and Settlement areas are calculated. Conversion of Wetlands and Other Land to Forest Land does not occur in the UK. The reported forest area and carbon stock changes take account of losses of forest land converted to other land use categories (deforestation) and the associated carbon stock changes and emissions and removals are then estimated and reported under the category concerned.

In the UK inorganic nitrogen fertilisers are only applied to forest when absolutely necessary. This occurs during the first rotation on 'poor' soils, such as reclaimed slag heaps, impoverished brown field sites and upland organic soils, hence N fertilisation is assumed for all areas of Settlements converted to Forest Land and Grassland converted to Forest Land on organic soils. $N_2O$ emissions from this fertilisation are reported under 4.A.2 in CRF Table 4(I). Nitrogen fertilisers are not generally applied to native woodlands, mature forests or re-planted forests in the UK, so emissions of $N_2O$ from N fertilisation of forests (CRF Table 4(I)) for 4.A.1 are reported as Not Occurring.

Drainage of forest land occurs in UK forests planted since 1920 on certain soil types. It is assumed that all forests planted on organic soils are 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 and $N_2O$ emissions from drainage in Table 4(II). There is insufficient information to enable reporting of methane and rewetting emissions.

Controlled burning of forest land (for example for habitat management) does not take place in the UK. Wildfires do occur but the activity data are not sufficient to split reporting between 4.A.1 and 4.A.2. Therefore emissions of greenhouse gases from wildfires are all reported under 4.A.1 in Table 4(V). It is assumed that land-use change does not occur following wildfire.

## 6.2.2 Information on approaches used for representing land areas and on land use databases used for the inventory preparation

The agencies responsible for forests in the UK are the Forestry Commission (England and Scotland), Natural Resources Wales (Wales) and the Forest Service (Northern Ireland). Areas of forest planted annually are published in Forest Statistics[75] and a detailed breakdown (by forest type and management) is used as input to the CARBINE model, supplemented by information from the National Forest Inventory (NFI) field survey. The allocation of land-use change from other land use categories is based on the proportional changes in the land-use change matrices from the Countryside Survey (see **Section 6.3** and **Annex 3.4**).

## 6.2.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

The UK uses the following definition of forest for reporting UK forestry statistics as it relates to the UK's greenhouse gas inventory submitted under the UNFCCC:

- Minimum area of 0.1 hectares;
- Minimum width of 20 metres;
- Tree crown cover of at least 20 per cent, or the potential to achieve it;
- Minimum height of 2 metres, or the potential to achieve it.

This definition includes felled areas awaiting restocking and integral open spaces (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 woodlands" report providing the additional area of woodlands between 0.1-0.5 ha[75]. 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).

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[75] https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/

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 methodological improvements to the CARBINE model for this submission: these improvements and their impact are described in the recalculations (**Section 6.2.7**).

Other greenhouse gas emissions, including those arising from forest fertilisation and wildfires together with estimates of $N_2O$ 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

These uncertianties are based on a new uncertainty analysis that has been completed in 2019, broadly following the methodology of the previous uncertainty analysis, but using the latest version of the CARBINE model. 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.

A significance analysis has been undertaken for key categories in the LULUCF sector. In Forest Land the 4.A.1 Forest Land remaining Forest land is the most significant sub-category (**Table 6.6**).

**Table 6.6        Significance analysis of the Forest Land category**

| Sub-category | Pool | Percentage contribution to total[1] | |
|---|---|---|---|
| | | **1990** | **2018** |
| **A1. Forest Land remaining Forest Land** | | **95%** | **99%** |
| | Carbon stock change in living biomass | 64% | 49% |
| | Net carbon stock change in dead wood | 16% | 20% |
| | Net carbon stock change in litter | 4% | 2% |
| | Mineral Soils | 12% | 25% |
| | Organic Soils | 0% | 3% |
| **A2.1. Cropland converted to Forest Land** | | **0%** | **0%** |
| **A2.2. Grassland converted to Forest Land** | | **5%** | **1%** |
| **A2.4. Settlements converted to Forest Land** | | **0%** | **0%** |
| **A2.5. Other Land converted to Forest Land** | | **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 6.11**. 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 2020).

A review of inventory data and models has been undertaken (Levy and Rowland, 2011), during which data were collated and critically assessed on soil carbon stocks following afforestation. Generally, soil carbon stocks are assumed to increase after afforestation in the UK, following on as a result of the increased above-ground biomass and litter inputs, based on a small number of long term studies. In fact, in the UK studies which attempt to measure this, soil carbon stocks in forested plots were 15 to 60 % lower than in adjacent unplanted, grassland or moorland (Reay et al., 2001; Chapman et al. 2003; Zerva and Mencuccini 2005; Mitchell et al. 2007; Bellamy and Rivas-Casado 2009; Levy and Clark 2009). These results are in agreement with global meta-analyses, which have reported mean changes in soil carbon stocks of around -10 %, -7 %, +3 % and -4 % associated with conversion of pasture to forest plantation (Guo and Gifford 2002; 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 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 reduced by between 0.1 and 1.5 Mt $CO_2e$ (1-9%) across the time series compared to the 1990-2017 inventory.

The changes were mainly seen in the carbon stock changes in all pools under Forest Remaining Forest. The main causes of this change were the correction of the previous double-counting of input to the deadwood and litter pools at harvest in the CARBINE model.

The changes and their justification are:
- **Reconciliation of harvest volume and forest age data:** The process of generating activity data for the Forest Land category takes information from the forest inventories for the private and public forest estates and assigns the forest areas to either afforestation or restocking (i.e. this land has been restocked at least once, so the age of the forest in the inventory does not represent the year the land was afforested) with a range of forest management regimes. In order to better model this ratio of yearly forest area afforested and replanted in earlier years, wood production in the years 1961-1975 was estimated using data from the Food and Agriculture Organization (FAO), with the IPCC overlap method used to ensure consistency with the data from Forest Statistics. There were also some adjustments made to the assumed forest management used as input to the algorithm to improve the consistency of the predicted wood production later in the time series.

- **Improvements to CARBINE**

  - **Correction of potential double-counting of litter and deadwood**. There was an issue with managed non-clearfell stands where we assume restocking will occur before the overstory is removed. This led to a potential to double count the litter/deadwood and removed yearly losses from the pools twice.

  - **Correction of deadwood on deforested land not being reported**, thus leading to an underestimate of dead organic matter (DOM) on deforested land.

  - **Improvement to the foliage decay function** which was using generic meteorological data, rather than the more specific data we use for the inventory modelling.

  - **Improvement to the soil model** due to a change to the model describing soil acidity. The assumption in the model is that saturated soils are more acidic. This was implemented as a change is pH at a specific level of saturation, when "fully saturated". This meant that results were too sensitive to when this threshold was met - and this was dependent of the compiler options used for the precision of the calculations and led to a higher than expected sensitivity to rainfall. This was because a relatively small difference at a certain (higher) level

of rainfall could trigger this change in pH. Instead of a set threshold triggering a large change, there is now a smooth transition from an assumed non-saturated pH to the assumed saturated pH.

- **Use of CARBINE estimates for biomass lost during deforestation**: Biomass lost during deforestation is now estimated using the CARBINE model rather than using average biomass densities with the deforested area time series. This affects emissions from controlled burning and carbon stock changes following deforestation.

The magnitude of the changes and the abbreviated justification are given in **Table 6.7**.

**Table 6.7        4A Category specific recalculations to activity data since previous submission**

| IPCC Category | Source Name | 2019 Submission | | 2020 Submission | | Units | Comment / Justification |
|---|---|---|---|---|---|---|---|
| | | 1990 | 2017 | 1990 | 2017 | | |
| 4A1 | Carbon stock change in living biomass - gains | -10,848.3 | -15,671.5 | -10,311.1 | -15,313.3 | Gg C | Reconciliation of harvest volume and forest age data |
| 4A1 | Carbon stock change in living biomass - losses | 8,057.4 | 13,112.3 | 7,672.3 | 12,832.8 | Gg C | |
| 4A1 | Net carbon stock change in litter | -111.6 | -87.4 | -145.1 | -113.9 | Gg C | Improvements to CARBINE |
| 4A1 | Net carbon stock change in dead wood | -625.2 | -1,003.3 | -641.5 | -1,009.6 | Gg C | |
| 4A1 | Net carbon stock change in soils - mineral soils | -428.0 | -1,078.1 | -504.6 | -1,218.6 | Gg C | Reconciliation of harvest volume and forest age data |
| 4A1 | Net carbon stock change in soils - organic soils | 11.0 | -183.6 | 10.8 | -142.9 | Gg C | Improvements to CARBINE |
| 4A1/4(V) | Biomass burning - wildfires | 10.2 | 8.1 | 9.9 | 7.9 | Gg C | Use of CARBINE derived biomass densities |
| 4A2.1 | Carbon stock change in living biomass - gains | -54.8 | -42.5 | -63.7 | -44.4 | Gg C | Reconciliation of harvest volume and forest age data |
| 4A2.1 | Carbon stock change in living biomass - losses | 10.0 | 7.6 | 12.7 | 8.4 | Gg C | |
| 4A2.1 | Net carbon stock change in litter | -1.1 | -0.8 | -1.8 | -1.1 | Gg C | Reconciliation of harvest volume and forest age data |
| 4A2.1 | Net carbon stock change in dead wood | -1.5 | -1.0 | -2.0 | -1.2 | Gg C | Improvements to CARBINE |
| 4A2.1 | Net carbon stock change in soils - mineral soils | 40.0 | 27.5 | 38.9 | 28.5 | Gg C | Reconciliation of harvest volume and forest age data |
| 4A2.1 | Net carbon stock change in soils - organic soils | 3.4 | 1.1 | 4.4 | 1.4 | Gg C | Improvements to CARBINE |
| 4A2.2 | Carbon stock change in living biomass - gains | -867.8 | -309.9 | -1,028.9 | -332.7 | Gg C | Reconciliation of harvest volume and forest age data |
| 4A2.2 | Carbon stock change in living biomass - losses | 147.1 | 53.1 | 197.2 | 61.6 | Gg C | |
| 4A2.2 | Net carbon stock change in litter | -16.6 | -5.6 | -31.1 | -9.2 | Gg C | Improvements to CARBINE |
| 4A2.2 | Net carbon stock change in dead wood | -23.4 | -7.7 | -33.4 | -9.7 | Gg C | |
| 4A2.2 | Net carbon stock change in soils - mineral soils | 496.7 | 213.0 | 495.7 | 215.6 | Gg C | Reconciliation of harvest volume and forest age data |
| 4A2.2 | Net carbon stock change in soils - organic soils | 117.4 | 17.7 | 152.9 | 22.5 | Gg C | Improvements to CARBINE |

| IPCC Category | Source Name | 2019 Submission | | 2020 Submission | | Units | Comment / Justification |
|---|---|---|---|---|---|---|---|
| | | 1990 | 2017 | 1990 | 2017 | | |
| 4A2.4 | Carbon stock change in living biomass - gains | -19.0 | -41.6 | -23.0 | -44.5 | Gg C | Reconciliation of harvest volume and forest age data |
| 4A2.4 | Carbon stock change in living biomass - losses | 3.2 | 7.2 | 4.4 | 8.3 | Gg C | |
| 4A2.4 | Net carbon stock change in litter | -0.4 | -0.8 | -0.7 | -1.2 | Gg C | Improvements to CARBINE |
| 4A2.4 | Net carbon stock change in dead wood | -0.5 | -1.0 | -0.7 | -1.3 | Gg C | |
| 4A2.4 | Net carbon stock change in soils - mineral soils | 11.2 | 28.5 | 11.3 | 29.1 | Gg C | Reconciliation of harvest volume and forest age data |
| 4A2.4 | Net carbon stock change in soils - organic soils | 2.6 | 2.1 | 3.4 | 2.6 | Gg C | Improvements to CARBINE |
| 4A1/4(V) | Biomass burning - wildfires | 0.115 | 0.092 | 0.134 | 0.117 | Gg $CH_4$ | Use of CARBINE biomass densities |
| 4A1/4(V) | Biomass burning - wildfires | 0.006 | 0.005 | 0.007 | 0.006 | Gg $N_2O$ | |
| 4A2.1/4(III) | Direct $N_2O$ from N mineralisation | 0.042 | 0.029 | 0.041 | 0.030 | Gg $N_2O$ | Reconciliation of harvest volume and forest age data |
| 4A2.2/4(III) | Direct $N_2O$ from N mineralisation | 0.520 | 0.223 | 0.519 | 0.226 | Gg $N_2O$ | |
| 4A2.4/4(III) | Direct $N_2O$ from N mineralisation | 0.012 | 0.030 | 0.012 | 0.030 | Gg $N_2O$ | |
| 4A2/4(I) | Direct $N_2O$ emissions from inorganic fertilisers | 0.029 | 0.009 | 0.029 | 0.009 | Gg $N_2O$ | Reconciliation of harvest volume and forest age data |
| 4A/4(II) | Emissions and removals from drainage of organic and mineral soils | 0.167 | 0.190 | 0.172 | 0.196 | Gg $N_2O$ | Reconciliation of harvest volume and forest age data |

### 6.2.8  Category-Specific Planned Improvements

A piece of work is in progress to better quantify the uncertainties associated with outputs from the CARBINE model. This work will revise the uncertainty analysis published in the 1990-2010 National Inventory Report.

## 6.3  CATEGORY 4B – CROPLAND

### 6.3.1  Description

| Emissions sources | 4B Cropland: carbon stock change<br>4B Cropland:4(III) $N_2O$ emissions from disturbance associated with LUC to Cropland<br>4B Cropland:4(V) Biomass burning |
|---|---|
| Gases Reported | $CO_2$, $CH_4$, $N_2O$ |
| Methods | T3 for carbon stock changes, T1 for other emissions |
| Emission Factors | Country-specific for T3 methods, T1/2 for other emissions |
| Key Categories | 4B: Cropland - $CO_2$ (L1, T1, L2, T2) |
| Key Categories (Qualitative) | None identified |
| Completeness | No known omissions. |
| Major improvements since last submission | A change in the soil carbon density used for calculating the effect of cropland management on mineral 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 6.9.

Net emissions from the Cropland category include carbon stock gains and losses and GHG emissions due to land-use change (LUC), cropland management 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 soil net carbon stock changes are the largest component of the category total emissions, and are calculated using a Tier 3 dynamic soil carbon model.

Other contributors to the Cropland net total emissions are:

- carbon emissions resulting from drainage of organic soils;
- carbon stock changes in biomass and soils resulting from changes in cropland management;
- biomass carbon stock changes due to LUC;
- $N_2O$ 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.

Ongoing $N_2O$ emissions from soil as a result of land-use change > 20 years ago are reported in the Agricultural sector inventory as $N_2O$ emissions from managed agricultural soils. UKCEH provide the appropriate areas and carbon stock changes to Rothamsted Research. Nitrous

oxide emissions from loss of soil organic matter as a result of Cropland Management are also reported in the Agricultural sector inventory as $N_2O$ 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 6.1.1 for details).

Data sources that contain area information for reporting carbon stock changes and/or emissions from Cropland are:

- Habitat/landscape surveys
    - The Countryside Survey (1984, 1990, 2000, 2007) is used to compile land use transition matrices.
- An assessment of Cropland drainage on organic soils
    - Areas of Cropland that are losing carbon due to historical drainage (reported under Cropland remaining Cropland) have been assessed by Anthony *et al*. (personal communication - unpublished report from Defra project AC0114, 2013). Their analysis overlaid areas of Cropland from the Land Cover Map and the Integrated Administration and Control System (IACS) with mapping of organic soils from soil surveys. All Cropland on organic soils was assumed to be drained. The vast majority of Cropland on drained organic soils is in England, but small areas in the other UK administrations also exist.
- Agricultural survey data
    - Areas of the main crop types are obtained from the June Agricultural Censuses for each UK administration.
    - The areas of Cropland receiving inputs of manure, fertiliser and crop residues are obtained from the British Survey of Fertiliser Practice.
- Data on wildfires on agricultural land from Fire and Rescue service and satellite data.
    - Areas of wildfire on Cropland for 2010 to the present come from Fire and Rescue service data.
    - Between 2001 and 2009 the area of wildfire on Cropland is calculated by using satellite data on the total area of wildfires in the UK which are apportioned to land use using the same ratios as found in the Fire and Rescue service data 2010-present.
    - Cropland wildfire areas prior to 2001 are extrapolated (see **Annex 3.4.5** for details)

## 6.3.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

Cropland is defined in accordance with the Agriculture, Forestry and Other Land Use Guidance (IPCC 2006). For pre-1980 land use matrices cropland is the sum of the Crops, Orchards and Market Garden land cover types in the Monitoring Landscape Change project (MLC 1986). Post-1980, Cropland is the area of cropland reported in the June Agricultural censuses. Crop type definitions are those used in the June Agricultural censuses.

## 6.3.4 Methodological Issues

### 6.3.4.1 Land-Use Change

Activity data for land-use change are estimated using a land-use change (LUC) matrix approach. Detailed descriptions of the methods, emission factors and data flows used for Cropland activities are given in **Annex 3.4.2**.

A dynamic model of carbon stock change is used with the LUC matrices to estimate soil carbon stock changes due to all LUC. Soil carbon stock changes are modelled as changing exponentially between initial and final land uses with the most rapid change in the early years following the transition. It is assumed that LUC does not occur on cropland on organic soils because of the high productivity (and high monetary value) of these areas.

The carbon stocks for each land use category are calculated as averages for Scotland, England, Northern Ireland and Wales using a database of soil carbon density for the UK (Milne and Brown 1997; Cruickshank *et al.* 1998; Bradley *et al.* 2005) which has been constructed based on information on soil type, land cover and carbon content of soil cores to a depth of 1 m or to bedrock, whichever was the shallower, for mineral and organo-mineral soils. The rate of loss/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 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 and shrubby perennial crops (see **Annex 3.4** for details).

### 6.3.4.3 Drained organic soils

Emissions from Cropland on drained organic soils are reported using Tier 1 emission factors which assume constant rates of soil organic carbon loss and activity data from Anthony (personal communication, 2013).

### 6.3.4.4 Biomass burning emissions

Emissions from controlled burning on cropland are only reported for Forest Land conversion to Cropland and are estimated using Tier 1 emission factors and country-specific fuel densities.

Emissions from wildfires on Cropland are reporting using Tier 1 emission factors and activity from a range of sources (see 6.3.2).

## 6.3.5 Uncertainties and Time-Series Consistency

4B Cropland is estimated to have a combined uncertainty of 45% for $CO_2$, 55% for $CH_4$ and 35% for $N_2O$.

The areas undergoing land-use change are the biggest source of uncertainty in the LULUCF inventory (see **Annex 3.4.12**), but model choice and soil carbon parameters are also significant. Emissions from Cropland on drained organic soils has the largest uncertainties of the minor emissions sources (i.e. not land-use change) as the effects of drainage are highly uncertain.

With regard to time series consistency:

- Drainage of organic soils: it is assumed that all drainage of organic soils on Cropland occurred before 1990 as recent policy has favoured protection of organic soils. There have been no policy incentives to encourage new land drainage for agricultural use since 1990, and major drainage of large areas of Cropland on organic soils in areas such as the East Anglian fens is known to have occurred well before this. No Cropland on drained organic soils has been rewetted since 1990 as there have been no incentives to promote this, therefore a single area is used throughout the time series.

- Changes in biomass and soil carbon due to LUC: the data sources for Great Britain have maintained consistent methodology across the time series. Consistency between these and Northern Ireland data sources has improved with better methodological integration between land use surveys.

- Controlled biomass burning after conversion of Forest Land to Cropland: 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 6.8).**

**Table 6.8        Significance analysis of the Cropland category**

| Sub-category | Pool | Percentage contribution to total[1] | |
|---|---|---|---|
| | | 1990 | 2018 |
| **B1. Cropland remaining Cropland** | | **21%** | **53%** |
| | Carbon stock change in living biomass | 0% | 0% |
| | Mineral Soils | 10% | 38% |
| | Organic Soils | 11% | 15% |
| **B2.1. Forest Land converted to Cropland** | | **0%** | **0%** |
| **B2.2. Grassland converted to Cropland** | | **80%** | **47%** |

| Sub-category | Pool | Percentage contribution to total[1] | |
|---|---|---|---|
| | | 1990 | 2018 |
| | Carbon stock change in living biomass | -3% | -2% |
| | Net carbon stock change in soils | 77% | 46% |
| **B2.4. Settlements converted to Cropland** | | **-1%** | **0%** |

- [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 6.11.**

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 increased by between 0.2 and 0.4 Mt $CO_2e$ (2 to 3%) across the time series compared to the 1990-2017 inventory. The changes were mainly in soil carbon stock change in Cropland remaining Cropland.

The changes and their justification are:

- **Change in soil carbon density for cropland management:** A change in the equilibrium soil carbon density from values for 0-100 cm of the soil profile to values for the top 0-30 cm of soil (Bradley et al. 2005), as recommended in the 2019 in-country review. As a result, soil carbon stock changes have increased throughout the time series.

- **Correction of cropland areas in England:** Correction of a transposition error from the agricultural census data for England for the areas of potatoes and sugarbeet in 2017, which had resulted in higher than actual areas of these crops (affecting biomass carbon stock change), and correction of an area calculation for oats for England 1971-1973 (affecting soil carbon stock change).

- **Use of CARBINE estimates for biomass lost during deforestation**: Biomass lost during deforestation is now estimated using the CARBINE model rather than using average biomass densities with the deforested area time series. This affects emissions from controlled burning and carbon stock changes following deforestation.

- **Revision of deforestation activity data**: The deforestation time series 1990-1999 was revised to use the same precision as reprocessed Countryside Survey data (QA improvement). Areas for England 2017-18 from the latest statistical report.

Changes in emissions are described in **Table 6.9**.

**Table 6.9** **4B Category specific recalculations to activity data since previous submission**

| IPCC Category | Source Name | 2019 Submission | | 2020 Submission | | Units | Comment / Justification |
|---|---|---|---|---|---|---|---|
| | | 1990 | 2017 | 1990 | 2018 | | |
| 4B1 | Carbon stock change in living biomass - losses | 6.1 | 8.1 | 6.1 | 5.5 | Gg C | Correction of cropland areas |
| 4B1 | Net carbon stock change in soils - mineral soils – Cropland Management | -239.8 | -173.9 | -146.6 | -100.4 | Gg C | Change in soil carbon density for crop management |
| 4B2.1/4(V) | Biomass burning - controlled burning | 0.2 | 0.0 | 0.2 | 0.0 | Gg C | Use of CARBINE biomass densities |
| 4B2.1 | Carbon stock change in living biomass - losses | 0.3 | 0.0 | 0.3 | 0.0 | Gg C | Use of CARBINE biomass densities |
| 4B2.1 | Carbon stock change in dead organic matter | 0.0 | 0.0 | 0.1 | 0.0 | Gg C | |
| 4B2.1 | Carbon stock change in soils - mineral soils | 0.0 | 0.2 | 0.0 | 0.2 | Gg C | Revision of deforestation activity data |

### 6.3.8  Category-Specific Planned Improvements

A vector based approach to tracking land-use change has been piloted in Scotland. It assimilates data to provide a more accurate assessment of land-use change history (Levy et al. 2018). Further implementation at UK scale of this approach is under discussion, in addition to work building on the outcome of related projects on the potential of earth observation to track LUC in the UK. A method to improve the tracking of land-use change will be implemented after agreement on the approach at the NISC.

The ERT inquired about the estimation, and reporting of, inorganic carbon stock change in soil where Tier 3 models are applied (as for soil carbon stock change due to land-use change in the UK). Inorganic carbon is not currently considered but a recommendation will be made to the NISC for a literature review of inorganic carbon and anthropogenic stock change in soils for the UK context, which will be used to assess the need for further research.

## 6.4    CATEGORY 4C – GRASSLAND

### 6.4.1  Description

| Emissions sources | 4C Grassland: carbon stock change<br>4C Grassland: 4(II) Emissions from drainage of organic soils.<br>4C Grassland: 4(III) Direct $N_2O$ emissions from N mineralisation.<br>4C Grassland: 4(V) Biomass burning |
|---|---|
| Gases Reported | $CO_2$, $CH_4$, $N_2O$ |
| Methods | T3 for carbon stock changes, T1 for other emissions |
| Emission Factors | Country-specific for T3 methods, T1/2 for other emissions |
| Key Categories | 4C: Grassland - $CO_2$ (L1, T1, L2, T2) |
| Key Categories (Qualitative) | None identified |
| Completeness | No known omissions- areas are reported for land uses with no associated emissions. |
| Major improvements since last submission | $CO_2$ emissions from organic soils are now reported in CRF table 4.C rather than CRF table 4(II). Updates to activity data for Forest Land converted to Grassland have increased carbon stock changes and emissions from controlled burning slightly. |

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 6.9**.

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 and biomass burning. It is the second largest net sink in the LULUCF sector.

Ongoing carbon stock changes in soils arising from LUC to Grassland are reported under both 4.C.2 Land Converted to Grassland (for LUC in the past 20 years) and 4.C.1 Grassland Remaining Grassland (for historic LUC >20 years before the inventory reporting year). These soil net carbon stock changes are the largest component of the category total emissions and removals, and are calculated using a Tier 3 dynamic soil carbon model.

The area of undisturbed grassland which has not been converted from other land uses in the past is reported in 4.C.1. "Undisturbed" grassland is used as a buffer category on the

recommendation of UNFCCC reviewers, as Grassland is the most extensive land type in the UK. The undisturbed grassland area is calculated as the difference between the total land area (from the official national statistic of UK land area, Office for National Statistics) and the sum of all other land use areas (calculated from land use matrices, afforestation areas, peat extraction areas etc.) for each year. No anthropogenic emissions or removals are associated with this undisturbed area.

Other contributors to the Grassland net total emissions are:

- carbon emissions resulting from drainage of organic soils
- carbon stock changes in biomass resulting from changes in grassland 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 grassland; and
- biomass burning emissions of GHGs due to wildfires.

Carbon stock changes from drainage of improved Grassland on organic soils arise from areas which were drained many decades ago for agriculture. Soil carbon in these areas continues to oxidise and be released as $CO_2$, resulting in an ongoing change in soil carbon stock. These emissions are reported in Table 4(II). There are large areas of organic and organo-mineral soils under unimproved Grassland throughout the UK and it is known that there has been some drainage of these areas but the exact extent is currently unclear. These areas are currently included with grassland on mineral soils. This knowledge gap has been addressed in the BEIS-funded project on the implementation of the Wetlands Supplement guidance. This workis awaiting the completion of checking before sign-off for implementation in the inventory.

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 for details).

Data sources that contain area information for reporting carbon stock changes and/or emissions from Grassland:

- Habitat/landscape surveys;
    - Countryside Survey (1984, 1990, 2000, 2007) is used to compile land use transition matrices. Changes in grassland types and in hedge length/condition are used to calculate biomass carbon stock changes under grassland management.
- Data on deforestation areas from various sources;
    - Post-2000 deforestation areas are assessed from the NFI and administrative records of the conversion of areas in the public forest estate as art of habitat restoration and windfarm development.
    - Pre-2000 deforestation areas are estimated from unconditional felling licence data (felling licences granted without a requirement to restock), national forest estate administrative information and land conversion ratios from Countryside Survey. Details are given in **Annex 3.4.4**.
- An assessment of the area of improved Grassland on drained organic soils (see Section 6.3.2 for further details).
- 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, which are assigned to the 4.C.1 "undisturbed grassland" sub-category and calculated as the area remaining after all other land use areas are subtracted from the total UK land area. This is the buffer land use category for the UK, so may contain small areas of other land uses that are not directly managed.

Grazing is the main land use on peatland habitats that would otherwise fall within in the Wetland category, so areas of peatland habitat not used for peat extraction, such as bogs, are also included in the Grassland category.

For pre-1980 LUC the grassland area is the sum of the following land cover types in the Monitoring Landscape Change project (MLC 1986): upland heath, upland smooth grass, upland coarse grass, blanket bog, bracken, lowland rough grass, lowland heather, gorse, neglected grassland, marsh, improved grassland, rough pasture, peat bog, fresh marsh and salt marsh. For post-1980 LUC, grassland is the sum of the following Broad Habitat types in the Countryside Survey: improved grassland, neutral grassland, calcareous grassland, acid grassland, bracken, dwarf shrub heath, fen/marsh/swamp, bogs, montane, supra littoral sediment and littoral sediment (Jackson, 2000).

### 6.4.4 Methodological Issues

#### 6.4.4.1 land-use change

Activity data for land-use change are estimated using a land use matrix approach. Detailed descriptions of the methods, emission factors and data flows used for the Grassland are given in **Annex 3.4.2**.

The dynamic model of soil carbon stock change is described in **Section 6.3.4**. Biomass carbon stock change is calculated using the LUC matrix and literature-derived Tier 2 stock change factors with all stock gains or losses assumed to occur in a single year.

$N_2O$ emissions associated with the soil disturbance from LUC are reported using the areas of Forest land converted to Grassland from the LUC matrices and the IPCC Tier 1 emission factors.

#### 6.4.4.2 Grassland management

Carbon stock changes in biomass due to grassland management activities are estimated using literature-derived Tier 2 stock change factors and activity data from agricultural surveys. All carbon stock changes associated with changes in the length and conditionof hedgerows are reported under this activity.

#### 6.4.4.3 Drained organic soils

Emissions from Grassland on drained organic soils are reported using Tier 1 emission factors which assume constant rates of soil organic carbon loss and activity data from Steve Anthony (personal communication, 2013).

#### 6.4.4.4 Biomass burning emissions

Emissions from controlled burning on grassland are only reported for Forest Land conversion to Grassland and are estimated using Tier 1 emission factors and country-specific fuel densities.

Emissions from wildfires on Grassland (agricultural grassland and semi-natural grassland) are 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

4C Grassland is estimated to have a combined uncertainty of 50-55% for $CO_2$, 55% for $CH_4$ and 55-105% for $N_2O$.

The areas undergoing land-use change are the biggest source of uncertainty in the LULUCF inventory (see **Annex 3.4.12**), but model choice and soil carbon parameters are also significant. Emissions from Grassland on drained organic soils has the largest uncertainties of the minor emissions sources (i.e. not land-use change) as the effects of drainage are highly uncertain.

With regard to time series consistency:

- Drainage of organic soils: it is assumed that all drainage of organic soils under improved Grassland occurred before 1990, as policy has favoured protection of organic soils. There have been no policy incentives to encourage new land drainage for agricultural use since before 1990, and major drainage of large areas of improved Grassland on organic soils in areas such as the Somerset Levels fens is known to have occurred well before this. No improved Grassland on drained organic soils has been rewetted since 1990 as there have been no policy incentives for this, therefore a single area is used throughout the time series.

- Changes in biomass and soil carbon due to LUC: the data sources for Great Britain have maintained consistent methodology across the time series. Consistency between these and Northern Ireland data sources has improved with better methodological integration between land use surveys.

- Controlled biomass burning after conversion of Forest Land to Grassland: there is good time series consistency as there has been continutity 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. In Grassland the 4.C2.2 Cropland converted to Grassland and the 4.C1 Grassland remaining Grassland are the most significant sub-categories (**Table 6.10**).

**Table 6.10  Significance analysis of the Grassland category**

| Sub-category | Pool | Percentage contribution to total[1] | |
|---|---|---|---|
| | | 1990 | 2018 |
| **C1. Grassland remaining Grassland** | | **30%** | **56%** |
| | Carbon stock change in living biomass | 9% | -1% |
| | Mineral Soils | 24% | 58% |
| | Organic Soils | -2% | -2% |
| **C2.1. Forest Land converted to Grassland** | | **-1%** | **-9%** |
| **C2.2. Cropland converted to Grassland** | | **62%** | **42%** |
| | Carbon stock change in living biomass | -6% | -6% |
| | Net carbon stock change in soils | 68% | 48% |

| Sub-category | Pool | Percentage contribution to total[1] | |
| --- | --- | --- | --- |
| | | 1990 | 2018 |
| **C2.3. Wetlands converted to Grassland** | | **0%** | **1%** |
| **C2.4. Settlements converted to Grassland** | | **9%** | **11%** |

[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 6.11**.

As discussed in **Section 6.3.6** resampling of the 1980-based National Soil Inventory (NSI) in England and Wales in 1995-2003 found large losses of soil carbon across all land use types (Bellamy *et al.* 2005) but, a more recent study using Countryside Survey (CS) data (Reynolds *et al.* 2013) found no significant change in soil carbon stocks under most Grassland habitat types between 1978 and 2007. The possible reasons for these differences are unclear, as discussed in **Section 6.3.6**.

## 6.4.7 Category-Specific Recalculations

The reported overall net GHG sink in category 4C has reduced slightly between 0.0 - 0.1 Mt $CO_2e$ (0-2%) across the time series compared to the 1990-2017 inventory. The changes were in controlled burning and in biomass carbon stock change in Forest Land converted to Grassland.

The changes and their justification are:

- **Use of CARBINE estimates for biomass lost during deforestation**: Biomass lost during deforestation is now estimated using the CARBINE model rather than using average biomass densities with the deforested area time series. This affects emissions from controlled burning and carbon stock changes following deforestation.

- **Revision of deforestation activity data**: The deforestation time series 1990-1999 was revised to use the same precision as reprocessed Countryside Survey data (QA improvement). Deforestation areas for England 2017-18 have been used from the latest statistical report.

- **Adjustment of average biomass densities due to error correction:** the IPCC default method for calculating emissions from wildfires had been misapplied as the UK does not use the combustion factors with mass burnt.

Changes in emissions are described in **Table 6.11**.

**Table 6.11        4C Category specific recalculations to activity data since previous submission**

| IPCC Category | Source Name | 2019 Submission | | 2020 Submission | | Units | Comment / Justification |
|---|---|---|---|---|---|---|---|
| | | 1990 | 2017 | 1990 | 2017 | | |
| 4C1 | Net carbon stock change in soils - organic soils | IE | IE | 48.2 | 48.2 | Gg C | Carbon emissions from organic soils were previously reported in CRF Table 4(II) |
| 4C2.1/4(V) | Biomass burning - controlled burning | 4.7 | 51.2 | 5.4 | 52.3 | Gg C | Use of CARBINE biomass densities |
| 4C2.1 | Carbon stock change in living biomass - losses | 7.9 | 86.7 | 7.7 | 69.2 | Gg C | Use of CARBINE biomass densities |
| 4C2.1 | Net carbon stock change in dead organic matter | 0.3 | 3.1 | 1.8 | 22.5 | Gg C | |
| 4C2.1 | Net carbon stock change in soils - mineral soils | 0.1 | 63.8 | 0.1 | 62.2 | Gg C | Revision of deforestation activity data |
| 4C2.3 | Carbon stock change in living biomass - gains | -3.5 | 0.0 | -3.5 | -0.2 | Gg C | Revision of peat extraction activity dataset |
| 4C1/4(V) | Biomass burning - wildfires | 0.347 | 0.149 | 0.344 | 0.151 | Gg CH$_4$ | Adjustment of average biomass densities due to error correction |
| 4C2.1/4(V) | Biomass burning - controlled burning | 0.051 | 0.563 | 0.060 | 0.574 | Gg CH$_4$ | Use of CARBINE biomass densities |
| 4C1/4(V) | Biomass burning - wildfires | 0.032 | 0.014 | 0.031 | 0.014 | Gg N$_2$O | Use of CARBINE biomass densities |
| 4C2.1/4(III) | Direct N$_2$O from N mineralisation | 0.000 | 0.067 | 0.000 | 0.065 | Gg N$_2$O | Revision of deforestation activity data |
| 4C2.1/4(V) | Biomass burning - controlled burning | 0.003 | 0.031 | 0.003 | 0.032 | Gg N$_2$O | Use of CARBINE biomass densities |

### 6.4.8 Category-Specific Planned Improvements

A BEIS-funded research project has been completed to improve understanding of the effect of grassland management practices on carbon stock changes in organic and organo-mineral soils. It is currently a draft. An initial review of the research results suggests standard grassland management practices in the UK do not have a significant impact on soil carbon that can be seprated from the soil carbon stock change associated with historic land-use change.

A vector based approach to tracking land-use change has been piloted in Scotland. It assimilates data to provide a more accurate assessment of land-use change history (Levy et al. 2018). Further implementation of this approach is under discussion, in addition to work building on the outcome of related projects on the potential of earth observation to track LUC in the UK. A method to improve the tracking of land-use change will be implemented after agreement on the approach at the NISC.

There is a small inconsistency in the reporting of hedgerow areas, as some hedges fall within the Boundary and Linear Feature Broad Habitat in the Settlement land-use category). All carbon stock changes explictly arising from changes in hedgerows are reported under 4.C Grassland (grassland management activities). A coordinated plan of improvements to the land-use change matrices is under consideration (see paragraph above), which will include resolving all remaining inconsistencies in the definitions and allocation of hedgerows.

The inventory improvement project to assimilate activity data and emission factors from the Wetlands Supplement implementation project into the LULUCF inventory (see box in **Section 6.5.8**) is undergoing final revisions and checks, which will enable further disaggregation of organic/mineral and drained/undrained soils in the LULUCF sector.

## 6.5 CATEGORY 4D – WETLANDS

### 6.5.1 Description

| Emissions sources | 4D Wetlands: Carbon stock change<br>4D Wetlands: 4(II) Non-$CO_2$ emissions from drainage of soils |
|---|---|
| Gases Reported | $CO_2$, $N_2O$ |
| Methods | Tier 1 |
| Emission Factors | Country specific and default EFs |
| Key Categories | None identified |
| Key Categories (Qualitative) | None identified |
| Completeness | No known omissions- areas are reported for land uses with no associated emissions. |
| Major improvements since last submission | None. |

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 6.9**.

Net emissions from the Wetlands category includes emissions from peatlands that are cleared and drained for peat production (for energy or horticultural purposes) and for areas converted to permanently flooded land (reservoirs). As most UK wetland habitats (e.g. marsh, bog, swamp and fen) are grazed their emissions and removals are estimated within the Grassland category. A research project (Evans *et al.* 2017) has been completed to identify UK-specific activity data and emission factors to use with the 2013 Wetlands Supplement methodology;

additional work to implement it in the GHGI methodology is underway (see 6.5.8 for further discussion).

Emissions from on-site peat production and off-site emissions from horticultural peat are reported under 4.D.1 Wetlands remaining Wetlands. Small areas of grassland converted to Wetland for peat extraction (4.D.2.1) and to flooded land (4.D.2.2) are reported under 4.D.2. The associated soil emissions and living biomass carbon stock changes estimated using the appropriate Tier 1 methodologies. $N_2O$ emissions from wetland drainage (as part of peat production) are reported under 4.D and 4(II).

The area of UK natural inland water is reported in the category Other Wetlands remaining Other Wetlands and the area of reservoirs created before 1990 is reported in Flooded Land remaining Flooded Land.

## 6.5.2 Information on approaches used for representing land areas and on land use databases used for the inventory preparation

The approach used for representing Wetlands differs from that used for other land use categories because peat extraction sites and reservoirs are not explicitly identified in the habitat and landscape surveys used for the land use matrix.

Data from the Directory of Mines and Quarries, Google Earth, the Minerals Extraction in Great Britain report (and its predecessor the Minerals Raised Inquiry, Office for National Statistics), and papers on peat extraction in Northern Ireland were used in combination to produce an activity dataset for active peat extraction areas in the UK (see **Annex 3.4.8** for further details).

Activity data for post-1990 constructed reservoirs were compiled from the Public Register of Large Raised Reservoirs (supplied by the Environment Agency for England and Wales) and the SEPA Water Body Classification database (see **Annex 3.4.9** for further details).

The remaining area of inland water (natural water bodies and reservoirs established before 1990) is known from the area of inland water reported as part of the Standard Area Measurement. There are no emissions or removals associated with this area.

## 6.5.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

Areas of peat extraction are defined as areas that are currently undergoing, or have recently undergone, peat extraction activities (locations are known from administrative records: see Section 6.5.2). It is assumed that extraction areas continue to produce emissions while there is visible evidence of exposed peat soil from Google Earth satellite imagery. An extraction site is considered to have ceased emissions when there is visible evidence of the re-establishment of vegetation cover on the satellite imagery. This is further supported where possible with online documentation of the restoration works and communication with site managers.

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 a Tier 1 methodology, which does not distinguish between peat extraction production phases, i.e. it includes conversion and vegetation clearing. On-site emissions associated with peat extraction are reported under 4.D.1.1. All carbon in horticultural peat is assumed to be emitted during the extraction year. Methane emissions are assumed to be insignificant. $N_2O$ emissions from drainage are reported, although emissions are considered insignificant on nutrient-poor peatlands. The administrative records categorise sites as producing horticultural or energy source (fuel) peat. This information is used to extract the area of nutrient-rich peats that will produce $N_2O$ emissions, following the IPCC Tier 1 methodology. Further information is given in **Annex 3.4.8**.

Google Earth imagery is used to track the change in the area of individual extraction sites over time. Google Earth is imagery is checked annually and extraction site areas are updated as new imagery becomes available.

The site records show that the area under active peat extraction diminished between 1990 and 2002 for Great Britain and 1991 and 2007 for Northern Ireland. Sites that have no active record of extraction, and show no change in area on the Google Earth imagery, are assumed to be abandoned extraction sites that are still producing emissions (reported under 4D1). Sites where extraction is no longer visible on the Google Earth imagery are assumed to have been converted to Grassland. As these sites are often part of peatland restoration schemes managed by UK nature reserves, information on site history and success of the restoration works are gathered online and from reserve managers to support the land-use change. Changes in biomass carbon and organic soil carbon from this land-use change are reported using the Tier 1 approach from the IPCC 2006 Guidelines.

A small area of land conversion to Wetlands occurs in 2003, 2005, and 2018-18 which is assumed to be all from Grassland based on the examination of Google Earth imagery. This area and the associated on-site emissions are reported under 4D.2 Land converted to Wetlands, using the 5-year transition period recommended by the IPCC 2006 Guidelines.

#### 6.5.4.2 Land converted to Flooded Land

A Tier 1 methodology was applied for emissions from Flooded Lands. This estimated carbon stock changes in living biomass stock in the year of flooding (for reservoirs established since 1990) but not carbon stock changes in soils. The locations of the reservoirs was established on maps, and due to their location in upland areas, all were assumed to be Grassland prior to flooding. A living biomass density of 2 t dry matter/ha was used to estimate carbon stock losses.

### 6.5.5 Uncertainties and Time-Series Consistency

4D Wetland is estimated to have a combined uncertainty of 100% for $CO_2$ and 100% for $N_2O$.

Uncertainties in the emission factors for peat extracted for horticultural and fuel use and for emissions from Flooded Land are the default IPCC values given in the 2006 Guidelines. Uncertainty in the Flooded Land activity data is very low as there have only been five reservoirs established since 1990 and their extents are well quantified.

Time-series consistency for activity data for peat extraction sites is affected by uncertainty in survey dates. Time- series consistency for flooded lands was good due to the complete nature of the data set.

The 4D category is not key but the sub-category 4D1.1 "Peat extraction remaining Peat extraction" accounts for 99-100% of net emissions from this category.

### 6.5.6  Category-Specific QA/QC and Verification

The peat extraction site activity dataset has been partially verified by comparing the measured areas with reported areas of planning permission, which were available for some extraction sites in England and Scotland. The measured areas either matched or were smaller than the planning permission areas, which is to be expected as it is known that not all areas with planning permission are undergoing active extraction.

The locations and previous land-use of new reservoirs were verified using the www.magic.gov.uk geographic information portal.

### 6.5.7  Category-Specific Recalculations

The reported overall net GHG source in category 4D did not change in the latest submission compared to the 1990-2017 inventory.

### 6.5.8  Category-specific planned improvements

A BEIS-funded project to implement the Wetlands Supplement (IPCC, 2013a) guidance has been published (Evans et al. 2019) (see box). During 2019 the compilation and reporting of the LULUCF sector was adapted to take account of these research results and there was a review of recently published scientific literature to identify new emissions data. Rigorous QA/QC has been done to ensure that all assumptions and expert judgment are fully justified and robust: this is essential to build confidence domestically in the new dataset and to ensure that it passes expert scrutiny during international review.Due to the complexity of the new data, QA/QC has been time-consuming and was not completed in time for inclusion in the 2020 submission.

**Implementing the IPCC 2013 Wetlands Supplement in the UK**

BEIS funded a research project (Evans *et al.* 2019) to develop and implement a new method for reporting GHG emissions from peatlands (highly organic soils) in the UK's emissions inventory.

The project:

- Collated and analysed UK-relevant measurement data to develop Tier 2 EFs for the broad range of peat condition categories present in the UK;
- Developed methods to quantify current status and change in peat condition since 1990, based on a new 'unified' map of peat extent for all four UK countries, collated spatial land cover and peat condition datasets, and records of peat restoration and management activities; and
- Implemented an emissions inventory for UK peatlands and assessed the associated uncertainties.

Peatland condition categories comprised near-natural peatlands, semi-natural peatlands affected by human activity (such as drainage, controlled burning and livestock grazing), cropland, extensive and intensive grassland, woodland, peat extraction areas and active peatland restoration areas. Peatland soils occur in all LULUCF categories in the UK apart from 4E Settlement, 4F Other Land and 4G Harvested Wood Products. The KP-LULUCF categories of Deforestation, Forest Management, Cropland Management, Grazing Land Management and Wetland Drainage and Rewetting will also be affected.

Tier 2 EFs and 95% confidence intervals were derived for $CO_2$, $CH_4$ and $N_2O$ for each peatland condition category. It was not possible to quantify uncertainties for the activity data, and consequently more than 50% of the total emissions calculated by the project could only be estimated with a low level of confidence.

Next steps:

- Completion of QC checks of the Tier 2 emission factors and peat condition maps (particularly for rewetted sub-categories) and full documentation of the statistical methods used for EF analysis (Summer 2020). Consideration by the NISC and incorporation of any recommendations (Anticipated September 2020).
- Sign-off by the NISC (Dependent on progress in previous steps).

## 6.6 CATEGORY 4E – SETTLEMENTS

### 6.6.1 Description

| Emissions sources | 4E Settlements: Carbon stock change<br>4E Settlements: 4(III) Direct $N_2O$ emissions from N mineralization<br>4E Settlements: 4(V) Biomass burning |
|---|---|
| Gases Reported | $CO_2$, $CH_4$, $N_2O$ |
| Methods | T3 for carbon stock changes, T1 for other emissions |
| Emission Factors | Country-specific for T3 methods, T1/2 for other emissions |
| Key Categories | 4E: Settlements – $CO_2$ (L1, T1, L2, T2) |
| Key Categories (Qualitative) | None identified |
| Completeness | No known omissions- areas are reported for land uses with no associated emissions. |
| Major improvements since last submission | Updates to activity data for Forest Land converted to Settlements have increased carbon stock changes and emissions from controlled burning slightly. |

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 6.9**.

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 soil net carbon stock changes are the largest component of the category total emissions, and are calculated using a Tier 3 dynamic soil carbon model.

Other contributors to the Settlements net total emissions are:

- biomass carbon stock changes due to LUC;
- $N_2O$ 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 for details).

Data sources that contain area information for reporting carbon stock changes and/or emissions from Settlements are:

- Habitat/landscape surveys

- o Countryside Survey (1984, 1990, 2000, 2007) is used to compile land use transition matrices.
- Data on deforestation areas from various sources;
    - o Post-2000 deforestation areas are assessed from the NFI and administrative records of the conversion of areas in the public forest estate as art of habitat restoration and windfarm development.
    - o Pre-2000 deforestation areas are estimated from unconditional felling licence data (felling licences granted without a requirement to restock), national forest estate administrative information and land conversion ratios from Countryside Survey. Details are given in **Annex 3.4.4**.

## 6.6.3 Land-use definitions and the classification system used and their correspondence to the LULUCF categories

Settlement is defined in accordance with the Agriculture, Forestry and Other Land Use Guidance (IPCC 2006).

For pre-1980 LUC Settlement land is the sum of the Built-up, Urban open, Transport, Mineral workings and Derelict land cover types in the Monitoring Landscape Change project (MLC 1986). For post-1980 LUC, Settlement land corresponds to the "Built-up and Gardens" and "Boundary and linear features" Broad Habitat types in the Countryside Survey (Haines-Young *et al.* 2000, Appendix A), defined as:

- Built-up and Gardens: "Covers urban and rural settlements, farm buildings, caravan parks and other man-made built structures such as industrial estates, retail parks, waste and derelict ground, urban parkland and urban transport infrastructure. It also includes domestic gardens and allotments."; and
- Boundary and linear features: "a diverse range of linearly arranged landscape features such as hedgerows, walls, stone and earth banks, grass strips and dry ditches. This habitat type also includes some of the built components of the rural landscape including roads, tracks and railways and their associated narrow verges of semi-natural habitat."

Although hedgerows are included in the definition of the "Boundary and linear features" Broad Habitat type, any carbon stock changes associated with hedgerow change are calculated separately under grassland management. The "Boundary and linear features" Broad Habitat type is a very small component of the UK land area (<2% in the 2007 Countryside Survey) so the overlap in definitions will not materially affect net LULUCF emissions.

## 6.6.4 Methodological Issues

### 6.6.4.1 Land-Use Change

A summary of the land use matrix approach and the dynamic model of soil carbon stock change used to estimate changes in biomass and soil carbon due to LUC is given in **Section 6.3.4**. Detailed descriptions of the methods, emission factors and data flows used for the Settlement category are given in **Annex 3.4.7**.

$N_2O$ emissions associated with the soil disturbance from LUC are reported using the areas from the LUC matrices and the IPCC Tier 1 emission factors.

### 6.6.4.2 Biomass burning emissions

Emissions from controlled burning on settlement land are only reported for Forest Land conversion to Settlements and are estimated using Tier 1 emission factors and country-specific fuel densities.

### 6.6.5  Uncertainties and Time-Series Consistency

4E Settlement is estimated to have a combined uncertainty of 50% for $CO_2$, 55% for $CH_4$ and 15-135% for $N_2O$.

The areas undergoing land-use change are the biggest source of uncertainty in the LULUCF inventory (see **Annex 3.4.12**), but model choice and soil carbon parameters are also significant.

With regard to time series consistency:

- Changes in biomass and soil carbon due to LUC: the data sources for Great Britain have maintained consistent methodology across the time series. Consistency between these and Northern Ireland data sources has improved with better methodological integration between land use surveys.

- Controlled biomass burning after conversion of Forest Land to Settlement: there is good time series consistency as there has been continuity in the activity data source.

A significance analysis has been undertaken for key categories in the LULUCF sector. In Settlement 4.E2.3 Grassland converted to Settlement is the most significant sub-category (**Table 6.12**Table 6.10).

**Table 6.12     Significance analysis of the Settlement category**

| Sub-category | Pool | Percentage contribution to total[1] | |
|---|---|---|---|
| | | **1990** | **2018** |
| **E1. Settlements remaining Settlements** | | **23%** | **34%** |
| | Net carbon stock change in soils | 21% | 32% |
| **E2.1. Forest Land converted to Settlements** | | **2%** | **11%** |
| **E2.2. Cropland converted to Settlements** | | **12%** | **12%** |
| **E2.3. Grassland converted to Settlements** | | **63%** | **43%** |
| | Carbon stock change in living biomass | 0% | 0% |
| | Net carbon stock change in soils | 57% | 39% |

[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 increased slightly by up to 0.2 Mt $CO_2e$ (0-1 %) across the time series compared to the 1990-2017 inventory. The changes were in controlled burning and in biomass carbon stock change in Forest Land converted to Settlement.

The changes and their justification are:

- **Use of CARBINE estimates for biomass lost during deforestation**: Biomass lost during deforestation is now estimated using the CARBINE model rather than using average biomass densities with the deforested area time series. This affects emissions from controlled burning and carbon stock changes following deforestation.

- **Revision of deforestation activity data**: The deforestation time series 1990-1999 was revised to use the same precision as reprocessed Countryside Survey data (QA improvement). Areas for England 2017-18 from the latest statistical report.

Changes in emissions are described in **Table 6.13**.

**Table 6.13      4E Category specific recalculations to activity data since previous submission**

| IPCC Category | Source Name | 2018 Submission | | 2020 Submission | | Units | Comment / Justification |
|---|---|---|---|---|---|---|---|
| | | 1990 | 2017 | 1990 | 2017 | | |
| 4E2.1/4(V) | Biomass burning - controlled burning | 10.9 | 30.0 | 12.7 | 41.7 | Gg C | Use of CARBINE biomass densities |
| 4E2.1 | Carbon stock change in living biomass - losses | 18.6 | 50.8 | 18.0 | 56.3 | Gg C | Use of CARBINE biomass densities |
| 4E2.1 | Net carbon stock change in dead organic matter | 0.6 | 1.8 | 4.2 | 16.8 | Gg C | |
| 4E2.1 | Net carbon stock change in soils - mineral soils | 10.4 | 77.5 | 10.4 | 82.0 | Gg C | Revision of deforestation activity data |
| 4E2.1/4(V) | Biomass burning - controlled burning | 0.120 | 0.330 | 0.139 | 0.458 | Gg $CH_4$ | Use of CARBINE biomass densities |
| 4E2.1/4(III) | Direct $N_2O$ from N mineralisation | 0.011 | 0.081 | 0.011 | 0.086 | Gg $N_2O$ | Revision of deforestation activity data |
| 4E2.1/4(V) | Biomass burning - controlled burning | 0.007 | 0.018 | 0.008 | 0.025 | Gg $N_2O$ | Use of CARBINE biomass densities |

### 6.6.8  Category-Specific Planned Improvements

A vector based approach to tracking land-use change has been piloted in Scotland. It assimilates data to provide a more accurate assessment of land-use change history in the UK (Levy et al. 2018). Further implementation of this approach at the UK scale is under discussion, in addition to work building on the outcome of related projects on the potential of earth observation to track LUC in the UK. A method to improve the tracking of land-use change will be implemented after agreement on the approach at the NISC.

There is a small inconsistency in the reporting of hedgerow areas, as some hedges fall within the Boundary and Linear Feature Broad Habitat in the Settlement land-use category). All carbon stock changes explictly arising from changes in hedgerows are reported under 4.C Grassland (grassland management activities). A coordinated plan of improvements to the land-use change matrices is under consideration (see **Section 6.4.8**), which will include resolving all remaining inconsistencies in the definitions and allocation of hedgerows.

## 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**

### 6.7.3  Land-use definitions and the classification system used and their correspondence to the LULUCF categories

Other Land is defined as areas that do not fall into the other land use categories. For pre-1980 land use matrices Other Land is the sum of the bare rock, sand/shingle, inland water and coastal water land cover types in the Monitoring Landscape Change project (MLC 1986). Post-1980, Other Land contains the inland rock, standing water and canals and rivers and streams broad habitat types in the Countryside Survey (Jackson, 2000). As described in **Section 6.5**,

areas of inland water exceeding 1km$^2$ are included in 4D Wetlands, but water bodies below this threshold would still be included under Other Land.

### 6.7.4 Category-specific recalculations

There are no emissions associated with Other Land and no recalculations.

### 6.7.5 Category-specific planned improvements

None planned.

## 6.8 CATEGORY 4G – HARVESTED WOOD PRODUCTS

### 6.8.1 Description

| | |
|---|---|
| Emissions sources | 4G Harvested Wood Products |
| Gases Reported | $CO_2$ |
| Methods | Tier 3 |
| Emission Factors | Country-specific |
| Key Categories | 4G Harvested Wood Products – $CO_2$ (T1, T2) |
| Key Categories (Qualitative) | None identified |
| Completeness | No known omissions |
| Major improvements since last submission | Activity data on historic forest planting rates have been adjusted after reconciliation of harvest volume and forest age data. This affects the modelled timing and quantity of harvested wood products. Corrected the half-life applied to palletwood to use the sawnwood half-life of 35 years, not 25 years. |

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 45% for $CO_2$.

These uncertainties are based on a new uncertainty analysis that has been completed in 2019, broadly following the methodology of the previous uncertainty analysis, but using the latest version of the CARBINE model. 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 6.14**Table 6.10).

**Table 6.14        Significance analysis of the Harvested Wood Products category**

| Sub-category | Pool | Percentage contribution to total | |
|---|---|---|---|
| | | **1990** | **2018** |
| **HWP Produced and Consumed Domestically** | | **85%** | **92%** |
| | Paper and Paperboard | 11% | 0% |
| | Solid Wood | 75% | 93% |
| | Wood panels | 42% | 38% |
| **HWP Produced and Exported** | | **15%** | **8%** |

## 6.8.4  Category-Specific QA/QC and Verification

This source category is covered by the general QA/QC procedures, which are discussed in **Section 6.11**. 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 increased by 0.1 to 0.7 Mt $CO_2$e across the time series, apart from 2012 where there was a 0.5 Mt $CO_2$e reduction in the net sink, (-14 to +55%) compared to the 1990-2017 inventory.

The changes resulted from the automated reconciliation of harvest volume and change data reacting to the extended wood production time series, as described in **Section 6.2.7**.

The changes are described in **Table 6.15**.

**Table 6.15        4G Category specific recalculations to activity data since previous submission**

| IPCC Category | Source Name | 2019 Submission | | 2020 Submission | | Units | Comment / Justification |
|---|---|---|---|---|---|---|---|
| | | 1990 | 2017 | 1990 | 2017 | | |
| 4G | Total HWP from domestic harvest | -447.0 | -549.7 | -571.8 | -647.5 | Gg C | Reconciliation of harvest volume and forest age data. |

### 6.8.6 Category-Specific Planned Improvements

There will be an updated uncertainty analysis to better quantify the uncertainties from varying the parameters of the CARBINE model. This will be a revision of the uncertainty analysis published in the 1990-2010 National Inventory Report.

## 6.9 LULUCF EMISSIONS AND REMOVALS IN THE OVERSEAS TERRITORIES AND CROWN DEPENDENCIES

### 6.9.1 Description

| Emissions sources | Carbon stock change: 4A Forest Land, 4B Cropland, 4C Grassland, 4D Wetlands, 4E Settlements, 4G Harvested Wood Products<br>4(III) Direct $N_2O$ emissions from N mineralization (4B Cropland, 4C Grassland, 4E Settlements)<br>4(V) Biomass Burning (4A Forest Land, 4C Grassland) |
|---|---|
| Gases Reported | $CO_2$, $CH_4$, $N_2O$ |
| Methods | Tier 1 (Tier 3 for Forest Land) |
| Emission Factors | Default EFs |
| Key Categories | None identified |
| Key Categories (Qualitative) | None identified |
| Completeness | Not estimated: Grassland drained organic soils, |
| Major improvements since last submission | Inclusion of Gibraltar, Cayman Islands and Bermuda areas and net emissions. Inclusion of GHG emissions from wildfires. |

GHG emissions and removals from the UK Crown Dependencies (CD) and Overseas Territories (OT) are reported under the relevant categories for the LULUCF sector in the CRF GBR and GBK (omitting Bermuda) submissions (**Table 6.16**). 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 6.16        LULUCF Sector in all Overseas Territories and Crown Dependencies (Mt $CO_2e$)**

| LULUCF Categories | 1990 emissions total | | 2017 emissions total | | 2018 emissions total | | Recalculations 1990 | | Recalculations 2017 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Submission** | GBK | GBR | GBK | GBR | GBK | GBR | GBK | GBR | GBK | GBR |
| Total LULUCF | 0.259 | 0.265 | 0.299 | 0.265 | 0.299 | 0.304 | 0.274 | 0.280 | 0.299 | 0.265 |
| A. Forest Land | -0.033 | -0.033 | -0.035 | -0.033 | -0.034 | -0.034 | 0.004 | 0.004 | 0.003 | 0.005 |
| B. Cropland | 0.011 | 0.011 | 0.036 | 0.011 | 0.036 | 0.036 | - | - | -0.000 | -0.025 |
| C. Grassland | 0.190 | 0.190 | 0.171 | 0.190 | 0.170 | 0.170 | 0.198 | 0.198 | 0.198 | 0.218 |

| LULUCF Categories | 1990 emissions total | | 2017emissions total | | 2018 emissions total | | Recalculations 1990 | | Recalculations 2017 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Submission** | GBK | GBR | GBK | GBR | GBK | GBR | GBK | GBR | GBK | GBR |
| D. Wetlands | - | - | - | - | - | - | - | - | - | - |
| E.Settlements | 0.092 | 0.098 | 0.127 | 0.098 | 0.127 | 0.133 | 0.072 | 0.078 | 0.098 | 0.069 |
| G. Harvested Wood Products | - 0.000 | - 0.000 | 0.000 | - 0.000 | 0.000 | 0.000 | - | - | - | - 0.000 |
| Indirect N$_2$O emissions | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | - | 0.000 | 0.000 | - 0.000 |

The Forest Land category is a net sink 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, driven by $CO_2$ emissions from organic soils in the Falkland Islands and Cayman Islands. 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 source, with net sources in cropland and settlement counterbalanced by net sinks in forest and grassland
- Jersey: moves from being a small net source to a small net sink from 2017 onwards.
- Falkland Islands: slowly increasing net source, due to disturbance of organic soils and expansion of settlement
- Cayman Islands: stable net source 1990-2006, then increasing net source due to conversion of mangrove (organic) soils to settlement
- Bermuda: small stable net source across the time series.

## 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. It has not been possible to obtain the necessary input data to apply the CARBINE model to forest land in the OTs and CDs. A Tier 3 method using the forest carbon model C-Flow has been applied for forestry in the Isle of Man and Guernsey, and a Tier 1 method has been used to estimate forest carbon stock changes for the Cayman Islands and Bermuda. The UK proposes to use a Tier 1 approach for estimating forest land carbon

stock changes for all OTs and CDs in the 2021 submission - there was not sufficient time to implement a Tier 1 approach for all non-UK terrritories in this submission. 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 a 0.280 Mt $CO_2e$ increase in the net source in 1990 and a 0.304 Mt $CO_2e$ increase in the net source in 2017.

These changes are due to the inclusion of net emissions from the Cayman Islands and Bermuda to achieve more complete reporting, and the reporting of emissions for activities reported as insignificant in the 1990-2017 inventory, as the insignificance threshold cannot be applied to geographical sub-regions within a category for which emissions are already reported (as is the case for wildfires). There were also changes made to improve the consistency between the assumptions and calculations made for each OT/CD, as calculations were transferred from a spreadsheet to a coded model.

Emissions from wildfires on forest land and grassland have been included for the first time. These emissions are calculated using Tier 1 methodology, following the geographical proxy guidelines. The calculations for forest wildfires in Guernsey, Jersey and Isle of Man are based on the rate of burning in UK forests, and those for the Cayman Islands are based on the rate of burning in Cuba. The calculations for grassland wildfires in Guernsey, Jersey, Isle of Man, the Falkland Islands and the Cayman Islands are based on the rate of burning of UK grassland as a geographical proxy (with no closer proxy available for the Falkland Islands and the Cayman Islands). There is no forest land in the Falkland Islands and the fire statistics for Bermuda state zero forest area burnt.

### 6.9.5 Planned improvements

Net emissions from forest land in all OTs and CDs will be calculated using the Tier 1 method in the next submission, as this will improve consistency and ease of processing. There will be improvements to the land use matrix to ensure consistency in total areas and land use transitions.

## 6.10 INDIRECT N₂O 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 and the fraction of N that is volatilised from inorganic fertiliser N applications to forest land (FracGasF). 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)). The default IPCC (2006) FracLEACH values are used for both sources.

## 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 began in 2016. This includes verification of model calculations, improvement of documentation, addition of built in QA checks and storage in a version control repository. So far nine LULUCF models have been upgraded. A Microsoft Access database is used to compile all the LULUCF inventory numbers and associated data. This database is used to produce consistent outputs for the CRF and other national and international reporting requirements, and for archiving purposes.

Issue management software is used for project management and tracking issues such as recording requests for data from stakeholders and external parties.

In collaboration with Ricardo Energy & Environment, 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<br>5B: Biological Treatment of Solid Waste<br>5C: Waste Incineration<br>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)<br>5B: Biological treatment of waste – $CH_4$ (T1, L2, T2)<br>5B: Biological treatment of waste – $N_2O$ (L2, T2)<br>5C: Waste incineration – $CO_2$ (L2, T2)<br>5D: Wastewater handling – $CH_4$ (L1, T1, L2)<br>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.<br>A general assessment of completeness for the inventory is included in **Section 1.8**. |
| Major improvements since last submission | 5C1: Previously, carbon emission factors for the incineration of municipal solid waste (MSW) were based on uncertain UK-specific data. The Inventory Agency considers this approach is no longer justified, and so have reverted to the use of IPCC Tier 1 default emission factors. Additionally, biodegradable waste emissions from incineration are calculated for the first time, using IPCC Tier 1 default emission factors. |

Emissions from the waste sector contributed 5.0% to greenhouse gas emissions in 2018 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 69% since 1990. This is mostly due to the implementation of methane recovery systems at UK landfill sites and reductions in the amount of waste disposed of at landfill sites.

**Figure 7.1** **Breakdown of total GHG emissions from the Waste sector in the latest inventory year[76]**



- 5A = 69.6%
- 5B = 9.2%
- 5C = 1.4%
- 5D = 19.9%
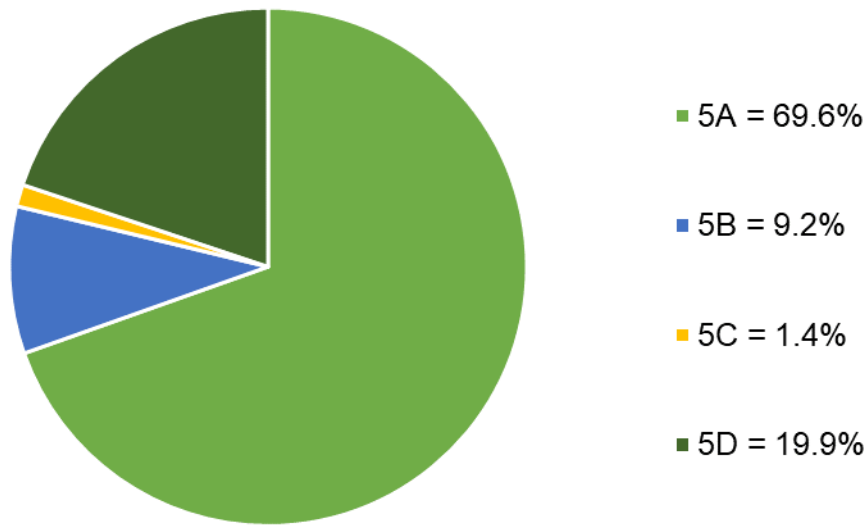
**Figure 7.2** **Trend in total GHG emissions in the Waste sector**



- N2O
- CH4
- CO2

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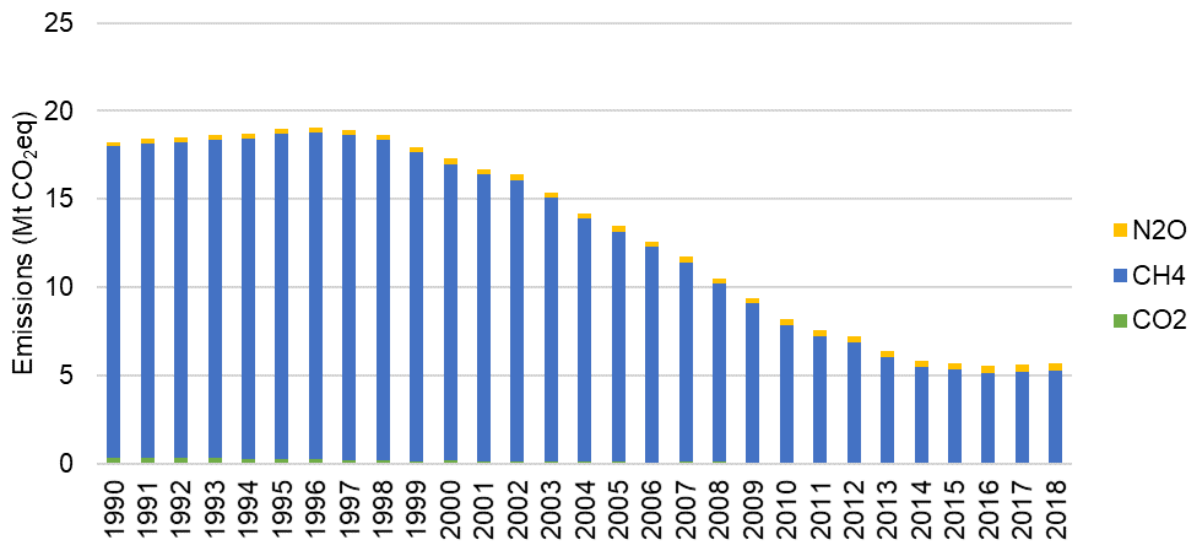
[76] The categories in the Waste sector are explained in the IPCC categories section.

## 7.2 SOURCE CATEGORY 5A – SOLID WASTE DISPOSAL ON LAND

### 7.2.1 Source category description

| Emissions sources | Sources included | Method | Emission Factors |
|---|---|---|---|
| | 5A: Landfill | OTH, T2 | CS |
| Gases Reported | $CH_4$, NMVOC | | |
| Key Categories | 5A: Solid waste disposal - $CH_4$ (L1, T1, L2, T2) | | |
| Key Categories (Qualitative) | None identified | | |
| Overseas Territories and Crown Dependencies Reporting | OT & CD emissions for 5A are included as a separate category within 5A. | | |
| Completeness | No known omissions. A general assessment of completeness for the inventory is included in **Section 1.8**. | | |
| Major improvements since last submission | Data on the quantity of waste landfilled, methane collection and combustion in landfill gas engines and flares have been updated. | | |

The NAEI category "Landfill" maps directly on to IPCC category 5A Solid Waste Disposal for methane emissions. Emissions are reported from Solid Waste Disposal Sites (SWDS – also known as landfills) that started receiving waste in 1980, when legislative changes took effect to improve management of landfill sites, and old unmanaged waste disposal sites that closed prior to 1980. Emissions from the use of landfill gas to generate power are reported in IPCC sector 1A1a (see MS1).

Estimated emissions from this sector in 2018 were 14.4 Mt $CO_2$e. Emissions have been on a downward trend since 1996, although emissions in 2017 and 2018 were marginally higher than in 2016.

In addition to $CH_4$, anaerobic decomposition also produces an approximately equivalent amount of carbon dioxide and further $CO_2$ is also produced by aerobic decomposition processes. However, as the decaying organic matter originates from biomass sources derived from contemporary crops and forests, we do not need to consider the greenhouse impacts of this carbon dioxide. Waste also contains fossil-derived organic matter, predominantly in the form of plastics, but these are essentially non-biodegradable under landfill conditions, and so emissions of fossil-derived $CO_2$ from solid waste disposal sites (SWDS) are not considered further. Emissions of $CO_2$ from landfills are not estimated as they are considered to be entirely biogenic in origin and therefore not counted towards the national total as this would introduce a double count with net carbon losses reported in the LULUCF sector.

Non-methane volatile organic compounds (NMVOCs) are also released by SWDS. These are estimated using an emission factor relating the NMVOC to the amount of $CH_4$ emitted. An emission factor of 0.0036 kg NMVOC/tonne landfill gas was used (Broomfield et al., 2010).

The 2006 guidelines confirm that nitrous oxide emissions from SWDS are not significant.

The amount of methane emitted from landfills depends primarily on the amount of carbon in biodegradable waste landfilled and how the sites are operated to reduce the escape of the methane produced from such wastes. Policy measures to reduce methane emissions from landfills have focused on both these aspects. Diverting biodegradable waste away from landfill

avoids the future formation of methane, but landfills continue to produce $CH_4$ for many years from waste that has already been deposited. Improving the efficiency of gas capture from landfills results in an immediate reduction in emissions, but is by nature an "end of pipe" solution, which does not itself prevent the formation of methane. In practice, a combination of measures based on both reducing the amount of biodegradable waste landfilled and improving the management of sites have, in the UK, provided the foundations for reducing emissions from this source. These two broad approaches are outlined below.

The most important legislative and regulatory measures which have reduced the emissions of methane from UK landfills derive from the 1999 Landfill Directive (1999/31/EC). The requirements of the Directive were transposed into national legislation through the Landfill (England and Wales) Regulations 2002, subsequently amended in 2004 and 2005 to transpose the requirements of Council Decision 2003/33/EC on Waste Acceptance Criteria. The provisions were re-transposed 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)[77] decay under the airless conditions in landfills to form methane, carbon dioxide and a variety of stable decomposition products that remain in the landfill, and represent a sink for carbon. First order means that the rate of reaction is proportional to the amount of reactant (i.e. DDOC) present at any given time. This means that as the reactant is used up, the rate of reaction slows down.

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

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[77]  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).

$$
\textbf{EQUATION 3.1} \\
\textbf{CH}_4 \textbf{ EMISSION FROM SWDS} \\
CH_4 \; Emissions = \left[ \sum_x CH_4 \; generated_{x,T} - R_T \right] \bullet (1 - OX_T)
$$

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.

$$
\textbf{EQUATION 3.2} \\
\textbf{DECOMPOSABLE DOC FROM WASTE DISPOSAL DATA} \\
DDOCm = W \bullet DOC \bullet DOC_f \bullet MCF
$$

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% |

| | Lignin | Hemicellulose | Cellulose | Starch | Sugar | Fat | Proteins | Fibre | Readily soluble | Inert |
|---|---|---|---|---|---|---|---|---|---|---|
| Soil and other organic | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 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**.

- o Lignin     65.1% dry matter
- o Hemicellulose     44.6% dry matter
- o Cellulose     40.0% dry matter
- o Starch     44.4% dry matter
- o Sugar     42.1% dry matter
- o Fat     76.0% dry matter
- o Proteins     40.0% dry matter
- o Fibre     45.0% dry matter
- o Readily soluble     45.0% dry matter
- o 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 DOCf 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% |

| Component | Moisture content (% fresh matter) | Lignin bio-degradability DOC$_f$ | Non-lignin bio-degradability DOC$_f$ |
|---|---|---|---|
| Miscellaneous combustible | 20% | 5.0% | 65.0% |
| 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 7.1and 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 L₀**

$$L_o = DDOCm \bullet F \bullet 16/12$$

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:

- o The mass of DDOC remaining from the preceding year
- o Plus the mass of DDOC landfilled in that year
- o 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:

- o Rapidly decaying waste: Starch, Sugar, Fat, Proteins, Fibre, Readily soluble
- o Medium decaying waste: Hemicellulose, Cellulose
- o 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**
**CH₄ GENERATED FROM DECAYED DDOCm**

$$CH_4 \, generated_T = DDOCm \, decomp_T \bullet F \bullet 16/12$$

The values used tor DOC and DOCf for different material types, and the composition of different material types, are set out in **Table A3.5.2**.

The total methane generated in each inventory year is determined by summing the quantity of methane emitted over all waste types, all three decomposition pools, all landfill types, and all years in which the waste is landfilled.

A Methane Correction Factor (MCF) is used as a multiplier on methane formation to reflect the fact that shallow or unmanaged disposal sites do not develop extensive anaerobic conditions typical of modern landfills and hence a proportion of waste decays aerobically and does not produce methane. For modern landfills, the MCF term is given the value of 1 (IPCC 2006 Table 3.1), but the Guidelines allow the use of a 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 2018 are published by the Environment Agency.
- Data on waste consignments landfilled in Scotland for the period 2005 to 2018 are published by the Scottish Environmental Protection Agency.
- Data on waste consignments landfilled in Wales for the period 2006 to 2018 are published by Natural Resources Wales.
- Data on waste consignments landfilled in Northern Ireland for the period 2008 to 2018 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)
$\times$ 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, 2019), is given in **Table A 3.5.4**. In 2018, 3916 GWh renewable electricity was generated from combustion of landfill gas. Carbon dioxide emitted from the combustion of landfill gas is biogenic in origin and is therefore not reported.

### 7.2.3.3 Flaring

Since 2009, operators of landfills in England and Wales permitted under the Integrated Pollution Prevention and Control (IPPC) Directive have been required to report the annual quantity of methane flared at the regulated sites under the terms of their operating permits. As it has been obtained under the terms of IPPC operating permits, this data has documentation and quality control built in via the permitting procedures and operator obligations at an individual site level. The use of this dataset is therefore a robust and appropriate basis on which to evaluate the quantities of methane flared by operators. Based on guidance from the Expert Review of the 2013 GHG Inventory (para 98 of the 2013 Annual Review Report), this dataset was used to estimate the quantity of methane flared at landfill sites in England and Wales in 2008.

Similarly, landfill site operators in Scotland have been required to compile a similar annual report on the quantity of landfill gas flared since 2013. This dataset was used to evaluate the quantity of methane flared by operators at landfill sites in Scotland from 2013 onwards.

Further work was commissioned by BEIS (then DECC) to identify all reasonably available data on the quantities of methane flared at landfill sites in England, Scotland and Wales for other years (DECC, 2015). This project identified some additional site-specific data which was also taken into account in compiling the inventory. Additionally, landfill operators voluntarily provided further site-specific data on the quantities of methane flared at older sites without a reporting requirement set in permit conditions for 2010 to 2015.

The landfill methane flaring data provided represents information for approximately 250 individual sites in 2018. Data checking/validation therefore relies on the regulatory authorities and processes, rather than comprising additional checks on individual operators. The information on landfill gas flaring is provided via under the Environmental Permitting (England/Wales) and Pollution Prevention and Control (Scotland/Northern Ireland) regulatory processes. This information is consequently subject to quality obligations under these regulations, as with any other information reported to the regulatory authorities by regulated process operators under the terms of their operating permits. The data is then forwarded to the compilation agency by each regulatory authority.

At all other sites and inventory years, robust data on landfill gas flaring was not available, and it was conservatively assumed that no landfill gas was flared.

The estimates shown in **Table A 3.5.4** are based on the estimate of methane used for power generation added to the estimated quantity of methane flared. The minor proportion of landfill gas used for non-electricity generation purposes such as direct use and as a vehicle fuel is neglected in these calculations due to a lack of data, and assumed to be emitted to the atmosphere as a conservative assumption.

### 7.2.3.4 Overseas Territories and Crown Dependencies

The IPCC landfill model is used for all landfill estimates. Where available, country-specific waste generation and composition data have been applied and appropriate defaults have been chosen e.g. taking into account climatic variation. There are no landfill emissions for Gibraltar as waste is exported. Parameters used in these calculations are shown in **Annex 3.5**.

## 7.2.4 Uncertainties and time-series consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and fuel type. There are many uncertainties in estimating methane emissions from landfill sites. The model is sensitive to the values assumed for the degradable organic carbon (DOC) present in different fractions of waste, and the amount of this that is dissimilable (i.e. is converted to methane and carbon dioxide), as well as to the quantity of methane

combusted in engines and flares, and the oxidation factor. A recent programme of work has assisted in reducing these uncertainties. The uncertainty estimates in **Annex 2** are intended to reflect the current uncertainties in data and model parameters.

The estimates for all years have been calculated from the MELMod model and thus the methodology is consistent throughout the time series. Estimates of waste composition and quantities have been taken from different sources as described in **Section 7.2.3.** The new sources of data on waste receipts from 2005 – 2008 onwards are considered to be more robust and consistent than the previous combination of data sources. The approach to calculating DDOC, the main driver behind methane formation, was reviewed and updated in 2011, and was endorsed by peer reviewers.

Uncertainty in the quantity of methane collected is also an important contributory factor to uncertainty in the calculation of overall landfill methane emissions. Uncertainties in the key components of this calculation are as follows.

- Current and historical combustion of methane in landfill gas engines: Reliable data on methane collected for power generation are available, based on national statistics for energy generated from landfill gas engines (BEIS 2018). The methane to carbon dioxide ratio of gas burnt in landfill gas engines is assumed to be 50:50, following the IPCC default approach. Gas engine efficiency is assumed to be 30% up to 1996, increasing linearly to 36% in 2012 and thereafter, following peer review (Golder Associates, 2014). This is considered to be a reasonably reliable calculation of the quantity of methane combusted in landfill gas engines; and
- Combustion of methane in flares. These data are based on site-specific records where available and are considered to be accurate for the sites where data exist. However, records of the quantity of landfill gas are incomplete, particularly for the years prior to 2008. In cases where records of landfill gas flaring are not available, the quantity of methane flared was assumed to be zero. This means that the landfill methane inventory is subject to greater uncertainty for the years prior to 2008, although because of the conservative approach adopted in respect of landfill gas flaring, it is considered that the inventory represents an over-estimate of methane emissions from landfill sites in the UK, particularly for the years prior to 2008.

Landfill permit conditions are designed to deliver a high standard of gas collection and combustion efficiency. Requirements to design and operate landfills in order to minimise gas escape have strengthened considerably since the 1990s. In this context, the calculated collection efficiencies of 56% to 63% for the period 2013 to 2018 derived in this analysis appear reasonable. Lower collection efficiencies in the years between 1990 and 2012 are likely to be more conservative.

Oxidation of methane in the surface layers of landfills is a further source of uncertainty in overall emissions. In the absence of better data, the IPCC oxidation default factor of 10% is applied to the estimated quantity of gas released as a fugitive emission. A pilot survey carried out on behalf of the UK Government and Environment Agency included measurements of surface methane oxidation. This study did not support a move away from the IPCC default position. A particular challenge in deciding oxidation rates for use in a national landfill model is the high level of variability in field measurements, reflecting a wide range of factors such as nature and porosity of the surface layers, moisture content and temperature, along with methane production rates in the underlying waste.

## 7.2.5  Source-specific QA/QC and verification

This chapter provides the information described in IPCC (2006) Section 3.8 "QA/QC, Reporting and Documentation."

Methodological data are described in **Section 7.2.2** above, with quantitative data in **Annex 3.5.1**. Activity data are described in **Section 7.2.3** above, with quantitative data on annual waste amounts and the quantities of landfill gas collected in **Annex 3.5.1**. A breakdown of waste composition for each year is available but as noted in IPCC (2006) Section 3.8, it is not practical to provide all documentation in the National Inventory Report.

In relation to specific recommendations of IPCC (2006) Section 3.8:

- "*Countries using other methods or models should provide similar data (description of the method, key assumptions and parameters)*" – this is provided in Section 7.2.2.
- "*If country-specific data are used for any part of the time series, it should be documented.*" – country-specific data on DOC, DOCf and MCF are used, as documented in **Section 7.2.2** and **Table A 3.5.2**.
- "*The distribution of waste to managed and unmanaged sites for the purpose of MCF estimation should also be documented with supporting information.*" This is documented in **Section 7.2.2**.
- "*If $CH_4$ 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 2018 is based on records from a total of 284 individual facilities in England, 56 in Scotland, 18 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 2018..

The landfill methane model has been subject to peer review in 2011 and 2014 (see Eunomia Consulting and Research, 2011; Golder Associates 2014). The landfill methane model is subject to normal quality assurance procedures, as described in **Section 1.6.**

IPCC (2006) guidelines, section 3.8 suggests that calculated emissions can be compared with those of similar countries. Relatively few countries have a similar history of landfill use to the UK, but emissions were compared to data taken from NIRs recently produced by Ireland and Italy where landfill use has been extensive in the past, and continues to be a significant component of waste disposal to the present, as shown in **Table 7.4**.

**Table 7.4        UK calculated emissions compared to Ireland and Italy**

| Year | Waste landfilled (MT) | | | Methane generated (kT) | | | Methane collected (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | UK | EI (approx.) | IT | UK | EI | IT | UK | EI | IT |
| 1990 | 93.3 | 1.9 | 25.2 | 2709 | 53 | 726 | 1% | 0% | 15% |
| 1995 | 104.5 | 2.0 | 28.5 | 2939 | 64 | 677 | 5% | 0% | 21% |
| 2000 | 84.9 | 2.1 | 27.4 | 3028 | 74 | 776 | 17% | 32% | 28% |
| 2005 | 72.6 | 2.3 | 21.2 | 2870 | 90 | 787 | 32% | 55% | 40% |
| 2010 | 51.4 | 1.6 | 19.1 | 2278 | 98 | 701 | 53% | 89% | 60% |
| 2011 | 52.5 | 1.4 | 16.7 | 2159 | 96 | 678 | 55% | 84% | 65% |
| 2012 | 49.6 | 1.2 | 14.4 | 2041 | 93 | 680 | 55% | 87% | 61% |
| 2013 | 48.4 | 1.0 | 13.8 | 1929 | 89 | 612 | 60% | 79% | 76% |

| Year | Waste landfilled (MT) | | | Methane generated (kT) | | | Methane collected (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | UK | EI (approx.) | IT | UK | EI | IT | UK | EI | IT |
| 2014 | 48.2 | 0.8 | 12.6 | 1820 | 84 | 600 | 63% | 69% | 74% |
| 2015 | 51.0 | 0.6 | 11.4 | 1716 | 80 | 565 | 62% | 63% | 81% |
| 2016 | 52.3 | | | 1627 | | | 62% | | |
| 2017 | 52.3 | | | 1544 | | | 59% | | |

There is no more than a very approximate connection between the amount of waste landfilled in any year, and the amount of methane generated. The connection is stronger in cases where the quantities and composition is constant over a longer period of time. Nevertheless, for the majority of years, the reported quantity of methane generated in all three countries was in the range 24 to 50 kT methane per MT waste landfilled. The UK was in the range 28 to 44 kT methane per MT waste landfilled throughout the time series, with both higher and lower values exhibited by Italy and Ireland. This indicates that there are no causes for concern regarding any obvious inconsistency in the overall results for methane generation with the values reported by these other countries. Since 2013, the UK has reported an estimated methane collection efficiency of between 59% and 63%. This is comparable with, and if anything lower than, the collection efficiencies reported by Ireland and Italy. This indicates that there are no causes for concern regarding any obvious inconsistency in the estimated methane collection efficiency with the values reported by these other countries.

This comparison was performed to compare the methane collection efficiencies between the countries but was not carried out for the purposes of verification of MELMod model.

Verification of the MELMod model was also carried out by comparing the estimation of emissions 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 model results are compared with each other, and with results derived from analysis of environmental methane measurements, in **Figure 7.3**.

**Figure 7.3** **Comparison of UK GHG inventory for Sector 5A with IPCC Tier 1 model results and estimates derived from environmental measurements ("InTEM")**
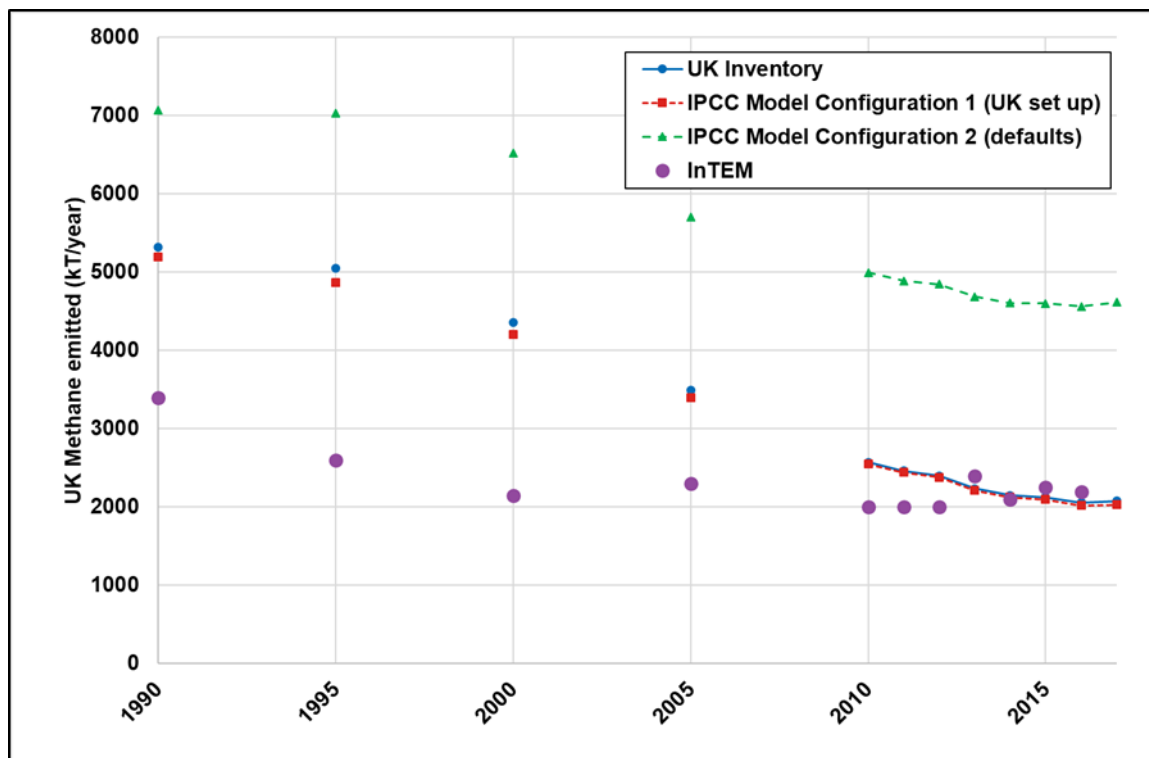


The following conclusions were drawn from this analysis:

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.

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.

The MELMod outputs have been compared to the outputs that would result from applying the IPCC Tier 1 methodology to the available data on UK waste receipts. This process indicated that the UK model does not have significant errors in how it is set up, and the use of UK-specific inputs to the UK Tier 2 model or the IPCC Tier 1 model gives more reliable results than the use of the IPCC Tier 1 model with IPCC default inputs. This provides confidence in the greenhouse gas inventory for Sector 5.A.

As described in **Section 1.6.3**, the UK GHGI is verified against data measured from the InTEM network of measurement masts. These measurements indicate good agreement with the UK inventory for the period 2010 onwards, during which time there has been no strong trend in the landfill methane inventory, the total UK methane inventory, or the estimated inventory derived from the InTEM measurements. However, over the period 1990 – 2010, the InTEM measurements indicate a reduction of about 30% to 40% in methane emissions, whereas the GHGI indicates a more significant reduction of up to 60%. The trend in the UK GHGI is driven mainly by reductions in landfill methane emissions. The reasons for this discrepancy are currently under review, as discussed in Section 7.2.7.

## 7.2.6  Source-specific recalculations

There has been one change to the UK landfill methane inventory for 2017, as follows:

Data on waste landfilled for Scotland in 2017 had previously been provided in an aggregated form. The disaggregated data were provided along with the data for 2018. Additionally, updated waste data for Northern Ireland and Wales for 2017 were provided. As a result, slight changes to the landfill methane inventory for Scotland, Wales and Northern Ireland in 2017 were calculated. The UK inventory of methane emissions from this sector is set out in **Table A 3.5.2**. This table shows the quantity of methane generated, combusted in engines and flares, oxidised by the landfill surface and emitted to the atmosphere.

## 7.2.7  Source-specific planned improvements

The Inventory Agency is working on improvements to the spatial distribution of landfill methane emissions data. This will enable verification of the calculated inventory against the InTEM field measurements to be carried out in more detail.

## 7.3 SOURCE CATEGORY 5B – BIOLOGICAL TREATMENT OF SOLID WASTE

### 7.3.1 Source Category Description

| Emissions sources | Sources included | Method | Emission Factors |
|---|---|---|---|
| | 5B: Composting (non-household)<br>Composting (household)<br>Anaerobic digestion (non-agricultural)<br>Mechanical biological treatment | T2<br>T2<br>T2<br>T2 | D<br>D<br>D<br>D |
| Gases Reported | $CH_4$, $N_2O$ | | |
| Key Categories | 5B: Biological treatment of solid waste - $CH_4$ (T1, T2, L2)<br>5B: Biological treatment of solid waste – $N_2O$ (T2) | | |
| Key Categories (Qualitative) | None identified | | |
| Overseas Territories and Crown Dependencies Reporting | Estimates have been made for OT and CD emissions from 5B1, composting of municipal solid waste, where data on the total amount of waste composted is available. In these cases 2006 IPCC default EFs are applied. These estimates are included within 5B for CRF reporting. | | |
| Completeness | No known omissions.<br>A general assessment of completeness for the inventory is included in **Section 1.8**. | | |
| Major improvements since last submission | None. | | |

### 7.3.2 Methodological Issues

Emissions of methane and nitrous oxide from composting of MSW (Category 5.B.1) and anaerobic digestion and Mechanical Biological Treatment (MBT) (Category 5.B.2) are estimated using a Tier 2 methodology. This was identified as an appropriate approach in view of the scale of emissions from this sector (DECC, 2015b).

Activity data for composting and anaerobic digestion relies on the approaches used in the GHG and ammonia inventories. Activity data for composting was derived from Devolved Administrations' data on organic waste fractions. Inputs to household composting were calculated by using population statistics and district level analysis for home composting in the UK (Parfitt, 2009).

Activity data for MBT and whether the MBT is aerobic or anaerobic is based on annual organics recycling reports, published between 1998 and 2013 by: The Waste and Resources Action Programme (WRAP, 2009 to 2014), The Association for Organics Recycling (2006 to 2008), The Composting Association (1998 to 2005). Some extrapolation and interpolation is required to generate a complete and consistent time series.

Activity data for anaerobic digestion was derived from a site information database recorded in the National Non-Food Crops Centre (NNFCC 2019). 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, 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 a renewable source of organic matter. The emission factors for the anaerobic digestion component of mechanical biological treatment were assumed to be the same as for anaerobic digestion.

### 7.3.2.1  Overseas Territories and Crown Dependencies

Emissions from 5.B.1 have been estimated, however due to data availability, only estimates for Guernsey and Bermuda can be derived. Within Guernsey, composting has only occurred on the Island since 2008, due to creation of a new national composting scheme. The total amount of waste composted within this scheme has been supplied by Guernsey. Official statistics provide the amount of waste composted in Bermuda. IPCC 2006 default emission factors for both $CH_4$ 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 2018.

## 7.3.4  Source Specific QA/QC and Verification

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

## 7.3.5  Source Specific Recalculations

The method for interpolating the quantities of MBT residues composted between historical data points was revised.

The methodology for calculating home composting quantities was revised following a re-evaluation of a reference which indicated larger quantities of materials diversion to home composting per household than had previously been identified. This resulted in an increase in the quantity of waste assumed to be composted at domestic properties, and associated methane emissions.

For information on the magnitude of recalculations, see **Section 10**.

## 7.3.6  Source Specific Planned Improvements

Emission factors and activity data will be kept under review.

## 7.4  SOURCE CATEGORY 5C – WASTE INCINERATION

## 7.4.1  Source Category Description

| Emissions sources | Sources included | Method | Emission Factors |
|---|---|---|---|
| | 5C1: Incineration: MSW | T2,T1 | CS, D |
| |     Incineration: sewage sludge | T1 | CR, D |
| |     Incineration: clinical | T1 | OTH, D |
| |     Incineration: chemical | T2, T1 | CS, D |
| |     Incineration: animal carcases | T1 | CS |
| |     Crematoria | CS | CS |
| | 5C2: Accidental fires: dwellings | CS | OTH |
| |     Accidental fires: other buildings | CS | OTH |
| |     Accidental fires: vehicles | CS | OTH |
| |     Bonfire night | CS | OTH |
| |     Fireworks | CS | OTH |
| |     Small-scale waste burning | CS | OTH |
| Gases Reported | $CO_2$, $CH_4$, $N_2O$, $NO_x$, CO, NMVOC, $SO_2$ | | |
| Key Categories | None identified | | |
| Key Categories (Qualitative) | None identified | | |
| Overseas Territories and Crown Dependencies Reporting | Included in the CRF with the UK MSW incineration, since the same emission factors are applied, apart from 5C2.1b, incineration of waste from small scale burning, where estimates are now made for Guernsey using IPCC default method. | | |
| Completeness | A general assessment of completeness for the inventory is included in **Section 1.8**. | | |
| Major improvements since last submission | No major improvements have been made since the last submission. | | |

This source category covers the incineration of wastes (excluding waste-to-energy facilities). The UK also reports indirect GHG emissions from various other sources including crematoria, small-scale waste burning, accidental fires, and fireworks under 5C2. Methane emission estimates are included for accidental fires.

In the UK, all MSW incineration plants have recovered energy since 1997, and so emissions are reported under CRF source category 1A1a. For the years 1990-1996, at least some MSW was incinerated at plants with no energy recovery, so emissions are split between 1A1a and 5C for those years, in proportion to the waste burnt with and without energy recovery respectively. All incineration of chemical wastes, clinical wastes, sewage sludge and animal carcasses is reported under 5C1, since we have no information on any recovery of energy from these processes. In-situ burning of agricultural waste e.g. crop residue burning is reported under category 3F.

The numbers of chemical waste, clinical waste and sewage sludge incinerators in the UK are not known with certainty, although that number has almost certainly decreased significantly between 1990 and 2018. A total of 27 incinerators regulated under the Industrial Emissions

Directive (IED) have been identified as operating in 2018 - 4 burning sewage sludge, 17 burning clinical wastes, and 6 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 299 in 2018 compared with 239 in 1999 (based on statistics published by the Cremation Society of Great Britain, website at http://www.cremation.org.uk/).

This source category also includes emissions from the open burning of wood waste in Guernsey.

## 7.4.2  **Methodological Issues**

Emissions of $CO_2$, CO, $NO_x$, $SO_2$, and VOC from chemical waste incinerators are estimated based on analysis of emissions data reported to the Pollution Inventory (Environment Agency, 2019), the Welsh Emissions Inventory (NRW, 2019) and the Northern Ireland Pollution Inventory (NIEA, 2019). 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 VOC from sewage sludge incineration are estimated using literature-based emission factors, while emissions of $NO_x$ are estimated using Pollution Inventory data. The factor for $N_2O$ is the average of the range of emission factors given in the 2000 IPCC good practice guidance for UK sewage sludge incineration. Emission factors for other pollutants are taken from the EMEP/EEA Emission Inventory Guidebook. The quantity of waste burnt annually is estimated using data from various sources:

1990        RCEP, 1993

1991-1998        Digest of Environmental Statistics (Defra, 2004)

2006-2018        Environment Agency, waste disposal data for individual sites in England

2004-2018        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 VOC from clinical waste incineration are estimated using literature-based emission factors. The factors for $CO_2$ and $N_2O$ are IPCC default factors. Emission factors for other pollutants are largely taken from the EMEP/EEA Emission Inventory Guidebook. The quantity of waste burnt annually is also estimated, these estimates being based on information given in the following sources:

1991            RCEP, 1993

1997            Wenborn *et* al, 1998

2002            Entec, 2003

2006-2017        Environment Agency, waste disposal data for individual sites in England and Wales

2004-13, 2015-17 Scottish Environment Protection Agency, estimates of total clinical waste incinerated in Scotland

Interpolation between the various estimates is used to fill the gaps in the activity data time series.

Emission estimates for animal carcass incinerators are taken directly from a Defra-funded study (AEA Technology, 2002) and are based on emissions monitoring carried out at a cross section of incineration plants. No activity data are available and so the emission estimates given in this report are assumed to apply for all years.

Emissions of CO, $NO_X$, $SO_2$ and VOC from crematoria are based on literature-based emission factors, expressed as emissions per corpse, and taken from US EPA (2008). Data on the annual number of cremations is available from the Cremation Society of Great Britain (2018).

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, 2019). These statistics give the number and severity of fires in dwellings and other buildings, and the number of fires in road vehicles by type. The statistics have then been converted into masses of material burnt by applying country-specific assumptions for each type of fire e.g. for the many fires in dwellings that are limited to just a single item, the mass of material combusted is assumed to be 1 kg. The total material burnt is then combined with emission factors to obtain emission estimates for methane, CO, $NO_X$ and NMVOC. The methane factors are taken from AP 42 (USEPA, 2014) and relate to open burning of municipal waste (for dwellings and other buildings) and automobile parts (for vehicle fires). Factors for other pollutants are taken from the same source, or from UK-specific literature. The UK is not aware of any source of appropriate emission factors for carbon or nitrous oxide emissions from this source, but emissions of these pollutants from this source are expected to be small.

The tonnage of MSW burnt in incinerators in the Cayman Islands and the Falklands is provided by their respective local governments. UK GHGI EFs were then applied to these activity data to estimate emissions from this sector. Emissions from waste incineration in Jersey and the Isle of Man are reported under 1A1a. Data are available for the amount of waste open-burned in Guernsey, so these are used to estimate emissions for 5C2 using IPCC 2006 default EFs. It is assumed that this source is not occurring in the remaining territories.

The inventory also includes estimates for emissions of:

- CO, $NO_X$ & VOC from small-scale burning of domestic and garden waste, for example on domestic grates and on garden bonfires;
- CO from open fires lit as part of 'bonfire night' celebrations; and
- CO from fireworks.

All of these estimates are very uncertain, because of the need for expert judgements and assumptions in order to derive any activity data from waste arising data, and the need, because of a lack of suitable emission factors, to instead use factors that were designed for other types of emission source such as domestic fires.

Activity and emissions data for this sector can be found in **Annex 3**, **Table A 3.5.5** and **Table A 3.5.6**.

### 7.4.3   Uncertainties and Time-Series Consistency

The uncertainty analysis in **Annex 2** provides estimates of uncertainty according to IPCC source category and gas.

### 7.4.4   Source Specific QA/QC and Verification

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

### 7.4.5   Source Specific Recalculations

The following recalcualtions apply to the estiamtes submitted in this compilation cycle:

- Detailed analysis of waste incineration statistics indicated some double-counting of emissions already accounted within the greenhouse gas inventory, and hence these small double-counts were removed, reducing emissions slightly in 5C.
- 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.

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<br>5D2: Industrial Waste-water Treatment | T1, CS<br>T1 | CS, D<br>D |
| Gases Reported | $CH_4$, $N_2O$ | | |
| Key Categories | 5D: Wastewater Handling - $N_2O$ (L2, T2)<br>5D: Wastewater Handling – $CH_4$ (L2)<br>5D: Wastewater treatment and discharge - $CH_4$ (T1, L1, L2) | | |
| Key Categories (Qualitative) | None identified | | |
| Overseas Territories and Crown Dependencies Reporting | Emissions from wastewater handling within OTs and CDs are included in 5D1. Estimates are based on 2006 IPCC Guidelines and EFs with country-specific parameters applied, where available. | | |
| Completeness | No known omissions.<br>A general assessment of completeness for the inventory is included in **Section 1.8**. | | |
| Major improvements since last submission | None | | |

Emissions reported in 5D2 arise from wastewater handling in a number of industry sectors in the UK where organic content of effluent is high. No data are currently available on sludge removal so all water treatment, sludge treatment and disposal emissions are reported as aggregated under 5D2.

Emissions reported in 5D1 arise from wastewater handling, sludge treatment and disposal in the UK's municipal waste-water treatment system and private waste-water management systems. The UK's municipal waste-water treatment system encompasses the treatment of effluent and sludge from residential and commercial sectors as well as trade waste from many industrial sites in the UK.

Methane is released from handling of wastewater and its residual solid by-products (i.e. sludge) under anaerobic conditions, due to the decomposition of organic matter by bacteria.

Nitrous oxide is released from human sewage during waste-water handling due to the release of nitrogenous material from proteins.

### 7.5.2  Methodological Issues

The emissions from 5D1 and 5D2 are estimated for the following sources in the UK:

- **5D1 Domestic and Commercial Waste-Water.** Which consists of 4 main aspects:
  - o **UK $CH_4$ emissions from municipal waste-water treatment.** UK-specific method, using activity data for the municipal waste-water treatment volumes, organic content and sludge treatment and disposal routes. Emission factors are derived from water company reported since 2013 and extrapolated back to 1990;

- o **UK CH$_4$ emissions from private waste-water management.** Default IPCC methodology using UK-specific per capita Biochemical Oxygen Demand (BOD) and estimated population using private waste-water management systems;
- o **UK N$_2$O emissions.** Default IPCC methodology applied to UK time series of population and protein intake estimates from food surveys;
- o **OT and CD Sewage Treatment.** For the majority of overseas territories and crown dependencies, wastewater emissions are estimated using UK data and scaled by population. Data specific to Bermuda were provided by the territory and used within the time series, interpolating and extrapolating where necessary.
- **5D2 Industrial Waste-water Treatment (CH$_4$).** Default IPCC methodology applied to UK waste-water estimates of organic load from the food and drink and chemical industries.

### 7.5.2.1   5D1: UK CH$_4$ emissions from municipal waste-water treatment

The UK estimates for methane from municipal domestic and commercial waste-water and sewage sludge treatment and disposal are derived from a time series of activity data for (i) total mass of sewage sludge disposed, and (ii) population equivalent of effluent treated in the municipal water treatment systems. These data cover most of the UK water company activity since 1990, which reflects shifts in UK water sector regulation and management.

*7.5.2.1.1 UK Industry Overview*

The UK waste water treatment industry is a highly-regulated sector that has undergone a high level of investment in infrastructure and improvement of management practices over several decades in order to deliver a service that achieves high environmental standards and meets key performance indicators (e.g. treatment parameters and volumes, economic and sustainability standards). Even prior to 1990 the UK network of waste water treatment plants were at the fore-front of engineering and technological development globally, and this has been strengthened by the impacts of successive and more stringent regulations in the intervening years, notably the Urban Waste Water Treatment Directive in the late 1990s / early 2000s which banned dumping of sewage to sea.

The UK water sector was previously publicly owned, and is now comprised of around 15 individual companies that operate regional networks and infrastructure. There is a long history of UK-wide research and co-operation across these companies, and in response to the challenge to monitor and report environmental performance, all major UK water companies engage via a central body, UK Water Industry Research, through which common reporting frameworks and systems are researched, developed and updated to reflect latest science and industry practices.

In the UK, a typical Waste Water Treatment Plant (WWTP) involves a number of interrelated processes each of which have different emissive behaviour. The different combinations of treatment options and the local waste water arising characteristics (especially where high volumes of industrial waste are combined and treated together with municipal waste water, altering the waste water input characteristics away from "typical" municipal waste water arisings) lead to a range of performance in the management of organic waste and the emission performance of the treatment works. The UK tools to monitor WWTP performance, estimate the input water characteristics (which in the UK is linked to regulatory and charging regimes for industrial customers, often based on periodic sampling of industrial effluents that pass into the predominantly municipal system), and to estimate the GHG emissions from these activities have been developed through research focussed on the UK waste water sector and the existing infrastructure. This research underpins the UK GHGI estimates of methane emissions, as the country-specific model uses company-reported data via the Carbon Accounting Workbook (CAW) which accounts for plant specific processes using CS emission

factors that reflect UK circumstances. Figure 7.4 provides an overview of the key processes in a typical UK WWTP.

**Figure 7.4      Waste water flow diagram**
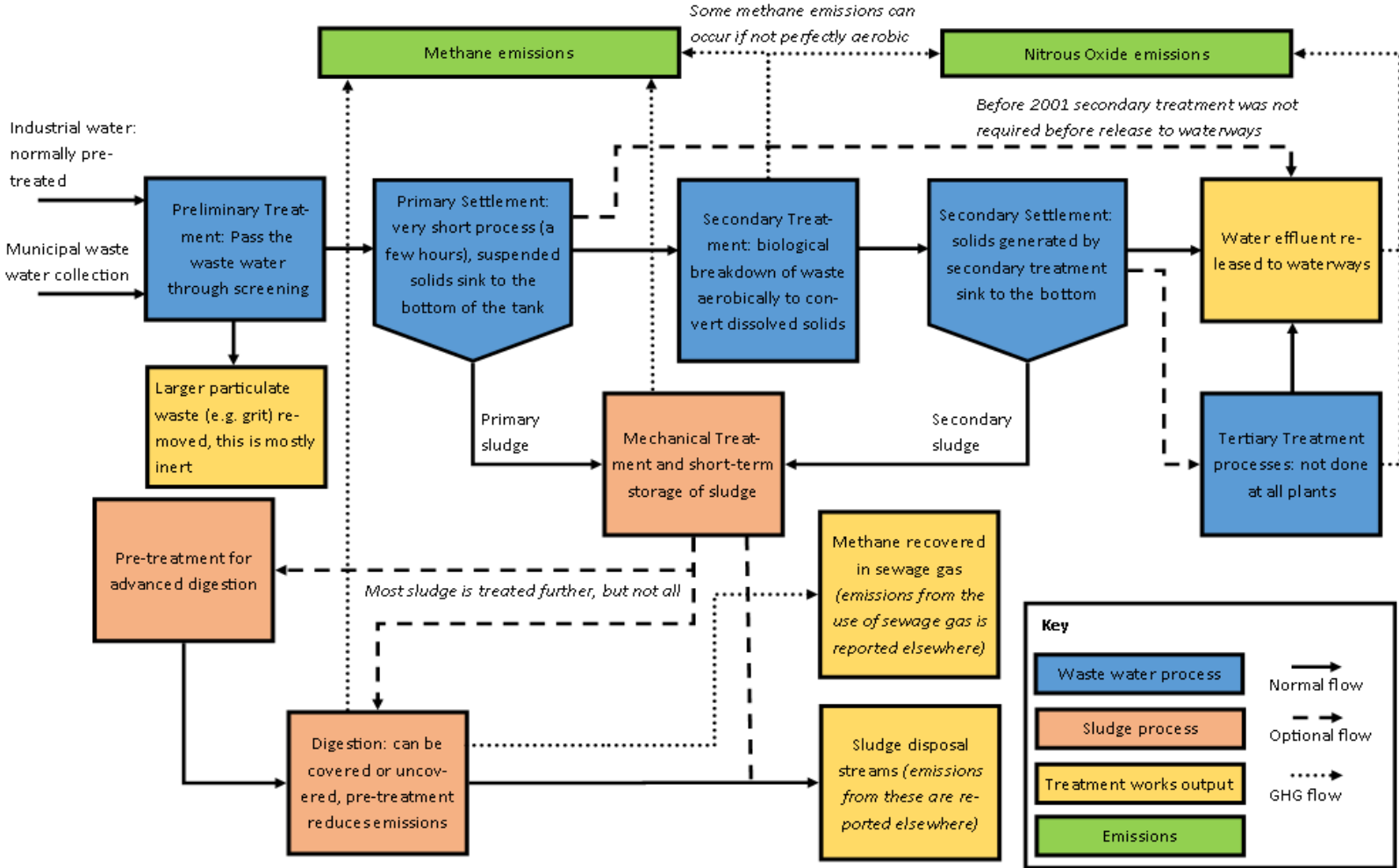
#### 7.5.2.1.1.1    Preliminary Treatment

All waste water is initially filtered for large objects and particulate matter. The filtering process is not emissive and the screened material is largely inert. Any emissions associated with the disposal of non-inert content of the screened waste are included in estimates for other sectors (e.g. landfill in sector 5A).

#### 7.5.2.1.1.2    Settlement (Primary, Secondary and Tertiary)

After preliminary treatment all waste water undergoes primary settlement. Primary settlement involves allowing suspended solids to settle at the bottom of the tank to form a sludge. The sludge can then be extracted for separate sludge treatment. The process is relatively short (a few hours), and hence there is 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 Waste Water 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 waste water disposed to waterways, to account for the increased biological load of this water. The additional biological load is estimated by finding the difference between the sludge generated per capita before and after 2001.

Secondary treatment is a source of nitrous oxide emissions, and a small amount of methane emissions (primarily due to potential disruptions in the process which may allow anaerobic conditions to occur). Emissions of nitrous oxides are included in the company reported data; the Inventory Agency does not use this as we do not have sufficient information to determine what impact this process has on downstream nitrous oxide emissions. Emissions of methane are reported with mechanical treatment and short term storage of sludge in the CAW, and the Inventory Agency uses these values as part of the emissions estimates.

#### 7.5.2.1.1.4    Tertiary Treatment(s)

In many UK WWTPs, there is a requirement for tertiary waste water treatment, in order to meet the regulatory permit conditions and/or to meet water quality criteria for the water-ways receiving the WWTP effluent outflow. There are a number of tertiary processes that can occur depending on what products require removal from the water.

The most common tertiary treatments are nitrification and denitrification which aim to reduce the nitrogen load of effluents. These processes can be a significant source of nitrous oxide within the WWTP, but they also reduce the level of nitrous oxide emissions occurring downstream due to the removal of nitrogen from the effluent. Similar to secondary treatment, the UK cannot estimate nitrous oxide emissions from this source (using the directly-reported emissions from WWTP operators) without introducing a potential double count with downstream emissions, as the data are not available to establish the impact of these tertiary treatments on the residual nitrogen loads in WWTP effluent.

Similar to secondary treatment processes, methane emissions from tertiary treatments do not occur through routine operation and are considered negligible by the UK industry.

### 7.5.2.1.1.5    Mechanical Treatment and Short Term Storage

All sludge extracted from waste water goes through an initial mechanical treatment and to short term storage. This process thickens, dewaters and homogenises the sludge to reduce the volume of the sludge and prepare it for further treatments. The gravity thickening process and storage of sludge under anaerobic conditions leads to methane emissions which are reported by waste water companies via the CAW, and these data are used to derive the UK inventory estimates.

### 7.5.2.1.1.6    Digestion

In the UK the vast majority of sludge undergoes anaerobic digestion after mechanical treatment, particularly in recent years. This process allows anaerobic bacteria to process the sludge, reducing the volume of sludge and generating methane. WWTPs collect the generated methane and burn it in engines to generate electricity; this generation of electricity by the industry using sewage gas is reported within the UK energy statistics. Emissions from the burning of sewage gas are reported in the UK inventory within sector 1A1a Power generation, whilst emissions from the disposal of sludge is reported according to the water company reporting of sludge fate, to landfills (5A), incinerators (5C) and agricultural soils (3D).

There is an increasing trend in the UK to pre-treat the sludge before digestion to improve the efficiency of digestion; this is known as advanced digestion. There are two main advanced digestion processes; Cambi's patented Thermal Hydrolysis Process (CambiTHP™) which involves high pressure steam to improve anaerobic digestion conditions and Acid Phase Digestion (APD) which involves creating two sets of conditions which suits two types of bacteria. These processes allow for a higher biogas yields and greater reductions in sludge volume than conventional digestion.

Digestion is the main source of methane emissions in UK WWTP as methane is intentionally generated but not all methane is collected. The data reported to the UK inventory team by waste water companies via the CAW accounts for the types of digestion occurring and whether or not the digestion is enclosed.

Nitrous oxide emissions from digestion are negligible, due to the lack of oxygen in the system.

### 7.5.2.1.1.7    Composting

In some cases, UK WWTPs may compost the sludge after mechanical treatment, instead of digestion. This is a source of methane and nitrous oxide emissions. These emissions are reported by waste water companies in the UK through the CAW, the method for which applies default methane and nitrous oxide emission factors for composting from the 2006 IPCC guidelines.

### *7.5.2.1.2 Waste-water Treatment and Sludge Disposal Activity Data*

Activity data are available at an aggregated level (across countries: England and Wales, Scotland, Northern Ireland, and with no detail on treatment) for the early part of the time series within EPSIM data published by UK Government (Defra, 2006).

In recent years, each of the UK's 12 water and sewerage companies report annual activity data on water treatment, sewage sludge arising and the ultimate fate of sewage sludge, to UK industry regulators. The activity data reported by each company includes data that are used to estimate company GHG emissions:

- Total volume of sludge disposed (kt total dissolved solids (tds)); and

- Population Equivalent (PE) Served ('000), this is the estimated resident and non-resident (e.g. tourist) population served which acts as an alternative indicator of sewage load.

In addition, each company provides a detailed split of sewage sludge disposal routes, including data (kt tds per year) for the following activities:

- Incineration;
- Composted;
- Landfill;
- Land reclamation;
- Farmland;
- Disposal at sea (up to the year 2000, when this activity was banned); and
- Other.

For the 2013 inventory cycle the Carbon Accounting Workbook (CAW), developed by UK Water Industry Research (UKWIR), was the tool used by the water industry for reporting emissions to Defra and OFWAT. It was adapted to provide detailed data for the inventory. The inventory team was provided with a methodology report that included a number of the underlying assumptions and emission factors and activity (in PE for secondary treatment, $m^3$ 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 companies in England and Wales reported sludge disposal activity to the industry regulator, OFWAT, broken down across 8 sludge disposal routes: incineration, composting, landfill, land reclamation, farmland untreated, farmland conventional, farmland advanced and other. After 2009 the requirements of data reported to OFWAT changed, and data was no longer publicly available. For 2013 onwards, company reported data from the CAW has been available.

For 1991 to 2005, the EPSIM data present a breakdown of sewage sludge disposal data across five options: farmland, incineration, landfill, sea disposal and other, and for 1986-2005 this data set gives total estimates sewage sludge arising. No additional information is available, such as the BOD loading of the municipal sewerage system, treatment methods, or the population equivalents treated by UK water companies. The overlap in time-series between the EPSIM data and company reported data confirms that the total and split of disposal methods are largely consistent with each other.

In Scotland the same level of detailed activity data as outlined above for companies in England and Wales have been available since 2002 and continues to be published, from the Water Commissioner for Scotland; EPSIM data are used for 1990-2001. The totals reported in the

EPSIM data fit the company reported data very well, but because the disposal split fits very poorly in the overlapping years the company reported split from 2002 is used with the EPSIM total for the earlier part of the time series.

In Northern Ireland, data are only available from the water regulator, UREGNI, for 2006-9 and 2012. Northern Ireland Water, the sole provider of water and sewerage services in Northern Ireland have reported data for 2013 onwards. The Defra EPSIM statistics are used to provide activity data for the early part of the time series to 2005, whilst the gap between these data sets are interpolated. The EPSIM time-series trend fits well with the company reported trend in later years, as the disposal split is similar in the 2013 reported data and at the end of EPSIM time-series it is reasonable to assume a similar split for the intervening years.

*7.5.2.1.3 Emission Estimation: Use of UK-specific Factors*

The UK GHG inventory mostly follows the UK water industry GHG emission estimation methodology developed by UKWIR, and used by all UK water companies to generate their annual emission estimates from all sources / activities. UKWIR have not provided an approach for estimating emissions associated with waste to sea in the 1990s, so to avoid an omission the 2006 IPCC default approach using the Methane Correction Factor (MCF) for sea, river and lake discharge has been used. Discharges would have only been to the cold seas with low organic loadings around the UK, so this is likely to be a very conservative approach for estimating emissions.

Methane emissions from sewage sludge disposed to landfill and incineration are accounted for in 5A and 5C, and hence no estimates are included in 5D1 to avoid a double-count. Waste disposed of via 'other' means has been given a weighted average emission factor based on the emissions from other disposal methods. Where the treatment before disposal isn't specified, the treatment split is estimated based on the profile given in CAW reported data for since 2013; for example it was only after 2013 that the sludge disposed to landfill has been disaggregated based on treatment, this split has been used to estimate the treatment split for the earlier years where none is specified.

UK-specific emission factors are applied to the treatment and disposal methods reported in the CAW, outlined above. Most of these factors are derived from UK water industry emissions data reported to the Inventory Agency, through use of the UKWIR estimation spreadsheet tool that all UK water companies utilise. The UKWIR tool provides emission factors for sub-processes within the industry, enabling water companies to calculate their methane emissions based on their stock of water treatment equipment and effluent inputs to individual water treatment works. From the aggregated industry reported emissions and activity data, implied emission factors for each of the treatment and disposal approaches can be derived. The emission factor for composted sewage sludge treatment is derived from the 2006 IPCC guidelines.

Water company reporting of emissions to the Inventory Agency is not comprehensive; emissions data are only available from 2009 onwards, and only from up to 9 of the 12 UK water companies in any one year before 2013; for example in 2009, emission reporting by water companies was estimated to cover around 53% of total UK water treatment.

During 2013 the Inventory Agency met with all UK water company carbon managers and the authors of the UKWIR reporting tool that all companies use under a voluntary mechanism for GHG emissions reporting. Through this consultation, 9 out of 12 water companies provided 2012 emissions data, covering around 65% of UK water company activities. In addition, a reporting template has been drafted for inclusion within the UKWIR tool, which means that since 2013 we have received data from all 12 of the water companies. In future we should continue to receive this much more comprehensive data from the industry, and therefore have much more confidence in emissions estimates.

Despite limitations to data collection in previous years, there is good consistency across the emission factors derived from the different water companies and the data are based on UK-specific water treatment facilities, effluent inputs and treatment / disposal activities, and therefore are regarded as the best available data upon which to derive inventory estimates.

*7.5.2.1.4 Reporting of Methane Recovery from Sewage Treatment*

The methodology report provided by UKWIR for the 2013 version of the CAW provides the emission factor assumed for digestion without capture. Using this factor we calculated what emissions would have been reported had there been no methane capture, then necessarily the difference between reported emissions and this unabated emission estimate would be the amount of methane captured.

Data on the annual amount of sewage gas being produced are provided in DUKES (BEIS, 2017). Using this we can establish a link between the DUKES estimate based on energy use and the mass based estimate based on the difference between unabated and reported methane emissions. Assuming that the relationship between energy use and methane captured is consistent throughout the time series, the amount of methane removed can be calculated for all years and removed from the estimate for unabated emissions.

### 7.5.2.2  5D1: UK $CH_4$ emissions from private waste-water management

An estimate of the number of households that are likely to be using off-grid systems in the UK in 2013 has been made based on data provided by the Environment Agency (EA), the Scottish Environmental Protection Agency (SEPA), the Northern Ireland Department of the Environment (NIEA) and Natural Resources Wales (NRW).

A time series of emissions has been developed using population data. This time series of number of households has been combined with ONS data for average household occupancy and the calculated volume of waste produced per person per year based on water company statistics to produce an estimate of total waste-water being disposed of via off-grid systems.

The emissions are then calculated following the method set out in the 2006 guidelines Volume 5, Chapter 6: Wastewater treatment and discharge. Equation 6.2 in the GLs, reproduced below, calculates the emission factor.

$$EF_j = B_0 * MCF_j$$

Where

      $EF_j$ = emission factor, kg $CH_4$/kg BOD (Biochemical Oxygen Demand)

      j = each treatment/discharge pathway or system

      $B_0$ = maximum $CH_4$ producing capacity, kg $CH_4$/kg BOD

      $MCF_j$ = 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 |
|-----------|-------------|-------|-------|
| $B_0$ | Maximum $CH_4$ producing capacity | kg $CH_4$/kg BOD | 0.6 |
| MCF | Methane correction factor | Fraction | 0.5 |

| Parameter | Description | Units | Value |
|-----------|-------------|-------|-------|
| **EF** | **Emission factor** | **kg CH$_4$/kg BOD** | **0.3** |

The emission factor is then combined with total amount of organically degradable material in the waste-water (TOW), expressed as kg BOD/year, which is calculated using Equation 6.3 in the 2006 GLs:

$$TOW = P \cdot BOD \cdot 0.001 \cdot I \cdot 365$$

Where:

TOW = total organics in wastewater in inventory year, kg BOD/yr

P = country population in inventory year, person

BOD = country-specific per capita BOD in inventory year, g/person/day

0.001 = conversion from grams BOD to kg BOD

I = correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00).

The population figure used is for only the proportion of the population using septic tanks. The BOD value is assumed to be similar to the BOD per capita implied by the data provided by the major water companies. Data on BOD values applied and estimated population connected to private waste water management systems are presented in **Annex 3.5.4**.

### 7.5.2.3 5D1: UK N$_2$O emissions from Domestic and Commercial Waste-water

Nitrous oxide emissions from the treatment of human sewage are based on the 2006 IPCC default methodology. The most recent average protein consumption per person is based on the Expenditure and Food Survey (Defra, 2017); see Table 7.6**.** 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, 2018).

In previous years, the protein consumptions used to estimate emissions were "household intakes". However, Defra now produce a time series of the estimates of the small amount of additional protein from consuming meals eaten outside the home; this intake is called "eating out intakes". This time series is only available from 2000 onwards. For values between 1990 and 2000 an average of the data available is applied. The sum of the "household intakes" and "eating out intakes" then provides the total protein consumption per year per person.

**Table 7.6    Per capita protein consumption in the UK (kg/person/yr), 1990-2018**

| Year | Protein consumption (kg/person/yr) |
|------|-----------------------------------|
| 1990 | 27.9 |
| 1995 | 28.6 |
| 2000 | 29.9 |
| 2005 | 29.8 |
| 2010 | 28.7 |
| 2014 | 27.1 |
| 2015 | 27.3 |
| 2016 | 27.1 |
| 2017 | 27.4 |
| 2018 | 27.3 |

Nitrous oxide emissions are calculated by multiplying:

1. UK population;

2. annual total protein consumption per person;
3. the fraction of nitrogen in protein (0.16kg N/kg protein);
4. the fraction of municipal nitrogen load from unconsumed protein (1.16; Henze and Comeau, 2008); and,
5. the fraction of municipal nitrogen load from commercial and industrial sources, as per the 2006 IPCC guidelines (1.25).

This derives a total for the UK nitrous oxide emissions from sewage sludge, but not all of those emissions are allocated to 5D1. The nitrous oxide emissions from sludge spread on agricultural land are reported under IPCC source category 3D Agricultural Soils and emissions from waste incineration are included in 5C. Therefore to avoid a double-count in the UK GHG inventory, the emissions reported in 5D1 are the difference between the UK total from the IPCC default method, and the estimates included in 3D and 5C.

*7.5.2.3.1 Use of UK-Specific Protein Consumption Data instead of FAO Data*

The FAO estimate of per capita protein consumption is based on supply balance sheets for all commodity items. For each commodity supply balance sheet, factors are applied to the estimate of supply for human consumption to derive total protein consumption and a per capita figure is obtained by dividing by population statistics. These are summed across the supply balance sheets to derive a total protein consumption estimate for a country.

The FAO estimate is therefore an aggregate calculation based on aggregate commodity supply data. It uses common conversion factors (not specific to any country) to derive food, protein and fat per capita consumption estimates. It also relates to quantities available for consumption and does not account for losses (e.g. fat trimmed from meat) beyond the farm-gate through to retail. These methodological limitations of the FAO estimates are more significant for developed countries such as the UK where a greater proportion of consumption is in the form of processed products.

The UK GHGI estimate of protein consumption is derived from the Expenditure and Food Survey (Defra, 2017). This is a sample household survey in which households record the actual purchases of food they make. UK-specific conversion factors are then applied to these individual food items to estimate consumption of protein and other nutrients. The UK-specific conversion factors are based on a detailed analysis of the individual types of food purchased and contrasts to the more broad-brush factors used by the FAO. The Expenditure and Food Survey estimate is also net of any losses through the food chain through to retail as it is based on actual purchases. The only limitation to the Expenditure and Food Survey is that it may have an element of under-recording due to purchases of some food items not being included in the diary of survey participants, but the Inventory Agency considers that it is more representative of UK protein consumption per capita than the FAO estimate.

### 7.5.2.4  5D2: Industrial Waste-water Treatment

In the UK, a high proportion of industry trade waste-water is disposed to the municipal sewer system and treated by water companies together with the sewage and effluent from domestic and commercial sectors.

In the data reported by the water companies and used to generate methane emission estimates in 5D1 (see above), some of the annual reporting to water regulators includes explicit data on the BOD from "trade waste" and the total BOD treated (i.e. including domestic and commercial effluent) in the municipal systems. The share of total BOD that is attributable to the industry sector (i.e. "trade waste", managed via contracts between water companies and industry operators) is variable across the UK and across years. In 2008 (before the economic down-turn) the trade waste share of total BOD treated in the municipal waste-water systems (i.e. emissions from which are reported in 5D2) has been estimated to be 13.2%, but from 2009-2012 the figure has been in the range 10.8-11.7%. We are attempting to collect

information on the domestic-industrial split in wastewater treatment from water companies in order to have confidence in building a time series that removes this double count.

In addition to the above, where large industrial sites that have on-site waste-water treatment plant are regulated under IPPC/EPR, the annual IPPC/EPR reporting to regulator inventories (PI/SPRI/NIPI) includes the requirement to report any methane emissions from the waste-water effluent plant. The PI/SPRI/NIPI data on methane emissions are used within the UK GHGI, and included within many IPCC source categories, but the lack of source-specific detail in the PI/SPRI/NIPI reporting does not enable the waste-water treatment emission estimates from these industrial facilities to be split out and reported separately in the CRF.

In practice it is not straightforward to ascertain the extent to which emissions from waste-water treatment are consistently included in operator estimates across different industry sectors, as the IPPC/EPR data are not presented "by source", but rather "by installation". Within sector-specific guidance to plant operators on pollution inventory data preparation, emissions of methane from wastewater treatment are not highlighted as a common source to be considered, whilst in guidance for several industrial sectors, wastewater treatment is singled out as a potentially significant source of ammonia and nitrous oxide emissions.

Therefore, some industrial waste-water treatment methane emissions are already reported within a range of IPCC source categories, but cannot be quantified explicitly due to the lack of transparency of available source data from UK environmental regulatory reporting systems.

At the 2012 in-country review, the lack of transparency and level of emissions reported in 5D2 led the expert review team to recommend that the UK introduces new separate estimates of emissions of methane from industrial waste-water treatment. Therefore in the 2013 submission the Inventory Agency added a new time series estimates using the IPCC default methodology and available UK activity data from high-BOD-emitting UK industry sources, primarily in the food and drink and chemical production sectors. The UK Inventory Agency considers that this introduces a double count to the inventory, but is a conservative estimate to ensure completeness. The method is retained to the present, as no further evidence has been obtained by the Inventory Agency.

*7.5.2.4.1 Summary of Estimation method for UK 5D2 Estimates*

In developing industrial waste-water methane emission estimates, the following UK industries have been considered, as they are high-BOD-emitting waste-water source sectors in the UK economy:

- Organic Chemicals; and
- Food and Drink, including:
  - milk-processing;
  - manufacture of fruit and vegetable products;
  - potato processing;
  - meat processing;
  - production of alcohol and alcoholic beverages;
  - breweries;
  - manufacture of animal feed from plant products;
  - manufacture of gelatine and of glue from hides, skin and bones
  - malt houses; and
  - fish processing.

The estimation methodology is based on the following data and assumptions:

- Default values for Chemical Oxygen Demand (COD) and amount of wastewater generated used for organic chemical production from the IPCC 2006 GLs;
- PRODCOM data (supplied by the Office for National Statistics) used for organic chemical production (2009) and scaled using Office for National Statistics Index of

Production (IOP) for other years (1997 is earliest year for IOP so 1990-1996 estimates use the 1997 value); and

- Total organic load obtained for food and drink industry sub-sectors in a 2002 paper by Defra[78], scaled across the time series using Office for National Statistics Index of Production data (as above, 1997 data are used for 1990-1996 also).

*[The UK activity data are summarised for selected years across the time series in **Annex 3.5.4**]*

The Inventory Agency considers that these new emission estimates are very conservative, and likely to be over-estimates, noting that:

- There is no information currently available on how much wastewater for the chemical and food and drinks industries are treated on site and how much is included in emissions of wastewater sent to sewers. We have therefore used IPCC default values for the amount of wastewater consumed per tonne of output and amount of COD in the wastewater, and assumed all wastewater is treated on site rather than any of it disposed to municipal sewers;
- There is no information currently available on how much sewage sludge is removed and sent to landfill or applied to agricultural land. Although it is likely that this activity does take place, due to the absence of information, the default value of zero has been used;
- There is no information on the amount of methane recovered, so the default value of zero has been used, although it is likely that this activity also takes place. There is some evidence from the EU ETS dataset that several UK food and industry facilities collect methane from anaerobic digestion systems and use the gas as a fuel source; and
- There is no UK specific information on the split of aerobic and anaerobic industrial wastewater treatment and therefore the IPCC default estimate has been used. It is likely that aerobic treatment systems will be used in many UK facilities.

### 7.5.2.5 Overseas Territories and Crown Dependencies

Estimates from the OTs and CDs are calculated using the Tier 1 approach from the 2006 IPCC Guidelines and default EFs. Country-specific parameters have been chosen based on information provided through a waste survey (distributed in 2014) and through expert judgement. Per capita protein consumption data were taken from FAOSTAT with data for Bermuda applied to all OTs other than Gibraltar, and data from the UK applied to all CDs and Gibraltar.

## 7.5.3 Uncertainties and Time-Series Consistency

As outlined in **Section 7.5.2**, the method for deriving methane emission estimates for 5D1 uses activity data from across the time series, and applies emission factors that are derived from reported emissions data from 2009 onwards. The method uses a published national set of activity statistics that reflect the changing fate of sewage sludge treatment and disposal; the UK water industry has undergone a marked shift in treatment and disposal practices since the Urban Waste-water Treatment Directive of 1999 banned the dumping of sewage to sea and in 2001 the same directive required all large WWTP to conduct secondary treatment; the sludge disposal trends are consistent with this regulatory change.

Not all UK water companies reported their emission estimates in all years since 2009, and the available dataset for deriving country-specific factors is limited in some cases to only around 50% coverage of UK water treatment and sludge treatment / disposal activity. The Inventory

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[78] http://www.defra.gov.uk/publications/files/pb6655-uk-sewage-treatment-020424.pdf

Agency has continued to develop working relationships with the 12 UK water companies and from 2013 onwards obtained activity and emissions data from all of the 12 water companies. Therefore, we have a much more complete, consistent set of activity and emissions data reported from across the UK. This helps to further develop the UK-specific dataset from which estimates can be derived, improving accuracy through accessing more complete, representative data which reflects the range of waste-water quality and the design / stock of waste-water treatment facilities across the UK.

The reported emissions and activity by UK water companies since 2013 has been used to derive country-specific emission factors for water treatment, methane capture, sludge treatment and most disposal routes, and these factors are applied to the activity dataset back to 1990. We are therefore using the best available data to estimate the emissions back to 1990. The use of the IPCC default for methane emissions from waste disposal to sea introduces a significant uncertainty to the early part of the time series where the activity is known to have taken place. This is because the IPCC default factor is for a wide range of situations including stagnant lakes with high organic loads in temperate climates, which would have very different emissive behaviour to the cold, low organic load seas around the UK. Furthermore, the limited activity data time series for 5D1 due to changes in data reporting across the time series limits the accuracy and time series consistency of the estimates for the early part of the time series; however it is observed that the overlaps in trend between the data sets typically show strong agreement.

See **Annex 3.5.4** for further details on the activity data, implied emissions factors and emissions estimates, and **Section 7.5.6** below for an insight into the planned improvements for this source method.

## 7.5.4  Source Specific QA/QC and Verification

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

The 2016 UK GHGI reviews under the EU ESD and the UNFCCC Expert Review Team (ERT) concluded that the UK should carry out a verification of the methodology by comparing it with a tier 1 default methodology set out in the 2006 IPCC guidelines. Below this comparison is detailed.

The UK currently uses a 2006 IPCC default methodology to estimate emissions from waste water disposed to waterways and private waste management systems. The verification calculations below compare the emission estimates using the IPCC 2006 GLs Tier 1 method against the UK's country-specific model for all other waste water sources, i.e. from emission sources at UK WWTP where the 2006 IPCC Guidelines are not directly applied.

As outlined in **Section 7.5.2.1.1.3** the UK uses well-managed centralised aerobic treatment for waste water treatment. The UK also has a well-managed, flowing, closed sewer system. The 2006 IPCC default MCF for these sources is "0", which means that should the UK follow the 2006 IPCC default methodology it would be reporting zero emissions of methane.

We note, however, that the MCF of "0" may be due to a rounding of a small number rather than inferring that zero methane emissions would occur. It is likely that some methane emissions *will* occur. Even at well-managed WWTPs there will be incidences that lead to temporary anaerobic conditions. At an EU Working Group 1 meeting in February 2016 it was flagged that having an MCF of "0" for some sources in the 2006 IPCC guidelines meant that some countries will be under-reporting emissions.

The UK uses a country specific factor which accounts for several processes that occur at UK WWTPs including aerobic treatment[79]. 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.

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 per kg BOD | 2.7 kg per tonne raw DS | IPCC MCF is 0 for Centralized, aerobic treatment plant. UK factors from the CAW, which additionally includes emissions associated with temporary storage and gravity thickening of sludge. |
| Flowing sewer (closed) | 0 kg per kg BOD | Not Estimated | This is not included in the CAW, and the UK has not investigated further as the IPCC default is 0. While strictly speaking there probably are non-0 emissions from this source it is likely very close to 0 in the UK's well developed, managed, closed and flowing sewer system. |
| Private waste water management systems | 0.3 kg per kg BOD | 0.3 kg per kg BOD | UK uses IPCC default methodology for this source. |
| Sea, river and lake discharge | 0.06 kg per kg BOD | 0.06 kg per kg BOD | UK uses IPCC default methodology for this source. |
| Digestion (Chapter 4 of the 2006 IPCC guidelines) | 2 kg per tonne dry waste treated | 4.46 to 18.1 kg per tonne raw DS | UK factors from the CAW, this accounts for several different methods of digestion. The Chapter 4 IPCC Digestion factor includes the impact of methane recovery; the chapter 5 digestion factor does not. Given that anaerobic digestion is rarely done without methane recovery it is very conservative to assume it does not occur. |
| Digestion (Chapter 5 of the 2006 IPCC guidelines) | 0.48 kg per kg BOD | | |
| Composting | 10 kg per tonne dry waste treated | 10 kg per tonne raw DS | UK uses IPCC default methodology for this source. This source is included in the CAW, but they additionally used the 2006 IPCC guidelines |
| 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. |

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[79] 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 |
|---|---|---|---|
| Correction factor for industrial BOD discharged in sewers | 1.25 | Not Estimated | This is a parameter that the guidance gives to derive activity data. The reported data via CAW and other waste water reporting systems should already account for industrial co-discharge. |
| **Total Emissions for 1990** | **57 to 174 kt** | **59 kt** | **The range of IPCC Default emissions is dependent on which digestion factor is used; note that the higher value does not account for methane capture, which we know is occurring at UK sites.** |
| **Total Emissions for 2015** | **16 to 594 kt** | **29 kt** | **The UK's estimate remains within the range of emissions estimates based in IPCC methodologies for both 1990 and 2015. The only notable differences between the UK's method and the default method is the use of a non-0 UK factor for well-managed, centralised aerobic treatment, and using specific factors for different methods of anaerobic treatment.** |

## 7.5.5  Source Specific Recalculations

A number of minor recalculations have occurred due to, for example, revisions in index of production data, population statistics and more up to date protein data becoming available.

For information on the magnitude of recalculations, see **Section 10**.

## 7.5.6  Source Specific Planned improvements

It is noted that $N_2O$ emissions from waste-water has been highlighted as a key category, and we are currently using a tier 1 method. It should also be noted that the 2006 IPCC GLs do not provide a higher tier method.

The 2019 UNFCCC Expert Review Team (ERT) encouraged the UK, in order to impove transparency, to calculate the emissions from sludge treatment and private wastewater management systems separately, and to report them in the NIR. This approach will be implemented in next compilation cycle. Supporting informationon on activity data and emission factors will be reported in the 2021 submission of the UK GHGI.

# 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$_2$O is not mandatory. The UK calculates indirect emissions of N$_2$O 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$_2$O 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$_2$O-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$_2$O 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 2019 NIR submission (1990-2017 inventory), including responses to reviews of the inventory. It summarises material that has already been presented and discussed in more detail in **Chapter 3** to **Chapter 7**.

Each year the UK greenhouse gas inventory is *updated*, *extended* and may be *expanded*.

Updating often entails revision of emission estimates, most commonly because of revision to the core energy statistics presented in the Digest of UK Energy Statistics (DUKES). The inventory also makes use of other datasets (see **Table 1.6** for a summary) and these too may be revised. Updating also covers adoption of revised methodologies. Updating, particularly involving revised methodologies may affect the whole time series, so estimates of emissions for a given year may differ from estimates of emissions for the same year reported previously. Therefore comparisons between submissions should take account of whether there have been changes to the following:

- the emission estimation methodology, including revisions to assumptions or conversion factors;
- the reporting guidelines under which the submissions are made (for this submission, the IPCC 2006 guideline); the emission factors applied; and/or
- the activity data.

The time series of the inventory is extended by included a new inventory year. For example, the previous report covered years up to and including 2017. This report gives emission estimates for 2017 and also includes estimates for the year 2018.The time series of the inventory may also be expanded to include emissions from additional sources if a new source has been identified within the context of the IPCC Guidelines there are sufficient activity data and suitable emission factors.

## 10.1 EXPLANATIONS AND JUSTIFICATIONS FOR RE-CALCULATIONS, INCLUDING IN RESPONSE TO THE REVIEW PROCESS

**Table 10.1** to **Table 10.12** summarise the recalculations that have occurred in estimates of $CO_2$, $CH_4$, $N_2O$ and F-gases since the 2019 NIR submission (1990-2017 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 (2017).

**Table 10.15** summarises where changes to methodological descriptions have been made and where these descriptions can be found in the main text of this document.

All revisions to source data and methods, and all recalculations that are reported in the latest UK GHG inventory are conducted by the Inventory Agency in agreement with the BEIS GHG inventory management team; all major recalculations and systematic improvements to the UK GHG inventory are approved and managed via the NISC, with new outputs approved through the UK's system for pre-submission review. The inventory improvement process that manages the prioritisation and implementation of revisions to inventory data and methods uses the guiding principles of the 2006 IPCC Guidelines to govern the decisions over whether to

implement changes to inventory estimates or not. The most common justifications for implementing changes that lead to recalculations are:

- ✓ Improved **accuracy** of the estimates, e.g. where underlying data from data providers has been revised (e.g. revisions to energy statistics), where less uncertain data are now available (e.g. use of EU ETS activity data to inform energy allocations, in preference to UK energy statistics data sources), or where the Inventory Agency has applied more representative (ideally 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** | 566833.21 | 566342.35 | -490.86 | -0.09% | see explanations in individual categories |
| 1. Energy Industries | 235851.47 | 235816.24 | -35.23 | -0.01% | Minor revisions to carbon emission factors for natural gas (revised gross to net conversion) and OPG. |
| 2. Manufacturing industries and construction | 95723.43 | 95359.89 | -363.54 | -0.38% | Revision to coal emission factor for the cement inventory in the early 90s to use more recent data. Correction to coal data for lime production. |
| 3. Transport | 119742.52 | 119757.29 | 14.77 | 0.01% | Minor changes due to improvement of fuel consumption factors relating to rail locomotives and real drive cycles. |
| 4. Other sectors | 110222.36 | 110115.49 | -106.87 | -0.10% | Review of CV time series as part of transition to energy units improvement work - the time series for public sector and miscellaneous industrial/commercial combustion has be revised to improve time series consistency. |
| 5. Other | 5293.44 | 5293.44 | 0.00 | 0.00% | No changes. |
| **B. Fugitive emissions from fuels** | 7476.49 | 7476.49 | 0.00 | 0.00% | No changes. |
| 1. Solid fuels | 1698.56 | 1698.56 | 0.00 | 0.00% | No changes. |
| 2. Oil and natural gas | 5777.92 | 5777.92 | 0.00 | 0.00% | No changes. |
| | | | | | |
| **2. Industrial Processes and product use** | | | | | |
| A. Mineral industry | 9803.78 | 9759.72 | -44.06 | -0.45% | Correction to methodology for early time series for lime production (2A2) |
| B. Chemical industry | 6770.09 | 6986.06 | 215.97 | 3.19% | Revision to analysis of EU ETS petrochemical sites, resulting in an increase in estimated emissions from use of process off-gases. |
| C. Metal industry | 7400.69 | 7400.09 | -0.59 | -0.01% | No significant recalculations. |
| D. Non-energy products from fuels and solvent use | 552.81 | 552.81 | 0.00 | 0.00% | 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 |
|---|---|---|---|---|---|
| G. Other product manufacture and use | NO | 14.10 | | 100.00% | Addition of new estimates of emissions from uses of sodium bicarbonate, to improve completeness of the UK GHGI. |
| H. Other | IE,NE,NO | IE,NE,NO | | 0.00% | |
| | | | | | |
| **3.Agriculture** | | | | | |
| G. Liming | 1012.43 | 1012.43 | 0.00 | 0.00% | No significant recalculations. |
| H. Urea application | 327.60 | 327.60 | 0.00 | 0.00% | No significant recalculations. |
| | | | | | |
| **4. Land use, Land-use change and forestry** | | | | | |
| A. Forest land | -15026.26 | -15337.63 | -311.37 | 2.07% | Improvements and corrections to forestry model and forestry activity data updates. |
| B. Cropland | 14265.93 | 14607.95 | 342.02 | 2.40% | Change in reference SOC stocks for cropland management. |
| C. Grassland | -7111.03 | -7103.44 | 7.60 | -0.11% | Improvements to the deforestation modelling and activity data. |
| D. Wetlands | 486.95 | 486.95 | 0.00 | 0.00% | No significant recalculations |
| E. Settlements | 7011.30 | 7106.81 | 95.51 | 1.36% | Improvements to the deforestation modelling and activity data. |
| G. Harvested wood products | -1639.08 | -2096.71 | -457.63 | 27.92% | Revisions to activity data, to achieve a closer match with wood production statistics. |
| | | | | | |
| **5. Waste** | | | | | |
| C. Incineration and open burning of waste | 1300.71 | 1311.98 | 11.27 | 0.87% | Implementation of database method for processing regulators inventories. This included critical review of inputs and assumptions, leading to small changes in the early time series. |

**Table 10.2    Recalculations to CO₂ in 2017 (kt CO₂)**

| IPCC category name | Previous submission (CO₂ eq., kt) | Latest submission (CO₂ eq., kt) | Difference (CO₂ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| **1. Energy** | | | | | |
| **A. Fuel combustion activities** | 367695.81 | 368331.39 | 635.58 | 0.17% | see reasons below in individual categories |
| 1. Energy Industries | 102629.11 | 102452.86 | -176.25 | -0.17% | Revision to remove double count for reported emissions from a specific oil and gas extraction installation. Revisions to fuel use statistics (DUKES). |
| 2. Manufacturing industries and construction | 51175.55 | 52157.57 | 982.02 | 1.92% | Revisions to fuel use statistics (DUKES). Revisions to emission factors for Iron and Steel combustion. |
| 3. Transport | 123345.32 | 123523.33 | 178.01 | 0.14% | Minor changes due to improvement of fuel consumption factors relating to rail locomotives and real drive cycles. Revisions to fuel use statistics (DUKES). |
| 4. Other sectors | 88987.64 | 88610.54 | -377.10 | -0.42% | Revisions to fuel use statistics (DUKES) resulting in less natural gas use in stationary residential combustion than previously estimated. Minor revisions to the allocation of gas oil for 1A4cii (off-road Agriculture/Forestry/Fishing). |
| 5. Other | 1558.20 | 1587.10 | 28.90 | 1.85% | No significant recalculations. |
| **B. Fugitive emissions from fuels** | 4590.18 | 4545.86 | -44.32 | -0.97% | see reasons below in individual categories |
| 1. Solid fuels | 359.54 | 360.37 | 0.83 | 0.23% | No significant recalculations. |
| 2. Oil and natural gas | 4230.64 | 4185.49 | -45.16 | -1.07% | Removal of duplicate emission estimates for three upstream oil and gas facilities. |
| | | | | | |
| **2. Industrial processes and product use** | | | | | |
| A. Mineral industry | 6249.48 | 6286.52 | 37.05 | 0.59% | No significant recalculations. |
| B. Chemical industry | 4931.56 | 5089.96 | 158.40 | 3.21% | Revision to analysis of EU ETS petrochemical sites, resulting in an increase in estimated emissions from use of process off-gases. |

| IPCC category name | Previous submission ($CO_2$ eq., kt) | Latest submission ($CO_2$ eq., kt) | Difference ($CO_2$ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| C. Metal industry | 2572.86 | 2573.31 | 0.45 | 0.02% | No significant recalculations. |
| D. Non-energy products from fuels and solvent use | 519.22 | 411.65 | -107.57 | -20.72% | Revisions to demand figures within DUKES resulting in downward revisions to total use of petroleum coke within 2D3. |
| G. Other product manufacture and use | NO | 35.81 | | 100.00 % | Addition of new estimates of emissions from uses of sodium bicarbonate, to improve completeness of the UK GHGI. |
| H. Other | NO,NE,IE | NO,NE,IE | | 0.00% | |
| | | | | | |
| **3. Agriculture** | | | | | |
| G. Liming | 936.67 | 936.67 | 0.00 | 0.00% | No significant recalculations. |
| H. Urea application | 343.95 | 343.95 | 0.00 | 0.00% | No significant recalculations. |
| | | | | | |
| **4. Land use, land-use change and forestry** | | | | | |
| A. Forest land | -18211.77 | -18459.91 | -248.14 | 1.36% | Improvements and corrections to forestry model and forestry activity data updates. |
| B. Cropland | 10971.23 | 11230.53 | 259.30 | 2.36% | Change in reference SOC stocks for cropland management. |
| C. Grassland | -8861.80 | -8857.28 | 4.52 | -0.05% | Improvements to the deforestation modelling and activity data. |
| D. Wetlands | 336.78 | 336.79 | 0.02 | 0.00% | Improved activity data for peat extraction. |
| E. Settlements | 6451.34 | 6688.92 | 237.58 | 3.68% | Improvements to the deforestation modelling and activity data. |
| G. Harvested wood products | -2015.60 | -2374.22 | -358.61 | 17.79% | Revisions to activity data, to achieve a closer match with wood production statistics. |
| | | | | | |
| **5. Waste** | | | | | |
| C. Incineration and open burning of waste | 258.91 | 245.12 | -13.79 | -5.32% | Detailed analysis of waste incineration statistics indicated some double-counting of emissions already accounted within the |

| IPCC category name | Previous submission ($CO_2$ eq., kt) | Latest submission ($CO_2$ eq., kt) | Difference ($CO_2$ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| | | | | | GHGI, and hence these small double-counts were removed, reducing emissions slightly in 5C. |

**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** | 3152.63 | 3175.64 | 23.01 | 0.73% | see explanations in individual categories |
| 1. Energy Industries | 204.00 | 205.29 | 1.29 | 0.63% | Revisions to calorific values. |
| 2. Manufacturing industries and construction | 116.67 | 115.78 | -0.89 | -0.76% | Minor changes in relation to transition in method to conduct calculations in energy units, including some revisions to improve the applied calorific values for some fuels and sub-sectors. |
| 3. Transport | 1259.48 | 1259.32 | -0.16 | -0.01% | No significant recalculations. |
| 4. Other sectors | 1568.92 | 1591.69 | 22.77 | 1.45% | Revised allocation of straw combustion within fuel statistics to Agriculture/Forestry/Fishing. |
| 5. Other | 3.56 | 3.56 | 0.00 | 0.00% | No changes. |
| **B. Fugitive emissions from fuels** | 34171.92 | 34205.72 | 33.80 | 0.10% | see explanations in individual categories |
| 1. Solid fuels | 21826.86 | 21826.76 | -0.10 | 0.00% | No changes. |
| 2. Oil and natural gas | 12345.07 | 12378.97 | 33.90 | 0.27% | Minor revisions to base year estimates of methane from onshore petroleum processes, following re-analysis of installation-level reported data in the early 1990s and addition of estimates for a number of installations which report methane in later years. |
| | | | | | |
| **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 |
|---|---|---|---|---|---|
| B. Chemical industry | 204.89 | 221.63 | 16.74 | 8.17% | Revision to analysis of installation-level reported data within the "Chemical Release Inventory" in the early 1990s, and addition of methane estimates for a number of installations, e.g. to fill gaps for sites that reported methane in later years. |
| C. Metal industry | 36.90 | 36.94 | 0.05 | 0.13% | No significant recalculations. |
| | | | | | |
| **3 Agriculture** | | | | | |
| A. Enteric fermentation | 25392.50 | 25392.50 | 0.00 | 0.00% | No significant recalculations. |
| B. Manure management | 4732.53 | 4732.53 | 0.00 | 0.00% | No significant recalculations. |
| F. Field burning of agricultural residues | 186.57 | 187.03 | 0.46 | 0.24% | No significant recalculations. |
| | | | | | |
| **4. Land use, land-use change and forestry** | | | | | |
| A. Forest land | 2.89 | 3.75 | 0.86 | 29.85% | Improved carbon stock densities for biomass burning. |
| B. Cropland | 0.09 | 0.10 | 0.01 | 7.33% | Improved carbon stock densities for biomass burning. |
| C. Grassland | 9.97 | 10.68 | 0.72 | 7.18% | Improved carbon stock densities for biomass burning. |
| E. Settlements | 3.00 | 3.48 | 0.48 | 15.95% | Improved carbon stock densities for biomass burning. |
| | | | | | |
| **5. Waste** | | | | | |
| A. Solid waste disposal | 60432.98 | 60433.94 | 0.96 | 0.00% | No significant recalculations. |
| B. Biological treatment of solid waste | 18.13 | 18.13 | 0.00 | 0.00% | No significant recalculations. |
| C. Incineration and open burning of waste | 134.83 | 135.61 | 0.78 | 0.58% | Analysis of installation-level reported data in the early 1990s has led to the addition of methane estimates for a number of |

| IPCC name | Previous submission (CO₂ eq., kt) | Latest submission (CO₂ eq., kt) | Difference (CO₂ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| | | | | | 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. |
| D. Waste water treatment and discharge | 4218.90 | 4218.80 | -0.10 | 0.00% | Minor revision to number of households and therefore activity data. |

**Table 10.4      Recalculations to CH₄ in 2017 (kt CH₄)**

| IPCC name | Previous submission (CO₂ eq., kt) | Latest submission (CO₂ eq., kt) | Difference (CO₂ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| **1. Energy** | | | | | |
| **A. Fuel combustion activities** | 1580.53 | 1580.31 | -0.22 | -0.01% | see explanations in individual categories |
| 1. Energy Industries | 381.11 | 377.16 | -3.95 | -1.04% | Revisions to fuel use statistics (DUKES) and calorific values. |
| 2. Manufacturing industries and construction | 124.01 | 113.57 | -10.44 | -8.42% | Revisions to fuel use statistics (DUKES) dominate. Changes are mainly seen in 1A2gviii; other sub-sectors are hardly affected. The dominant change is a reduction in estimated biomass use in 1A2gviii, partly offset by small increases in allocation of coal and burning oil. |
| 3. Transport | 104.21 | 103.09 | -1.11 | -1.07% | Minor changes due to improvement of fuel consumption factors relating to rail locomotives and real drive cycles. |
| 4. Other sectors | 970.17 | 985.45 | 15.28 | 1.57% | Revised allocation of straw combustion within fuel statistics to Agriculture/Forestry/Fishing. |
| 5. Other | 1.03 | 1.04 | 0.01 | 0.72% | No significant recalculations. |
| **B. Fugitive emissions from fuels** | 5423.01 | 5425.68 | 2.67 | 0.05% | see explanations in individual categories |
| 1. Solid fuels | 487.76 | 487.69 | -0.08 | -0.02% | No significant recalculations. |
| 2. Oil and natural gas | 4935.25 | 4937.99 | 2.74 | 0.06% | Revision to installation-level estimates for upstream oil and gas facilities. |

| 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** | | | | | |
| B. Chemical industry | 61.41 | 63.99 | 2.58 | 4.21% | Revision to analysis of installation-level consumption of process off-gases using EU ETS data, which are used to generate estimates of OPG fuel use. |
| C. Metal industry | 10.68 | 10.70 | 0.02 | 0.15% | No significant recalculations. |
| | | | | | |
| **3 Agriculture** | | | | | |
| A. Enteric fermentation | 21458.44 | 21458.44 | 0.00 | 0.00% | No significant recalculations. |
| B. Manure management | 4226.81 | 4226.81 | 0.00 | 0.00% | No significant recalculations. |
| | | | | | |
| **4. Land use, land-use change and forestry** | | | | | |
| A. Forest land | 2.31 | 3.20 | 0.89 | 38.36% | Improved carbon stock densities for biomass burning. |
| B. Cropland | 0.02 | 0.02 | 0.00 | 0.00% | No significant recalculations |
| C. Grassland | 17.78 | 18.71 | 0.93 | 5.23% | Improved carbon stock densities for biomass burning. |
| E. Settlements | 8.25 | 11.46 | 3.21 | 38.90% | Improved carbon stock densities for biomass burning. |
| | | | | | |
| **5. Waste** | | | | | |
| A. Solid waste disposal | 14261.40 | 14309.88 | 48.48 | 0.34% | Revision of methane emitted following correction to formula to derive flaring quantities. |
| B. Biological treatment of solid waste | 1193.62 | 1220.39 | 26.77 | 2.24% | Revision to activity data for waste quantities and composition across waste treatment streams. |

| IPCC name | Previous submission (CO$_2$ eq., kt) | Latest submission (CO$_2$ eq., kt) | Difference (CO$_2$ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| C. Incineration and open burning of waste | 10.45 | 10.13 | -0.31 | -3.00% | Changes to installation level extrapolation/gap filling of reported emissions. |
| D. Waste water treatment and discharge | 3445.75 | 3447.09 | 1.34 | 0.04% | Minor revision to number of households and therefore activity data. |

**Table 10.5        Recalculations to N$_2$O in 1990 (kt N$_2$O)**

| 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** | 3592.64 | 3622.07 | 29.43 | 0.82% | see explanations in individual categories |
| 1. Energy Industries | 1370.01 | 1402.01 | 32.01 | 2.34% | Changes to calorific values ratios |
| 2. Manufacturing industries and construction | 321.80 | 316.43 | -5.38 | -1.67% | Changes to calorific values ratios to use values specific to reported data from Installations, revisions to fuel use data (DUKES) across industry. |
| 3. Transport | 1451.62 | 1451.57 | -0.05 | 0.00% | No significant recalculations |
| 4. Other sectors | 393.08 | 395.93 | 2.85 | 0.73% | Minor revisions to calorific values used in stationary residential combustion (1A4bi) and the calorific value for coal within commercial/institutional combustion. Minor updates to activity drivers such as household numbers, used to drive activity data for household and garden machinery (1A4bii). |
| 5. Other | 56.12 | 56.12 | 0.00 | 0.00% | No changes. |
| **B. Fugitive emissions from fuels** | 40.85 | 40.85 | 0.00 | 0.00% | see explanations in individual categories |
| 1. Solid fuels | 0.09 | 0.09 | 0.00 | -0.01% | No changes. |
| 2. Oil and natural gas | 40.75 | 40.75 | 0.00 | 0.00% | No changes. |

| 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** | | | | | |
| B. Chemical industry | 23797.27 | 23797.38 | 0.11 | 0.00% | No significant recalculations |
| C. Metal industry | 17.74 | 18.02 | 0.28 | 1.58% | Changes to installation level extrapolation/gap filling of reported emissions. |
| G. Other product manufacture and use | 593.57 | 595.89 | 2.31 | 0.39% | No changes. |
| | | | | | |
| **3 Agriculture** | | | | | |
| B. Manure management | 3442.70 | 3442.70 | 0.00 | 0.00% | No changes. |
| D. Agricultural soils(3) | 13610.39 | 13610.39 | 0.00 | 0.00% | No changes. |
| F. Field burning of agricultural residues | 57.66 | 57.80 | 0.14 | 0.24% | No changes. |
| | | | | | |
| **4. Land use, land-use change and forestry** | | | | | |
| A. Forest land | 231.22 | 232.60 | 1.37 | 0.59% | Improvements in activity data for LUC and forest drainage |
| B. Cropland | 1019.85 | 1019.86 | 0.00 | 0.00% | No significant recalculations |
| C. Grassland | 10.33 | 207.53 | 197.20 | 1908.62% | Improved carbon stock densities for biomass burning. |
| D. Wetlands | 4.13 | 4.13 | 0.00 | 0.00% | No significant recalculations |
| E. Settlements | 584.68 | 584.99 | 0.32 | 0.05% | Improved carbon stock densities for biomass burning. |
| H. Other (Indirect $N_2O$) | 401.48 | 401.40 | -0.08 | -0.02% | Indirect $N_2O$. Minor 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 | 12.97 | 12.97 | 0.00 | 0.00% | No changes. |
| C. Incineration and open burning of waste | 46.66 | 50.91 | 4.25 | 9.10% | Changes to installation level extrapolation/gap filling of reported emissions. |
| D. Waste water treatment and discharge | 783.59 | 783.72 | 0.13 | 0.02% | No changes. |

**Table 10.6      Recalculations to N$_2$O in 2017 (kt N$_2$O)**

| 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** | 2473.92 | 2448.84 | -25.08 | -1.01% | see explanations in individual categories |
| 1. Energy Industries | 751.36 | 739.11 | -12.25 | -1.63% | Changes to calorific values ratios, revisions to fuel use data (DUKES) |
| 2. Manufacturing industries and construction | 249.64 | 231.69 | -17.95 | -7.19% | Changes to calorific values ratios to use values specific to reported data from Installations, revisions to fuel use data (DUKES) across industry. |
| 3. Transport | 1211.08 | 1212.21 | 1.13 | 0.09% | Minor changes in railways due to improvement of fuel consumption factors relating to rail locomotives and revision of activity data for 2017 due to data availability. |
| 4. Other sectors | 245.36 | 248.97 | 3.61 | 1.47% | Minor revisions to calorific values used in stationary residential combustion (1A4bi). Minor updates to activity drivers such as household numbers, used to drive activity data for household and garden machinery (1A4bii). |

| IPCC name | Previous submission (CO$_2$ eq., kt) | Latest submission (CO$_2$ eq., kt) | Difference (CO$_2$ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| 5. Other | 16.48 | 16.86 | 0.39 | 2.35% | No significant recalculations. |
| **B. Fugitive emissions from fuels** | 39.38 | 39.25 | -0.13 | -0.32% | see explanations in individual categories |
| 1. Solid fuels | 0.02 | 0.02 | 0.00 | -0.01% | No changes. |
| 2. Oil and natural gas | 39.36 | 39.23 | -0.13 | -0.32% | No significant recalculations. |
| | | | | | |
| **2. Industrial processes and product use** | | | | | |
| B. Chemical industry | 39.10 | 39.18 | 0.09 | 0.22% | No significant recalculations. |
| C. Metal industry | 6.19 | 6.29 | 0.10 | 1.57% | No significant recalculations. |
| G. Other product manufacture and use | 843.87 | 850.20 | 6.33 | 0.75% | Minor revisions to estimates of N$_2$O emissions from recreational use, and an update to milk utilisation data which revises the N$_2$O from squirty cream estimates. |
| | | | | | |
| **3 Agriculture** | | | | | |
| B. Manure management | 2814.79 | 2814.79 | 0.00 | 0.00% | No significant recalculations. |
| D. Agricultural soils(3) | 11466.79 | 11478.51 | 11.72 | 0.10% | Update to the sewage sludge and mineralisation data for 2017. |
| | | | | | |
| **4. Land use, land-use change and forestry** | | | | | |
| A. Forest land | 144.65 | 148.26 | 3.60 | 2.49% | Improvements in activity data for LUC and forest drainage |

| IPCC name | Previous submission ($CO_2$ eq., kt) | Latest submission ($CO_2$ eq., kt) | Difference ($CO_2$ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| B. Cropland | 461.97 | 461.97 | 0.00 | 0.00% | No significant recalculations |
| C. Grassland | 33.24 | 230.52 | 197.28 | 593.58% | Improved carbon stock densities for biomass burning. |
| D. Wetlands | 0.30 | 0.30 | 0.00 | 0.00% | No significant recalculations |
| E. Settlements | 524.99 | 528.74 | 3.74 | 0.71% | Improved carbon stock densities for biomass burning. |
| H. Other **(Indirect N₂O)** | 243.60 | 244.12 | 0.52 | 0.21% | Indirect $N_2O$. Minor recalculations. |
|  |  |  |  |  |  |
| **5. Waste** |  |  |  |  |  |
| B. Biological treatment of solid waste | 728.03 | 738.12 | 10.09 | 1.39% | Revision to activity data for waste quantities and composition across waste treatment streams. |
| C. Incineration and open burning of waste | 39.63 | 45.37 | 5.74 | 14.49% | Changes to installation level extrapolation/gap filling of reported emissions. |
| D. Waste water treatment and discharge | 725.93 | 725.92 | -0.01 | 0.00% | No significant recalculations |

**Table 10.7      Recalculations to SF₆ 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.G.1. Electrical equipment | 783.25 | 790.37 | 7.13 | 0.91% | Revision to OfGem data |

**Table 10.8        Recalculations to SF$_6$ in 2017 (CO$_2$ eq., kt)**

| IPCC name | Previous submission (CO$_2$ eq., kt) | Latest submission (CO$_2$ eq., kt) | Difference (CO$_2$ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| **2. Industrial processes and product use** | | | | | |
| 2.G.1. Electrical equipment | 281.17 | 265.35 | -15.82 | -5.63% | Revision to data from the UK electricity supply sector regulator (OFGEM), which leads to slightly lower emission estimates from electrical insulation since 2013. |

**Table 10.9        Recalculations to HFC in base year (CO$_2$ eq., kt)**

| IPCC name | Previous submission (CO$_2$ eq., kt) | Latest submission (CO$_2$ eq., kt) | Difference (CO$_2$ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| **2. Industrial processes and product use** | | | | | |
| 2.B.9. Flurochemical production | 17670.77 | 17670.77 | 0.00 | 0.00% | No change. |
| 2.E.1. Integrated circuit or semiconductor | 8.73 | 8.73 | 0.00 | 0.00% | No change. |
| 2.F.1. Refrigeration and air conditioning | 531.30 | 531.30 | 0.00 | 0.00% | No change. |
| 2.F.2. Foam blowing agents | 184.49 | 184.49 | 0.00 | 0.00% | No change. |
| 2.F.3. Fire protection | 0.97 | 0.97 | 0.00 | 0.00% | No change. |
| 2.F.4. Aerosols | 663.00 | 663.03 | 0.03 | 0.00% | No change. |
| 2.F.6. Other applications | 36.88 | 36.99 | 0.11 | 0.30% | No change. |

**Table 10.10    Recalculations to HFC in 2017 (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 | 2.55 | 0.00 | -2.55 | -100.00% | HCFC manufacturing had ceased prior to 2017, so the previously estimated (extrapolated) emissions of HFCs from the production site have been removed from the inventory. |
| 2.C.4. Magnesium production | 2.29 | 2.29 | 0.00 | 0.00% | No change. |
| 2.E.1. Integrated circuit or semiconductor | 21.18 | 21.18 | 0.00 | 0.00% | No change. |
| 2.F.1. Refrigeration and air conditioning | 11653.11 | 11645.62 | -7.49 | -0.06% | No significant recalculations |
| 2.F.2. Foam blowing agents | 450.52 | 450.75 | 0.23 | 0.05% | No significant recalculations |
| 2.F.3. Fire protection | 324.69 | 324.63 | -0.06 | -0.02% | No significant recalculations |
| 2.F.4. Aerosols | 1658.10 | 1657.67 | -0.43 | -0.03% | No significant recalculations |
| 2.F.5. Solvents | 18.67 | 16.64 | -2.03 | -10.87% | Revision to include latest activity data from EU F-gas Report. |
| 2.F.6. Other applications | 61.71 | 62.10 | 0.39 | 0.63% | No significant recalculations |

**Table 10.11    Recalculations to PFC in base year (CO$_2$ eq., kt)**

| IPCC name | Previous submission (CO$_2$ eq., kt) | Latest submission (CO$_2$ eq., kt) | Difference (CO$_2$ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| There were no recalculations to PFC in the base year | | | | | |

**Table 10.12      Recalculations to PFC in 2017 (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 | 172.90 | 294.62 | 121.72 | 70.40% | Replacement of extrapolated data with reported data |
| 2.C.3. Aluminium production | 15.07 | 15.07 | 0.00 | 0.00% | No change. |
| 2.G.2. SF$_6$ and PFCs from other product use | 183.51 | 183.51 | 0.00 | 0.00% | No change. |

**Table 10.13      Recalculations to NF$_3$ in base year (CO$_2$ eq., kt)**

| IPCC name | Previous submission (CO$_2$ eq., kt) | Latest submission (CO$_2$ eq., kt) | Difference (CO$_2$ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| There were no recalculations to NF$_3$ in the base year | | | | | |

**Table 10.14      Recalculations to NF$_3$ in 2017 (CO$_2$ eq., kt)**

| IPCC name | Previous submission (CO$_2$ eq., kt) | Latest submission (CO$_2$ eq., kt) | Difference (CO$_2$ eq., kt) | Difference % | Explanation for recalculations |
|---|---|---|---|---|---|
| There were no recalculations to NF$_3$ in the latest inventory year | | | | | |

**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 |

| GREENHOUSE GAS SOURCE AND SINK CATEGORIES | DESCRIPTION OF METHODS | RECALCULATIONS | REFERENCE |
|---|:---:|:---:|---|
| A. Fuel Combustion (sectoral approach) | Y | Y | Chapter 3 |
| 1. Energy industries | Y | Y | Chapter 3 |
| 2. Manufacturing industries and construction | Y | Y | Chapter 3 |
| 3. Transport | Y | Y | Chapter 3 |
| 4. Other sector | Y | Y | Chapter 3 |
| 5. Other | Y | Y | Chapter 3 |
| B. Fugitive emissions from fuels | Y | Y | Chapter 3 |
| 1. Solid fuels | Y | Y | Chapter 3 |
| 2. Oil and natural gas and other emissions from energy production | Y | Y | Chapter 3 |
| C. $CO_2$ transport and storage | N | N | Chapter 3 |
| **2. Industrial processes and product use** | Y | Y | Chapter 4 |
| A. Mineral industry | Y | Y | Chapter 4 |
| B. Chemical industry | Y | Y | Chapter 4 |
| C. Metal industry | Y | Y | Chapter 4 |
| D. Non-energy products from fuels and solvent use | Y | Y | Chapter 4 |

| GREENHOUSE GAS SOURCE AND SINK CATEGORIES | DESCRIPTION OF METHODS | RECALCULATIONS | REFERENCE |
|---|---|---|---|
| E. Electronic industry | Y | Y | Chapter 4 |
| F. Product uses as substitutes for ODS | Y | Y | Chapter 4 |
| G. Other product manufacture and use | Y | Y | Chapter 4 |
| H. Other | Y | Y | Chapter 4 |
| **3. Agriculture** | Y | Y | Chapter 5 |
| A. Enteric fermentation | Y | Y | Chapter 5 |
| B. Manure management | Y | Y | Chapter 5 |
| C. Rice cultivation | N | N | Chapter 5 |
| D. Agricultural soils | Y | Y | Chapter 5 |
| E. Prescribed burning of savannahs | N | N | Chapter 5 |
| F. Field burning of agricultural residues | Y | Y | Chapter 5 |
| G. Liming | Y | Y | Chapter 5 |
| H. Urea application | Y | Y | Chapter 5 |
| I. Other carbon containing fertilisers | Y | Y | Chapter 5 |
| J. Other | Y | Y | Chapter 5 |
| **4. Land use, land-use change and forestry** | Y | Y | Chapter 6 |

| GREENHOUSE GAS SOURCE AND SINK CATEGORIES | DESCRIPTION OF METHODS | RECALCULATIONS | REFERENCE |
|---|---|---|---|
| A. Forest land | Y | Y | Chapter 6 |
| B. Cropland | Y | Y | Chapter 6 |
| C. Grassland | Y | Y | Chapter 6 |
| D. Wetlands | Y | Y | Chapter 6 |
| E. Settlements | Y | Y | Chapter 6 |
| F. Other land | Y | Y | Chapter 6 |
| G. Harvested wood products | Y | Y | Chapter 6 |
| H. Other | Y | Y | Chapter 6 |
| **5. Waste** | Y | Y | Chapter 7 |
| A. Solid waste disposal | Y | Y | Chapter 7 |
| B. Biological treatment of solid waste | Y | Y | Chapter 7 |
| C. Incineration and open burning of waste | Y | Y | Chapter 7 |
| D. Wastewater treatment and discharge | Y | Y | Chapter 7 |
| E. Other | N | N | |
| **6. Other (as specified in Summary 1.A)** | N | N | |
| **KP LULUCF** | Y | Y | Chapter 11 |

| GREENHOUSE GAS SOURCE AND SINK CATEGORIES | DESCRIPTION OF METHODS | RECALCULATIONS | REFERENCE |
|---|:---:|:---:|---|
| **Article 3.3 activities** | Y | Y | Chapter 11 |
| Afforestation/reforestation | Y | Y | Chapter 11 |
| Deforestation | Y | Y | Chapter 11 |
| **Article 3.4 activities** | Y | Y | Chapter 11 |
| Forest management | Y | Y | Chapter 11 |
| Cropland management (if elected) | Y | Y | Chapter 11 |
| Grazing land management (if elected) | Y | Y | Chapter 11 |
| Revegetation (if elected) | Y | Y | Chapter 11 |
| Wetland drainage and rewetting (if elected) | Y | Y | Chapter 11 |

| NIR Chapter | DESCRIPTION | | REFERENCE |
|---|:---:|:---:|---|
| **Chapter 1.2 Description of national inventory arrangements** | N | N | |

## 10.1.1 KP-LULUCF Activities

Justifications for the recalculations are given in Chapter 6, sections 6.2.7, 6.3.7 and 6.4.7.

*Article 3.3 Afforestation* has been affected by:

Carbon stock change: **Reconciliation of harvest volume and forest age data**, **Improvements to CARBINE**

Direct and indirect $N_2O$ emissions from N fertilization**: Reconciliation of harvest volume and forest age data**

$CH_4$ and $N_2O$ emissions from drained and rewetted organic soils: **Reconciliation of harvest volume and forest age data**

$N_2O$ emissions from N mineralization: **Reconciliation of harvest volume and forest age data**

GHG emissions from wildfires: **Use of biomass densities from CARBINE model**

HWP**: Reconciliation of harvest volume and forest age data**


*Article 3.3 Deforestation* has been affected by:

Carbon stock change: **Use of biomass densities from CARBINE model, Revision of deforestation activity dataand Inclusion of deforestation in the Cayman Islands**

$N_2O$ emissions from N mineralization: **Revision of deforestation activity data**

GHG emissions from biomass burning: **Use of biomass densities from CARBINE model.**


*Article 3.4 Forest Management* has been affected by:

Carbon stock change: **Reconciliation of harvest volume and forest age data**, **Improvements to the CARBINE model**

$CH_4$ and $N_2O$ emissions from drained and rewetted organic soils: **Reconciliation of harvest volume and forest age data**


GHG emissions from biomass burning: **Inclusion of emissions from wildfires in the OTs and CDs**

HWP**: Reconciliation of harvest volume and forest age data**


*Article 3.4 Cropland Management* has been affected by:

Carbon stock change: **Change in soil carbon density for crop management, Correction of cropland areas** and **Changes to cropland LUC time series in the Falkland Islands and Jersey**

Emissions from $N_2O$ mineralisation: **Change in soil carbon density for crop management** and **Changes to cropland LUC time series in the Falkland Islands and Jersey**


*Article 3.4 Grazing Land Management* has been affected by:

Carbon stock change: **Re-running of the Monte Carlo soil carbon model**

Emissions from $N_2O$ mineralisation: **Re-running of the Monte Carlo soil carbon model** and **Changes to cropland LUC time series in the Falkland Islands and Jersey**

GHG emissions from biomass burning: **Adjustment of average biomass densities due to error correction** and **Inclusion of emissions from wildfires in the OTs and CDs**

## 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 an increase in net emissions of 0.34 Mt $CO_2$ equivalent in 1990, and an increase in net emissions of 0.98 Mt $CO_2$ equivalent in 2017.

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.**
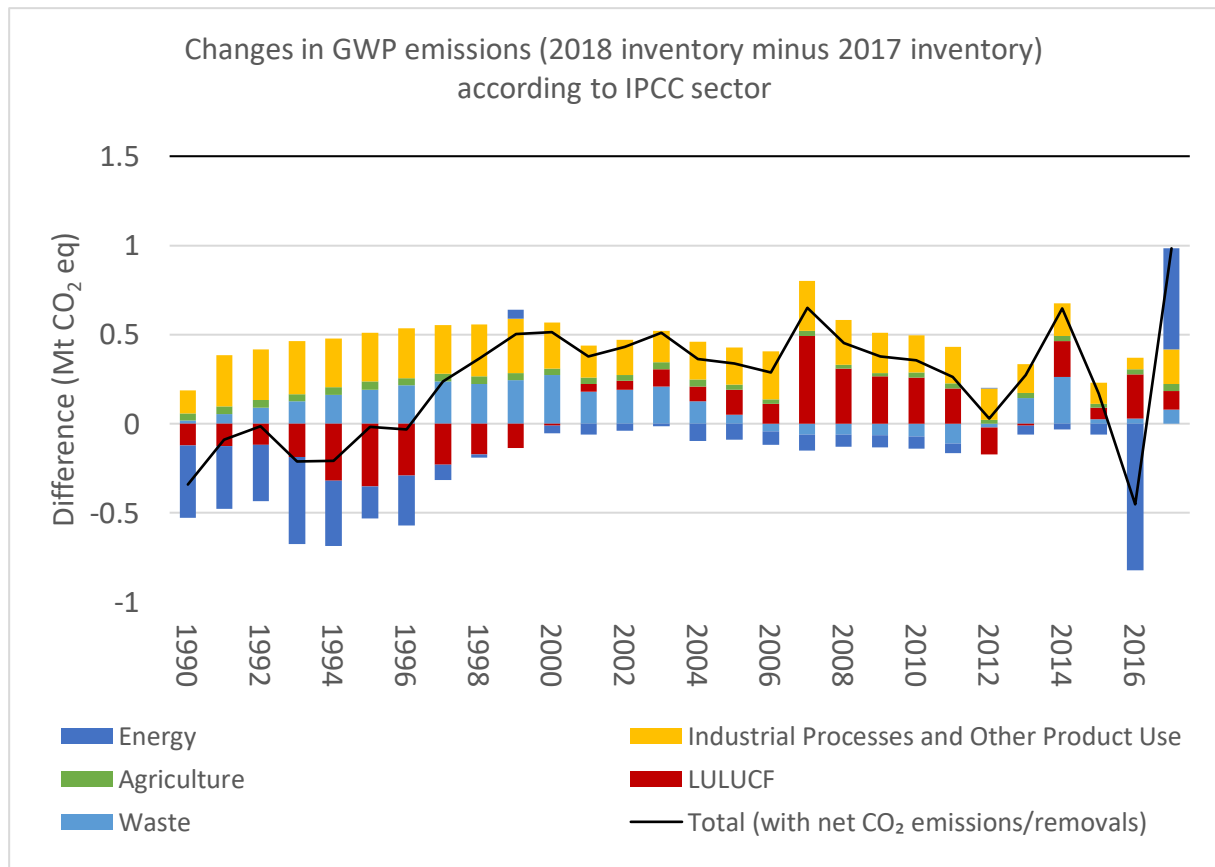


**Figure 10.2** shows the net impact of all recalculations in absolute and percentage terms.

**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.**



Difference and percentage change (2018 relative to 2017 inventory estimates) in total GWP emissions (Basket of 7 Kyoto GHGs)
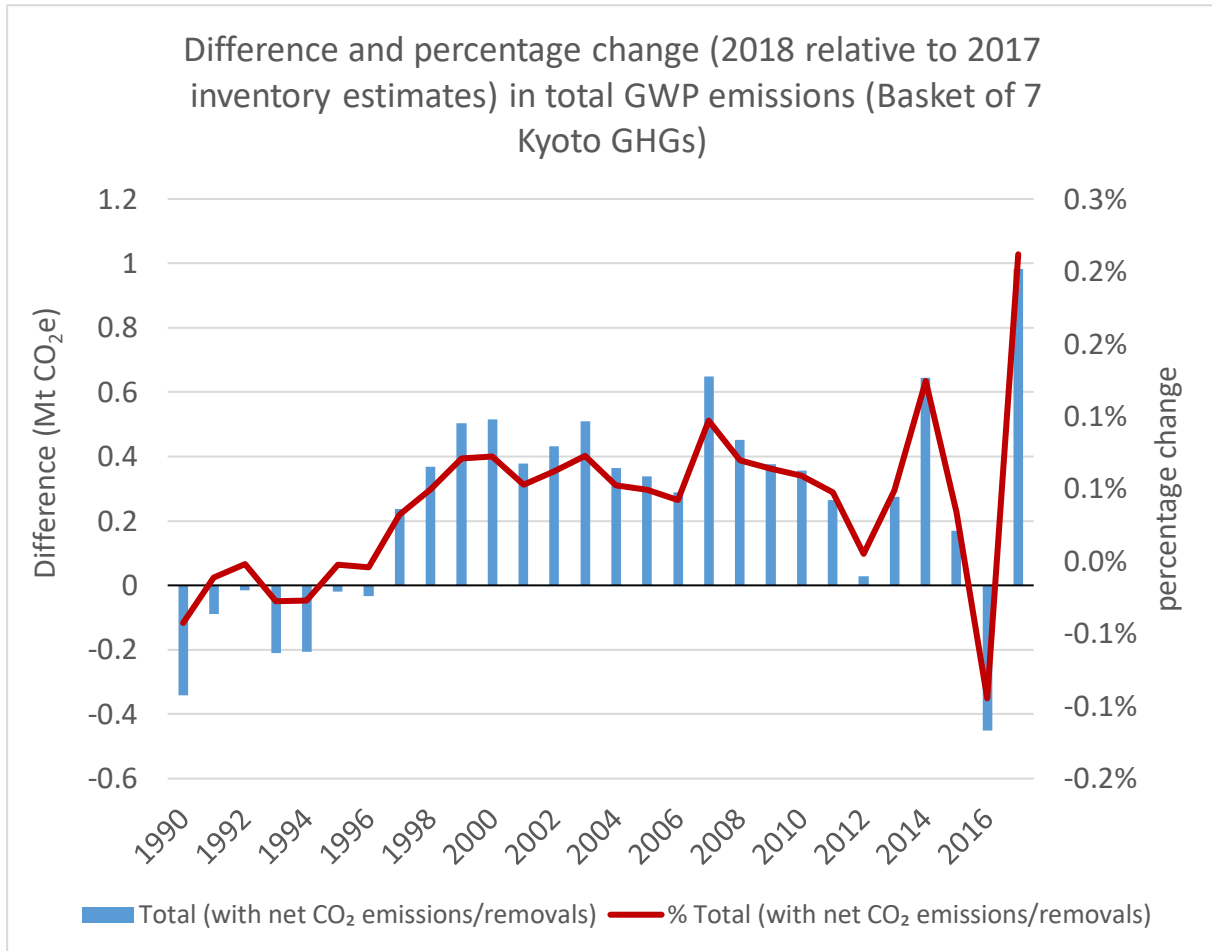
## 10.2.2 KP-LULUCF Activities

Information on the reasons for recalculations is included in **Section 11.3.1.4**. As the KP-LULUCF Inventory contains both emissions and removals of GHGs, expressing the change in trend from the base year to the latest inventory year as a percentage difference is inappropriate.

## 10.3 IMPLICATIONS FOR EMISSION TRENDS, INCLUDING TIME SERIES CONSISTENCY

### 10.3.1 GHG Inventory

There has been a very minor change in the reported trend in emissions. The reported trend from 1990 to 2017 in the 2019 inventory submission was a decrease of 41.8%. The recalculated trend from 1990 to 2017, as presented in the 2020 submission is a decrease of 41.7%.

The chart below displays the trend from both the 2018 and 2019 submissions.

**Figure 10.3      Reported trends from the current and previous inventory submissions**
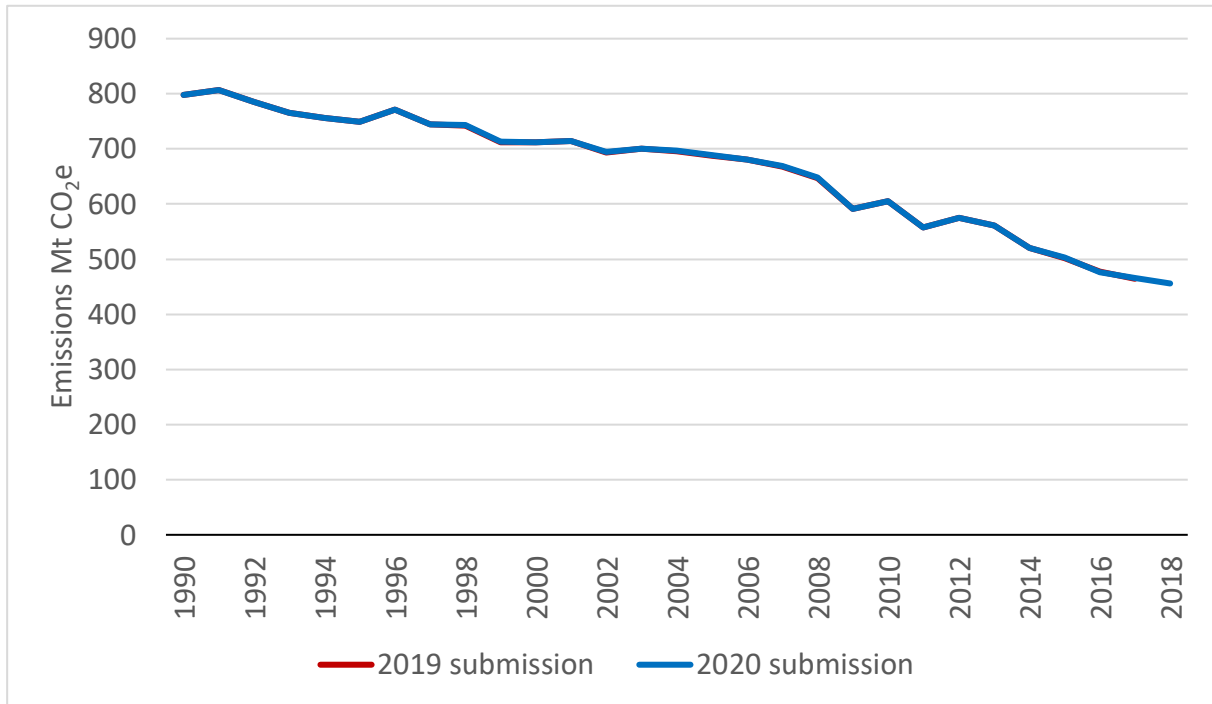


## 10.3.2 KP-LULUCF Activities

Information on the reasons for recalculations is included in **Chapter 10** and **Section 11.3.1.4**. There has been a small increase in the size of the KP-LULUCF net sink (0.49 Mt $CO_2$e in 2017) between the previous and the current inventory submission. This is due to to increases in the Art. 3.4 FM and GLM, and HWP, sinks outweighing increases in the Art 3.3 D and Art. 3.4 CM sources.

## 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 an in-country review of the 2019 UK greenhouse gas inventory submission from the 30th September to the 5th October 2019, 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 2019 Annual Review Report, was published on the 7th February 2020, as a result of the timings, there is limited scope to consider review items within this compilation cycle, however the expert review team (ERT) did not identify any issues that required a resubmission 2019 submission. Each review report reconsiders items raised during the previous 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 responses to the last UNFCCC review, conducted on the 2017 submission, but has been updated to cross reference with the 2019 Annual Review Report when necessary. **Table 10.17** includes new items raised during the 2019 review and responses from the UK to date.

The ESD review of the 2019 UK greenhouse gas inventory submission took place in April 2019. The Final Review Report presented the findings from the first step of the annual review, pursuant to Article 19(2) of Regulation (EU) No 525/2013. The checks performed within the initial step did not identify any significant issues, therefore the United Kingdom is not subject to the second step of the ESD review process. No revised estimates or technical corrections were deemed necessary, and so the GHG emissions data officially reported under the Monitoring Mechanism Regulation can form the basis for determination of ESD emissions. No further changes in response to the ESD review are therefore  detailed within this inventory report.

## 10.4.1 GHG Inventory Improvements

**Table 10.16       Improvements to the UK GHG Inventory Submission in response to UNFCCC Review Findings 2017/2019**

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| Recalculations | The ERT recommends that the United Kingdom continue to improve the transparency of reporting by providing explanations of recalculations in the NIR in accordance with paragraph 44 of the UNFCCC Annex I inventory reporting guidelines. The ERT also recommends that the Party improve the consistency in the reporting of recalculations between the NIR and CRF tables, providing in the NIR the explanations for differences therein shared with the ERT during the review (i.e. the differences in recalculations owing to different territorial coverage under the Convention and the Kyoto Protocol). | 2017 ARR G.10 (G.6 2019 ARR) | **Resolved.** The UK has reviewed the descriptions which are provided to explain the recalculations. The UK provides explanations for recalculations which are not insignificant. The differences in inventory data arising from changes in territorial coverage were an issue specific to the 2017 submission (and hence the 2017 ARR) due to the divergence of the UK's UNFCCC and KP territorial scopes  The ERT reviewed the explanations of recalculations in the NIR, during the 2019 in-country review and concludes that the discussion of recalculations in the NIR is sufficient and consistent with the UNFCCC Annex I inventory reporting guidelines | Chapter 10.1 |
| Feedstocks, reductants and other non-energy use of fuels - liquid fuels - $CO_2$ | There are six blank rows in CRF tables 1.A(b) and 1.A(d) corresponding to cells that should be labelled as "NO".  The ERT recommends that the United Kingdom ensure reporting is complete as well as consistent between CRF tables 1.A(b) and 1.A(d) by reporting data or notation keys for other gaseous fuels in CRF table 1.A(b) and by using the same data or notation keys for other liquid fossil fuels, other gaseous fuels, other fossil fuels and other fossil fuels in CRF table 1.A(b) in the corresponding cells in CRF table 1.A(d). | 2017 ARR E.13 (E.3 2019 ARR) | **Resolved.** The nodes in question in the CRF have been populated with 'NO' instead of being left blank to indicate that these data should be zeros. | N/A |
| 1.A.1.c Manufacture of solid fuels and other energy | The ERT recommends that the United Kingdom justify in the NIR the application of high $N_2O$ EFs (e.g. that they are | 2017 ARR E.15 (E.7 2019 ARR) | **Resolved.** Text has been added to MS2, "Assumptions & Observations", to present the justification for the use of operator-reported emissions of $N_2O$ from upstream | Chapter 3.4 MS 2 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| industries - liquid fuels - $N_2O$ | informed by operator-reported data and are dominated by offshore combustion of natural gas). | | oil and gas installations. The latest 2019 ARR report confirms this is now resolved. | |
| 1.A.2.b Non-ferrous metals - solid fuels - $CH_4$ | The ERT recommends that the United Kingdom describe in the NIR the fluctuation in the $CH_4$ IEF over the time series, especially between 2012 and 2015. | 2017 ARR E.16 (E.9 2019 ARR) | **Resolved.** Text has been added to MS3 to explain the trends in methane in those years. . The latest 2019 ARR report confirms this is now resolved. | Chapter 3.4 MS 3 |
| 1.A.3.a Domestic aviation - liquid fuels - $CH_4$ | The ERT recommends that the United Kingdom describe in detail in the NIR any changes in assumptions for the $CH_4$ EF for aviation fuel to justify the unique trend in IEF between 2009 and 2010. | 2017 ARR E.17 (E.10 2019 ARR) | **Resolved.** Text has been added to the NIR "time-series consistency" in the MS7 to address the variation in $CH_4$ IEF. . The latest 2019 ARR report confirms this is now resolved. | Chapter 3.4 MS7 |
| 1.A.4.a Commercial/institutional - biomass - $N_2O$ | The ERT recommends that the United Kingdom ensure that the notation key "NO" is used for biomass combustion in CRF table 1.A(a)s4, and that a brief mention in the corresponding method statement in the NIR is made about this source not occurring. | 2017 ARR E.18 (E.11 2019 ARR) | **Resolved.** A node has been added to the CRF to facilitate the reporting of data for 1.A.4.a biomass use. Incidentally, there are now data for $CO_2$ emissions associated with biogas use reported here. | N/A |
| 1.B Fugitive emissions from fuels – all fuels – $CO_2$, $CH_4$ and $N_2O$ | The ERT recommends that, where possible, the United Kingdom include all subcategory EFs for $CO_2$, $CH_4$ and $N_2O$ and corresponding references for their sources for category 1.B (fugitive emissions from fuels) in the NIR or the accompanying background data file.<br><br>Further, the ERT recommends that, for all subcategories where emissions are directly reported and EFs cannot be reported, the Party provide information in the NIR to clarify how the estimates are compiled from operator-reported data. | 2017 ARR E.20 (E.12 2019 ARR) | **Resolved.** The UK has addressed the omission in reporting within the supplementary background data file, such that all AD and EFs for fugitive emission sources are included, consistent with how the data were provided to the previous ERT during the 2017 submission review week.<br><br>Further, we have added text to the MS18 to clarify the inventory method for those source categories where there are no AD and EFs but operator-reported estimates are aggregated and installation-level data checked between reporting systems. . The latest 2019 ARR report confirms this is now resolved. | Chapter 3.4 MS18 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 1.B.1 Solid fuels - $CH_4$ | The ERT recommends that the United Kingdom elaborate on the method description in the NIR to explain that the estimates are complete and that, although EF data are not available for 2015, the EFs for 2013 and 2014 were applied to the complete and consistent AD time series of coal production. | 2017 ARR E.21 (E.14 2019 ARR) | **Resolved.** The UK has added additional details to MS17 in the NIR to clarify how it has ensured completeness and time-series consistency in estimates of $CH_4$ emissions from deep-mined coal, coal storage and transport and open-cast coal. The latest 2019 ARR report confirms this is now resolved. | Chapter 3.4 MS17 |
| 1.B.2 Oil and natural gas and other emissions from energy production - all fuels - $CO_2$, $CH_4$ and $N_2O$ | The ERT recommends that the United Kingdom describe in more detail the QC measures in place to verify the completeness of the onshore exploration and production given the incomplete (voluntary) nature of EEMS and EU ETS data. | 2017 ARR E.24 (E.15 2019 ARR) | **Resolved.** Further clarification is provided in the NIR in MS18 about the steps taken to ensure time-series consistency in the latest years of the inventory, when reporting to EEMS has been voluntary for onshore terminals. The NIR text very clearly states that the emission estimates are complete and consistent across the time series. The latest 2019 ARR report confirms this is now resolved. | Chapter 3.4 MS18 |
| 1.B.2 Oil and natural gas and other emissions from energy production - all fuels - $CO_2$, $CH_4$ and $N_2O$ | The ERT recommends that the United Kingdom enhance the transparency of the reporting on the coverage and allocation of fugitive emissions from oil and natural gas by including all IPCC subcategories in NIR table 3.5 as they are reported in CRF table 1.B.2 (e.g. if a subcategory is reported as "IE" in CRF table 1.B.2, include the respective IPCC category in the appropriate row of NIR table 3.5 where the emissions are reported). Further, the ERT recommends that the Party review all fugitive emissions from oil and natural gas that are reported as "IE" in the NIR but not able to be distinguished in the CRF tables owing to aggregation levels (i.e. the United Kingdom reports in the NIR subcategories under natural gas exploration) or not transparent in the NIR and report its findings in the NIR. | 2017 ARR E.25 (E.16, 2019 ARR) | **Resolved.** NIR Table 3.5 has been updated with additional details to clarify the scope of methods for categories reported "IE". **Resolved.** Clarification has been added in MS18 to indicate that Natural Gas Production (1B2b2) is reported as IE, explaining the source data from EEMS and the limited data resolution for different fugitive emission sources. | Chapter 3.4 MS18 |
| 1.B.2 Oil and natural gas and other – all fuels – $CO_2$ and $CH_4$ | The ERT recommends that the United Kingdom describe in the NIR the coverage of the AD, methods and EFs for estimating emissions from well drilling, well testing and well | 2017 ARR | **Resolved.** Additional details have been added to the NIR in MS18 outlining that emissions are taken from operator-reported data in EEMS and that activity data is derived through the assumption that 1997 activity | Chapter 3.4 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| | 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.27 (E.18, 2019 ARR) | data is appropriate for all years prior to 1998, with emissions from well testing reported under 1B2. The findings of research and consultation regarding emissions from well drilling, completions and testing are also documented in MS18. | MS18 |
| 1.B.2.a  Oil - liquid and gaseous fuels - $CO_2$ | The ERT recommends that the United Kingdom include in NIR table 3.17, under the methodological description for subcategory 1.B.2.c (flaring at upstream oil, gas facilities), the information that $CO_2$ emissions from refinery flaring are reported as "IE" under combustion-related emissions from petroleum refining (1.A.b).<br><br>Further, the ERT recommends that the Party clearly note in the NIR under Method Statement 1 (Power stations, refineries and other energy industries (p.125)) – 1.A.1.b (petroleum refining) that fugitive $CO_2$ emissions from 1.B.2.a.4 (oil refining/storage) are reported with the corresponding combustion emissions from refining. | 2017 ARR E.28 (E.19, 2019 ARR) | **Resolved.** The MS18 Table (now 3.16) has been amended to state clearly that all flaring emissions from refineries are reported in 1A1b.<br><br>**Resolved.** MS1 has been updated to clarify that $CO_2$ emissions from flaring at oil refineries are included within the estimates reported under 1A1b.<br><br>The latest 2019 ARR report confirms this item is now resolved. | Chapter 3.4 MS1, MS18 |
| 1.B.2.b  Natural gas - gaseous fuels - $CO_2$ and $CH_4$ | The ERT recommends that the United Kingdom estimate and report $CO_2$ and $CH_4$ emissions from exploratory activities or, if the Party considers them insignificant, report them as "NE" and justify that the likely level of emissions is below the significance threshold established in paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. | 2017 ARR E.29 (E.21, 2019 ARR) | **Addressing.** The NIR text (*Method Approach* section) now includes justification of reporting these emissions as "NE".We note, however, that "NE" can only be used at category level and as such an estimate for this source should be included. This will be considered as part of the improvement programme. | Chapter 3.4 MS18 |
| 2.A.2  Lime  production – $CO_2$ | The ERT recommends that the United Kingdom collect lime production data so that it may be made available upon request to future ERTs in order to enable them to assess the accuracy, comparability and completeness of the emissions reported under this subcategory in accordance with the UNFCCC review guidelines. | 2017 ARR I.14  (I.1 2019 ARR) | **Resolved.** The Inventory Agency has researched additional AD from the Office of National Statistics and reported findings in NIR section 4.3.6. | Chapter 4.3 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 2.A.4 Other process uses of carbonates – $CO_2$ | The ERT recommends that the United Kingdom either estimate and include in the inventory the $CO_2$ emissions associated with the non-glass use of soda ash or include in the NIR a justification, consistent with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines, for these emissions being considered insignificant. | 2017 ARR I.15 (I.2 2019 ARR) | **Resolved.** Research has been commissioned and is due to report during 2019 on the very low level of emissions from other process uses of carbonates. These new estimates are included in the 2020 submission of the UK GHGI, despite them falling well below the threshold of significance for the inventory. | Chapter 4.5 |
| 2.B.2 Nitric acid production - $N_2O$ | The ERT recommends that the United Kingdom include information in the NIR on the abatement systems of the nitric acid production plants that were in operation in the country during the years 2012 to 2015 that justifies the low IEFs. | 2017 ARR I.16 (I.3 2019 ARR) | **Resolved.** The UK Inventory Agency has consulted with the operator and the regulator for the remaining UK nitric acid production sites and obtained information on the design and performance of the EnviNO$_X$ SCR abatement systems in place since 2011, and this information is included in NIR section 4.7.2.<br><br>The latest 2019 ARR report confirms this item is now resolved. | Chapter 4.7 |
| 2.B.2 Nitric acid production - $N_2O$ | The ERT recommends that the United Kingdom update the uncertainty analysis to reflect that $N_2O$ emissions from nitric acid production are based on continuous monitoring. | 2017 ARR I.17 (I.4 2019 ARR) | **Resolved.** The UK has reviewed and adjusted the uncertainty parameters used in the uncertainty analyses for $N_2O$ from nitric acid in 1990 and in the latest inventory year. The UK has checked that the uncertainty data presented in the NIR are consistent with the data used in the uncertainty analysis. The latest 2019 ARR report confirms this item is now resolved. | Chapter 4.7, Annex 1, Annex 2 |
| 2.C.I Iron and steel production - $CO_2$ | The ERT recommends that the United Kingdom update figure 3.1 in the NIR to clarify the subcategories under which $CO_2$ emissions from sintering, blast furnaces and oxygen furnaces are reported. | 2017 ARR I.18 (I.5 2019 ARR) | **Resolved.** The figure 3.1 has been updated to present the correct source category allocations for emissions from sintering, blast furnaces and oxygen furnaces. The latest 2019 ARR report confirms this item is now resolved. | Chapter 3.4<br><br>MS 4 |
| 2.C.4 Magnesium production - HFCs and PFCs | The ERT recommends that the United Kingdom either estimate and include in the submission emissions of PFCs and/or HFCs that are the decomposition products from the use of FK 5-1-12 and HFC-134a by magnesium dye | 2017 ARR I.19 (I.6 2019 ARR) | **Resolved.** The NIR includes information as provided to the previous ERT to explain the existence of the source and the reason for the UK not estimating and reporting it, as it falls well below the threshold for reporting and | Chapter 4.19.2 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| | casters or include in the next NIR the information presented to the ERT during the review that justifies, in accordance with the UNFCCC Annex I inventory reporting guidelines, these emissions being considered insignificant. | | is considered insignificant. This is now also reflected in the CRF. PFC emissions are reported as 'NE' with the appropriate explanation. | CRF Tables |
| 2.D.2 Paraffin wax use - $CO_2$ | The ERT recommends that the United Kingdom examine the availability of paraffin wax AD for the entire time series (1990–2015). The ERT also recommends that the Party explain the differences between the data used from DUKES for the inventory and Eurostat data. | 2017 ARR I.20 (I.7 & I.8 2019 ARR) | **Resolved.** The Inventory Agency has consulted with the UK energy statistics team, and now has access to a full, consistent time-series of paraffin wax consumption data. These new data have been used to replace the previous gap-filling approach based on total miscellaneous petroleum products, and further there is now no difference between the data used in the inventory and that reported to Eurostat. The latest 2019 ARR report confirms this item is now resolved. | Chapter 4.23 |
| 2.D.3 Other (non-energy products from fuels and solvent use) - $CO_2$ | The ERT recommends that the United Kingdom describe in the NIR that $CO_2$ emissions from urea use in Euro VI standard HGVs and buses are included in the reported estimates from urea use in road transport catalysts, that fuel consumption data are determined using the same approach as is described in the NIR for Euro IV and V HGVs and buses, but, in accordance with the EMEP/EEA air pollution emission inventory guidebook 2016, a 3.5 per cent urea solution in fuel is considered, and that 100 per cent of Euro VI HGVs and buses are equipped with selective catalytic reduction abatement. | 2017 ARR I.21 (I.10 2019 ARR) | **Resolved.** The UK has updated the NIR description of the methodology for the estimation of emissions of $CO_2$ from urea use in heavy duty vehicles to reflect that the UK inventory estimates also account for Euro VI vehicles using urea. The latest 2019 ARR report confirms this item is now resolved. | Chapter 4.24.2 |
| 2.F.I Refrigeration and air conditioning - HFCs | The ERT recommends that the United Kingdom include in the NIR the scaling factors (e.g. population, GDP) used to calculate emissions from refrigeration and air-conditioning equipment in OTs and CDs. | 2017 ARR I.22 (I.11 2019 ARR) | **Resolved.** The UK addressed this issue in the 2018 submission. The scaling factors are now reported annually in the NIR. The latest 2019 ARR report confirms this item is now resolved. | Chapter 4.29.2 |
| 2.F.I Refrigeration and air conditioning - HFCs | The ERT recommends that the United Kingdom improve the description in the NIR of the tier level of the methodology that is applied for the estimation of emissions | 2017 ARR I.23 (I.12 2019 ARR) | **Resolved.** The UK addressed this issue in the 2020 submission, describing the UK methodology as a Tier 2a modelling approach. | Chapter 4.29.2 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| | from subcategory 2.F.1, noting a tier 2a method, in line with the 2006 IPCC Guidelines, has been implemented. | | [Note that the CRF software does not facilitate reporting a T2a or T2b methodology, only T2 can be entered.] | |
| 2.G.2 $SF_6$ and PFCs from other product use - $SF_6$ and PFCs | The ERT recommends that the United Kingdom continue to include in its improvement plan the need for an update of the AD, based on actual consumption, for the estimation of $SF_6$ and PFC emissions from semiconductor manufacture, and report any progress thereon in the NIR. | 2017 ARR I.24 (I.13 2019 ARR) | **Addressing**. As noted by the previous ERT, resolution of this issue is dependent on access to new activity data based on actual consumption which are not currently available. Therefore as recommended in ARR 2017, the issue remains on the UK's improvement programme and the UK will continue to report on any progress made in future submissions. | Chapter 4.39 |
| 3. General (agriculture) | The ERT recommends that the United Kingdom estimate and report emissions from categories 3.F, 3.G and 3.H for OTs and CDs or, if the Party considers them insignificant, report them as "NE" and provide a detailed explanation in the NIR on the likely level of emissions from categories 3.F, 3.G and 3.H for OTs and CDs in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. | 2017 ARR A.6 (A.1 2019 ARR) | **Addressing.** The inventory now includes estimates of field burning for Crown Dependencies, based on UK implied EFs. Grassland burning in the overseas territories has been estimated and is reported in the LULUCF category. . | 3F (Field burning): Chapter 5, section 5.6.2.1 |
| 3. General (agriculture) | The ERT recommends that the United Kingdom estimate and report emissions from categories 3.F, 3.G and 3.H for OTs and CDs or, if the Party considers them insignificant, report them as "NE" and provide a detailed explanation in the NIR on the likely level of emissions from categories 3.F, 3.G and 3.H for OTs and CDs in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. | 2017 ARR A.6 (continued) (A.1 2019 ARR) | **Addressing.** 3G (Liming): There continues to be no quantitative data available for Bermuda, . For the Cayman Islands, the latest information from the in-country contact stated that no liming currently occurs and therefore emissions are estimated as 0. 3G (Liming): No quantitative data on liming is available for Overseas Territories, but local expert input suggests that liming does not occur in the Falklands or Cayman Islands. In Bermuda, this category has not been estimated as no expert judgement is available. Efforts to improve data collection for this category are planned; however, it is thought that these emissions would be insignificant relative to total UK emissions. This improvement will be considered for future submissions as part of the prioritised inventory improvements, | 3G (Liming): Chapter 5, section 5.7.2.1 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | | | taking into account available resources. This explanation has been added to the NIR. | |
| 3. General (agriculture) | The ERT recommends that the United Kingdom estimate and report emissions from categories 3.F, 3.G and 3.H for OTs and CDs or, if the Party considers them insignificant, report them as "NE" and provide a detailed explanation in the NIR on the likely level of emissions from categories 3.F, 3.G and 3.H for OTs and CDs in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. | 2017 ARR A.6 (continued) (A.1 2019 ARR) | **Addressing.** 3H (Urea application): There continues to be no data available for Bermuda. For the Falkland islands, no data are available but information from the in-country contact suggests that fertiliser use (including urea) is "minimal", as most of the land is extensive rangeland 3H (Urea application): Emissions for the Falklands Islands and Bermuda were not estimated, due to lack of data availability. However, local expert judgement suggests that urea application in the Falkland islands is minimal, if not zero. Efforts to improve data collection for this category are planned; however, it is thought that these emissions would be insignificant relative to total UK emissions. This improvement will be considered for future submissions as part of the prioritised inventory improvements, taking into account available resources. This explanation has been added to the NIR. | 3H (Urea application): Chapter 5, section 5.8.2.1 |
| 3.D.a Direct $N_2O$ emissions from managed soils - $N_2O$ | The ERT recommends that the United Kingdom provide in the NIR a complete reference to the data sources used, and a clear description of the method, assumptions and calculations used to calculate the country-specific EFs for inorganic fertilizer, animal manure applied to soils, and urine and dung deposited by grazing animals. | 2017 ARR A.7 (A.6, 2019 ARR) | **Resolved.** As requested by the ERT, the UK has provided in the NIR a complete reference to the data sources used, and a clear description of the method, assumptions and calculations used to calculate the country-specific EFs for inorganic fertilizer, animal manure applied to soils, and urine and dung deposited by grazing animals. The latest 2019 ARR report agrees this item is now resolved. | Chapter 5.4.2 |
| 3.D.a.6 - Cultivation of organic soils (i.e. histosols) - $N_2O$ | The ERT recommends that the United Kingdom provide in its NIR an explanation and further supporting evidence for the classification of organic soils in the Falkland Islands as unmanaged, and explain why the areas of organic soils in OTs and CDs are not included as a contributing source to $N_2O$ emissions from the cultivation of organic soils. | 2017 ARR A.8 (A.8, 2019 ARR) | **Resolved.** Information from the in-country contact and Falkland government website (http://www.fig.gov.fk/agriculture/) confirms that grassland on histosols is characterised as an extensive rangeland system, which receives no fertiliser, liming, cultivation nor drainage. Although this may technically | Chapter 5, Section 5.4.2.10 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | | | qualify as "managed" under the IPCC definition as it is used for production, the rationale for calling it "unmanaged" is that there are no management activities that would lead to release of $N_2O$ following loss of soil C. This explanation has been added to the NIR. | |
| 4. General (LULUCF) | The ERT recommends that the United Kingdom correct the inconsistencies identified within the NIR in the general and sector-specific sections and between the NIR and the CRF tables (i.e. ensure consistency in the reporting of the area of wetlands between NIR table 6.1 and CRF table 4.D and the reporting of the trends for the forest land and cropland categories, and include WDR among the activities elected under Article 3, paragraph 4, of the Kyoto Protocol). | 2017 ARR L.14 (L.4, 2019 ARR) | **Resolved.** This issue was resolved in the 2018 submission.<br><br>(a) the area of wetlands remaining wetlands in the OTs and CDs is now reported in both locations<br><br>(b) LULUCF trends are now described only in section 2.3.4<br><br>(c) Inconsistencies have been corrected<br><br>The latest 2019 ARR report confirms this item is now resolved. | (a) Chapter 6 section 6.9 (b) Chapter 2 (c) Chapter 2 |
| 4. General (LULUCF) | The ERT recommends that the United Kingdom implement a significance analysis to determine which carbon pools and subcategories are significant in each key category using the guidance provided in the 2006 IPCC Guidelines, and provide in the NIR detailed information on the results of the analysis. | 2017 ARR L.15 (L.5 2019 ARR) | **Resolved.** A significance analysis of the pools and sub-categories within the key LULUCF categories has been undertaken and is included in the 2020 submission NIR. | Relevant sections of Chapter 6. |
| Land representation | The ERT recommends that the United Kingdom correct all inconsistencies with regard to the representation of land use and land-use changes. In particular, the ERT recommends that the Party:<br>(a) Report, for all land-use categories, final land areas each year in CRF table 4.1 that equal initial land areas in the next year;<br>(b) Report, for all land-use categories, final land areas for each year in CRF table 4.1 that equal the total land areas in the background sectoral CRF tables 4.A–4.F; | 2017 ARR L.16 (L.7 2019 ARR) | **Resolved.** The land use transition matrix was revised for the 2020 submission and all land areas are reported in CRF table 4.1 and the background sectoral tables 4.A-4.F . Annual land use matrices and 20-year transition matrices are reported in NIR. The total country area has been revised to take account of the additional land area in the Cayman Islands, Bermuda and Gibraltar and stability of land area has been ensured by using conversion from unmanaged wetland | Chapter 6 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | (c) Report all land areas under their territorial coverage (United Kingdom, OTs and CDs) in CRF table 4.1 and the background sectoral CRF tables 4.A–4.F;<br>(d) Ensure that the total country area reported in CRF table 4.1 and the background sectoral CRF tables 4.A–4.F remains constant throughout the time series.<br><br>Further, the ERT recommends that the Party provide in the NIR detailed information on how the data sources have been combined to estimate land areas and on the methodology followed for the development of the land-use conversion matrix. The ERT encourages the United Kingdom to include in the NIR a complete set of both annual and 20-year land-use conversion matrices. | | to account for a small area of land reclamation in Jersey. | |
| 4.A Forest land - CO$_2$ | The ERT recommends that the United Kingdom obtain the necessary input data so as to be able to apply the CARBINE model for estimating carbon stock changes in forest land in OTs and CDs. | 2017 ARR<br>L.17 (L.13 2019 ARR) | **Not resolved.** It has not been possible to obtain the necessary input data to apply the CARBINE model to forest land in the OTs and CDs. This matter was discussed with the in-country review team in October 2019, and the UK proposes to use a Tier 1 approach for estimating forest land carbon stock changes for all OTs and CDs in the 2021 submission. Tier 1 has been used to estimate forest carbon stock changes for the Cayman Islands and Bermuda. There was not sufficient time to implement a Tier 1 approach for all non-UK territories in the 2020 submission. | n/a |
| 4.A Forest land - CO$_2$ | The ERT recommends that the United Kingdom estimate and report carbon stock changes in biomass from forests not used for timber production in accordance with the 2006 IPCC Guidelines (volume 4, chapter 4) owing to biomass losses associated with harvesting and/or gathering (e.g. fuelwood) or provide transparent information justifying that such losses are not occurring. | 2017 ARR<br>L.18 (L.14 2019 ARR) | **Addressing.** The carbon increment of forests not used for timber production is already estimated using the CARBINE model. No reliable estimates are currently available on the quantity of wood removed by gathering or disturbance. The second cycle of the National Forest Inventory (2015-2020) will provide additional information to resolve this issue. | Annex 3.4.1.2 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 4.A.1 Forest land remaining forest land - $CO_2$ | The ERT recommends that the United Kingdom adjust wood harvest data derived from the modelling of the management of forests to take into account data from recent forest inventories (NFI in 2011 and an inventory of the Public Forest Estate in 2014) in order to avoid an inconsistent time series, using the overlap or any other method consistent with those described in the 2006 IPCC Guidelines (volume 1, chapter 5). | 2017 ARR L.19 (L.15 2019 ARR) | **Resolved.** An automated algorithm (RECONCILE) has been introduced in the 2019 submission to adjust the assumed forest management to harmonise with the level of timber production, ensuring better time series consistency and accuracy. | Chapter 6, section 6.2 |
| 4.A.2.5 Other land converted to forest land - $CO_2$ | The ERT recommends that the United Kingdom develop the necessary AD for the original land-use category currently reported in other land converted to forest land and allocate these land areas to the appropriate land-use conversion category when developing the land-use conversion matrix, or alternatively, if this is not possible, reclassify this land-use change as grassland converted to forest land, given that the grassland category is used as the buffer category. | 2017 ARR L.20 (L.16 2019 ARR) | **Resolved.** This recommendation was implemented in the 2018 submission, with the small area of Other Land converted to Forest Land now re-allocated to Grassland converted to Other Land. | Chapter 6, section 6.2 (6.2.7) |
| 4.B Cropland 4.C Grassland – $CO_2$ | The ERT recommends that the United Kingdom enhance the transparency and comparability of reporting in the LULUCF and agriculture sectors by: (a) Providing information in the NIR about areas of organic soils for all lands, separating drained and undrained cropland and grassland; (b) Reporting organic soils separately from mineral soils in CRF tables 4.B, 4.C and 4(II) for the United Kingdom, including its OTs and CDs; (c) Reporting $CO_2$ emissions from organic soil drainage in CRF tables 4.B and 4.C, avoiding double counting of emissions in table 4(II); (d) Providing an explanation in the NIR for the discrepancies between areas of organic soils reported in CRF table 3.D and in CRF tables 4.B, 4.C and 4(II). | 2017 ARR L.21 (L.24 2019 ARR) | **Addressing.** 2018 submission: $CO_2$ emissions from drainage on Cropland are reported in 4.B and the area of organic soils is consistently reported in the Agriculture and LULUCF sectors. 2019 submission: the area of cultivated grassland on organic soil currently reported in CRF table 4(II) will be reported in table 4.C (Grassland remaining Grassland -United Kingdom). The inventory improvement project to assimilate activity data and emission factors from the Wetlands Supplement implementation project into the LULUCF inventory is undergoing final revisions and checks, which will enable further disaggregation of organic/mineral and drained/undrained soils in the CRF tables. | Chapter 6, section 6.3 and 6.4 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 4.B. Cropland - $CO_2$ | The ERT recommends that the United Kingdom incorporate data from NIR table A.3.4.20 into the tables NIR A.3.4.15–A.3.4.18 and revise carbon stock changes in living biomass from land conversions to and from cropland. | 2017 ARR L.22 (L.19 2019 ARR) | **Resolved.** This item was addressed in the 2019 submission. The carbon stock changes arising from land-use change and management now use the same set of UK-specific living biomass carbon densities. | Chapter 6, section 6.3, 6.4, 6.6 |
| 4.B.1 Cropland remaining cropland - $CO_2$ | The ERT recommends that the United Kingdom develop country-specific EFs for manure and residue inputs or continue to investigate the appropriateness of the application of default EFs to reference SOC stocks for 1 m layer soil. | 2017 ARR L.23 (L.20 2019 ARR) | **Resolved.** Addressed in the 2020 submission. The UK extracted reference SOC stocks for 0-30 cm soil from the original source used for the 1 m reference SOC stocks. | n/a |
| 4.B.1 Cropland remaining cropland - $CO_2$ | The ERT recommends that the United Kingdom include in the NIR information on the calculation of carbon stock changes of different components of living biomass of cropland (e.g. transitions among orchards, annual cropland and shrubby perennial crops). | 2017 ARR L.24 (L.21, 2019 ARR) | **Resolved.** Information on the calculation of carbon stock changes of different components of living biomass of cropland has been included in the text of the 2019 NIR submission. The latest 2019 ARR report agrees this item is now resolved. | Section 6.3 and Annex 3.4.3.1 |
| 4.C Grassland - $CO_2$ | The ERT recommends that the United Kingdom allocate rural hedges to settlements or grassland, ensuring time-series consistency of the accounting of these areas to a single land-use category, and clearly indicate in the NIR where they are included. | 2017 ARR L.25 (L.22 2019 ARR) | **Addressing.** All carbon stock changes explicitly arising from changes in hedgerows are reported under 4.C Grassland. A coordinated plan of improvements to the land-use change matrices is under consideration, which will include resolving all remaining inconsistencies in the definitions and allocation of hedgerows. | n/a |
| 4.C.2.1 Forest land converted to grassland - $CO_2$ | The ERT recommends that the United Kingdom report carbon stock changes from the dead organic matter and mineral soil pools. | 2017 ARR L.26 (L.23 2019 ARR) | **Resolved.** Addressed in the 2020 submission. The UK report carbon stock changes in dead organic matter and net carbon stock changes in mineral soils under Grassland remaining Grassland as NA (as a Tier 1 methodology is applied). | Section 6.9 |
| 4.C.2.3 Wetlands converted to grassland - $CO_2$, $CH_4$ and $N_2O$ | The ERT recommends that the United Kingdom include in the NIR detailed information on the methodology applied and assumptions used for classifying abandoned peat extraction sites as wetlands converted to grassland, noting | 2017 ARR L.27 (L.24 2019 ARR) | **Resolved.** Text in the NIR clarifying the methodology was updated in the 2018 submission. Additional information on site-specific restoration of former peat extraction sites was used in the 2020 submission. | Section 6.5 and Annex 3.4.8 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | that in accordance with the 2006 IPCC Guidelines (volume 4, section 7.2) GHG emissions from post-extraction lands continue and should be reported as long as the land is not converted to another use. | | | |
| 4.D Wetlands - $CO_2$, $CH_4$ and $N_2O$ | The ERT recommends that the United Kingdom (a)collect the necessary data to enable it to report emissions/removals from peat extraction remaining peat extraction in OTs and CDs, and (b)until then change the notation key in CRF table 4.D for the OTs and CDs from "NO" to "NE". Further, the ERT recommends that the United Kingdom provide in its NIR detailed information to describe that land conversion to peat extraction in OTs and CDs is not occurring. | 2017 ARR L.28 (L.25 2019 ARR) | **Addressing.** The notation keys have been modified and additional text added to the NIR methodology Annex 3.4 for the 2019 submission. **Not resolved.** The update to the NIR to clarify the data, and present justification of "NO" for land conversion to peatland cannot be done until further work is completed. | Annex 3.4.11 |
| 4.D.1 Wetlands remaining wetlands - $CO_2$, $CH_4$, $N_2O$ | The ERT recommends that the United Kingdom report areas of flooded land remaining flooded land for OTs and CDs and the associated emissions, or, if that is not possible, report in the NIR on the progress in collecting suitable data in order to estimate emissions and removals from flooded land remaining flooded land for OTs and CDs. | 2017 ARR L.29 (L.27 2019 ARR) | **Resolved**. An assessment of the extent of flooded land has been undertaken for the OTs and CDs. No flooded land areas exceed the area threshold of 1 $km^2$ used for the UK, so the notation key IE has been used where areas of flooded land remaining flooded land have been included with other wetland remaining other wetland. | Annex 3.4.11 |
| 4 (V) Biomass burning - $CO_2$, $CH_4$, $N_2O$ | The ERT recommends that the United Kingdom assess the areas of and emissions from wildfires on forest land remaining forest land, land converted to forest land, grassland remaining grassland and land converted to grassland for all OTs and CDs. | 2017 ARR L30 (L.28 2019 ARR) | **Resolved.** Addressed in the 2020 submission: the extent of biomass burning in the OTs and CDs is estimated using geographical proxy burning rates. The pro rata area of grassland wildfires in the UK was used for grassland biomass burning in the Crown Dependencies, Cayman Islands and Falkland Islands (more appropriate data will be sought for the next submission). The pro rata area of forest wildfires in the UK was used for forest biomass burning in the Crown Dependencies, and the pro rate for Cuba was used for the Cayman Islands. Bermuda fires statistics reported no wildfire area for either forest or grassland. There is | Annex 3.4.11 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | | | no forest in the Falkland Islands so no wildfire occurrence there. | |
| 4.G Harvested wood products - CO$_2$ | The ERT recommends that the United Kingdom include in the NIR information on how the conversion factors for HWP are derived. | 2017 ARR L.31 (L.29 2019 ARR) | **Resolved.** The IPCC 2006 Guideline default values for HWP conversion have been used in the 2019 submission. Review of the basis for the previous UK data indicated a lack of sufficient data on the average density of harvested wood in the UK, with limited information across the time series. Therefore to improve transparency, the IPCC defaults have been used. We consider there to be no reduction in accuracy from this change in method to use defaults. The latest 2019 ARR report agrees this item is now resolved. | Section 6.8 |
| 4.G Harvested wood products - CO$_2$ | The ERT recommends that the United Kingdom correct the error in the HWP submodel in order to take into account the decay in HWP from the beginning of each year, and provide in the NIR detailed, transparent and verifiable information in the NIR in accordance with paragraph 41 of the UNFCCC Annex I inventory reporting guidelines. | 2017 ARR L.32 (L.30 2019 ARR) | **Resolved.** The error was corrected in the 2018 submission. More explanatory text has been added to the Annex 3.4 in the 2019 submission. The latest 2019 ARR report agrees this item is now resolved. | Section 6.8 |
| 5.A Solid waste disposal on land – CH$_4$ | The ERT recommends that the United Kingdom include in section 7.2.2 of the NIR how equations 3.1 to 3.6 from the 2006 IPCC guidelines (volume 5) are adapted for use in the MELMod model (i.e. provide more information on equation parameters removed or added) and how the Party conducts model verification in line with paragraph 41 of the UNFCCC Annex I inventory reporting guidelines on the verification of higher-tier methods and models. | 2017 ARR W.11 (W.3 2019 ARR) | **Resolved.** The information on adaptation of the 2006 IPCC Guideline calculation methods is provided in Section 7.2.2 from the 2018 NIR onwards in the format recommended. Further information on model verification in the context of the 2006 IPCC guidelines is provided in section 7.2.5 of the 2019 NIR. The latest 2019 ARR report confirms this item is now resolved. | Section 7.2 |
| 5.A Solid waste disposal on land – CH$_4$ | The ERT recommends that the United Kingdom change the text in NIR table 5.A (p.414), which shows the improvements in the waste sector estimates, from "The methodology for calculating methane production in landfill sites has been updated" to "The input data and parameters for the MELMod model were updated based on new data" | 2017 ARR W.12 (W.4 2019 ARR) | **Resolved.** Table 10.4 entry 5.A was updated in the 2018 NIR to reflect data and DA allocation changes, and does not imply landfill methane methodology change, as recommended by the ERT. The NIR states: "Changes due to MELMOD upgrade (move to 4 Devolved Administration specific models; incorporation | Section 7.2 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | to reflect that updates in the MELMod model focused on input data and parameters and not on the methodology itself. | | of DA specific data)." Text has also been added to the methodology secton 7.2.2, to explain this aspect of the development of the UK data and method. The latest 2019 ARR report confirms this item is now resolved. | |
| 5.A Solid waste disposal on land – $CH_4$ | The ERT recommends that the United Kingdom include in the NIR information on energy recovered from landfill gas and a cross-reference to the category in the energy sector where emissions from $CH_4$ recovered (from landfill gas) and used for power generation are reported. | 2017 ARR W.13 (W.5 2019 ARR) | **Resolved.** The NIR Chapter 3 section headed "Relevant fuels, activities" confirms that emissions from landfill gas combustion are included in Category 1A1a. This category includes both $CH_4$ and $N_2O$ emissions from landfill methane combustion both in power stations for energy recovery, and in flares. A cross-reference to 1A1a and MS1 has been added to section 7.2.1. Data on landfill gas used for energy recovery are provided in the 2019 NIR Annex A3 Section A3.5.1. The latest 2019 ARR report confirms this item is now resolved. | Section 7.2 Annex A3.5.1 |
| 5.B. Biological treatment of solid waste – $CH_4$ and $N_2O$ | The ERT recommends that the United Kingdom provide in sections 7.3.2 and 7.3.5 of the NIR details on how AD are collected to enable the split of mechanical–biological treatment process emissions between composting and anaerobic digestion at biogas facilities. | 2017 ARR W.14 (W.6 2019 ARR) | **Resolved.** The UK has updated the methodology presented in the NIR for biological treatment of solid waste to present the source of MBT activity data and whether MBT is aerobic or anaerobic. The latest 2019 ARR report confirms this item is now resolved. | Section 7.3.2 |
| 5.D.1 Domestic wastewater – $CH_4$ | The ERT recommends that the United Kingdom report AD for domestic wastewater in BOD, and ensure that the organic product in private wastewater treatment systems is included in the total organic product. | 2017 ARR W.15 (W.8 2019 ARR) | **Resolved.** The United Kingdom has included organic product in private wastewater treatment systems in the total organic product reported in the CRF. | [CRF tables] |
| 5.D.1 Domestic wastewater – $N_2O$ | The ERT recommends that the United Kingdom include in CRF table 5.D the values of $Frac_{NON-CON}$ and $Frac_{IND-COM}$ applied. | 2017 ARR W.16 (W.11 2019 ARR) | **Resolved.** The United Kingdom include in CRF table 5.D the values of $Frac_{NON-CON}$ and $Frac_{IND-COM}$ applied. The latest 2019 ARR report confirms this item is now resolved. | [CRF tables] |
| 5.D.1 Domestic wastewater – $N_2O$ | The ERT recommends that the United Kingdom exclude N removed with sludge in the calculation of the emission | 2017 ARR | **Not resolved.** This issue is being considered as part of a wider waste water improvement task for the UK GHGI | n/a |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | 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.17 (W.12 2019 ARR) | improvement programme and will be implemented subject to priorities and available resources. | |
| 5.D.1 Domestic wastewater – CH$_4$ | The ERT recommends that the United Kingdom report CH$_4$ recovery consistent with the United Kingdom's energy statistics. | 2017 ARR W.19 (W.9 2019 ARR) | **Not resolved.** This issue is being considered as part of a wider waste water improvement task for the UK GHGI improvement programme and will be implemented subject to priorities and available resources. | n/a |
| 5.D.2 Industrial wastewater – CH$_4$ | The ERT recommends that the United Kingdom collect information on the proportions of aerobic and anaerobic treatment systems and revise the MCF used accordingly.<br><br>Furthermore, the ERT recommends that the Party review whether the notation key "NA" is correctly used for CH$_4$ recovery. | 2017 ARR W.20 (W.14 & W.15 2019 ARR) | **Not resolved.** This issue is being considered as part of a wider waste water improvement task for the UK GHGI improvement programme and will be implemented subject to priorities and available resources.<br><br>**Resolved.** The CRF notation keys have been updated in the 2019 submission. The latest 2019 ARR report agrees with this specific case of notation keys and considers it now resolved. | n/a<br><br>[CRF tables] |
| General (KP-LULUCF) | The ERT recommends that the United Kingdom revise the land areas reported in different CRF tables (in particular the areas of afforestation, deforestation and CM reported in CRF table NIR-2, the areas of CM and GM reported in CRF tables NIR-2, 4(KP-I)B.2 and 4(KP-I)B.3, and the total area of the country reported in CRF table NIR-2 as well as the total land area reported under the Convention and for KP-LULUCF activities) ensuring the consistency of the reported information among CRF tables as well as between the CRF tables and the NIR, and provide a transparent explanation for any differences remaining. | 2017 ARR KL.15 (KL.5 2019 ARR) | **Resolved.** Land areas have been revised for the 2020 submission to ensure consistency between the CRF tables and the areas reported under the Convention and KP-LULUCF activities. The total country area has been revised to take account of the additional land area in the Cayman Islands, Bermuda and Gibraltar and stability of land area has been ensured by using conversion from unmanaged wetland to account for a small area of land reclamation in Jersey. | Chapter 6, chapter 11, |
| General (KP-LULUCF) | The ERT recommends that the United Kingdom report information in CRF table NIR-1 consistently with the information reported in other sectoral tables, and enhance QA/QC procedures to avoid inconsistencies in the | 2017 ARR KL.16 (KL.6 2019 ARR) | **Resolved.** This inconsistency was corrected in the 2018 submission and a QA/QC check is now included for these tables. The latest 2019 ARR report agrees this item is now resolved. | Chapter 11 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | reporting of information between CRF tables in future submissions. | | | |
| Deforestation - $CO_2$ | The ERT recommends that the United Kingdom estimate and report carbon stock changes from deforestation in below-ground biomass, litter, deadwood and soil organic matter in the OTs and CDs. | 2017 ARR KL.17 (KL.8 2019 ARR) | **Resolved.** Addressed in the 2019 submission: below-ground biomass is reported as IE (included with above-ground biomass), CSC in litter and deadwood is reported under litter, and CSC in soils will be reported for both mineral and organic soils. Explanatory text has been added to the NIR. The latest 2019 ARR report agrees this item is now resolved. | Chapter 11 |
| Forest management - $CO_2$ | The ERT recommends that the United Kingdom estimate and report, in accordance with the 2006 IPCC Guidelines (volume 4, chapter 4), carbon stock changes in biomass from forests not used for timber production owing to biomass losses associated with harvesting and/or gathering (e.g. fuelwood) or provide transparent information justifying that such losses are not occurring. | 2017 ARR KL.18 (KL.13 2019 ARR) | **Addressing.** The carbon increment of forests not used for timber production is already estimated using the CARBINE model. No reliable estimates are currently available on the quantity of wood removed by gathering or disturbance. The second cycle of the National Forest Inventory (2015-2020) will provide additional information to resolve this issue. It will be necessary to wait till these data have been thoroughly quality checked before they can be used. | TBC |
| Forest management - $CO_2$ | The ERT recommends that United Kingdom report separately carbon stock changes for above-ground and below-ground biomass. | 2017 ARR KL.19 (KL.14 2019 ARR) | **Addressing.** These carbon stock changes are reported separately in the 2019 submission. | Chapter 11 |
| Forest management - natural disturbances | The ERT recommends that the United Kingdom: <br><br> (a) Estimate the background level and margin using a consistent and initially complete time series containing emissions for the period 1990–2009, in accordance with decision 2/CMP.7, annex, paragraph 33, using, if appropriate, methodologies from the 2006 IPCC Guidelines (e.g. volume 1, chapter 5); | 2017 ARR KL.20 (KL.15 2019 ARR) | **Not resolved.** Progress to address the issues raised will require a specific piece of inventory improvement work. This work will be discussed at the next UK National Inventory Steering Committee in early 2020. The existing information about the background level and margin for natural disturbance is reported in the 2018 submission. | Chapter 11 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | (b) Report in the NIR detailed information on the background level of emissions associated with annual natural disturbances that have been included in the FMRL, on how the background levels and margins for AR and FM have been estimated, on how the Party avoids the expectation of net credits or net debits during the commitment period, and on how the FMRL technical correction addresses emissions from natural disturbances for which the Party intends to apply the provision (e.g. substitution of natural disturbances emissions in the FMRL by the background level estimated); <br><br> (c) Report the background level and margin estimated for AR and FM in CRF tables 4(KP-I)A.1.1 and 4(KP-I)B.1.3. <br><br> Further, the ERT recommends that the United Kingdom provide detailed information on any recalculations performed in the time series of emissions from natural disturbance types for which the Party intends to apply the natural disturbances provision. | | | |
| Cropland management Grazing land management | The ERT recommends that the United Kingdom: establish a hierarchy of elected activities under Article 3, paragraph 4; apply consistently the specified hierarchy to determine under which activity the land is to be reported in accordance with the Kyoto Protocol Supplement (section 1.2); in the cases in which a land falls into two activities, report over time that land under only one activity according to the established hierarchy; and provide detailed information in the NIR on the hierarchy and how it is consistently applied. Alternatively, in the cases of rotation of land between CM and GM, the United Kingdom may report all land subject to CM and GM under a single activity. | 2017 ARR <br><br> KL.21 <br> (KL.10 2019 ARR) | **Resolved.** The UK notes that Parties are at liberty to decide the hierarchy of Cropland Management, Grazing Land Management and Revegetation. We have determined that CM and GM are equal in the hierarchy and have ensured that there is no risk of double-counting in our methods. We consider our approach to be consistent with IPCC guidance and the best use of the available data. | Chapter 11 (section 11.1.4) |
| Cropland management - $CO_2$ | The ERT recommends that the United Kingdom define the category of land under which hedges are to be accounted, | 2017 ARR | **Resolved.** Addressed in 2019 submission. Hedges are now included under GM only. In addition,carbon stock | Chapter 11 (and |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | ensure that corresponding GHG emissions and removals are estimated, and report consistently thereon for the entire time series. | KL.22 (KL.17 2019 ARR) | changes in soil due to cropland management activities has been revised in the 2020 submission to use 0-30 cm reference SOC stocks. | Annex 3.4.3, also mentioned in Section 6.4.8) |
| Grazing land management - $CO_2$ | The ERT recommends that the United Kingdom report the same area of organic soils in grassland and GM in CRF tables 4(II) and 4(KP-I)B.3, respectively. | 2017 ARR KL.23 (KL.18 2019 ARR) | **Resolved.** The same land area for organic soils in grassland and GM is now reported within CRF tables 4(II) and 4(KP-1)B.3. The latest 2019 ARR report agrees this item is now resolved. | [CRF tables] |
| Grazing land management - $CO_2$, $CH_4$ and $N_2O$ | The ERT recommends that the United Kingdom develop the necessary AD on controlled burning throughout the year and in land areas smaller than 1 ha, and estimate and report the associated $CO_2$ and non-$CO_2$ emissions for the entire territory. | 2017 ARR KL.24 (KL.19 2019 ARR) | **Not resolved.** Not yet implemented. The UK has identified potential data sources for the estimation of controlled burning, and is awaiting the publication of further information for Scotland (https://www.gov.scot/groups/grouse-moor-management-group/). An initial analysis based on rates of burning of heather moorland in different parts of the UK assessed the emissions from biomass burning to be <500 kt $CO_2e$ per year. | Chapter 11 |
| Wetland draining and rewetting - AD | The ERT recommends that the United Kingdom: (a) Report the timetable for the ongoing project to incorporate WDR into the annual submission, including when the final results will be available for use in estimating $CO_2$ and non-$CO_2$ emissions from lands in the entire territory subject to WDR; (b) Follow, until the final results from the project are available, an interim approach (using alternative data sources) to obtain the necessary AD and use appropriate methodologies from the Wetlands Supplement to estimate $CO_2$ and non-$CO_2$ emissions for all the carbon pools from lands in the entire territory subject to WDR, noting the | 2017 ARR KL.25 (KL.20 2019 ARR) | **Not resolved.** Not yet implemented. A summary box describing the project was included in chapter 6, section 6.5.8 of the 2019 NIR. During 2019 the LULUCF inventory team worked on adapting the compilation and reporting of the national GHG inventory to take account of these new data. There was also a review of recently published scientific literature to identify any new relevant emissions data. The team undertook rigorous QA/QC to ensure a full understanding of how the data have been developed (i.e. the source data and the statistical analysis used to combine it for emission factors) and that all assumptions and expert judgment were fully justified and robust. Due to the complexity of the new data, this | Chapter 11 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | provisions of decision 2/CMP.7, annex, paragraph 26, decision 2/CMP.8, annex II, paragraph 2(a), (d) and (e), and decision 6/CMP.9, paragraph 10;<br><br>(c) Report $CO_2$ and non-$CO_2$ emissions in CRF tables 4(KP-I)B.5, 4(KP-II)1, 4(KP-II)2 and 4(KP-II)4, and explain in the NIR how it has estimated them. | | QA/QC process has been time-consuming, and was not complete in time to implement the new dataset in the 1990-2018 inventory cycle (this implementation also requires ministerial sign-off). | |
| Harvested wood products - $CO_2$ | The ERT recommends that the United Kingdom estimate the HWP contribution for HWP from deforestation on the basis of instantaneous oxidation. | 2017 ARR<br>KL.26 (KL.21 2019 ARR) | **Resolved.** This information has been included in the UK submission for many years, as communicated to the previous ERT. The method is clarified as "instantaneous oxidation" throughout section 11.3.1. The latest 2019 ARR report agrees this item is now resolved. | Chapter 11 |
| Annual submission | Improve the transparency of the NIR by including sufficient information in the annual submission. | 2017 ARR<br>G.1 (G.1 2019 ARR) | **Addressing**. Of the two outstanding items noted in item G.1 from the 2017 ARR, item L.5 is resolved and item W.1 is addressing. This is the assessment of the ERT in the 2019 ARR. | L.5: Annex A3.4.1.2<br>W.1: Annex table A3.5.5 |
| Key Category Analysis | Provide justification for the level of category disaggregation used and the rationale for its use if there is any deviation from the level suggested by the 2006 IPCC Guidelines. | 2017 ARR<br>G.2 (G.3 2019 ARR) | **Resolved.** The justification of the level of category disaggregation used in the UK KCA and explanations of deviations is provided in the NIR, with specific clarifications for LULUCF and agriculture included in Section A 1.3. The latest 2019 ARR report confirms this item is now resolved. | Annex A 1.3 |
| Methods | Address the transparency issues identified in the previous review reports. | 2017 ARR<br>G.3 (G.4 2019 ARR) | **Adressing.** This was a duplicate item for G.1, which in turn links to L.5 (resolved) and W.1 (addressing). | See responses for G.1, L.5 and W.1 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| Uncertainty analysis | Include in the NIR a brief description of and reference to the information used to quantitatively assess the uncertainty for all categories where expert judgment was used. | 2017 ARR<br><br>G.5 (G.8 2019 ARR) | **Resolved.** Justifications for uncertainty parameters are given in Tables A 2.3.1-2.3.4. We have prioritised documentation of parameters where the parameter has a significant impact on the KCA. The latest 2019 ARR report confirms this item is now resolved. | Annex<br><br>A 2.3 |
| Commitment period reserve | When preparing the NIR, compare the 90 per cent of assigned amount value against the total GHG emissions, excluding LULUCF, in the most recent year. | 2017 ARR<br><br>G.7 (G.2 2019 ARR) | **Resolved.** The CPR calculation has been updated and in reported in the NIR, section 12.5, consistent with the approach recommended by the ERT. | Section 12.5 |
| National system | Strengthen the national system in order to ensure the completeness of the coverage of the LULUCF and KP-LULUCF estimates of emissions and removals, and report on improvements made in the NIR. | 2017 ARR<br><br>G.8 (G.5 2019 ARR) | **Addressing.** This issue relates to the completeness of reporting from OTs (items L.4 and KL.5), for which there is progress through development of institutional networks with both the Cayman Islands and Bermuda. This has led to access to new data, and resultant progress in a more complete national inventory and KP submission. | See responses for L.4 and KL.5. |
| General | Clearly indicate the geographical coverage of DUKES and demonstrate how fuel consumption data at the subcategory level for each OT and CD are obtained and incorporated into the national totals for that subcategory. | 2017 ARR<br><br>E.1 (E.1 2019 ARR) | **Resolved.** DUKES coverage and the provision of AD from OTs and CDs is clarified in the 2019 NIR. Activity data for the OTs and CDs and their sources are included in Annex 3.6. | Section 1.1.2.2<br><br>Annex 3.6 |
| General | Rectify the stock data in the energy statistics and implement relevant recalculations in the CRF tables, as necessary, and explain all the recalculations in the NIR. | 2017 ARR<br><br>E.2 (E.2 2019 ARR) | **Resolved.** The energy statistics team have aligned stock changes reported in national energy statistics and the IEA returns for 2017 onwards, and these should remain largely consistent in future. The latest 2019 ARR report confirms this item is now resolved. | N/A |
| International navigation – liquid fuels – $CO_2$, $CH_4$ and $N_2O$ | Ensure the accuracy of the emission estimates for international navigation bunkers as well as the internal consistency between CRF tables 1.D and 1.A(b) by using the correct calorific values to convert activity from a mass basis to an energy basis. | 2017 ARR<br><br>E.5 (E.4 2019 ARR) | **Resolved.** The Inventory Agency has reviewed the available data and is satisfied that the approach to estimating and reporting data are consistent. The differences between the data reported in tables 1.D and 1.A(b) are primarily due to the use of independent simplified and weighted calorific values used in the | [CRF tables] |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | | | reference approach compared to the source-specific calorific values in the sectoral approach. | |
| | | | For Aviation fuels there is also an inconsistency in the structure of the CRF between the reference and sectoral approaches, meaning it is not clear where aviation spirit should be reported in the reference approach. The UK includes it with jet kerosene, which then results in a small discrepancy when compared to the jet kerosene data presented in the sectoral approach. | |
| | | | The UK is satisfied that this doesn't represent an issue with emissions calculations. The latest 2019 ARR report confirms this item is now resolved. | |
| 1.A.1.c Manufacture of solid fuels and other energy industries – liquid fuels – $CO_2$, $CH_4$ and $N_2O$ | Provide a clear and concise explanation that the estimates for AD and for $CO_2$, $CH_4$ and $N_2O$ emissions from subcategory 1.A.1.c.ii (oil and gas extraction) are complete, including relevant information (i.e. that the gap in data reporting applies to onshore terminals only and that the data from the EU ETS are very closely consistent with other reporting of emissions from the same installations under parallel regulatory mechanisms). | 2017 ARR E.6 (E.5 2019 ARR) | **Resolved.** This additional information is included within the full NIR of the 2019 submission, within the method approach, QA/QC and improvements sections of MS 2. We clearly state that "It is important to note however that despite these different methods and data availability, the UK Inventory Agency does report in a time series consistent manner for each source, and that the UK inventory is complete for all emission sources in this Method Statement." Supporting information explains the data available across the time series, the specific known gaps and how they are addressed, and the QA/QC section lists all of the specific quality checks that are conducted between different datasets for each installation. The latest 2019 ARR report confirms this item is now resolved. | MS 2 |
| 1.A.1.c Manufacture of solid fuels and other energy industries – liquid fuels – $CO_2$, $CH_4$ and $N_2O$ | Provide in the NIR up-to-date information on the consideration of, or progress made in, efforts to improve the energy statistics collection system for LPG and other | 2017 ARR E.7 (E.6 2019 ARR) | **Resolved.** The MS 2 section "Improvements" clearly presents up to date information to establish the status of this issue. The inventory is complete; the NIR is transparent in the UK approach to addressing a known | MS 2 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | petroleum gas fuels abstracted from upstream oil and gas exploration and production sources. | | data gap for LPG/OPG use at upstream oil and gas terminals. The latest 2019 ARR report confirms this item is now resolved. | |
| 1.A.2.b Non-ferrous metals – solid fuels – $CO_2$ | Investigate the underlying cause of the drop in the $CO_2$ EF for coal use in the Lynemouth aluminium smelter between 2003 and 2005 and report the findings of this investigation in the NIR. | 2017 ARR<br><br>E.9 (E.8 2019 ARR) | **Resolved.** The "method approach" section of MS 3 explains the review of EU ETS data, the findings and the change in method to improve time series consistency that has been implemented to address this issue. The latest 2019 ARR report confirms this item is now resolved. | MS 3 |
| 2.D.2 Paraffin wax use – $CO_2$ | Examine possible sources of AD, especially the IEA (OECD), Eurostat and UNECE questionnaires. | 2017 ARR<br><br>I.10 (I.9 2019 ARR) | **Resolved.** See also response to I.20.<br><br>The UK energy statistics team have provided the petroleum wax-specific data used for IEA and Eurostat submissions to the Inventory Agency, and these data will be used in future. The latest 2019 ARR report confirms this item is now resolved. | Chapter 4.23 |
| 3.A Enteric fermentation – $CH_4$ | Implement the planned improvement of digestible energy data through the commissioned research projects. | 2017 ARR<br><br>A.1 (A.6 2019 ARR) | **Resolved.** The UK has revised the methodology to implement the improvements derived from extensive UK research into this source category. This is explained in the NIR from the 2018 submission onwards. The latest 2019 ARR report confirms this item is now resolved. | Chapter 5 |
| 3.A Enteric fermentation – $CH_4$ | Apply a methodology that more closely reflects the country-specific conditions, for instance by moving to the IPCC tier 2 methodology for the sheep subcategory, in addition to documenting national circumstances leading to methodological choice. | 2017 ARR<br><br>A.2 (A.3 2019 ARR) | **Resolved.** The UK has revised the methodology to move to higher tier methods for several livestock categories, including for sheep, in order to improve accuracy of the UK method, to better reflect UK-specific circumstances (e.g. housing, feed, livestock size / weight / breed type). This is explained in the NIR from the 2018 submission onwards, with supplementary reports detailing the UK research findings. The latest 2019 ARR report agrees this item is now resolved. | Chapter 5 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 3.A.4 Other livestock – $CH_4$ and $N_2O$ | Fully document in the NIR: (1) the method used to estimate the annual population of horses, deer and goats, including any adjustments to the original population data that the Party receives from national statistical agencies; and (2) the use of any additional data sources and estimations, as required by the 2006 IPCC Guidelines (volume 4, section 10.2.2 and equation 10.1). | 2017 ARR A.3 (A.4 2019 ARR) | **Resolved.** The UK has revised the methodology for estimating horse population and now presents details of how the AD are derived for all livestock types in the NIR from the 2018 submission onwards. The latest 2019 ARR report agrees this item is now resolved. | Chapter 5 |
| 3.B.4 Other livestock (horses) – $N_2O$ | Make efforts to determine the number of horses in stabling and the corresponding type of manure management in order to determine the fraction of the total amount of N excretion for each manure management system for category 3.B.4 (manure management – horses). | 2017 ARR A.4 (A.5 2019 ARR) | **Resolved.** The UK has revised the methodology for estimating manure management from horses. This is explained in the NIR from the 2018 submission onwards. The latest 2019 ARR report agrees this item is now resolved. | Chapter 5 |
| 3.D.a.3 Urine and dung deposited by grazing animals – $N_2O$ | Provide complete references for the data sources, a clear description of the method, assumptions and calculations used, and an explanation for the difference between the country-specific EF and the default EF from the 2006 IPCC Guidelines. | 2017 ARR A.5 (A.7 2019 ARR) | **Resolved.** All data references, and a full method description including assumptions, input data and calculation method are included in the NIR from the 2018 submission onwards. The latest 2019 ARR report agrees this item is now resolved. | Chapter 5 |
| 4. General (LULUCF) 4.B Cropland 4.C Grassland – $CO_2$ | Report mineral and organic soils separately under cropland and grassland. | 2017 ARR L.1 (L.1 2019 ARR) | **Addressing.** The UK is still working on the inclusion of the complete set of Grassland organic soils under table 4C. | Chapters 6.3 and 6.4. |
| 4. General (LULUCF) 4.B Cropland 4.C Grassland – $CO_2$ | Assess the use of notation keys for the reporting of organic cropland and grassland soils, as appropriate. | 2017 ARR L.2 (L.2 2019 ARR) | **Addressing.** Whilst several of the notation key issues raised by the ERT have been resolved, there remain some to be addressed. We have no information yet on the extent of drained grassland in the Falkland Islands (where the organic soils are located within the OTs and CDs) but the land management is low intensity. Further research in the Falklands may resolve this issue. | Chapter 6.9. |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| Land representation – $CO_2$ | Provide estimates of emissions and removals for the missing land areas (Bermuda, Cayman Islands, Gibraltar and Montserrat). | 2017 ARR L.4 (L.6 2019 ARR) | **Addressing.** Gibraltar has been assessed as having zero LULUCF emissions and removals. The UK is working with the Cayman Islands and Bermuda governments to obtain activity data and estimate emissions and removals. Montserrat is not within the scope of UK GHGI reporting to the UNFCCC. | Annex 3.4 section 3.4.11. |
| 4.A Forest land – $CO_2$ | Continue efforts to gather information on the management of privately owned forests and include in the NIR information on the management prescriptions and rotation ranges. | 2017 ARR L.5 (L.9 2019 ARR) | **Resolved.** Additional details are provided in the NIR Annex section A.3.4.1.2 from the 2018 submission onwards. The latest 2019 ARR report agrees this item is now resolved. | Annex 3.4 Section A3.4.1.2 |
| 4.A Forest land – $CO_2$ | Include additional information on the management of privately owned forests in the NIR, specifically that: (a) Privately owned forests are assigned a species based on the National Inventory of Woodland and Trees species survey, then mapped to species for which the United Kingdom has suitable growth models; (b) The distribution of growth rates for these species is assumed to be the same as on the public forest estates for each devolved administration (Scotland, Wales, Northern Ireland, England); (c) The overall percentage of woodland being managed for wood production is estimated so as to calculate wood production over the period that is consistent with the wood production statistics; (d) The rotation lengths are based on the age of maximum mean annual increment, with a range to match the given age distribution and planting records. | 2017 ARR L.7 (L.10 2019 ARR) | **Resolved.** The information on management of privately owned forests is documented in the National Forestry Accounting Plan, which is referenced in NIR Annex 3.4.12 and can be found at: https://www.gov.uk/government/publications/uk-national-forestry-accounting-plan-2021-to-2025. The latest 2019 ARR report agrees this item is now resolved. | Chapter 6.2 Annex 3.4. |
| 4.A Forest land | Include information in the NIR on how data for the areas of forest land remaining forest land and land converted to forest land for the period 1990–1999 were calculated, and provide a more concise description of how the areas for different categories (forest land remaining forest land and | 2017 ARR L.8 (L.11 2019 ARR) | **Resolved.** The NIR Annex 3.4 provides the description of the derivation of land areas, and further information is provided in the National Forestry Accounting Plan, which is referenced in Annex 3.4 and can be found at: https://www.gov.uk/government/publications/uk-national-forestry-accounting-plan-2021-to-2025 | Chapter 6.2 Annex 3.7 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | land converted to forest land) have been estimated for 1990 onward. | | The latest 2019 ARR report agrees this item is now resolved. | |
| 4.A Forest land – $CO_2$ | Include information in the NIR on the verification of all carbon stock changes estimated using tier 3 methods and/or models (CARBINE, C-Flow and BSORT models). | 2017 ARR L.9 (L.12 2019 ARR) | **Addressing.** A report has been prepared to verify the carbon stock changes of the soil component of the CARBINE model. We will investigate future inventory improvements to include more verification. | Annex 3.4 |
| 4.B Cropland – $CO_2$ | Assign orchards to cropland and provide documentation on the method used to estimate the carbon stock changes over time, and ensure that changes in the area of orchards over time have been taken into account. | 2017 ARR L.10 (L.17 2019 ARR) | **Resolved.** This issue has been addressed, with text explaining the carbon stock changes over time within the NIR section 6.3.4. The latest 2019 ARR report agrees this item is now resolved. | Chapter 6.3 |
| 4.B Cropland – $CO_2$ | Report $CO_2$ emissions from all organic cropland soils in CRF table 4.B. | 2017 ARR L.11 (L.18 2019 ARR) | **Resolved.** The reporting of $CO_2$ emissions from organic cropland soils has been added into CRF Table 4.B, from the 2018 submission onwards. The latest 2019 ARR report agrees this item is now resolved. | CRF Table 4.B |
| 4.G.3 Other (harvested wood products) – $CO_2$ | Include verifiable production data from the CARBINE model and the corresponding factors used to convert the production data to carbon, and report those data in CRF table 4.Gs2 to enable a more thorough verification of the HWP estimates. | 2017 ARR L.13 (L.31 2019 ARR) | **Resolved.** The UK has included this verifiable data by the improvement of wood products to semi-finished categories for HWP in the 1990-2016 inventory, the Reconcile improvement programme in the 1990-2017 inventory and improvements to the completeness of data reported in the CRF. The UK also provided in CRF table 4.Gs2 the factors used for converting the production data to carbon as well as the data prior to 1990 (from 1960 onward). | Table 4.Gs2 of the CRF |
| 5.A Solid waste disposal on land – $CH_4$ | Implement the proposed improvements of the emission estimates for solid waste disposal sites in the OTs and CDs by providing further information on the methodologies used to estimate the emissions and by completing the CRF | 2017 ARR W.1 (W.1 2019 ARR) | **Resolved.** Information on activity data, MCFs, DOC and k values used for landfill emissions estimated for the OTs and CDs are presented in the Annexes of the NIR. The CRF references these data | Annex 3.5.1.3 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | tables with specific parameters such as AD, MCF and DOC. | | | |
| 5.A Solid waste disposal on land – CH$_4$ | Include in the NIR information on the parameters used in the MELMod model, including the exact figures and background information on their origin or method of derivation, and a weblink to the report on the review of landfill methane emissions modelling. | 2017 ARR W.2 (W.2 2019 ARR) | **Resolved.** From our records, the information requested by ARR was Methane Correction Factor; decay rates; DOC and DDOC for each waste stream; methane recovery; waste composition. The NIR includes the requested information as follows: Methane Correction Factor: Section 7.2.2 Decay rates: IPCC 2006 default values were used (confirmed in the 2018 NIR but not repeated in the 2019 NIR as this was not a change to the previous year and the IPCC 2006 default values were used) DOC and DOCf for each waste stream: Table A3.5.2 Methane recovery: Sections 7.2.3.1, 7.2.3.2, 7.2.3.3 and Table A3.5.4 Waste composition: Sections 7.2.3 and A3.5.1.1 and Table A3.5.1 A web link is provided to the review report in Section 17.6 as requested. | Sections 7.2.2, 7.2.3, 7.2.3.1, 7.2.3.2, 7.2.3.3, 17.6, A3.5.1.1 Tables A3.5.1, A3.5.2, A3.5.4 |
| 5.D.1 Domestic wastewater – CH$_4$ | Include information in the NIR on population number connected to a septic system, as well as the BOD values applied. | 2017 ARR W.8 (W.7 2019 ARR) | **Resolved.** This information is presented in the NIR, in Annex 3, Table A.3.5.12, and is outlined in Chapter 7. The latest 2019 ARR report agrees this item is now resolved. | Chapter 7 & Annex 3 |
| 5.D.1 Domestic wastewater – N$_2$O | In the NIR provide a detailed description and justification for the update of the fraction of N in protein (1.16) and the fraction of industrial and commercial co-discharged protein (1.25) and information on the consideration of sludge incineration and sludge spreading on agricultural lands, and update the CRF tables accordingly. | 2017 ARR W.9 (W.10 2019 ARR) | **Resolved.** The NIR section 7.5.2.3 presents the method description and justification for the factors applied in the UK. The fractions $F_{NON-CON}$ and $F_{IND-COM}$ were updated in the 2017 NIR; the CRF has since been updated to include these values as well. The latest 2019 ARR report agrees this item is now resolved. | Chapter 7 |
| 5.D.2 Industrial wastewater – CH$_4$ | Report on any progress in collecting the data needed to report AD and emissions from industrial wastewater separately from domestic wastewater. | 2017 ARR | **Not resolved.** The UK has an ongoing waste water research project that is seeking to address this issue, but to date we do not have access to industry data | n/a |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | | W.10 (W.13 2019 ARR) | resolved sufficiently to enable us to address this recommendation**.** | |
| General (KP-LULUCF) | Include specific information on how land under CM, GM and WDR is identified, especially related to the report developed as part of the ongoing project on areas of WDR. | 2017 ARR KL.1 (KL.1 2019 ARR) | **Addressing.** The results of the project on wetland drainage and rewetting are in preparation for implementation in forthcoming inventories but additional information was included in the 1990-2017 inventory chapter 6 (Box in section 6.5.8) and section 11.1.3. | Chapters 6 and 11 |
| General (KP-LULUCF) | Improve the QA/QC process and correct the inconsistency in the area of land converted to forest under the Convention and the Kyoto Protocol (i.e. the area of land converted to forest in CRF table 4.1 for 2014 (12.9 kha) does not match the area of AR (reported as 10.7 kha in table NIR-2)). | 2017 ARR KL.2 (KL.2 2019 ARR) | **Resolved.** The inconsistencies in the area of land converted to forest under the Convention and the KP have been resolved, in CRF tables 4.1 and NIR-2. The latest 2019 ARR report agrees this item is now resolved. | CRF Tables 4.1 and NIR-2. |
| General (KP-LULUCF) | Include information in the NIR in accordance with decision 2/CMP.8, annex II, paragraph 5(c) and (e). | 2017 ARR KL.4 (KL.3 2019 ARR) | **Resolved.** The relevant information has been added to the NIR from the 2018 submission onwards. The latest 2019 ARR report agrees this item is now resolved. | Chapter 11 sections 11.4 and 11.5 |
| General (KP-LULUCF) | Provide estimates of emissions and removals for the Cayman Islands and Gibraltar. | 2017 ARR KL.5 (KL.4 2019 ARR) | **Adressing.** The UK has contacted the Cayman Islands government to obtain activity data and estimate emissions and removals. We have researched the FAOSTAT dataset which indicates zero emissions from LULUCF from the Cayman Islands, and hence these are considered insignificant. Gibraltar have made their own calculations of their net LULUCF emissions (Annex 3.6) and these are determined to be zero, and therefore their KP emissions are also zero. | Annex 3.6 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| Deforestation – $CO_2$ | Find a method to verify that the carbon stocks in living biomass prior to deforestation are not underestimated. | 2017 ARR KL.8 (KL.7 2019 ARR) | **Not resolved.** The UK will continue to investigate what data might be available to demonstrate that underestimation is not occurring. The UK currently has initiated a rolling programme of National Forest Inventories (NFIs) to provide accurate information about the size, distribution, composition and condition of the UK's forests and woodlands and to provide information about the changes taking place in UK's woodlands through time. Since land is only assigned as permanently deforested after 10 years, it would take until a possible 3rd cycle of the NFI to detect deforestation reliably. This issue therefore may take some time to resolve using the NFI alone. | n/a |
| Article 3.4 activities | Provide estimates of the carbon stock changes in: litter and deadwood for CM; litter, deadwood and organic soils for GM; and all carbon pools under WDR, and include a description of how these changes are estimated. | 2017 ARR KL.9 (KL.9 2019 ARR) | **Addressing.** The results of the project on wetland drainage and rewetting are in preparation for implementation in forthcoming inventories but additional information was included in the 1990-2017 inventory (Box in section 6.5.8). As the UK has a forest area threshold of 0.1 ha, all tree-covered areas above this threshold are included under AR or FM. CM and GM are considered to only contain cropland or grassland vegetation respectively, and any litter or dead wood produced by these categories will decay within a single year and will not contribute to carbon stock change within the CM or GM categories. | Chapter 11 |
| Forest management– $CO_2$, $CH_4$ and $N_2O$ | Correct the value of the FM cap in the CRF table "Accounting". | 2017 ARR KL.10 (KL.11 2019 ARR) | **Resolved.** The FM Cap was corrected from the 2020 submission onwards, within the CRF table 'Accounting'. | Chapter 11 [CRF Tables] |
| Forest management – $CO_2$ | Include information in the NIR on the main changes in the inventory leading to the technical correction of the FMRL (including the inclusion of carbon emissions and removals | 2017 ARR | **Resolved.** This issue was addressed from the 2018 submission onwards, with the information on main changes in the inventory leading to technical | Chapter 11 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | from forest areas afforested prior to 1921, changes in the assumptions used for the species mix, growth rates and intensity of management). | KL. 11 (KL.12 2019 ARR) | corrections of the FMRL presented in NIR section 11.5.2. The latest 2019 ARR report agrees this item is now resolved. | |

**Table 10.17    Improvements to the UK GHG Inventory Submission in response to UNFCCC Review Findings 2019**

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| Key category analysis<br><br>Convention reporting adherence | The ERT noted that while the United Kingdom implemented a key category analysis following Approach 1 for its submission under the Convention, reporting the results in the NIR (annex I), an analysis was not conducted for the data submitted under the Kyoto Protocol. The ERT recommends that the United Kingdom conduct a key category analysis, following at least Approach 1, for the sources and sinks of the territory reported under the Kyoto Protocol. | 2019 ARR G.9 | **Resolved.** An additional key category analysis relating to the submissions under the Kyoto Protocol has now been undertaken and the results will be published alongside those also reported for the submission under the Convention inare included in the 2020 submission of the NIR | Annex 1 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| NIR | The ERT noted that the sectoral chapters of the NIR do not include the results of the uncertainty analysis at the category level for most categories, but rather refer to annex 2 to the NIR for this information.The ERT acknowledges that the values of and rationales for determining the uncertainties of AD and EFs applied are sufficiently described in annex 2, but considers that providing a summary of the uncertainty assessment for each category in the respective section of the body of the NIR would improve its readability. The ERT encourages the United Kingdom to include a brief description of the uncertainty associated with each category in the "Uncertainties and time series consistency" section under each category in the NIR. A brief sentence, as currently appears in these sections under the LULUCF sector, or a summary table, as is currently included in the overview descriptions of the energy and LULUCF sectors, would suffice. | 2019 ARR G.10 | (Not an issue.)<br><br>The UK will consider the ERT's encouragement for future submissions. | NIR (all sectors) |
| Other<br><br>Transparency | The ERT noted that in several sections of the NIR, the United Kingdom provided the explanation that emissions and removals from overseas territories and Crown dependencies have not been included because they are below the level of significance (see ID#s A.1, L.28 and KL.8 in table 3). In addition, in the energy sector, emissions from shale gas exploration are claimed to be insignificant and so are not included in the inventory (see ID# E.21 in table 3). The ERT considers that the Party does not always use the significance threshold in an appropriate way: the threshold cannot be used when the omissions are part of a category for which estimates have been provided in the annual submission. Further, the ERT finds that the Party has not made an overall assessment in its NIR to demonstrate that the total emissions excluded from reporting owing to insignificance remain below 0.1 per cent of total national emissions, as required by paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. The ERT, noting the recommendations already contained in ID#s E.21, A.1, and L.28 in table 3, recommends that the United Kingdom improve the transparency of its reporting regarding completeness by including in the NIR a table or other form of appropriate documentation summarizing the categories | 2019 ARR G.11 | **Addressing.** The UK now includes a summary in the NIR of sources that are not estimated in the inventory, the justification for not including each source, their expected level of emission compared to the national total and the total of  expected emissions from not estimated sources relative to the national total excluding LULUCF. | Section 1.8 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | determined to be insignificant and the level of assumed emissions for each of those categories; the table or other form of documentation may include a reference to the value of the threshold of 0.05 per cent of the total $CO_2$ eq, excluding LULUCF, each category should be compared with, and the value of the threshold of 0.1 per cent of total $CO_2$ eq, excluding LULUCF, to ensure that the sum of missing categories excluded does not exceed this threshold. | | | |
| Uncertainty analysis<br><br>Convention reporting adherence | The ERT noted that uncertainty analyses following Approach 1 and Approach 2 were conducted for data submitted under the Convention but not under the Kyoto Protocol. The ERT recommends that the United Kingdom conduct an uncertainty analysis, following at least Approach 1, for the territory reported under the Kyoto Protocol. | 2019 ARR G.12 | **Resolved.** An additional uncertainty analysis relating to the submissions under the Kyoto Protocol has now been undertaken and the results are included in the 2020 submission. | Annex 2 |
| Uncertainty analysis<br><br>Convention reporting adherence | The ERT noted that the uncertainty analyses have not always been conducted at the appropriate category level, as specified in the UNFCCC Annex I inventory reporting guidelines. For instance, for the IPPU sector, the United Kingdom estimated the uncertainty for $CO_2$ emissions at the level of category 2.B (chemical industry) and not at the level of the subcategories under it (e.g. 2.B.1 (ammonia production)) as suggested by paragraph 15 of the UNFCCC Annex I inventory reporting guidelines. As the results of the uncertainty analysis are used for the Approach 2 key category analysis, the disaggregation of the former analysis affects the latter analysis. The ERT recommends that the United Kingdom conduct uncertainty analyses, following at least Approach 1, at the appropriate level of category disaggregation in accordance with paragraph 15 of the UNFCCC Annex I inventory reporting guidelines. | 2019 ARR G.13 | **Resolved.** The UK has reviewed and revised the aggregation of data for the approach 1 KCA to improve the consistency of aggregation between sources and pollutants and to report in accordance with paragraph 15 of the UNFCCC reporting guidelines. | Annex 2 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 1.General (energy sector) – all fuels – $CO_2$, $CH_4$ and $N_2O$<br><br>Not an issue | The ERT welcomes the use of facility-level data by the United Kingdom to estimate GHG emissions from several categories in the energy sector (see ID#s E.13, E.15 and E.18 in table 3). Nevertheless, the United Kingdom acknowledged during the review, and the ERT agreed, that there are opportunities to expand the collection to obtain more data of benefit to the inventory. For example, while noting that fugitive $CO_2$ and $CH_4$ emissions from petroleum systems are not key categories in the United Kingdom, data already available at offshore oil and gas wells could be collected at a more disaggregated level (e.g. process, fugitive, flaring, venting, loading), making it possible to report these more disaggregated data in the CRF. The ERT encourages the United Kingdom to continue its efforts to obtain additional and/or improved facilityreported data for all energy sector categories, collected at a level of disaggregation and coverage that will allow their seamless integration with national energy data (in the case where the facility-level data do not represent the entire category) and consistent use in the inventory. | 2019 ARR E.22 | (Not an issue.)<br><br>The UK will consider the ERT's encouragement for future submissions.<br>In the upstream oil and gas sector, an inventory improvement project is underway which aims to access installation-level data. Improvements will be included in the 2022 submission. | n/a |
| 1.A Fuel combustion – sectoral approach – all fuels – $CO_2$, $CH_4$, and $N_2O$<br><br>2.Not an issue | The ERT noted that in some cases the United Kingdom used IPCC default EFs even though EFs derived from data reported under the EU ETS were available for the emissions source (e.g. $CO_2$ EFs for refinery fuel gas used in upstream oil and gas extraction facilities and gas separation plants). During the review, the Party explained that it sometimes uses different EFs to disaggregate combustion-related $CO_2$ emissions from the same fuel (e.g. LPG or refinery fuel gas) to different subcategories of the upstream oil and gas industry. Some of the EFs used for minor fuels (e.g. ethane) are IPCC default values. Given this background, and the fact that facility-reported data are available, the ERT encourages the United Kingdom to use up-to-date country-specific EFs to disaggregate fuels, incorporating consistent facility-level EU ETS data, where possible. | 2019 ARR E.23 | (Not an issue.)<br><br>The UK will consider the ERT's encouragement for future submissions. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 1.A.1.c Manufacture of solid fuels and other energy industries – refinery gas – $CO_2$<br><br>Transparency | The ERT noted that the United Kingdom's refinery gas $CO_2$ combustion EF (which is only used in conjunction with consumption at gas separation plants) is referenced as the EF for ethane contained in the 2006 IPCC Guidelines (NIR, p.137). The EF actually used by the Party (66.90 t/TJ), however, has a slightly different value than that of the ethane EF in the 2006 IPCC Guidelines (vol. 2, table 2.2) (61.60 t/TJ). During the review, the Party explained that the units for this EF had been inadvertently converted using the higher heating value (i.e. gross calorific value), rather than the lower heating value (i.e. net calorific value). The ERT noted that this is not an accuracy issue, as this EF is used only for allocating emissions reported by facilities (i.e. the EF is used to estimate emissions for gas separation plants, but the total emissions for category 1.A.1.c.ii (oil and gas extraction) are obtained from the reported operator $CO_2$ emissions). Therefore, the total $CO_2$ eq emissions reported in the annual submission are not affected. This issue does, however, lead to a slight misallocation of $CO_2$ emissions from refinery fuel gas by subindustry within the category. Furthermore, the description of the use of the EF is not clear in the NIR (e.g. the reference on p.137 does not describe which EF from the 2006 IPCC Guidelines has been applied). The ERT recommends that the United Kingdom ensure that it applies the lower net calorific value when inputting information in its models in order to estimate refinery gas emissions and clarify in the NIR the description of the methodology used and source of the $CO_2$ EF. | 2019 ARR E.24 | **Resolved.** In the 2020 submission the UK has corrected the CEF used for gas separation plant process off-gases to apply the correct ethane CEF, and applying the net calorific value. Further, the NIR method description has been updated, including to specify the origin of the $CO_2$ EF applied. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 1.A.3.e.ii Other (other transportation) – liquid and gaseous fuels – $CO_2$, $CH_4$ and $N_2O$<br><br>Accuracy | The ERT noted that potentially outdated technology data are being used in the United Kingdom's off-road estimates. The ERT noted that although the model is advanced, it was last updated in 2004 and therefore the equipment data used in it are slowly becoming outdated. The ERT considers that the use of equipment data from 2004 likely does not reflect current circumstances in the country. The ERT recommends that the United Kingdom 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. | 2019 ARR E.25 | **Addressing.** There is an ongoing inventory improvement study into the use of off-road machinery within urban areas, which includes an exercise via a government supported market survey, to collect data on the population and parameters of specific machinery types. There may be potential for this study to refine specific estimates within the model, providing a necessary update in future submissions. | |
| 1.B.2 Oil, natural gas and other emissions from energy production – liquid and gaseous fuels – $CO_2$ and $CH_4$<br><br>Not an issue | The ERT noted that the Elgin offshore rig blowout occurred in March 2012 (see, e.g., Gosden, 2012). The ERT also noted that no information on the estimation of $CO_2$ and $CH_4$ emissions from the blowout was provided in the NIR, although the United Kingdom mentioned that no data are currently available with which to estimate emissions from oil and gas well blowouts (p.200). The ERT believes that future ERTs should consider this issue further to ensure that emissions from this category are not underestimated. The ERT encourages the United Kingdom to obtain the environmental report and emission data for the Elgin offshore rig blowout, and, after appropriate evaluation, incorporate the data into the annual submission. The ERT also encourages the Party to investigate whether emissions from other oil and gas well blowouts are occurring in the country and, if data on the amount of fuel lost during the blowout exist, to estimate the emissions and update the NIR to include the AD, EFs and methodology, including sources of data used, for estimating all emissions from oil and gas well blowouts. | 2019 ARR E.26 | (Not an issue.)<br><br>The UK has included estimates for the emissions of methane and NMVOC from the 2012 Elgin blowout in the 2020 submission, based on research estimates of the mass emission rate during the event. Further, the Inventory Agency has reviewed the Hydrocarbon Release Database from the Uk Health and Safety Executive, and across the time series there is no other record of an oil and gas well blowout, and therefore we consider the 2020 submission to be complete for this source. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 3.General (IPPU)<br><br>Transaprency | The ERT identified several errors in the NIR that individually and collectively impacted its transparency, in particular that of the descriptions of several categories. The ERT recommends that the United Kingdom improve the transparency of its reporting by correcting in the NIR the following issues: (a) For category 2.A.1 (cement production), include in NIR figure 4.1 the year for which the data are presented, use the correct units for data in NIR figure 4.2 (data are presented as $CO_2$ emissions, not as carbon emissions), clarify that the data provided in NIR table 4.3 are IEFs not EFs, and define the abbreviation "CEF" in NIR table 4.3; (b) For category 2.A.2 (lime production), identify in NIR table 4.1 the correct tiers applied for estimating $CO_2$ emissions (i.e. tier 1 for 1990–1993 and tier 3 from 1994 onward); (c) In NIR table 4.4, change the units of the EF applied for $CO_2$ emissions from lime production from kt C/kt carbonate to t C/kt carbonate; (d) On page 224 of the NIR, update the text regarding the year in which FGD systems were introduced in the United Kingdom to clarify that $CO_2$ emissions from FGD systems have been reported since 1994, consistent with $CO_2$ emissions from category 2.A.4 (other process uses of carbonates) reported in CRF table 2(I)A-Hs1; (e) On page 239 of the NIR, correct the information stating that emissions from soda ash used in the manufacture of soda lime glasses are reported under category 2.A.4 (other process uses of carbonates) to clarify that these emissions are in fact reported under category 2.A.3 (glass production); (f) 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 the years 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; (g) On page 238 of the NIR, correct the name of category 2.B.7 so that it reads soda ash production, instead of soda ash production and use, which is consistent with the title in CRF table2(I).A-Hs1 and with the corresponding data reported by the Party in that table. | 2019 ARR I.14 | **Resolved.** In relation to the specific points raised: a) The header to figure 4.1 has an additional description noting the data pertains to the latest inventory year (in this submission - 2018). Figure 4.2 now refers to $CO_2$, not carbon, within its legend. the description of Table 4.3 has been revised; b) Table 4.1 has been revised with respect to the methodological tiers for lime production.; c) The units in Table 4.4 have been addressed; d) the description of FGD systems has been revised in Section 4.5.1; e) the description of soda ash has been updated in Section 4.12.1, to note that missions from soda ash used in the manufacture of soda lime glasses re in fact reported under category 2.A.3 (glass production); f) the incorrect information has now been removed ; g) the category name for 2.B.7 has been revised to soda ash production. | Chapter 4. |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 2.A.2 Lime production – $CO_2$ | According to the NIR (p.219), the EU ETS data for United Kingdom 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 activity. However, based on a recommendation in a previous review report (FCCC/ARR/2013/GBR, paras. 47–48), the United Kingdom included a default percentage of unreacted lime in its calculations. The ERT noted that, according to the information provided by the Party during the review, $CO_2$ emissions from lime production at sugar plants were estimated on the basis of an assumption that 24 per cent of the lime is not recarbonated after use in the process of sugar production. The ERT also noted that section 4.3.2 of the NIR does not contain details on the methodology used for estimating $CO_2$ emissions from sugar plants. The ERT acknowledges that the methodology for estimating emissions from sugar refining was assessed in 2013 and that the approach is consistent with the 2006 IPCC Guidelines, however concludes that the methodological description in the NIR is not transparent. The ERT recommends that the United Kingdom include in the NIR a more detailed description of the methodology used for estimating $CO_2$ emissions from lime production at sugar plants, including documenting the assumption that 24 per cent of lime produced at sugar plants is not recarbonated. | 2019 ARR I.15 | **Resolved.** A more detail description has been added to Section 4.3 of the NIR. | Section 4.3 |
| 2.A.2 Lime production – $CO_2$ | The ERT noted that according to CRF table 2(I).A-Hs1, the AD for lime production are "limestone used for lime production"; however, according to the NIR, the AD include a mix of limestone and dolomite (p.219). During the review, the United Kingdom confirmed that the AD used for estimating $CO_2$ emissions from lime production include both limestone and dolomite and agreed to change the AD identified in CRF table 2(I).A-Hs1 in the next submission. The ERT concludes that information on the AD for category 2.A.2 is not transparent. The ERT recommends that the United Kingdom clarify in the description of the AD for category 2.A.2 in CRF table 2(I).A-Hs1 that both limestone and dolomite are used for lime production. | 2019 ARR I.16 | **Resolved.** Data in the CRF for 2.B.8.g are now reported under 'Other petroleum gases (OPG) | CRF Tables |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 2.A.4 Other process uses of carbonates – $CO_2$ | The ERT noted that $CO_2$ emissions from stone wool production were reported under category 2.A.3 (glass production), which is not in compliance with the 2006 IPCC Guidelines: these emissions should be reported under subcategory 2.A.4.d (other). During the review, the United Kingdom agreed that $CO_2$ emissions were incorrectly allocated. The Party stated that the reporting of $CO_2$ emissions from stone wool production is difficult without disclosing confidential data from EU ETS reports. The ERT concludes that the Party's reporting of $CO_2$ emissions from stone wool production is not comparable with that of other Parties. The ERT recommends that the United Kingdom 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 category 2.A.4.d, if needed, providing a relevant explanation in the NIR as to where emissions are reported. | 2019 ARR I.17 | **Not Resolved.** We will need to consider how best to address this issue, given the likely confidentiality of data for this sector. This will therefore be addressed in the next submission. | N/A |
| 2.A.4 Other process uses of carbonates – $CO_2$ | The ERT noted that $CO_2$ emissions from limestone use for FGD systems used at energy plants are reported under subcategory 2.A.4.d (other) when, according to the 2006 IPCC Guidelines, $CO_2$ emissions from limestone use should be reported under the category in which the carbonates are consumed (vol. 3, section 2.5.1). During the review, the United Kingdom explained that it is not clear how FGD emissions could be reported under the energy sector in the CRF tables in a transparent manner. The ERT concludes that $CO_2$ emissions from FGD systems are not reported in a manner that is comparable with other Parties' reporting. The ERT recommends that the United Kingdom report $CO_2$ emissions from limestone use for FGD systems used at energy plants in the country under category 1.B.2.d (other (oil, natural gas and other emissions from energy production)). | 2019 ARR I.18 | **Not resolved.** This item hasn't been addressed during this cycle, but will be addressed in future cycles to align reporting with other parties. | N/A |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 2.A.4 Other process uses of carbonates – $CO_2$ | The ERT noted that according to the ongoing (unpublished) study on the non-glass uses of soda ash undertaken by Ricardo Energy and Environment provided to the ERT during the review, $CO_2$ emissions from the use of sodium bicarbonate in the United Kingdom amounted to 35.9 kt $CO_2$ in 2017. The Party explained that these emissions were not reported in the 2019 annual submission because the study has not been completed. The ERT concludes that although the inventory is not complete because $CO_2$ emissions from sodium bicarbonate use were not reported, the estimated emissions are below the threshold of significance for the United Kingdom (237 kt $CO_2$ eq in 2017) and therefore below the threshold for inclusion of this issue in the list of potential problems and further questions raised by the ERT in accordance with decision 22/CMP.1 in conjunction with decision 4/CMP.11, annex, paragraph 80(b). The ERT recommends that the United Kingdom 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 | 2019 ARR I.19 | **Resolved.** Emission estimates for (non-glass industry) use of soda ash have been included for the first time. This adds 83 ktonnes CO2 to the UK inventory for 1990 and 35 ktonnes CO2 to the 2017 figures. | Section 4.5 |
| 2.A.4 Other process uses of carbonates – $CO_2$ | The ERT noted that under subcategory 2.A.4.a (ceramics), only $CO_2$ emissions from brick production were reported. However, according to the NIR, other types of ceramics are also produced in the United Kingdom (e.g. wall and floor tiles, refractories, sanitary ware, household ceramics) (pp.227–228). Data provided in NIR table 4.7 for the period 2008–2012 show that clay consumption for ceramic products other than bricks (0.43 Mt) amounted to 11 per cent of the clay consumption for brick production (3.93 Mt). The ERT estimated that if the share of clay consumption for ceramic products other than bricks was the same in 2017 as in the period 2008–2012, emissions from these other ceramic products would be about 28 kt $CO_2$ eq. The ERT noted that AD for clay consumption for bricks, pipes and tiles are available in the United Kingdom Minerals Yearbook. During the review, the availability of AD and possible methods for estimating $CO_2$ emissions from ceramics other than bricks were discussed with the United Kingdom, and the Party agreed with the following assessment of the ERT. The ERT concludes that although $CO_2$ emissions from subcategory 2.A.4.a are not | 2019 ARR I.20 | **Not Resolved.** This item has been added to our list of potential improvements but the improvements to be treated as the highest priority and to therefore be addressed in time for the next submission are yet to be decided. | N/A |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | complete, the estimated emissions are below the threshold of significance for the United Kingdom (237 kt $CO_2$ eq in 2017) and therefore below the threshold for inclusion of this issue in the list of potential problems and further questions raised by the ERT in accordance with decision 22/CMP.1 in conjunction with decision 4/CMP.11, annex, paragraph 80(b). The ERT recommends that the United Kingdom 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 the period 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), and report these emissions under subcategory 2.A.4.a (ceramics). | | | |
| 2.B Chemical industry – $CO_2$ | The ERT noted that $CO_2$ emissions from several categories under category 2.B (chemical industry) were reported as constant for several years in the time series: 2.B.6 (titanium dioxide production) in 1990–1998 (104.63 kt $CO_2$), 2.B.7 (soda ash production) in 1990–1998 (231.55 kt $CO_2$), 2.B.8.a (petrochemical and carbon black production – methanol) in 1990–1997 (497.72 kt $CO_2$), 2.B.8.d (petrochemical and carbon black production – ethylene oxide) in 1990–1995 (131.00 kt $CO_2$) and 2.B.8.f (petrochemical and carbon black production – carbon black) in 1990–1998 (437.15 kt $CO_2$). During the review, the United Kingdom explained that the emission data or AD were not available for several categories of 2.B for early years of the time series. The Party therefore used the available average value of emissions for categories 2.B.6, 2.B.7 and 2.B.8.d and the maximum capacity of chemical installations for categories 2.B.8.a and 2.B.8.f to fill the gaps of AD and emissions in the time series. The ERT notes that the method used to determine emissions for periods where AD or emission data were not available does not correspond to the methods for ensuring time-series consistency in the 2006 IPCC Guidelines (vol. 1, chap. 5). The ERT concludes that the time series of emissions is not consistent for categories 2.B.6, 2.B.7, 2.B.8.a, | 2019 ARR I.21 | **Adressing -** 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 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 | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | 2.B.8.d and 2.B.8.f. The ERT recommends that the United Kingdom use the standard splicing techniques in the 2006 IPCC Guidelines (vol. 1, sections 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) in 1990–1998, 2.B.7 (soda ash production) in 1990–1998, 2.B.8.a (petrochemical and carbon black production – methanol) in 1990–1997, 2.B.8.d (petrochemical and carbon black production – ethylene oxide) in 1990–1995 and 2.B.8.f (petrochemical and carbon black production – carbon black) in 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 the Party is not able to apply the standard splicing techniques, the ERT recommends that the United Kingdom follow the 2006 IPCC Guidelines (vol. 1, sections 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. The ERT notes that, taking into account the Party's concerns about the significant efforts to resolve the issue, expressed in response to a draft version of this report, and in line with paragraph 73 of the UNFCCC Annex I inventory review guidelines, the Party could include in the NIR information on the amount of effort and resources required for this improvement relative to the impact of revised emission estimates for categories 2.B.6, 2.B.7, 2.B.8.a, 2.B.8.d and 2.B.8.f on the level and/or trend of total national GHG emissions and demonstrate that the change of the total national GHG emissions will be insignificant. | | 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:<br>• Production data by mass<br>• Production data by weight<br>• Production data by value<br>• Export data by weight/value<br>• Financial data of specific chemical sector<br>• General financial/physical indices of chemical production<br>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 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 | |

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| | | | 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 the relationship between plant capacity and emissions sufficient to simulate activity data back to 1990, in the absence of available surrogate data. Uncertainty parameters reflect this method; but the Inventory Agency considers this use of plant capacity equivalent to applying population data to extrapolate wastewater emissions. | |
| 2.B.1 Ammonia production – $CH_4$ and $N_2O$ | The ERT noted that in CRF table 2(I).A-Hs1, $CH_4$ (0.01 kt in 2017) and $N_2O$ (0.001 kt in 2017) emissions from ammonia production were reported under category 2.B.1. However, in the NIR, $CH_4$ emissions from ammonia production were reported under category 2.B.10 (other (chemical industry)) (pp.229 and 245). During the review, the United Kingdom explained that category 2.B.10 aggregates emissions across many chemical production sites, including those that produce ammonia within fertilizer production complexes, for which source-specific data on $CH_4$ and $N_2O$ emissions are not available (emissions represent totals across the installation). The Party also explained that IPCC default $CH_4$ and $N_2O$ EFs were applied to the combustion component of natural gas use in ammonia production, and these emissions were reported under category 2.B.1. The Party considers that the chosen approach ensures completeness but may result in a small amount of double counting, totalling 614 t $CO_2$ eq in 2017, which is 0.0001 per cent of the United Kingdom's total national GHG emissions, excluding LULUCF. The ERT concludes that the description of $CH_4$ and $N_2O$ emissions in the NIR is not transparent and that | 2019 ARR I.22 | **Addressing.** The description of methodologies has been revised for this submission. The removal of any double-counting between 2.B.1 and 2.B.10 will be addressed in future cycles, due to the timing of the ARR 2019 report. | |

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| | the total $CH_4$ and $N_2O$ emissions may not be accurately reported. The ERT recommends that the United Kingdom 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. The ERT also recommends that the Party 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. | | | |
| 2.B.8 Petrochemical and carbon black production – $CO_2$ | According to page 240 of the NIR, category 2.B.8.g was identified as "2.B.8.g chemicals: OPG" (referring to other petroleum gases). However, according to CRF table 2(I).A-Hs1, the correct name of the category is "2.B.8.g Other". The ERT noted that emissions reported under the latter category in CRF table 2(I).A-Hs1 were not specified and were reported under the row "Other (please specify)". During the review, the United Kingdom explained that the name of category 2.B.8.g in the NIR was changed to reflect the emissions reported under the category. The ERT concludes that the description of category 2.B.8.g is not transparent in the NIR because it does not use a naming convention consistent with that of the CRF tables. Further, the ERT concludes that the description in CRF table 2(I).A-Hs1 is not transparent because emissions reported under 2.B.8.g other were not specified. The ERT recommends that the United Kingdom specify in CRF table 2(I).A-Hs1 that $CO_2$ emissions from "OPG" are reported under subcategory 2.B.8.g (other) by changing the category description from "Other (please specify)" to "Other petroleum gases (OPG)". The ERT also encourages the Party to use the name of the category, 2.B.8.g (other), in the NIR, corresponding to the name specified in the CRF table and thereby ensuring transparency. | 2019 ARR I.23 | **Resolved**. Data in the CRF for 2.B.8.g are now reported under 'Other petroleum gases (OPG)'. | N/A |

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| 2.B.9 Fluorochemical production – HFCs | The ERT noted that in CRF table 2(II)B-Hs1, emissions of HFC-23 were reported under production of HCFC-22 (0.17 t HFC-23 in 2017), but according to the NIR, HCFC-22 production ceased in the country in 2016 (p.244). During the review, the United Kingdom explained that the operator of the plant manufacturing HCFC-22 reported HFC-23 emissions from HCFC-22 production in 2017 and emissions were included in the inventory under category 2.B.9 as fugitive emissions from HCFC-22 production. The Party indicated that it would consult the plant operator to clarify why emissions were reported after production ended. The ERT concludes that the reporting of HFC-23 emissions from HCFC-22 is not transparent because HCFC-22 production does not occur in the United Kingdom. The ERT recommends that the United Kingdom investigate why the operator of the plant manufacturing HCFC-22 continued to report HFC-23 emissions after production of HCFC-22 ended in the country in 2016, and pending the outcome of this investigation, recalculate the HFC-23 emission estimates, as appropriate. | 2019 ARR I.24 | **Addressing.** Emissions of HFC-23 reported in 2016 and 2017 against 2.B.9 have been revised to reflect the latest data from the operator and the very small emission reported for 2017 (after the industrial process is known to have ended) has been reallocated to 2.F.6.b until we have confirmation about what these data refer to. | CRF table 2(II)B-Hs1 |
| 2.C.1 Iron and steel production – $CO_2$ | The ERT noted that $CO_2$ emissions from the use of blast furnace gas, coke oven coke, fluxing agents, fuel oil and coal for pig iron production (except for losses of blast furnace gases) were reported in the energy sector under category 1.A.2 (manufacturing industries and construction) (NIR, p.146). The ERT also noted that the $CO_2$ IEF for pig iron production reported in CRF table 2(I).A-Hs2 (e.g. 0.18 t $CO_2$/t pig iron in 2017) is significantly lower than the IPCC default EF provided in the 2006 IPCC Guidelines (vol. 3, chapter 4, table 4.1) (1.35 t $CO_2$/t pig iron produced). During the review, the United Kingdom explained that all emissions associated with blast furnace gas use except for losses were reported under the energy sector and because of this, the $CO_2$ IEF for pig iron production is significantly lower than the IPCC default value. During the review, the ERT analysed the carbon balance model for $CO_2$ emission estimates for iron and steel production in the United Kingdom and came to the conclusion that the total $CO_2$ emission estimates were accurate. The ERT noted that the estimates are confirmed by EU ETS reports and peer reviews of the carbon balance model. However, the ERT concludes that the $CO_2$ emissions from pig iron production are not comparable | 2019 ARR I.25 | **Not Resolved.** The UK will consider whether it is possible to re-allocate emissions in the way suggested by the ERT without introducing new problems.  For example, it is possible that, because of UK-specific issues relating to activity data, it merely changes one allocation issue for another. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| | with those of other Parties because of their incorrect allocation between the energy and IPPU sectors. The ERT recommends that the United Kingdom 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). | | | |
| 2.C.5 Lead production – $CO_2$ | The ERT noted that according to the NIR, other non-ferrous metals, except for aluminium, have not been produced in the United Kingdom since 2003 (p.111), but according to NIR figure 2.17, there were three other non-ferrous plants in operation in 2017 in addition to aluminium plants. Further, the ERT noted that according to the United Kingdom Minerals Yearbook 2018 (British Geological Survey, 2019), lead is produced in the country. During the review, the United Kingdom explained that there were three sites producing lead in 2017: Britannia Refined Metals (refining of lead bullion, possibly also recovery of lead from batteries), HJ Enthoven (recovery of lead from batteries) and Envirowales (recovery of lead from batteries). These sites use fossil fuels to melt lead and also carry out simple refining operations such as the desilvering process that occurs at Britannia Refined Metals (using zinc metal). The Party has no evidence that the processes carried out at any of these works emit $CO_2$ emissions from any source other than fossil fuel combustion. The ERT agrees with the Party that non-process $CO_2$ emissions from lead production at these three sites are to be reported under the energy sector. The ERT concludes that the $CO_2$ emission estimates from secondary lead production are complete (as they are reported in the energy sector) but the description of category 2.C (metal industry) is not transparent regarding secondary lead production in the United Kingdom. The ERT recommends that the United Kingdom describe in the NIR the process or processes for secondary lead production in the country and report AD for lead production in CRF table 2(I).A-Hs2 based on, for example, data on lead production provided in the United Kingdom Minerals Yearbook 2018 (p.37) (British Geological Survey, 2019) and earlier editions. The ERT also recommends that the Party report $CO_2$ emissions from lead production either as "NA" in CRF table 2(I).A-Hs2, explaining in | 2019 ARR I.26 | **Resolved.** Lead production activity data has been added to the CRF for sector 2.C.5 and the documentation box has been populated to note that not all lead production results in process $CO_2$ emissions. Text has been added to Section 4.20 to detail lead production processes in the UK, noting that lead production past 2003 does not result in process emissions due to the specific methods of production in later years. | CRF tables, Section 4.20 |

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| | the NIR that the technologies applied for lead production do not result in process emissions and that energy-related emissions from lead production are reported under the energy sector, or as "IE" if the process emissions occur but are reported under another category, specifying the category. | | | |
| 2.D.1 Lubricant use – $CO_2$ | The ERT noted that $CO_2$ emissions from lubricants used in engines (except for lubricants used in mopeds, which is deemed to be intentional fuel use and hence reported under category 1.A.3.b.iv (motorcycles)) were estimated and reported under category 2.D.1 (NIR, p.257). However, the NIR does not contain any explanation as to which lubricants were accounted for and reported under this category. According to the 2006 IPCC Guidelines (vol. 3, chap. 5.2.2.2), $CO_2$ emissions from motor oils/industrial oils and greases are to be included under category 2.D.1. During the review, the United Kingdom provided the ERT with initial data from the energy balance used in the estimates and confirmed that both motor oils/industrial oils and greases were included in the estimates under category 2.D.1. The ERT concludes that the emission estimates are complete but the description of the lubricants included in the estimates is not transparent. The ERT recommends that the United Kingdom provide in the NIR a description of all types of lubricants included in the estimates of $CO_2$ emissions from lubricant use, including motor oils/industrial oils and greases. | 2019 ARR I.27 | **Resolved.** The UK has included a definition of what products are included under 'lubricants' in the NIR. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 2.E.4 Heat transfer fluid – PFCs | The ERT noted that in CRF table 2(I)s2, PFC emissions from categories 2.E.2 (thin-film transistor flat panel display), 2.E.3 (photovoltaics) and 2.E.4 (heat transfer fluid) were reported as "NO". The ERT also noted that in sections 4.26, 4.27 and 4.28 of the NIR it is stated that the absence of PFC emissions was confirmed by the market analysis prepared by Ricardo (2016). During the review, the United Kingdom provided the ERT with this report. The ERT noted that according to the report, perfluorohexanes are used in the country as heat transfer fluids and emitted in amounts of less than 2 kt $CO_2$ eq per year. The PFC emissions from categories 2.E.2 and 2.E.3 were confirmed as "NO" on the basis of consultation with manufacturers and suppliers (Ricardo, 2016). The ERT concludes that although the inventory is incomplete with respect to perfluorohexane emissions from category 2.E.4, the estimated emissions are below the threshold of significance included in the paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines for the United Kingdom (237 kt $CO_2$ eq in 2017) and therefore below the threshold for inclusion of this issue in the list of potential problems and further questions raised by the ERT in accordance with decision 22/CMP.1 in conjunction with decision 4/CMP.11, annex, paragraph 80(b). The ERT recommends that the United Kingdom report perfluorohexane emissions from category 2.E.4 in CRF table 2(II)B-Hs1, or report the emissions as "NE" instead of as "NO" and provide in the NIR information demonstrating that these emissions are below the threshold of significance in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. | 2019 ARR I.28 | **Resolved.** Some text has been included in the NIR to exaplin why emissions from this source are not estimated, and the CRF has been updated to present emissions as "NE" instead of "NO" | 4.28.2 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 2 .F.1 Refrigeration and air conditioning – HFCs | The ERT noted that HFC emissions from category 2.F.1 (refrigeration and air conditioning) significantly decreased between 2015 (13,369.52 kt $CO_2$ eq) and 2017 (11,636.57 kt $CO_2$ eq) – by 13.0 per cent. The ERT also noted that the United Kingdom contributed 39.11 per cent of European Union HFC emission reductions in the same period (European Union HFC emissions from category 2.F.1 decreased by 4,430.54 kt $CO_2$ eq to 93,047.74 kt $CO_2$ eq in 2017). However, the share of HFC emissions from the United Kingdom in the total HFC emissions from category 2.F.1 of the European Union is only 12.5 per cent. During the review, the ERT analysed in detail the HFC model used by the Party to estimate emissions from category 2.F.1. The ERT noted that the model is based on AD for HFC applications from 2010 and earlier years and assumptions based on the European Union F-gas regulation of 2014 (regulation 517/2014). The ERT also noted that assumptions for some HFC replacements and reductions are optimistic (e.g. according to the regulation, a prohibition on refrigerators and freezers for commercial use containing HFCs with GWPs of 2,500 or more will commence on 1 January 2020; however, according to the HFC model's assumption, limiting the consumption of HFCs by commercial refrigerators began several years ago). The ERT concludes that HFC emissions from category 2.F.1 may not be accurate because of the adopted assumptions and relatively old AD. The United Kingdom is aware of the limitations of the current model and informed the ERT about an ongoing study to update it, explaining the general approach for its development. The ERT commends the Party for developing a new HFC model, which will ensure the latest available AD and assumptions are used for estimating HFC emissions. The Party indicated that it would revise the HFC emission estimates for category 2.F.1 in the 2020 or 2021 annual submission. The ERT believes that future ERTs should continue to monitor the progress of reporting of the emission estimates for this category to ensure that emissions are not underestimated. The ERT recommends that the United Kingdom include in the NIR a justification that the assumptions made in the HFC model accurately reflect the actual HFC trends, and encourages the Party to include in that justification | 2019 ARR I.29 | **Addressing.** The UK is in the process of reviewing the RACHP model used for estimating emissions, and will be reviewing the latest data to generate our best estimate of emissions from this source, including how the phasing of trends is reflected. The UK has also included some further justification of the trends the ERT observed in the NIR. | 4.29.4 |

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| | an explanation of how the HFC emission estimates obtained from the model are consistent with the European Union's overall HFC emission trends for category 2.F.1. The ERT also recommends that the Party implement the provisions of paragraph 50(a) of the UNFCCC Annex I inventory reporting guidelines and include in the NIR information that will improve the transparency of the HFC model; in particular, the ERT encourages the United Kingdom to provide information on key assumptions, the estimation of model parameters, key inputs and outputs, model calibration and model evaluation. The ERT also encourages the Party to finalize the ongoing development of the new HFC model and revise the HFC emission estimates under category 2.F.1 using the most relevant data. | | | |
| 2.F.1 Refrigeration and air conditioning – HFCs | The ERT noted that the HFC model used for estimating HFC emissions from category 2.F.1 is based on the assumption that some HFCs with high GWPs are replaced by other HFCs and blends of gases with lower GWPs (e.g. HFC-32 is used to replace R134a, R407a, R410a and HFO; and HFO and HFC blends are used to replace R134a and R404a). The ERT also noted that HFO alone and HFO and HFC blends are used in the model for replacing some HFCs with higher GWPs; for example, HFO type 1 (GWP 5), HFO type 2 (GWP 600) and HFO type 3 (GWP 1,000). However, the ERT noted that emissions associated with HFO type 1, 2 and 3 applications were not reported under category 2.F.1. According to the HFC model, emissions from HFO type 1 were 22.99 kt $CO_2$ eq, from HFO type 2 were 51.17 kt $CO_2$ eq and from HFO type 3 were 1.10 kt $CO_2$ eq in 2017. The ERT encourages the United Kingdom to clarify if HFC emissions are occurring from the use of HFO types 1, 2 and 3 and report the HFC emissions under the relevant applications of category 2.F.1, if relevant. | 2019 ARR I.30 | **Addressing.** The UK is in the process of reviewing the RACHP model used for estimating emissions, including assumptions about the blends in use now that it is more clear which products UK industries are adopting to respond to changes in regulation. | N/A |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 2.F.4 Aerosols – HFCs | The ERT noted that the methodology the United Kingdom used for estimating HFC emissions from aerosols (NIR, p.276) is different from the methodology recommended by the 2006 IPCC Guidelines (vol. 3, section 7.3.2.1). In particular, in the Party's assessment, 1 per cent of HFC emissions from aerosols occur during product manufacture, 97 per cent during product lifetime and 2 per cent at the end of product life. However, according to the 2006 IPCC Guidelines, 50 per cent of the initial charge of aerosols is emitted in the first year and 50 per cent in the second year of aerosols use. The 2006 IPCC Guidelines also suggest that compilers should use alternative EFs only when empirical evidence for these factors is available (vol. 3, section 7.3.2.2). During the review, the United Kingdom could not provide a justification for the EFs applied for estimating HFC emissions from aerosols. The ERT concludes that the estimates are not accurate because the methodology applied by the Party does not take into account the delay in aerosols use. The ERT believes that future ERTs should consider this issue further to ensure that emissions from this category are not underestimated. The ERT recommends that the United Kingdom include in the NIR a justification for the choice of the current EFs for aerosols production and use (i.e. 1 per cent of HFC emissions from aerosols occur during product manufacture, 97 per cent during product lifetime and 2 per cent at the end product of life) or estimate HFC emissions from aerosols in accordance with the 2006 IPCC Guidelines. | 2019 ARR I.31 | **Not Resolved.** The UK will include this issue on the improvement programme and review the current approach for future submissions. | N/A |
| 3. General (agriculture) – $CO_2$, $CH_4$ and $N_2O$ | The United Kingdom did not include in the agriculture sector chapter of its NIR a description of trends in emissions, inter-annual variations in emissions and/or the main drivers of emissions, by category, in line with the appendix of the UNFCCC Annex I inventory reporting guidelines. The ERT notes that the Party including in the NIR more detailed information on emission trends by category could improve the transparency of the inventory submission. As an example of such information, during the review, the United Kingdom explained that the occurrence of foot andmouth disease caused a cull of cattle in 2001, decreasing the population and emissions for the year 2001 at the same time. The ERT encourages the United Kingdom to increase the transparency of the agriculture | 2019 ARR A.9 | **Adressing.** Figure 5.2 in the NIR shows the trend in emissions. Due to the major changes carried out in the inventory, most of the NIR chapter to describes the new methodologies. | |

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| | sector chapter of its NIR by including detailed descriptions of trends in emissions, inter-annual variations in emissions and all main drivers of the trends for each category. | | | |
| 3. General (agriculture) – $CO_2$, $CH_4$ and $N_2O$ | Owing to time constraints, the United Kingdom has not updated since the 2017 annual submission the uncertainty analysis to fully reflect the changes to uncertainty due to the adoption of new methods and data, for example, for estimating emissions from enteric fermentation (NIR, p.309). During the review, the Party indicated that it would review the uncertainty parameters for the next annual submission. The ERT recommends that the United Kingdom 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. | 2019 ARR A.10 | **Addressing,** An uncertainty analysis for the 2020 submission of the NIR will include the adoption of new methods and data, including those from enteric fermentation as recommended. | Annex 2 |
| 3. General (agriculture) – $CH_4$ and $N_2O$ | The United Kingdom applied an agriculture sector model with a fully revised structure for the 2019 submission to enable better representation of the key underlying driving variables of the GHG emissions from the sector, including soil, climate, livestock and cropping characteristics; farm management practices; and the uptake of specific climate change mitigation methods. The ERT reviewed the model during the review and commends the Party for improving its estimation methods in order to increase the accuracy of its inventory. However, the ERT notes that the transparency of the model description in the NIR could be improved. The ERT encourages the United Kingdom to include in its NIR, for example as part of annex 3, (1) detailed information on the agriculture sector model, including its basis, type, application, adaptation, main equations and processes, key assumptions, domain of application, parameters (how they were estimated), key inputs and outputs, calibration, evaluation, uncertainty and sensitivity analyses, QA/QC procedures and references to peer-reviewed literature, in line with footnote 11 to paragraph 50(a) of the UNFCCC Annex I inventory reporting guidelines; (2) a comparative analysis of emissions resulting from the agriculture sector model and those resulting from applying the tier 2 or 3 and tier 1 methodologies; and (3) a diagram showing the data and procedures flow for the agriculture sector model. | 2019 ARR A.11 | **Addressing.** The UK agriculture team are very grateful for the suggestions given by the ERT. We plan to produce a full report describing the models used and a shorter description of the model in the NIR; this is being updated over the next inventory compilation cycle. | |

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| 3 . General (agriculture) – $CH_4$ and $N_2O$ | The Party applied United Kingdom (England, Wales, Scotland and Northern Ireland) IEFs to estimate $CH_4$ and $N_2O$ emissions from enteric fermentation, manure management and agricultural soils in the Crown dependencies. During the review, the ERT checked the calculations made by the Party for estimating the emissions from these categories and found that the United Kingdom IEFs used in the spreadsheet for calculating emissions in 2016 and 2017 were from 2015. The Party explained to the ERT that it applied 2015 United Kingdom IEFs owing to the limited time available for preparing the estimates between receiving data from the Crown dependencies and submitting the inventory to the European Union and subsequently the secretariat. The ERT notes that, considering the relatively small amount of emissions from the Crown dependencies, an error introduced in the emissions from the use of constant IEFs for 2016 and 2017 would be below the threshold of significance in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines and therefore below the threshold of significance for inclusion of this issue in the list of potential problems and further questions raised in accordance with decision 22/CMP.1 in conjunction with decision 4/CMP.11, annex, paragraph 80(b). The ERT recommends that the United Kingdom 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 in sufficient time to apply them to the emission estimates for the Crown dependencies. The ERT encourages the Party to assess, and if appropriate improve, the inventory planning processes between mainland United Kingdom and the Crown dependencies to ensure that the Crown dependencies emission estimates contain the latest available data from the mainland United Kingdom. | 2019 ARR A.12 | **Addressing.** For the most recent submission the latest IEFs from the UK were applied to the crown dependencies, but the UK is discussing changes to the institutional structure which might make this process more robust in future. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 3.B Manure management – $CH_4$ and $N_2O$ | The United Kingdom reported the amount of N in composting and digesters MMS as "NE" in CRF tables 3.B(b) and 3.B(a)s2 for all livestock types. During the review, the Party explained to the ERT that information on the amount of N distributed in composting and digesters MMS is not available owing to the lack of robust information on animal distribution in these MMS. Further, the Party explained that composting and use of digesters are not common practices in the country, and, in any case, the amount of N that could be included in composting and digesters MMS is currently included in solid storage MMS, therefore, emissions are reported accordingly. The United Kingdom indicated that data for manure managed by anaerobic digesters had been collected and would be included in a future submission. The ERT noted that if the Party updates its MMS animal distribution (including in composting and digesters MMS) this will also impact reported $CH_4$ emissions through the updated methane conversion factor for these MMS. The ERT recommends that the United Kingdom estimate the animal distribution in composting and digesters MMS to estimate $CH_4$ and $N_2O$ emissions from manure management, using expert judgment to estimate the animal distribution in both MMS until which time the country-specific data are available for inclusion in the submission. | 2019 ARR A.13 | **Addressing.** Emissions of $CH_4$ and $N_2O$ emissions from the anaerobic digestion of livestock manures and from the application of digestates (from anaerobic digestion of manures, crop-based AD and food waste-based AD) are currently being incorporated in the UK model and will be fully reported in the 2021 submission. Activity data on composting and the application of composts to land are being reviewed. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
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| 3.B.4 Other livestock – $N_2O$ | The United Kingdom reported the amount of N from poultry manure burned for fuel or as waste in MMS as "NE" in CRF table 3.B(b). The ERT noted that the NIR does not include an explanation of this poultry manure management practice. During the review, the Party explained that poultry manure is burned after its treatment in solid storage MMS. The amount of N in burned poultry manure is discounted from the total amount of N applied to soils and is reported under the energy sector (when the manure is burned for energy purposes) or under the waste sector (when the manure is burned without energy recovery). The ERT agrees with the calculations applied by the Party. The ERT recommends that the United Kingdom report the notation key "NO" instead of "NE" in CRF table 3.B(b) for the amount of N from burned poultry manure to reflect the fact that poultry manure is burned after treatment and the combustion-related $CH_4$ and $N_2O$ emissions are reported under the energy sector (when the manure is burned for energy purposes) or under the waste sector (when the manure is burned without energy recovery). The ERT also recommends that the United Kingdom include in the NIR an explanation of the poultry manure management practice and the final destination of the manure. | 2019 ARR A.14 | **Resolved.** The NIR explains that the method used to calculate emissions corrects for the N content of manures used as fuel (poultry litter incineration) and therefore not applied to land; the UK will correct the notation keys used in the CRF | |
| 3.J Other ($CO_2$ emissions from liming, urea application and other carbon-containing fertilizers) – $CO_2$, $CH_4$ and $N_2O$ | The United Kingdom reported all $CO_2$, $CH_4$ and $N_2O$ emissions estimated from enteric fermentation, manure management, agricultural soils, liming and urea application for overseas territories and Crown dependencies under the UNFCCC Annex I inventory reporting guidelines, in which emissions from enteric fermentation are to be reported under category 3.A (enteric fermentation), emissions from manure management under category 3.B (manure management), emissions from agricultural soils under category 3.D (direct and indirect $N_2O$ emissions fromagricultural soils), emissions from liming under category 3.G (liming) and emissions from urea application under category 3.H (urea application). The ERT recommends that the United Kingdom 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)). | 2019 ARR A.15 | **Not resolved.** The UK will include on the improvement programme an item to discuss changes to the institutional structure which might make it more feasible to fully integrate overseas territory and crown dependency emissions and other data into the CRF for future reporting. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 4. General (LULUCF) | The United Kingdom used a tier 3 approach based on the CARBINE model to estimate changes in carbon stock in forest land. During the review, the ERT made reference to the report on the IPCC expert meeting on the use of models and measurements in GHG inventories (IPCC, 2011), which presents a list of typical items that, when reported, may lead to improved transparency in emission/removal estimates that are based on models. The following items are mentioned in the report regarding a model: basis, type, application, adaptation, main equations and processes, key assumptions, domain of application, parameters (how they were estimated), key inputs and outputs, calibration, evaluation, uncertainty and sensitivity analyses, QA/QC procedures and references to peer-reviewed literature. Many of these items are also referenced in footnote 11 to the UNFCCC Annex I inventory reporting guidelines. During the review, the United Kingdom provided the ERT with a file containing comprehensive information on each item, including references and the relevant peer-reviewed literature. The ERT commends the Party for providing information during the review that improves the transparency of the CARBINE model. The ERT encourages the United Kingdom to include in the NIR information on its work done in addressing the items included in footnote 11 to the UNFCCC Annex I inventory reporting guidelines and as elaborated in chapter 3 of the report on the IPCC expert meeting on the use of models and measurements in GHG inventories (IPCC, 2011). | 2019 ARR L.32 | **Resolved.** Summary paragraph and table (Table A 3.4.1) added to NIR | Annex 3.4.1 |
| 4. General (LULUCF) | The United Kingdom provided in NIR table A.3.6.5 the estimates of direct GHG emissions from LULUCF for the Cayman Islands, the Falklands Islands and Bermuda. During the review, in response to a question from the ERT regarding the estimates provided in the table, the Party clarified that the values are for the Falklands Islands only and are not aggregated estimates for the three overseas territories. The ERT recommends that the United Kingdom clarify either in the heading of NIR table A.3.6.5 or in a footnote to that table the specific overseas territories and/or Crown dependencies included in the emission estimates for specific categories of the LULUCF sector (if different from the heading). | 2019 ARR L.33 | **Resolved.** The LULUCF row in Table A 3.6.5 now includes emissions from the Cayman Islands, Falklands Islands, and Bermuda (compared to previous years where it was Falkland islands only). This means that the LULUCF data now reflects the title of the table. | Annex 3.6 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 4. General (LULUCF) | The ERT identified some inconsistencies between the NIR and the CRF tables; for instance, the area of grassland for 2015, which in NIR table 6.2 is 13,321 kha and in CRF table 4.1 is 14,580.25 kha. For 2015, the final area for grassland in CRF table 4.C is 14,387.38 kha. The ERT noted that a smaller number of inconsistencies between the NIR and the CRF tables were present than in the previous submission, but considers that further efforts to enhance QA/QC are needed. During the review, the Party acknowledged the inconsistencies. The ERT recommends that the United Kingdom correct the inconsistencies for grassland area between the NIR and CRF tables 4.1 and 4.C for the entire times series. | 2019 ARR L.34 | **Resolved.** Inconsistencies between the NIR and CRF tables have been addressed. There is nothing specific to report in the NIR. | N/A |
| 4. General (LULUCF) | In the NIR (p.115), the United Kingdom reported that the LULUCF sector covers emissions and removals of direct and indirect GHGs from eight land-use categories: 4.A (forest land), 4.B (cropland), 4.C (grassland), 4.D (wetlands), 4.E (settlements), 4.F (other land), 4.G (HWP) and 4.H other (LULUCF). The ERT noted that HWP is not a land-use category but is considered as a pool in the 2006 IPCC Guidelines (e.g. vol. 4, p.12.9). Other is also not considered a land-use category. During the review, the Party agreed with the ERT's assessment. The ERT recommends that the United Kingdom refer to HWP as a pool rather than a land-use category in the annual submission and consider as land-use categories only those six land uses included in the 2006 IPCC Guidelines (vol. 4, pp.3.6–3.7), that is, categories 4.A (forest land), 4.B (cropland), 4.C (grassland), 4.D (wetlands), 4.E (settlements) and 4.F (other land). | 2019 ARR L.35 | **Resolved.** The text has been revised and no longer describes HWP as a land-use category. The new sentence is:  The LULUCF sector covers emissions and removals of direct greenhouse gases under eight categories, of which Forest Land (4A), Grassland (4C) and Harvested Wood Products (4G) are net sinks, and Cropland (4B), Wetlands (4D), and Settlements (4E) are net sources (Figure 6.1) as well as indirect N2O emissions. The UK does not report any emissions or removals from the Other Land (4F) and Other (4H) categories. | Chapter 6 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 4.B.1 Cropland remaining cropland – $CO_2$ | The United Kingdom reported changes in carbon stock in cropland using a tier 3 dynamic soil carbon model (NIR, p.345). According to the 2006 IPCC Guidelines (vol. 4, equation 2.24), the estimation of changes in carbon stocks in soils using a tier 3 approach includes the annual change in inorganic carbon stock, which is assumed to be zero when applying tier 1 and tier 2 methods. The ERT did not find in the NIR any information indicating the inclusion of changes in inorganic carbon stocks when estimating changes in carbon stocks in soils. During the review, the Party explained that it does not currently consider changes in inorganic carbon stocks, and has no plans to do so in the short term, as other inventory improvements have taken priority. However, the United Kingdom provided the ERT with the results of some country-specific research on inorganic carbon stocks in the surface horizon of English soils. According to Rawlins et al. (2011), inorganic carbon may represent approximately 15.5 per cent of the carbon stored in the top 30 cm of the soil in England but the primary carbonate content is likely to change relatively slowly with time, hence no substantial difference is likely to occur in relation to the total stock of inorganic carbon. The ERT concludes that further research on this issue could enhance knowledge regarding the changes in inorganic carbon stocks in soils, and inclusion of these estimates is consistent with the application of a tier 3 dynamic soil carbon model. The ERT recommends that the United Kingdom develop a plan for estimating the annual change in inorganic carbon stock in soils, even if this is not a priority at present, and until the estimates can be included in the submission, include in the NIR information on the possible contribution of inorganic carbon stocks to changes in carbon stocks in soils based on the available literature. | 2019 ARR L.36 | **Resolved.** A note has been added to the NIR (Section 6.3.8) which outlines the process currently in train to determine how to incorporate this as an Inventory Improvement item. | Section 6.3.8 |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 4(II) Emissions and removals from drainage and rewetting and other management of organic/mineral soils – $CO_2$ and $CH_4$ | The United Kingdom reported in the NIR that all cropland on organic soils is assumed to be drained, and occurs mainly in England (p.346). The ERT noted that the areas of and $CO_2$ emissions from the drainage of organic soils in cropland, for the United Kingdom, overseas territories and Crown dependencies, are reported as "IE" in CRF table 4(II). $CH_4$ emissions from the drainage of organic soils in cropland are reported as "NE" in CRF table 4(II) for the United Kingdom, overseas territories and Crown dependencies owing to insufficient information, as reported in CRF table 9. During the review, in response to a question from the ERT regarding clarification of the use of "IE" in CRF table 4(II) for the area of cropland organic soils drained (mainland United Kingdom only), the Party explained that the comment that should have been appended to the table was likely lost during the upload of the data to CRF Reporter and should have read "Reported in table 4B". The ERT appreciates the clarification provided by the United Kingdom and understands that the notation keys used in the 2019 annual submission will be replaced with actual estimates after the research from Evans et al. (2017) is implemented in the LULUCF sector. The ERT recommends that, until the notation keys can be replaced with actual estimates, the United Kingdom review the final submission to ensure that the use of the notation key "IE" in CRF table 4(II) for the area of organic soils drained in cropland in mainland United Kingdom is explained in CRF table 9. | 2019 ARR L.37 | Addressed in CRF submission - no change to NIR | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 5.A Solid waste disposal on land – CH$_4$ | The United Kingdom reported the use of a tier 2 methodology (the MELMod model), which is based on national waste quantities, composition, properties and disposal practices (NIR, p.379), for estimating the emissions from landfills. As described in the waste sector methodology section (NIR, pp.380–381), CH$_4$ generation from solid waste disposal is calculated using a methodology adapted from equations 3.1–3.6 of the 2006 IPCC Guidelines (vol. 5). In the model, the Party uses country-specific parameters for DOC, DOCf and the composition of waste material, as reported in NIR table A.3.5.2. The other input parameters to the model, including MCF, oxidation factor and the fraction of CH$_4$ in generated landfill gas, are adapted from IPCC default values. The IPCC default FOD rate constant (k) for wet boreal and temperate climate conditions is also applied (see ID# W.2 in table 3). During the review, the United Kingdom demonstrated the MELMod model spreadsheet and input parameters used in the model and explained that the equations in the model are exactly the same as those of the IPCC FOD methodology. The MELMod spreadsheet allows the Party to apply country-specific DOC and DOCf parameters based on chemical properties (i.e. lignin, cellulose, hemicellulose, fat, sugar and protein content) specific to the composition of the waste material of the United Kingdom while applying IPCC default values for the remaining parameters. The ERT encourages the United Kingdom to report in the NIR that it applies the IPCC FOD methodology for estimating CH$_4$ emissions from solid waste disposal to avoid confusion regarding the difference between the MELMod model and the IPCC FOD methodology. | 2019 ARR W.16 | **Resolved.** The UK has indicated in the NIR that FOD methodology is applied to estimate methane generation from solid waste disposal. Section 7.2.2 indicates whether IPCC default values and country-specific parameters have been applied. Additional information on DOC and DOCf parameters based on chemical properties (i.e. lignin, cellulose, hemicellulose, fat, sugar and protein content) specific to the composition of the waste material of the United Kingdom have been provided in Table 7.1., 7.2 and 7.3. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 5.A Solid waste disposal on land – CH$_4$ | The United Kingdom performed QA/QC and verification of CH$_4$ emission estimates following the 2006 IPCC Guidelines (vol. 5, section 3.8) by comparing emissions calculated from the MELMod model with emission estimates for Ireland and Italy. Moreover, the MELMod model was peer reviewed in 2011 and 2014. The comparison determined that the amount of CH$_4$ generated in all three countries was in the range 24–50 kt CH$_4$/Mt waste landfilled (the value for the United Kingdom was in the range 28–44 kt CH$_4$/Mt waste landfilled) with no obvious inconsistency in the estimated CH$_4$ collection efficiencies (62 per cent for the United Kingdom, 63 per cent for Ireland and 81 per cent for Italy in 2015). During the review, the Party explained that the comparison was performed to compare the CH$_4$ collection efficiencies among the countries but not for the purpose of verifying the MELMod model. The Party also explained that verification of the MELMod model was carried out by comparing the estimation of emissions from the United Kingdom's tier 2 model and from the IPCC tier 1 model set up to reflect United Kingdom waste characteristics and IPCC tier 1 default inputs. The results obtained using the two models were similar. The comparison of results was demonstrated in graphic form to the ERT during the review, but the magnitude of the difference between the estimates obtained using the two models was not provided. The ERT commends the Party for conducting a peer review of the tier 2 country-specific MELMod model. The ERT encourages the United Kingdom to include in the NIR (section 7.2.5) information on any differences resulting from a comparison between the estimation of emissions using the United Kingdom tier 2 model and the IPCC tier 1 model. | 2019 ARR W.17 | **Resolved.** The UK has included a in section 7.5.2.a a comparison between the estimation of emissions using the United Kingdom Tier 2 model and the IPCC Tier 1 model. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 5.A Solid waste disposal on land – CH$_4$ | The United Kingdom reported the composition of waste sorting residues and mixed municipal waste in NIR table A.3.5.1; the data are based on a survey carried out on behalf of Defra (Resource Futures, 2012). The composition of the waste used in the estimation of emissions was assumed to be constant over the entire time series. During the review, the Party explained that the composition of mixed waste from the study in 2012 was the only available information for estimating emissions from this category. The Party recognizes that the composition of mixed waste could change over time and that assuming the composition to be constant may lead to inaccurate emission estimates. The ERT recommends that the United Kingdom 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. | 2019 ARR W.18 | **Resolved.** The UK has explained in the NIR that, in absence of new data sources for the composition of mixed waste, the waste composition data used are representative of current national circumstances. | |
| 5.A Solid waste disposal on land – CH$_4$ | In NIR table A.3.5.5, the United Kingdom described the parameters used for estimating landfill emissions for the overseas territories and Crown dependencies. The information includes the AD, MCF and DOC used in the estimation but there is no information about the first-order decay rate constant (k) applied. During the review, the Party provided information on the k value applied, referring to default values specified in the 2006 IPCC Guidelines for different climate zones (vol. 5, table 3.3), as follows: Falkland Islands (Malvinas) (wet temperate), Cayman Islands and Bermuda (moist and wet tropical), and Isle of Man and Guernsey (wet temperate). The ERT recommends that the United Kingdom provide in NIR table A.3.5.5 the FOD rate constant (k) values used for estimating landfill emissions for the overseas territories and Crown dependencies. | 2019 ARR W.19 | **Resolved.** The UK has included in Table 3.5.5 an added in an additional column with information on the parameters used for calculating the first order rate constant (k), identifying what Region and Methane generation rate constant (k) was used in the IPCC landfill model. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 5.A Solid waste disposal on land – $CH_4$ | In the NIR (p.383), the United Kingdom described the estimation of $CH_4$ recovered from landfills, which was reported in NIR table A.3.5.4. The recovered $CH_4$ was estimated from the renewable energy generated from the combustion of landfill gas, as reported in DUKES. In 2017, this renewable energy was 4,284 GWh, whereas 857 kt $CH_4$ was estimated to be consumed for electricity generation. The Party's assumptions regarding the relationship between $CH_4$ consumption and electricity generation were not described in the NIR. During the review, the Party explained this relationship, including its assumptions for landfill gas recovery percentages and of efficiencies of landfill gas engines used in the calculation for the time series (1990–2017). The ERT recommends that the United Kingdom provide in the NIR a clear explanation of and justification for the assumption used for conversion between the $CH_4$ used for power generation reported in the waste sector and electricity produced from landfill gas reported in the energy sector. | 2019 ARR W.20 | **Resolved.** The UK has included the requested additional information is provided in Section 7.2.3.2. | Section 7.2.3.2 |
| 5.B.1 Composting – $CH_4$ and $N_2O$ | In CRF table 5.B, the United Kingdom reported AD for the amount of municipal solid waste treated by composting in kt dry mass (kt dry matter). The Party used default EFs from the 2006 IPCC Guidelines (vol. 5, table 4.1) for this biological treatment process: 10 g/kg dry weight for $CH_4$ and 0.6 g/kg dry weight for $N_2O$ for composting were used for estimating the emissions. However, it is unclear why the AD reported in NIR table A.3.5.6 are in a wet weight unit. During the review, the Party explained that while the AD for municipal solid waste treated by composting are reported in the NIR on a wet weight basis, these values are required to be reported on a dry weight basis in the CRF tables. The United Kingdom applied a factor of 0.4, which is the IPCC default, for converting wet mass to dry mass. The ERT recommends that the United Kingdom report in NIR table A.3.5.6 the AD for the annual amount of waste treated in the composting process in the same units as those in CRF table 5.B, and explain in the NIR the assumption used in converting the AD between weight and dry weight. | 2019 ARR W.21 | **Resolved.** The UK has explained that AD for the amount of municipal solid waste treated by composting are reported in the NIR on a wet weight basis, while these values are required to be reported on a dry weight basis in the CRF tables. The assumption used in converting the AD between weight and dry weight have been included in in NIR Table A.3.5.6. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 5.D.1 Domestic wastewater – $CH_4$ | The ERT noted that the United Kingdom used the total amount of sludge disposed (in kt dry sludge/year) at sewage treatment plants for estimating $CH_4$ emissions from sludge treatment. For the population served by private wastewater treatment systems, population and per capita BOD load were used for estimating total BOD load (in kt BOD/year). Both AD were combined and reported as total organic product (kt DC) in CRF table 5.D, and sludge mass unit (total dissolved solids) was assumed to be comparable with BOD. The ERT considers the reporting of AD for private wastewater treatment systems as kt DC comparable with BOD is not consistent with the 2006 IPCC Guidelines. In response to a question from the ERT, the United Kingdom explained that the $CH_4$ emissions were estimated by multiplying the total organic product by the $CH_4$ IEF (0.0196 kg $CH_4$/kg DC in 2017) derived from the $CH_4$ IEF for sludge treatment (0.0109 kg $CH_4$/kg DC in 2017) and default $CH_4$ IEF for septic tanks (0.3 kg $CH_4$/kg BOD) (2006 IPCC Guidelines, vol. 5, chap. 6, tables 6.2 and 6.3). The ERT considers that estimating emissions by using sludge treatment and septic tank AD combined is not transparent as the mass of sludge (kg dissolved solids) and BOD (kg BOD) have different units, even though using the approach of combining them leads to the same emission estimate as if the two sources had been separately estimated. The ERT recommends that the United Kingdom calculate the emissions from sludge treatment at sewage treatment plants and private wastewater management systems using the EFs for sludge treatment and septic tanks, respectively, and report the emissions transparently in the NIR. The ERT encourages the Party to include in the documentation box of CRF table 5.D a reference to the description of the derivation of the IEF in the NIR. | 2019 ARR W.22 | **Not Resolved.** The UK will include this issue on the improvement programme and review the current approach for future submissions. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| 5.D.2 Industrial wastewater – $CH_4$ | The United Kingdom reported AD for industrial wastewater for the food and drink industries in NIR table A.3.5.13 in the unit "million population equivalents (PE)". In the NIR (p.405), the Party explained that the total organic load for the food and drink industry subcategories were obtained from a Defra study (2002) and scaled across the time series using data from the Index of Production data of the Office for National Statistics. The NIR does not, however, clearly explain how the emissions from the food and drink industries are estimated. During the review, the United Kingdom provided information on the conversion of population equivalent to BOD using BOD load per population (1 population equivalent = 0.054 kg/day); BOD is converted to COD using the IPCC default factor from 2006 IPCC Guidelines (vol. 5, p.6.12) (1 kg BOD = 2.4 kg COD) and the IPCC default $CH_4$ EF of COD from the 2006 IPCC Guidelines (vol. 5, table 6.2) (0.25 kg $CH_4$/kg COD). The ERT considers that the use of AD for industrial wastewater in this approach is not in line with the 2006 IPCC Guidelines, in which total organic degradable carbon is calculated from total industrial product (t), wastewater generated ($m^3$/t product) and COD ($kg/m^3$), as described in equation 6.6 of the 2006 IPCC Guidelines (vol. 5). The ERT notes that this results in a possible overestimation of emissions, as the United Kingdom adds the emissions from some industrial sources to the combined emissions from domestic and industrial wastewater (NIR, p.405). The ERT recommends that the United Kingdom improve the transparency of the industrial wastewater AD by presenting the assumptions used to convert these data to units suitable for applying IPCC default EFs and how these AD estimates differ from estimates derived from the methodology described in the 2006 IPCC Guidelines. | 2019 ARR W.23 | **Not Resolved.** The UK will include this issue on the improvement programme and review the current approach for future submissions. | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| General (KPLULUCF activities) | The ERT found it difficult to assess whether the United Kingdom had fulfilled the requirements under decision 2/CMP.8, annex II, as information relevant to the requirements was reported scattered throughout the NIR. For instance, the ERT could not find information for paragraph 5(c) on provisions related to the inclusion of carbon emissions and removals from forest areas afforested prior to 1921. The ERT notes that it would facilitate the complete assessment of the Party's reporting by future ERTs if the United Kingdom were to provide a table listing the requirements in decision 2/CMP.8 and a cross reference to where in the NIR the corresponding information is reported, including for paragraph 5(c). The ERT encourages the United Kingdom to include in the NIR a table listing all the requirements in decision 2/CMP.8, annex II, with a cross reference to the section in the NIR where the corresponding information is reported. | 2019 ARR KL.22 | **Resolved.** A new table (Table 11.1) has been added to Chapter 11 (Section 11.1) | Table 11.1 |
| Article 3.4 activities – $CO_2$, $CH_4$ and $N_2O$ | During the review, the ERT raised concerns regarding the fact that CM and GM lands and lands on which WDR occurs are not yet identifiable. In response to a question from the ERT on this issue, the United Kingdom explained that various options and data sources for identifying these lands are being explored, including moving from reporting method 1 in the Kyoto Protocol Supplement to the spatially explicit reporting method 2 in order to track land-use changes. However, the Party recognizes that there are challenges to implementing this approach before the end of the second commitment period, and is thus exploring other approaches, including a data assimilation approach that establishes land-use vectors by integrating the data available from various sources on land-use and land-use change in the United Kingdom, starting with a data set available for Scotland (Levy et al., 2017). The ERT acknowledges the efforts made by the Party in identifying CM, GM and WDR lands. The ERT recommends that the United Kingdom explore how to make the best possible use of available data to meet the reporting requirements under the Kyoto Protocol for elected Article 3, paragraph 4, activities, a process that may benefit from expert meetings with potential data providers, and then prepare and implement a workplan to enable the use of these data. | 2019 ARR KL.23 | **Not Resolved.** Ongoing inventory improvement - nothing to report in the 2020 submission as there is no Planned Inventory Improvement Section for the KP Chapter of the NIR | |

| CRF category / issue | Review recommendation | Review report / paragraph | MS response / status of implementation | Chapter / section in the NIR |
|---|---|---|---|---|
| Article 3.4 activities – $CO_2$, $CH_4$ **and N$_2$O** | In the NIR (p.472), the United Kingdom reported that the area of GM reported under the Kyoto Protocol is broadly consistent with that reported as grassland under the Convention, and reported a difference of 2 per cent in the total area in 2017. According to the Party, the difference is due to the slightly different definitions used, with 'grassland' under the Convention defined as the area remaining after all other land areas have been identified, and 'GM' defined as the area of grassland in the Countryside Survey, which started in 1990. The ERT found a larger difference of approximately 3.8 per cent in 2017 (14,468.90 kha reported under the Convention in CRF table 4.C for grassland versus 15,014.60 kha reported under the Kyoto Protocol in CRF table 4(KP-I)B.3 for GM). During the review, the United Kingdom agreed with the assessment of the ERT and, in response to a question from the ERT on this matter, provided an explanation for the difference. The ERT recommends that the United Kingdom update the text in the NIR to explain (1) that the difference between the areas of GM under the Kyoto Protocol and grassland under the Convention arises from the different definitions used for grassland and GM and (2) the adjustment made to account for the area that has been converted from grassland but remains subject to GM. | 2019 ARR KL.24 | **Resolved.** NIR text has been amended. | 11.1.3.5 |

# 11  KP-LULUCF

## 11.1  GENERAL INFORMATION

| Emissions sources | Forest Management<br><br>Afforestation and Reforestation<br><br>Deforestation<br><br>Cropland Management<br><br>Grazing Land Management |
|---|---|
| Gases Reported | $CO_2$, $CH_4$, $N_2O$ |
| Methods | As for LULUCF Sector 4 |
| Emission Factors | As for LULUCF Sector 4 |
| Key Categories (Quantitative) | Afforestation and Reforestation – $CO_2$<br><br>Deforestation – $CO_2$<br><br>Forest Management – $CO_2$<br><br>Cropland Management – $CO_2$<br><br>Grazing Land Management – $CO_2$ |
| Key Categories (Qualitative) | Not undertaken |
| Overseas Territories and Crown Dependencies Reporting | OTs and CDs are included at Tier 1 level |
| Major improvements since last submission | Reconciliation of harvest volume and forest age data (see section 6.2.7). Improvement to the soil model describing soil acidity. Correct the half-life used for palletwood to be that for sawnwood (35 years), not 25 years.<br><br>Updates to deforestation activity data.<br><br>A change in the soil carbon density used for calculating the effect of cropland management on mineral soils. |

A table showing the location of all information required by decision 2/CMP.8 annex II is given in Table 11.1 .

**Table 11.1      Location of information required under decision 2/CMP.8 annex II**

| Requirement paragraph | | Location in GHG inventory submission |
|---|---|---|
| 2 (a) | Information on how inventory methodologies have been applied | NIR section 11.3.1, Annex 3.4 |
| 2 (b) | The geographical location of the boundaries of the areas that encompass:<br><br>(ii) Units of land subject to activities under Art. 3.3;<br>(iii) Units of land subject to activities under Art. 3.3, which would otherwise be included in land subject to FM or elected activities under Art.3.4;<br>(iii) Land subject to FM under Art.3.4 to any elected activities under Art.3.4; | NIR section 11.2.1-3 |
| 2 (c) | The spatial assessment unit used for determining the area of accounting for ARD | NIR section 11.2.1 |
| 2 (d) | Information on anthropogenic GHG emissions from Art.3.3 and   Art.3.4 activities for all geographical locations reported in the current and previous years, since the beginning of the commitment period or the onset of the activity, whichever comes later. | CRF tables suffixed KP(I) and KP(II)<br><br>NIR section 11.3.1.7 |
| 2 (e) | Information on which pools were not accounted for, together with verifiable information that demonstrates that these unaccounted pools were not a net source of anthropogenic GHG emissions | NIR section 11.3.1.2 |
| 2 (f) | Natural disturbance provision | NIR section 11.3.1.1, 11.3.1.6, 11.4.4, |
| 2 (g) | Harvested wood products | NIR section 11.4.5, 11.5.2.5, Annex 3.4.10 |
| 3 | Factoring out of:<br><br>(a) Elevated carbon dioxide concentrations above pre-industrial levels;<br><br>(b) Indirect nitrogen deposition;<br><br>(c) The dynamic effects of age structure resulting from activities prior to 1 January 1990. | NIR section 11.3.1.3 |

| Requirement paragraph | | Location in GHG inventory submission |
|---|---|---|
| 4 (a) | Information that demonstrates that activities under Article 3, paragraph 3, began on or after 1 January 1990 and before 31 December of the last year of the commitment period, and are directly human-induced | NIR section 11.4.1 |
| 4 (b) | Information on how harvesting or forest disturbance that is followed by the re-establishment of a forest is distinguished from deforestation | NIR section 11.4.2-3 |
| 5 (a) | A demonstration that Art 3.4 have occurred since 1 January 1990 and are human induced; | NIR section 11.5.1 |
| 5 (b) | For Parties that elect cropland management and/or grazing land management and/or revegetation and/or wetland drainage and rewetting, anthropogenic GHG emissions by sources and removals by sinks for each year of the commitment period and for the base year for each of the elected activities on the geographical locations reported under paragraph 2(b) above; | CRF Tables KP(I)B.2 and KP(I)B.3 and tables suffixed KP(II) |
| 5 (c) | (c) Information that demonstrates that emissions by sources and removals by sinks resulting from forest management under Art.3.4, and any elected activities under Art3.4, are not accounted for under activities under Art.3.3 | NIR section 11.1.3, 11.1.4, 11.2 and 11.3.1.1 |
| 5 (d) | (d) Information on how all emissions arising from the conversion of natural forests to planted forests are accounted for; | NIR section 11.5.2.1 |
| 5 (e) | (e) Information that demonstrates methodological consistency between the reference level and reporting for forest management during the second commitment period, including the area accounted for, the treatment of harvested wood products, and the accounting of any emissions from natural disturbances; | NIR section 11.5.2.2 |
| 5 (f) | (f) Any technical corrections made pursuant to decision 2/CMP.7, annex, paragraph 14, to ensure consistency between the reference level and reporting for forest management during the second commitment period; | NIR section 11.5.2.3 |
| (g) | (g) Treatment of harvest and conversion of forest plantations to non-forest land, | NIR section 11.3.1.2 |

## 11.1.1 Definition of Forest

The UK uses the following definition of forest which has been agreed with the Forestry Commission:

- Minimum area of 0.1 hectares;
- Minimum width of 20 metres;
- Tree crown cover of at least 20 per cent, or the potential to achieve it;
- Minimum height of 2 metres, or the potential to achieve it.

This definition includes felled areas awaiting restocking and integral open spaces

(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 woodlands" report providing the additional area of woodlands between 0.1-0.5 ha[80]. The definitions are consistent with information provided by the UK to the Food and Agriculture Organization of the United Nations (FAO). If an international enquiry 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).

The UK does not distinguish between natural and planted forest areas, with the exception of relatively small areas of semi-natural and ancient woodland, which are usually actively managed to conserve their characteristics. All forest areas in the UK can be regarded as managed from the point of view of regulation against deforestation and protection against fire, storms and disease. In general, forest areas are actively managed for landscape, soil protection, habitat conservation, amenity and recreation, which may or may not include active management for wood production.

## 11.1.2 Elected activities under Article 3, paragraph 4 of the Kyoto Protocol

The UK elected Forest Management (FM) as an activity under Article 3.4 in the first commitment period (2008-2012). For the second commitment period (2013-2020), in addition to FM (reporting of which became mandatory in the second commitment period), the UK has elected Cropland Management (CM), Grazing Land Management (GM) and Wetland Drainage and Rewetting (WDR), as identified in the UK's Initial Report (DECC 2016).

The UK's original Forest Management Reference Level (FMRL) during the second commitment period, as identified in the appendix to the annex to Decision 2/CMP.7, was -3.442 Mt $CO_2$ eq./yr, or -8.268 Mt $CO_2$ eq./yr when applying first order decay function for harvested wood products. The UK has calculated a technical correction to the FMRL which is –12.231 Mt $CO_2$ eq./yr, or -9. 725 Mt $CO_2$ eq./yr when applying first order decay function for harvested wood products. This leads to a corrected FMRL of -15.673 Mt $CO_2$ eq./yr or 17.993 Mt $CO_2$ eq./yr when applying first order decay function for harvested wood products.

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[80] HYPERLINK "https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2018/uk-forests-and-climate-change/forest-carbon-stock/"

## 11.1.3 Description of how the definitions of each activity under Article 3.3 and each mandatory and elected activity under Article 3.4 have been implemented and applied consistently over time

### 11.1.3.1 Afforestation and Reforestation

Afforestation and reforestation are considered together and are consistent with the definition of forest given above. The Afforestation/Reforestation area is land that has been converted to forest land from other land uses since 1990. This area is estimated from the area of forest in the NFI age class that indicates the woodland was replanted[81] or afforested post-1990. New forest area can result from planting, seeding or natural colonisation. The replanted area is estimated based on the wood production information and assigned to FM, and the remainder is assigned as Afforestation. Areas of forest planting are reported by calendar year for both 4A Forest Land and AR and FM. The area of forest established since 1990 for the latest inventory year is the same in both the UNFCCC GHGI and Article 3.3 Afforestation. It is assumed that none of the AR area has been subsequently deforested.

The area and carbon stock changes of KP AR and the area of 4A2 Land converted to Forest were identical at the end of 2009, at 460.59 kha and 409 Gg $CO_2$, as the area of 4A2 in 2009 will include all forest planting since 1990.

### 11.1.3.2 Deforestation

Deforestation since 1990 is the land area permanently converted from forest land to non-forest land uses. Areas of annual forest conversion are reported in the UNFCCC GHGI, and the cumulative total for the latest inventory matches the area reported under Article 3.3 Deforestation.

Forest Research has collated data from multiple sources: unconditional felling licences granted, differences between forest area maps (2006 and 2015 NFI and NIWT), analysis of the public forest estate sub-compartment database, remote sensing of Forest land converted to settlement and information on open habitat restoration. There is an increase in the estimated level of deforestation from 2000. There were policies initiated at that time that led to habitat restoration of forests to heath land, and an increase in deforestation due to windfarm development. There is a paucity of data prior to 1999, but there are no known policies or land-use drivers that would significantly change the estimated level of deforestation in the 1990s. From 2000 onward, a low-end estimate of deforestation was made based on the areas of woodland permanently converted to another land-use from the comparison of the woodland area maps. Estimates of conversion to open habitat and windfarms, and unconditional felling licence data, were then used to supplement this low-end estimate to arrive at the current estimates of post-2000 deforestation.

There is an assumption of restocking after harvesting, although open habitat can make up 13-20% of stand area on restocking (so reducing stocking density from its previous level). Thinning is considered to be part of the normal forest management regime. A felling license is required for felling more than a threshold volume of wood outside the national forest estate; there is a legal requirement to restock under such a license unless an unconditional felling license is granted (in which case this would be formally reported as Deforestation).

Deforestation in the Overseas Territories and Crown Dependencies occurs on Guernsey and the Cayman Islands. Activity data for Guernsey is obtained from habitat surveys in 1999 and 2010 (Guernsey), extrapolated forward to the latest inventory year. The change in forest cover

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[81] Excludes re-stocking carried out as part of the cycle of sustainable forest management.

is a result of the changed areas losing sufficient tree cover to be reclassified as dense scrub or parkland, rather than conversion to settlement land or agriculture. Activity data on deforestation in the Cayman Islands comes from maps of mangrove loss to settlement (Annex 3.4.11).

### 11.1.3.3 Forest Management

The Forest Management area is the forest area established before the end of 1989 adjusted to reflect losses from deforestation (see Annex 3.4.1 and Annex 3.4.4 for details). In the UNFCCC GHGI the the 4A1 Forest remaining Forest Land area and carbon stock changes are adjusted to take account of deforestation.

### 11.1.3.4 Cropland Management

The area of Cropland Management reported under KP is broadly consistent with that reported as Cropland under UNFCCC (the total area of tillage crops, orchards, fallow and set-aside). Its starting point is the area of cropland recorded in the agricultural census in 1990, whereas the UNFCC methodology back-calculates from the 2015 cropland area, using Countryside Survey data for land-use changes areas. This leads to a 2.7% difference in total final areas in 2018. There are also small differences because (i) a small area of CM activity occurs on Deforested land (0.161 kha 1990-2018) and therefore this area and associated emissions and removals are reported under Deforestation; (ii) areas of CM land have been converted to Settlement (125.361 kha 1990-2018). As land cannot leave the KP reporting hierarchy once it has been included, this area has remained in KP CM land, but been included in the Settlement area for UNFCCC reporting.

### 11.1.3.5 Grazing Land Management

The area of Grazing Land Management reported under KP is consistent with that reported as Grassland under UNFCCC as all Grassland in the UK is considered to be grazed and managed to some degree. The area of Grassland in the UNFCCC inventory is the area remaining once all other land uses have been subtracted from the total country area, whereas the Grazing Land Management area uses the area of grassland in the Countryside Survey in 1990 as the starting point. This leads to a 1.8% difference in total final area in 2018. The area of KP-GM land is also different from the UNFCCC Grassland area because (i) some KP-GM activity occurs on Deforested land (52.716 kha 1990-2018) and therefore this area and associated emissions and removals from this are reported under Deforestation; (ii) some KP-GM land has been converted to Settlement and Wetland (333.373 kha 1990-2018). As land cannot leave the KP reporting hierarchy once it has been included, this area has remained in KP-GM land, but been included in the Settlement or Wetland area for UNFCCC reporting.

### 11.1.3.6 Wetland Drainage and Rewetting

BEIS commissioned a programme of research and methodological development to compile activity data and UK-specific emission factors for Wetland Drainage and Rewetting (WDR) activities (Evans et al. 2017). See box in section 6.5.8 for further details. During 2019 the compilation and reporting of the LULUCF sector was adapted to take account of these research results and there was a review of recently published scientific literature to identify new emissions data. Rigorous QA/QC has been done to ensure that all assumptions and expert judgment are fully justified and robust: this is essential to build confidence domestically in the new dataset and to ensure that it passes expert scrutiny during international review. Due to the complexity of the new data, QA/QC has been time-consuming and was not completed in time for inclusion in the 2020 submission.

## 11.1.4 Precedence conditions and hierarchy among Art. 3.4 activities

The UK has elected additional activities under Article 3.4 for the second commitment period. There is a programme of research and methodological development underway for the newly

elected activities (CM, GM and WDR) and the UK is now able to report some of the emissions and removals for these activities and expect to be able to account for emissions/removals from these activities by the end of the commitment period.

The UK will follow the precedence conditions recommended by the 2013 Kyoto Supplementary Guidance (section 1.2), with Article 3.3 Deforestation highest in the hierarchy, and Article 3.4 WDR lowest. Article 3.4 CM and GM are considered equivalent in the hierarchy: however, in some regions of the UK, rotational management is dominated by crops, with the occasional grass ley, and vice versa in other regions, therefore cropland-grassland land-use change is temporary. In the future land undergoing rotational crop/grass management will be specifically allocated to either CM or GM as a sub-category, rather than regularly moving between activities. Development work on land-use vectors (**see Annex 3.4.2**) may allow the identification and pattern of areas under rotational land-use.

There is no double-counting of emissions and removals from Article 3.4 activities under Article 3.3. The UK has consistent records for the land areas in all Article 3.3 and 3.4 activities since 1990, as illustrated by the NIR-2 tables in the CRF, and these are used as the activity data for estimating emissions and removals.

## 11.2   LAND-RELATED INFORMATION

### 11.2.1 Spatial assessment unit used for determining the area of the units of land under Article 3.3

The UK uses Reporting Method 1 for Article 3.3 and 3.4 activities. Data sources for tracking areas of afforestation and forest management are spatially explicit, whilst those for deforestation are mostly not. The data sources and methodology can detect a land-use change at a resolution consistent with the forest definition in **Section 11.1.1** (0.1ha). Data sources for Article 3.4 activities Cropland Management (CM) and Grazing Land Management (GM) are not spatially explicit at present although the inventory development programme's plans to integrate new datasets for reporting land-use change may enable more spatially explicit data to be used in future.

The geographic boundaries used for international reporting are the United Kingdom (for the GBE CRF submission) together with the combined area of the UK's Overseas Territories and Crown Dependencies (for the GBK and GBR CRF submissions). Disaggregated emissions and removals are estimated at the level of the four countries of the UK (England, Scotland, Wales and Northern Ireland) using both KP and UNFCCC methodology and are reported in an Annex to the annual report on Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland.

### 11.2.2 Methodology used to develop the land transition matrix

The land transition matrix is shown in CRF Table NIR 2 (Table 11.2). The same data sources are used for the UNFCCC greenhouse gas inventory (as described in **chapter 6.1.1** and **Annex 3.4.2**) and emissions/removals under Articles 3.3 and 3.4.

Forest Research has compiled a forest dataset of estimated forest age from 1500 to the present day. The Forestry Commission, Natural Resources Wales, Forestry and Land Scotland and Forest Service of Northern Ireland have provided national forest planting statistics from 1921 to the present. The age of establishment for pre-1921 forests is estimated using information on the distribution of forest area by age class from forest inventories and an algorithm to assign areas of forest to years based on assumed management and rotation length. The parameterisation of this algorithm is automated to ensure the best fit between modelled wood production and the published wood production statistics.

Areas planted since 1990 in this forest activity dataset are used in Article 3.3 Afforestation/ Reforestation**.**

There is currently no detailed information on the age and type of forests subject to deforestation, so it is assumed that for areas that have been afforested since 1990 very little deforestation will have taken place.

New planting in the UK is usually grant aided and it is a condition of these grants that the area of forest be maintained. Estimates of areas in Article 3.3 Deforestation are collated from multiple sources (see **Annex 3.4.4** for details). Further information on these data sources is in **Chapter 6** and a summary is given in Table 11.3**.**

The area of Article 3.4 Forest Management land is the area of forest planted before 1990, adjusted to take account of the area lost through deforestation.

The area of Art 3.4 Cropland Management 4 is estimated by combining annual agricultural census data and Countryside Survey data. The CM area at the start of 1990 is the area of cropland recorded in the agricultural census. The CM area at the end of each year is the sum of the initial cropland area and the area gained by land-use change from non-forest land, minus the area of cropland converted to Afforestation land or GM land (calculated using the Countryside Survey LUC matrices, described in **Annex 3.4.2**). The area of cropland at the start of the subsequent year is equal to the cropland area at the end of the previous year.

The area of Art. 3.4 Grazing Land Management is estimated from Countryside Survey data using the assumption that all grassland in the UK is subject to grazing and management to some degree (this area is greater than that reported in the agricultural census). The GM area at the start of 1990 is the area of grassland recorded in the Countryside Survey. The GM area at the end of each year is the sum of the initial grazing land area and the area gained by land-use change from non-forest land, minus the area of grazing land converted to Afforestation land or CM land (calculated using the Countryside Survey LUC matrices, described in **Annex 3.4.2).** The area of grazing land at the start of the subsequent year is equal to the grazing land area at the end of the previous year.

The area of Other Land in CRF table NIR 2 is adjusted so that the total area adds up to the land area reported for the UK and Overseas Territories and is constant for all years.

The UK is not yet in a position to report emissions from land in the Wetland Drainage and Rewetting (WDR) category, although emissions from some WDR practices on land classified under activities higher in the KP hierarchy have been reported in the latest inventory. A programme of research and methodological development is in progress which will enable the full reporting of WDR activities by the end of the commitment period.

In 2018, 585 kha were subject to Afforestation/Reforestation under Article 3.3; 73 kha were subject to Deforestation under Article 3.3, 0.2 kha would otherwise be subject to Art.3.4 Cropland Management and 53 kha would otherwise be subject to Art.3.4 Grazing Land Management; 2 977 kha were subject to Forest Management under Article 3.4; 4 818 kha were subject to Art.3.4 Cropland Management; and 15 409 kha were subject to Art.3.4. Grazing Land Management. The areas subject to Art.3.4 Wetland Drainage and Rewetting have not yet been finalised (see box in section 6.5.8 for further details).

**Table 11.2    Land area and changes in land areas in 2018 (UK, OT and CDs)**

| To current inventory year (2018) | | | Article 3.3 activities | | Article 3.4 activities | | | Other | Total (beginning of year) |
|---|---|---|---|---|---|---|---|---|---|
| From previous inventory year (2016) | | | Afforestation and Reforestation | Deforestation | Forest Management | Cropland Management | Grazing Land Management | | |
| Article 3.3 activities | Afforestation and Reforestation | kha | 572.4 | 0.0 | | | | | 572.4 |
| | Deforestation | | | 70.6 | | | | | 70.6 |
| Article 3.4 activities | Forest Management | | | 2.8 | 2976.9 | | | | 2979.7 |
| | Cropland Management | | 0.9 | | | 4764.3 | 99.2 | | 4863.5 |
| | Grazing Land Management | | 10.2 | | | 52.2 | 15219.3 | | 15271.5 |
| Other | | | 1.5 | | | 0.1 | 10.2 | 1977.2 | 1987.5 |
| Total (end of year) | | | 585.0 | 73.4 | 2976.9 | 4816.6 | 15328.7 | 1977.2 | 25757.7 |

**Table 11.3**     **Data Sources on Afforestation, Reforestation and Deforestation (ARD), Forest Management (FM), Cropland Management (CM), and Grazing Land Management (GM) Activities**

| Activity | Dataset | Available scale | Time period | Details |
|---|---|---|---|---|
| AR & FM | Annual planting statistics | UK | 1921 – latest inventory year | New planting on previously non-forested land. Updated annually. Categorized into conifer and broadleaved woodland. |
| AR & FM | Annual restocking statistics | UK | 1971 - latest inventory year | Restocking of existing forest. Updated annually. Categorized into conifer and broadleaved forest. Used to estimate the pre-1921 planting years. |
| AR & FM | Forestry Commission Sub-compartment Database | Every area of forest managed as part of the public forest estate | Latest inventory year | Information on the planting year, species, growth rate and management of the public forest estate. Used to estimate the distribution of tree species, growth rates and management of forests. |
| AR & FM | Timber production statistics | UK | 1976 - latest inventory year | Estimates from the Forestry Commission of timber production by year based on outturns from sawmills Used to estimate the percentage of private sector woodland that is managed (thinned or felled). |
| AR & FM | FAO Timber production statistics | UK | 1961-1975 | Wood production statistics to model historic annual afforestation and restocking rates |
| AR & FM | FAO Global Forest Resource Assessment | Overseas Territories and Crown Dependencies | 2010 | Areas of forest type and some management information. |
| D | Forestry Commission Unconditional Felling Licence data | England, Scotland, Wales | England: 1992-2013; Scotland: 1998-2013; Wales: 1996-2013 | Licences issued for felling without restocking. Used to estimate deforestation in rural areas (primarily for heathland restoration). Omits felling for development purposes, e.g. construction of wind turbines |
| D | National Inventory of Woodland and Trees (NIWT) | Great Britain (not Northern Ireland) | 2000 | Forest map used to estimate deforestation since 2000. |
| D | Land-use Change Statistics | England only | 1990-latest | Estimates of the conversion of forest to urban/developed land-use. Based on Ordnance Survey map updates, |

| Activity | Dataset | Available scale | Time period | Details |
|---|---|---|---|---|
| | (survey of land converted to developed uses) | | inventory year | identifying changes through aerial surveys and other reporting, expected to capture most changes within five years. English data are extrapolated to GB scale for pre-2000 areas. |
| D | Countryside Survey (CS) 1990, 1998, 2007 | UK | 1990-2007 | Estimated areas of woodland converted to other land uses from CS data (1990, 1998, and 2007). The CS over-estimates the extent of woodland conversion compared with the extent estimated by the Forestry Commission. This is due to differences in woodland definitions, amongst other causes. The CS data is used to estimate the relative split of woodland conversion between grassland, cropland and settlements, using other known data to "discount" the CS areas. There is no non-CS data for Northern Ireland so the discount rates for England or Wales are used, depending on availability. |
| D | Forestry Commission Internal Records | Great Britain (not Northern Ireland) | 2000-latest inventory year | Update to the deforestation to grassland areas based on data on publicly-owned forest areas converted to non-forest land-use from administrative records maintained by Forestry Commission England, Forestry Commission Scotland and Natural Resources Wales. |
| D | Preliminary estimates of the changes in canopy cover in British woodlands between 2006 and 2015 | Great Britain | 2006-15 | Revised information (remote sensing) on conversion of Forest land to settlement. |
| D | Journal paper (Jurn et al. 2018) | Overseas Territory (Cayman Islands) | 1965-2013 | Area of mangrove lost to urban development in the Cayman Islands |
| AR, FM and D | National Forest Inventory (NFI) | Great Britain (not Northern Ireland) | 2009-2013 | Species and growth rate by age class, used to estimate AR and FM area. Estimates of permanent woodland loss reported in National Forest Inventory Country Reports. |
| AR, FM, CM, GM | Habitat surveys, agricultural | Overseas Territories and Crown Dependencies | 1965-latest inventory year | Forest planting data by forest type for the Isle of Man. Habitat surveys and economic statistics were used to estimate forest, cropland, grassland and |

| Activity | Dataset | Available scale | Time period | Details |
|---|---|---|---|---|
| | statistics and planting data | | | settlement areas for Guernsey, Jersey and Cayman Islands. There is no forest meeting the forest definition in the Falkland Islands. Agricultural statistics are used for cropland and grassland areas in the Isle of Man and Falklands Islands. Gibraltar has no KP-LULUCF activities. |
| CM, GM | Countryside Survey | UK | 1984 – 2007 | Land-use change to and from Cropland and Grazing Land. Area under different grassland types. |
| CM | Agricultural census | UK | 1866 – latest inventory year | Areas under different crops. |
| CM | British Survey of Fertiliser Practice | Great Britain (not Northern Ireland) | 1992 – latest inventory year | Percentage of crop residues incorporated to soil. Fertiliser and manure inputs to Cropland and Grazing Land. |
| CM | Farm Practice Survey | England | 2010 | Percentage of Cropland under conventional, reduced and no tillage regimes. |
| CM | Scottish Survey of Agricultural Production Methods | Scotland | 2010 | Percentage of Cropland under conventional, reduced and no tillage regimes. |
| CM | Scottish Survey of Farm Structure and Methods | Scotland | 2013 | Percentage of Cropland under conventional, reduced and no tillage regimes. |
| CM, GM | Spatial extent of cultivated organic (Histosol) soils | UK | 2013 | Area of drained organic soils under cropland and improved grassland in the UK. |
| AR, D, FM, CM, GM | Fire and Rescue Service Incidence Reporting System | Great Britain (not Northern Ireland) | 2010-latest inventory year | Area of wildfires on forest, cropland and grassland. |

## 11.2.3 Maps and database to identify the geographical locations, and the system of identification codes for the geographical locations

The whole area of the United Kingdom and the combined area of the Overseas Territories and Crown Dependencies have been used as the geographical units for reporting. Net emissions from KP-LULUCF activities in the OTs/CDs of Isle of Man, Jersey, Guernsey, the Falkland Islands and Cayman Islands are reported. Gibraltar has no KP-LULUCF activities as the entire land area is categorised as 4E.1 Settlement remaining Settlement.

**Figure 11.1 Geographical areas used for reporting Kyoto Protocol LULUCF activities**

## 11.3   ACTIVITY-SPECIFIC INFORMATION

## 11.3.1 Methods for carbon stock change and GHG emission and removal estimates

### 11.3.1.1 Description of the methodologies and the underlying assumptions used

*11.3.1.1.1   ARD and FM carbon stock changes*

The methods for estimating carbon stock changes in forests for Article 3.3 Afforestation/Reforestation and Article 3.4 Forest Management are the same as those used for the UNFCCC greenhouse gas inventory: details are given in **Annex 3.4.1.** A Tier 3 carbon accounting model, CARBINE, is used to estimate the net change in pools of carbon in living biomass, litter and soil in conifer and broadleaved forests. In the KP CRF tables changes in carbon stock are reported for: above-ground and below-ground biomass (gains and losses), litter and dead wood (net changes) and soils (net changes in mineral and organic soils).

Estimates for carbon stock changes as a result of Article 3.3 Deforestation use the same methods as the UNFCCC greenhouse gas inventory (**Annex 3.4.4**). During deforestation, 40% of the above-ground biomass is assumed to be burnt and emissions of $CO_2$, $CH_4$ and $N_2O$ are reported in Table 4(KP-II)4. The remaining carbon stock in biomass is assumed to be immediately lost (instantaneous oxidation) (in UNFCCC reporting this biomass stock is transferred to the harvested wood products pool). This loss (in Gg C) is calculated as:

*Carbon stock loss = living biomass loss + dead organic matter loss* where *living biomass loss = biomass density * area * % biomass removed,* and

> *dead organic matter loss = DOM density * area * % biomass removed*

and *proportion of biomass removed = 60%*

> *area = area deforested, ha*
>
> *biomass density = average forest living biomass density, Gg C /ha*
>
> *DOM density = average dead organic matter density, Gg C/ha*

Carbon stock changes in soils as a result of deforestation are calculated using the dynamic model of carbon stock change discussed in **Annex 3.4**. It is not possible to report changes in mineral and organic soils separately since there are no separate activity data.

It is assumed that all deforestation occurs on Forest Management land, and the area of FM land and carbon stock changes calculated by CARBINE take account of deforestation.

The calculation of the Forest Management Reference Level is briefly described in Section 11.3.1.6, and fully in the UK's 2011 submission to the UNFCCC (DECC, 2011). The FMRL has been updated for this inventory submission and is described in **Section 11.5.2.4**.

The UK will take up the natural disturbances provision for forest land in the second commitment period, but has not yet needed to implement it. The background and threshold levels for natural disturbances on Forest Management and Afforestation/Reforestation land in the UK are shown in Table 11.4. The methodology used to estimate these background and threshold levels is explained in section 11.4.4 and in the United Kingdom's Initial Report under the Second Commitment Period of the Kyoto Protocol (DECC 2016). No emissions have been excluded as being due to natural disturbances in the current inventory.

**Table 11.4       The background emissions estimated for disturbance events over the calibration period for Forest Management and Afforestation and Reforestation**

|  | Background Level (ktCO$_2$e/yr) | Margin (ktCO$_2$e/yr) | Disturbance provision threshold (ktCO$_2$e/yr) |
|---|---|---|---|
| Forest Management | 270 | 112 | 382 |
| Afforestation and Reforestation | 34.9 | 18.8 | 54 |
| UNFCCC 4A Forestland | 307 | 132 | 440 |

Carbon stock changes in the HWP pool (CRF Table 4(KP-I)C) are calculated on a first-order decay function basis for AR and FM forests and on an instantaneous oxidation basis for deforestation, in accordance with the 2013 Kyoto Protocol Supplementary Guidance (see **Annex 3.4.10** for details). HWP from AR land includes all domestically produced HWP from Afforestation land since 1990. HWP is included in Forest Management in the second commitment period as the UK's FMRL was based on a projection. HWP is calculated from 1961 onwards and reported from 1990.

*11.3.1.1.2   CM and GM carbon stock changes*

Changes in soil and biomass carbon due to LUC under KP-Cropland Management and KP-Grazing Land Management are modelled using a Tier 3 model of dynamic stock change, driven by matrices of change calculated from the Countryside Survey and historical data sources. Further description of the model, country-specific soil and biomass carbon densities and rates of change can be found in **Annex 3.4.2**. Carbon stock changes resulting from deforestation to cropland or grazing land are reported under KP-Deforestation.

Carbon stock changes in biomass as a result of agricultural management activities on cropland are calculated for annual crops, orchards, shrubby perennial crops, perennial grasses grown as biomass fuel, short rotation coppice, and set aside and fallow. Soil carbon stock changes are estimated using data on crop areas supplemented with data on residue removals and fertiliser and manure inputs methodology full description of these Tier 1 and 2 methodologies is given in **Annex 3.4.2** and **Annex 3.4.3.**

Carbon stock changes in biomass as a result of agricultural management activities on grazing land are calculated using shrubby and non-shrubby grassland areas from Countryside Survey data and country-specific biomass carbon stocks (Tier 2). Details are given in **Annex 3.4.3**. The reporting of emissions from grazing land soils as a result of management activities is awaiting the outcome of further research in this area, as a literature review (Moxley et al, 2014a) suggested that Tier 1 emission factors were not appropriate for the high carbon organo-mineral soils underlying large areas of grazing land in the UK. An initial review of the research results suggests standard grassland management practices in the UK do not have a significant impact on soil carbon that can be seprated from the soil carbon stock change associated with historic land-use change.

### 11.3.1.1.3   Other GHG emissions from KP-LULUCF

Greenhouse gas emissions (rather than carbon stock changes) from LULUCF activities under the Kyoto Protocol are reported in CRF Tables 4(KP-II)1-4.

*Table 4(KP-II)1 Direct and indirect $N_2O$ emissions from N fertilization*

The method used to estimate emissions is the same as that used in the UNFCCC greenhouse gas inventory and described in **Annex 3.4.1**. It is assumed that nitrogen fertilizer is only applied to newly planted forests on settlement land and on grassland on organic soils (i.e. AR land) in the UK (see section 6.2) for more information). Indirect emissions from leaching and deposition of N fertiliser are calculated using a Tier 1 methodology.

*Table 4(KP-II)2 $CH_4$ and $N_2O$ emissions from drained and rewetted organic soils*

The method used to estimate $N_2O$ emissions from drained forest land is the same as that used in the UNFCCC greenhouse gas inventory and described in **Annex 3.4.1.** Drainage of forest land only occurs on certain soil types in the UK and is reported for AR and FM land. Carbon emissions from the drainage of forest soils are included with emissions from soils in the carbon stock change tables for AR and FM. There is insufficient information to estimate $CH_4$ emissions from drainage and non-$CO_2$ emissions from rewetted soils at this time. The programme to implement the results of Evans *et al*. (2017) may produce country-specific EFs and activity data to enable the reporting of emissions from these sub-categories.

*Table 4(KP-II)3 $N_2O$ emissions from N mineralization/immobilization due to carbon loss/gain associated with land-use conversion and management change in mineral soils*

Direct $N_2O$ following deforestation to Cropland, Grassland and Settlement and with land-use change between Forest Land, Cropland, Grazing Land and Settlement in the UK since 1990 are reported. $N_2O$ emissions resulting from the artificial drainage of mineral soils on AR and FM land are also reported in this table, as Table 4(KP-II)2 is for organic soils only. Indirect emissions of $N_2O$ from leaching of mineral soils as a result of N mineralization following land-use change are calculated at Tier 1 methodology.

*Table 4(KP-II)4 GHG emissions from biomass burning*

The method used to estimate emissions from controlled and wildfire biomass burning is the same as that used in the UNFCCC greenhouse gas inventory and described in **Annex 3.4.4** and **Annex 3.4.5**. There is no controlled burning of AR or FM forest land in the UK or on managed Cropland. Controlled burning on managed Grazing Land is not included in the inventory at present, pending the availability of activity data.

There is insufficient information on the occurrence of wildfires on different forest types so wildfire emissions have been split between AR land and FM land on the basis of their proportion of the whole forest area. As described above, it is assumed that 40% of the standing biomass and DOM undergoes controlled burning during Deforestation and emissions from that burning are reported in this table. It is assumed that wildfires that cause deforestation do not occur in the UK, as there is a general commitment to maintaining forest area. However, it is possible for previously deforested land to undergo wildfire (for example on restored heathland). The wildfire activity data are spatially explicit, so it was possible to assess of the incidence of wildfires on deforested areas but they do not occur every year. Estimated emissions from these events are included in Table 4(KP-II)4.

Emissions from wildfires on grassland and cropland not on Deforested land are reported under Grazing Land Management and Cropland Management, also in Table 4(KP-II)4.

**11.3.1.2 Justification for omitting any carbon pool or GHG emissions/removals from activities under Article 3.3 and elected activities under Article 3.4**

The UK has elected three additional Article 3.4 activities: Cropland Management, Grazing Land Management and Wetland Drainage and Rewetting. The UK has put in place a research and methodological development programme for these activities to enable full reporting by the end of the commitment period and progress has been made towards this goal.

*Table 4(KP-I)A.1.1 Article 3.3 activities: Afforestation and Reforestation. Additional information: emissions and removals from natural disturbance*

*(GBE, GBR and GBK submissions)* The UK has signed up to the provision to exclude emissions from natural disturbances with respect to Article 3(3) (Afforestation and Reforestation), but has not yet needed to implement it. The background levels of emissions from natural disturbances and the disturbance provision thresholds are shown in Table 11.4. No emissions from natural disturbance above the disturbance provision threshold level have occurred on Afforested and Reforested land in the period covered by the latest inventory. The tables have been filled with NA notation keys (Not Applicable) for the current submission.

*Table 4(KP-I)A.2 Article 3.3 activities: Deforestation. Deforestation land previously reported under afforestation/reforestation and forest management and subject to natural disturbances*

*(GBE, GBR and GBK submissions)* No emissions from natural disturbance above the disturbance provision threshold level have occurred in the period covered in the latest inventory. The tables have been filled with NA notation keys (Not Applicable) for the current submission.

*Table 4(KP-I)A.2 Article 3.3 activities: Deforestation. Information items: Land areas under deforestation by land-use category in the current reporting year*

*(GBE, GBR and GBK submissions)* The rows for Forest Land and Other land are filled with the Not Occurring (NO) notation key as only deforestation to Cropland, Grassland or Settlements occurs in the UK, and deforestation to Grassland, Wetlands and Settlements in the Overseas Territories and Crown Dependencies.

*Table 4(KP-I)B.1 Article 3.4 activities: Forest management. Newly established forest (CEF-ne) and Harvested and converted forest plantations (CEF-hc)*

*(GBE, GBR and GBK submissions)* The UK has not elected to report carbon-equivalent forests and therefore the relevant cells are filled with the notation key NA (Not Applicable).

*Table 4(KP-I)B.1 Article 3.4 activities: Forest management. Land subject to natural disturbances*

*(GBE, GBR and GBK submissions)* No emissions from natural disturbance above the disturbance provision threshold level have occurred on Forest Management land in the period covered in the latest inventory. The tables have been with filled NA notation keys (Not Applicable) for the current submission.

*Table 4(KP-I)B.2. Elected Article 3.4 activities: Cropland Management*

*(GBR and GBK submissions)* Carbon stock changes on cropland in the Overseas Territories and Crown Dependencies are calculated using Tier 1 methodologies, therefore carbon stock changes in below-ground biomass, litter and dead wood are reported as Not Estimated (no guidance).

*Table 4(KP-I)B.3. Elected Article 3.4 activities: Grazing Land Management*

*(GBR and GBK submissions)* Carbon stock changes on grazing land in the Overseas Territories and Crown Dependencies are calculated using Tier 1 methodologies, therefore

carbon stock changes in below-ground biomass, litter and dead wood are reported as Not Estimated (no guidance).

*Table 4(KP-I)B.5 Elected Article 3.4 activities: Wetland drainage and rewetting*

*(GBE, GBR and GBK submissions)* UK-specific activity data and emission factors are still in development for this activity so all carbon stock changes are currently reported as Not Estimated.

*Table 4(KP-I)C Carbon stock changes in the harvested wood products (HWP) pool*

*(GBE submission)* HWP resulting from deforestation is assumed to be instantaneously oxidised and is reported as NA in this CRF table.

*(GBK and GBR submission)* There is a very small amount of HWP arising from timber harvesting in the UK's Overseas Territories and Crown Dependencies, with none (NO) arising from AR or D land. The small amount from FM land is assumed to all go into paper products for domestic consumption only, and all other products are reported as NO.

*Table 4(KP-II)1 Direct $N_2O$ emissions from N fertilization*

*(GBE, GBR and GBK submissions)* It is assumed that nitrogen is only applied to newly planted forests on certain land-use types in the UK, and therefore that no N fertilization occurs on Deforestation or Forest Management land (NO).

*Table 4(KP-II)2 $CH_4$ and $N_2O$ emissions from drained and rewetted organic soils*

*(GBE, GBR and GBK submissions)* At present there is insufficient information to allow the estimation of $CH_4$ fluxes and non-$CO_2$ fluxes from drained and rewetted soils under CM, GM and WDR activities (Not Estimated). There are no known occurrences of rewetting on ARD and FM soils.

*Table 4(KP-II) $N_2O$ emissions from N mineralization/immobilization due to carbon loss/gain associated with land-use conversions and management change in mineral soils*

*(GBE, GBR and GBK submissions)* There are no continuing carbon stock losses, and hence no $N_2O$ emissions, associated with LUC from FM land in the UK or from ARD or FM land in the UK'S Overseas Territories and Crown Dependencies (Not Occurring).

*Table 4(KP-II)4. GHG emissions from biomass burning*

*(GBE submission)* There is no controlled burning for management in UK forests, so this is reported as Not Occurring for AR and FM. Controlled burning is prohibited on UK cropland (Not Occurring) but does occur on Grazing Land in the UK, particularly on heather moorland. However, these controlled burning events affect very small patches and occur intermittently and there is no activity data available on their occurrence and extent. At present, emissions for this activity have not been estimated (NE) but this is being kept under review.

Wildfires on Deforested land are infrequent and do not occur every year, so are reported using the notation key NO in most years.

*(GBR and GBK submissions)* There are no records of controlled burning in the UK's Overseas Territories and Crown Dependencies. These emissions are reported as Not Occurring.

### 11.3.1.3 Information on whether or not indirect and natural GHG emissions and removals have been factored out

The UK inventory approach to estimating forest carbon stock changes is based on modelled growth data rather than national-scale measurements of forest annual volume increments. The CARBINE model is based on yield class tables, and, in principle assumes constant weather and management conditions; therefore 'factoring out' of climate change effects is not required. Work has been undertaken to model the impact of climate, $CO_2$ and land-use change

on the carbon balance of terrestrial ecosystems in Great Britain (Levy and Clark 2009) and interaction between these factors. This suggested that interactions are small and the effects of these environmental factors are additive. Nitrogen dynamics were not considered in this work: the extent to which enhanced nitrogen deposition affects forest carbon sequestration remains contentious (Magnani *et al* 2007; Sutton *et al* 2008).

### 11.3.1.4 Changes in data and methods since the previous submission (recalculations)

Details of recalculations are given in Table 11.5. Justifications for the recalculations are given in Chapter 6, sections 6.2.7, 6.3.7, 6.4.7 and 6.8.7 for the UK, and in Chapter 6, section 3.9.4 for the Overseas Territories and Crown Dependencies.

**Table 11.5    Recalculations of previous emissions/removals in the latest KP-LULUCF submission (GBK submission)**

| IPCC Category | Source Name | 2019 Submission 2017 | 2020 Submission 2017 | Units | Comment/Justification |
|---|---|---|---|---|---|
| **UK** | | | | | |
| KP.A.1 | Afforestation and Reforestation- carbon stock change | -2543.341 | -2591.965 | Gg $CO_2$ | Reconciliation of harvest volume and forest age data. Improvements to CARBINE.[82] |
| KP.A.1 | GHG emissions from biomass burning - wildfires | 0.020 | 0.026 | Gg $CH_4$ | Use of CARBINE biomass densities |
| KP.A.1 | GHG emissions from biomass burning - wildfires | 0.001 | 0.001 | Gg $N_2O$ | Use of CARBINE biomass densities |
| KP.A.1/(KP-II)1 | Direct and indirect $N_2O$ emissions from N fertilization | 0.011 | 0.011 | Gg $N_2O$ | Reconciliation of harvest volume and forest age data[5] |
| KP.A.1/(KP-II)2 | $CH_4$ and $N_2O$ emissions from drained and rewetted organic soils | 0.033 | 0.033 | Gg $N_2O$ | Reconciliation of harvest volume and forest age data[5] |
| KP.A.1/(KP-II)3 | $N_2O$ emissions from N mineralization | 0.462 | 0.480 | Gg $N_2O$ | Reconciliation of harvest volume and forest age data[5] |
| KP.C | HWP from AR Land | -48.362 | -82.500 | Gg $CO_2$ | Reconciliation of harvest volume and forest age data[83] |
| KP.A.2 | Deforestation- Carbon stock change | 1048.850 | 1151.911 | Gg $CO_2$ | Use of CARBINE biomass densities .[84] Revision of deforestation activity data.[85] |
| KP.A.2/(KP-II)3 | $N_2O$ emissions from N mineralization | 0.184 | 0.192 | Gg $N_2O$ | Revision of deforestation activity data.[9] |
| KP.A.2/(KP-II)4 | GHG emissions from biomass burning | 67.151 | 344.804 | Gg $CO_2$ | Use of CARBINE biomass densities .[8] |
| | | 0.893 | 1.033 | Gg $CH_4$ | |
| | | 0.049 | 0.057 | Gg $N_2O$ | |

[82] See section 6.2.7 for justification

[83] See section 6.8.7 for justification

[84] See section 6.3.7 for justification

[85] See section 6.4.7 for justification

| | | | | | |
|---|---|---|---|---|---|
| KP.B.1 | Forest Management- carbon stock change | -15670.170 | -15861.819 | Gg CO$_2$ | Reconciliation of harvest volume and forest age data.[5] Improvements to CARBINE model [582] |
| KP.B.1/(KP-II)2 | CH$_4$ and N$_2$O emissions from drained and rewetted organic soils | 0.157 | 0.162 | Gg N$_2$O | Reconciliation of harvest volume and forest age data.[5] |
| KP.C | HWP from FM Land | -1845.394 | -2171.913 | Gg CO$_2$ | Reconciliation of harvest volume and forest age data [6] |
| KP.B.2 | Cropland Management- carbon stock change | 11740.730 | 11970.987 | Gg CO$_2$ | Change in soil carbon density for crop management .[8] Correction of cropland areas.[8] |
| KP.B.2 | Emissions from N$_2$O mineralisation | 2.762 | 2.245 | Gg N$_2$O | Change in soil carbon density for crop management |
| KP.B.3 | Grazing Land Management - Carbon stock change | -6156.747 | -6220.972 | Gg CO$_2$ | Re-running of Monte Carlo soil carbon model |
| KP.B.3 | Emissions from N$_2$O mineralisation | 1.193 | 0.986 | Gg N$_2$O | Re-running of Monte Carlo soil carbon model |
| KP.B.3GHG emissions from biomass burning 0.1490.151Gg CH$_4$Adjustment of average biomass densities due to error correctionKP.B.3 | GHG emissions from biomass burning | 0.014 | 0.014 | Gg N$_2$O | Adjustment of average biomass densities due to error correction |
| **Overseas Territories and Crown Dependencies** | | | | | |
| KP.A.2 | Deforestation - Carbon stock change | 0.253 | 38.670 | Gg CO$_2$e | Inclusion of deforestation in the Cayman Islands |
| KP.B.1 | GHG emissions from biomass burning - wildfires | | 2.592 | Gg CO$_2$e | Inclusion of emissions from wildfires |
| KP.B.1 | GHG emissions from biomass burning - wildfires | | 0.011 | Gg CH$_4$ | Inclusion of emissions from wildfires |
| KP.B.2 | Cropland Management - Carbon stock change | 23.193 | 36.284 | Gg CO$_2$e | Change in soil carbon density for crop management Changes to cropland LUC time series in the Falkland Islands and Jersey. |
| KP.B.2/(KP-II)3 | Emissions from N$_2$O mineralisation | 0.008 | 0.009 | Gg N$_2$O | Change in soil carbon density for crop management Changes to cropland LUC time series in the Falkland Islands and Jersey |
| KP.B.3 | Grazing Land Management - Carbon stock change | -0.150 | -0.261 | Gg CO$_2$e | Changes to cropland LUC time series in the Falkland Islands and Jersey |

| KP.B.3 | GHG emissions from biomass burning - wildfires | 0.000 | 0.023 | Gg CH$_4$ | Inclusion of emissions from wildfires |
|---|---|---|---|---|---|
| KP.B.3 | GHG emissions from biomass burning - wildfires | 0.000 | 0.663 | Gg N$_2$O | Inclusion of emissions from wildfires |
| | | | | | |

### 11.3.1.5 Uncertainty estimates

Uncertainty assessment and quantification of the inventory was undertaken during 2007-2009, with particular focus on the forest carbon modelling components (van Oijen and Thomson 2010). This analysis was based on the previously used carbon accounting model used to model carbon pools and fluxes in UK forests, CFlow (Dewar and Cannell 1992), but much of the analysis will also apply to the CARBINE model (described in **Annex 3.4.1** of this report) as they are very similar models, although CARBINE allows wider range of representation of species, growth rates (yield class) and assumed management.

There will be a new uncertainty analysis, following the methodology of the previous uncertainty analysis, which will include the latest version of the CARBINE model and the uncertainty inherent in the NFI due to the sampling intensity. The results of this analysis are likely to be included in the next National Inventory Report.

An uncertainty of 35% for Article 3.3 Afforestation/Reforestation and Article 3.4 Forest Management is used (as estimated for UNFCCC category 4A), an uncertainty of 50% for Article 3.3 Deforestation (based on expert judgement) and an uncertainty of 45% and 50%, respectively, for Article 3.4 Cropland Management and Grazing Land Management (as estimated for the UNFCCC categories 4B and 4C).

*Uncertainty from model inputs.*

CARBINE requires input data on the afforestation rate (ha yr$^{-1}$), species, yield class (mean wood volume production at time of maximum mean annual increment, m$^3$ ha$^{-1}$ yr$^{-1}$), whether the forest is thinned and felled, the age of harvesting, and whether the forest is clear-felled or not for different forest types and countries in the UK. The management and yield class of private sector woodlands is assumed to be the same as for the national forest estates. Information on the percentage of private sector woodland in production was estimated for each country by comparing the timber production estimated by CARBINE to the timber production statistics for each country.

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.

The areas undergoing land-use change are the biggest source of uncertainty in the LULUCF inventory (see **Annex 3.4.12**).

Activity data for the OTs and CDs are less complete, necessitating the use of gap-filling for time series consistency, and Tier 1 EFs are used for most calculations. Uncertainties are therefore higher, but the OTs and CDs contribute such a small amount of overall net emissions that their contribution to overall uncertainty is likewise very small. A quantitative assessment of the uncertainties arising from net emissions from the OTs and CDs will be included in the next submission,

### 11.3.1.6 Information on other methodological issues

*Natural disturbances.*

The UK has indicated that it will use the provision to exclude emissions from natural disturbances with respect to Article 3(3) Afforestation and Reforestation and Article 3(4) Forest Management, but has not yet needed to do so. The background levels of emissions from natural disturbances and the disturbance provision thresholds are shown in Table 11.4. Areas and emissions from wildfires on forest land, cropland and grazing land are included in the KP-LULUCF inventory (see section 6.2 and **Annex 3.4** for further details). Wildfires are not assumed to result in a permanent change in land-use.

*Inter-annual variability.*

The method used to estimate emissions and removals from AR and FM is based on the CARBINE model. This model is not sensitive to inter-annual variation in environmental conditions so these will not affect the annual growth and decay rates. The area burnt in wildfires does show inter-annual variation and this is included in the emissions methodology.

*Deforestation*

The method used to estimate emissions and removals from deforestation assumes the activity is evenly applied to the FM area – which implies that the deforestation has the same age, growth rate and species distribution as the FM area. It is unknown whether this assumption leads to an under- or over-estimate of emissions due to deforestation. We hope to investigate whether Forestry Commission records can be used to characterise any of the deforestation on the national forest estates to attempt to assess what the effect of this assumption might be.

### 11.3.1.7 The year of the onset of an activity, if after 2013

**Table 11.6    Areas converted to KP activities after 2013 (UK and OTs & CDs)**

| Year | Area converted to AR, kha | Area converted to D, kha | Area converted to CM, kha | Area converted to GM, kha |
|---|---|---|---|---|
| 2013 | 17.11 | 2.96 | 52.68 | 109.92 |
| 2014 | 15.06 | 2.85 | 52.35 | 110.98 |
| 2015 | 6.92 | 2.51 | 53.33 | 110.02 |
| 2016 | 6.40 | 3.75 | 52.35 | 110.29 |
| 2017 | 8.59 | 2.82 | 52.35 | 109.88 |
| 2018 | 12.58 | 2.82 | 52.35 | 109.92 |

## 11.4   ARTICLE 3.3

## 11.4.1 Information that demonstrates that activities began on or after 1 January 2013 and before 31 December 2020 and are directly human-induced

Under the current methodology the Forestry Commission, Natural Resources Wales, Forestry and Land Scotland and the Forest Service of Northern Ireland provide annual data on new planting (on land that has not previously been forested). This information is provided for the whole of the UK and the time series extends back before 1990. Information on new planting and restocking are published as separate figures for both state and private woodlands. New planting can be from planting, seeding or natural colonisation. Data come from administrative systems (state forests) and grant schemes (other woodland).

Information on deforestation is collated from multiple sources (see **Annex 3.4.4** for details), and remote sensing, all of which can be shown to be directly human-induced. The time series of activity data is not sufficiently detailed to demonstrate the exact date of deforestation within a year.

### 11.4.2 Information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from deforestation

The data sources used for estimating Deforestation do not confuse between harvesting or forest disturbance and deforestation. For the pre-2000 time series the unconditional felling licences used for the estimation of rural deforestation are only given when no restocking will occur, and the survey of land converted to developed use describes the conversion of forest land to the settlement category, which precludes re-establishment. The Countryside Survey data (used for time series extrapolation) are adjusted in order that deforestation is not over-estimated.

Data sources for the post-2000 time series clearly identify the post-deforestation land-use. The estimation of deforestation using analysis of aerial photographs to identify areas that have definitively changed is described in the report *Preliminary estimates of the changes in canopy cover in British woodlands between 2006 and 2015* (Forestry Commission, 2016). Land is only classified as deforested 10 years after the removal of trees is first identified, unless there has been an irreversible change such as conversion to settlement or administrative records, for example the granting of an unconditional felling licence, indicates intent to convert to another non-forest land cover.

### 11.4.3 Information on the size and geographical location of forest areas that have lost forest cover but which are not yet classified as deforested

Restocking is assumed for forest areas that have lost forest cover through harvesting or forest disturbance, unless there is deforestation as described above. Information on the size and location of forest areas that have lost forest cover is not explicitly collected on an annual basis. The National Forest Inventory will track areas of clear-felled forest (through satellite imagery and field survey) where canopy cover has been re-established, with any areas remaining unstocked after ten years being classified as confirmed woodland loss (Forestry Commission 2016). A partial assessment of clearfell and restocking in 2012 identified 29 kha of clearfell between 2006 and 2009, of which 18 kha had been restocked by 2012. Further partial assessments are due in 2018 (not yet published) and 2020, which will give a more complete picture of the proportions of clear-felled land awaiting restocking and confirmed deforestation over the second commitment period.

### 11.4.4 Information related to the natural disturbances provision under Article 3.3

The UK will take up the natural disturbances provision for forest land in the second commitment period. The background, margin and threshold levels for natural disturbances on Forest Management and Afforestation/Reforestation land in the UK are shown in Table 11.4. No emissions have been excluded as being due to natural disturbances in the latest inventory.

Forest management in the UK has evolved to cope with disturbance events, notably windstorms, wildfires and extreme weather events with guidance and decision support systems in place. Historical records show that drought, floods and snow and ice are unlikely to cause substantial damage to UK forests as even events which are extreme for the UK have not caused stand mortality. The UK is not subject to geological disturbance likely to affect forests.

As disturbance events are generally considered to be part of the forest management cycle in the UK, monitoring mechanisms have not yet been established to provide comprehensive, geo-referenced, data on disturbance events. Background levels and margins for natural disturbances with potential to affect stand mortality have been estimated from historical data

sets combined with expert judgement, following the methodology set out in Chapter 2 of the 2013 Kyoto Protocol Supplement of the 2006 IPCC Guidelines.

The timeframes covered by the individual data-sets do not overlap in all cases, with the longest continuous data-set being 2000 to 2013 (for windstorms), which is taken as the calibration period. Where data are not available for individual disturbance categories, data-filling has used the mean over their individual calibration periods. Assumptions concerning salvage logging (see details under individual disturbance categories, below) has allowed emissions associated with salvage-logging to be excluded from the background emissions.

The avoidance of net credits/debits during the accounting period has been achieved through establishing a margin of twice the standard deviation of the sum of emissions resulting from each of the disturbance categories over the calibration period, both for Forest Management and Afforestation and Reforestation, separately. Monitoring of disturbance events in the future will also be more robust than the data-sets over calibration period, ensuring that all disturbances are geo-referenced and excluded from Forest Management, Afforestation or Reforestation activities for the duration of the Commitment Period, if the disturbance provision is enacted. Emissions resulting from disturbance events (after the exclusion of emissions from salvage-logging) have been estimated on the basis of instantaneous oxidation. In the event that the UK claims under the natural disturbance provisions, a technical correction will amend the FMRL to account for emissions associated with the natural 'factor' in question, to ensure the avoidance of net credits.

For Forest Management, carbon stocks and thus emissions (per hectare) are estimated on the basis of mean carbon stocks for conifers (295 $tCO_2e/ha$) and broadleaves (298 $tCO_2e/ha$), respectively, reported by the National Forest Inventory. With the exception of wildfire events (see below) carbon stocks associated with Afforested and Reforested land are assumed to be 20% of those of Forest Managed land, reflecting their younger growth phase.

The annual emissions from wildfire on Forest Management and Afforestation and Reforestation land reported in the UK's LULUCF GHG inventory have been used for the calibration period. 45% of biomass is assumed to be burned, with no distinction made between total carbon stocks on Forest Management and Afforestation and Reforestation land. Wildfire is apportioned to Forest Management and Afforestation and Reforestation on the basis of the ratio between the two forest categories. Salvage-logging is not assumed to occur on land affected by wildfire. The more detailed data recorded by the UK Fire and Rescue Services will be used if the disturbance provision was implemented during the second commitment period.

Data on pest and disease infestations came from Statutory Plant Health Notices (SPHNs) which are issued when felling is required to combat the infestation (published in Forestry Statistics). Restocking is not required following issuance of an SPHN; however it is strongly encouraged, supported by grant-aid and experience to date indicates that more than 99% of the area has been restocked either by planting or natural regeneration. 80% of the SPHN area has been allocated to Forest Management and 20% to Afforestation and Reforestation (expert judgement), with 80% salvage-logging assumed for Forest Management land and 20% for Afforestation and Reforestation land. Further surveillance is provided through the field survey associated with the National Forest Inventory across approximately 1,500-2,000 one hectare sample squares per annum.

Data on wind damage came from detailed records which the Forestry Commission holds on the wind throw damage to the 250 kha of land it manages in England which was extrapolated to the UK. It is assumed that Afforestation and Reforestation land is not affected by windstorm due the young age of the forest, with all emissions from Forest Management land. 80% salvage-logging is assumed to have occurred in conifer woodland and 50% in broadleaf woodland, based on experience from a severe windstorm in 1987 (Forestry Commission 1996). Remote sensing is being deployed more extensively to monitor woodlands in the UK as part of the National Forest Inventory. If the disturbance provision was enacted to cover a major

windstorm event, these data would be used to provide robust coverage, including geo-referencing across public and private woodlands.

Extreme weather – flood: It is considered highly unlikely that due to the relatively small-scale of UK catchments and their floodplains that flood events would be of such extent or ferocity to lead to widespread forest mortality and associated emissions.

Extreme weather – heavy, wet snow/ice: Significant ice-storm events have not been recorded in the UK. Likewise, the impact of heavy, wet, snowfall events is not considered significant as experience in the UK indicates that they damage forest crowns rather than causing widespread mortality.

Extreme weather – drought: In the UK, the choice of forestry species for planting takes the ability to withstand drought episodes into account and experience suggests that the level of mortality associated with a single summer drought event is limited. The main impacts are generally early senescence and reduced growth in the year of the drought and, often, subsequent years. Even in the best documented 'drought years' (1976 and 1995), stand level mortality was not observed and GHG emissions are likely to have been limited.

It is therefore assumed that emissions resulting from drought are included in the growth and yield models that underpin the LULUCF GHG inventory. A background level of zero has therefore been set over the calibration period. If a significant drought event occurred during the commitment period requiring that the disturbance provision was enacted, a bespoke report providing robust geo-referenced data would be elaborated.

Geological disturbance: No significant geological disturbances have occurred during the calibration period. Background emissions have therefore been set at zero.

Full details of the methodology used to assess background levels, margins and thresholds for emissions from natural disturbances is in the UK's Initial Report under the Second Commitment Period of the Kyoto Protocol (DECC, 2016).

### 11.4.5  Information on Harvested Wood Products under Article 3.3

Carbon stock changes in the HWP pool (Table 4(KP-I)C) are calculated on a first-order decay function basis for AR and FM forests and on an instantaneous oxidation basis for Deforestation, in accordance with the 2013 Kyoto Protocol Supplementary Guidance (see **Annex 3.4.10** for details). The HWP pool includes all domestically produced HWP since 1990.

## 11.5   ARTICLE 3.4

### 11.5.1 Information that demonstrates that activities under Article 3.4 have occurred since 1 January 1990 and are human-induced

All managed forests (planted on or before 31st December 1989) that have not been deforested since 1990 are included in Article 3.4 Forest Management. The CARBINE model is used to calculate emissions that have arisen from thinning, harvesting and restocking since 1990. The area under Forest Management is adjusted to reflect losses from deforestation, as recorded in **Section 11.1.2**.

Emissions from Article 3.4 Cropland Management since 1990 are calculated using agricultural census data and surveys of farming practices collected from 1990 onwards. Cropland is subject to intensive management interventions, and therefore any changes in carbon stock can be assumed to be human-induced.

Emissions from Article 3.4 Grazing Land Management are calculated using Countryside Survey data from 1990 onwards. Grazing land in the UK is all subject to management activity, and therefore it can be assumed that any changes in carbon stocks are human-induced.

## 11.5.2 Information relating to Forest Management

### 11.5.2.1 Conversion of natural forest to planted forest

It is assumed that no emissions arise from the conversion of natural forests to plantation forests. It has been a long-standing and on-going policy in the UK to restore areas of woodland historically converted to plantations back towards semi-natural woodland.

### 11.5.2.2 Forest Management Reference Level (FMRL)

The UK's Forest Management Reference Level (FMRL) during the second commitment period, as identified in the appendix to the annex to Decision 2/CMP.7, is -3.442 Mt $CO_2$ eq./yr, or -8.268 Mt $CO_2$ eq./yr when applying first order decay function for harvested wood products.

The forest management reference level for the UK was estimated using the same methodology for forest carbon stock changes and GHG emissions as the UNFCCC LULUCF inventory, the KP-LULUCF inventory and national projections of LULUCF emissions and removals. The methodology is described in **Chapter 6** and **Annex 3**. A technical correction to the FMRL was calculated for the latest inventory submission and is described below.

### 11.5.2.3 Technical Corrections of FMRL

The UK has calculated a technical correction (TC) to the FMRL for the current inventory. The FMRL submitted by the UK in 2011 was based on the 1990-2008 UK greenhouse gas inventory. A technical correction was submitted based on the last inventory, since when the following changes in data and assumptions necessitate a new technical correction for the current submission:

- A switch in the model used from CFlow to CARBINE – this model can represent a wider range of tree species and management practices, though the methodology of both models is consistent.

- Inclusion of the age structure of the pre-1921 forest area – the NFI is used to provide information of the age class distribution of the pre-1921 forest area.

- Change in tree growth assumptions – the information from the NFI is used to give a better indication of the mix of tree species in the UK forests and information from data on the public forest estate is used to give a better indication of the growth rate distribution by species.

- Change in the assumptions about harvesting rates – CFlow assumed all post-1921 forests were harvested according to a specific small range of rotation lengths for both broadleaves and conifers. This change in assumptions is not policy based, but based on additional information on the management practices on the public forest estate, and information about the quantity of timber harvested each year.

- Updated information on the rate of deforestation – based on administrative data on the conversion from forest as part of open habitat restoration and the building of wind farms.

- Adjustments to the activity data and forest management assumptions to better match reported wood production

- A correction to double counting in the calculation of deadwood

Replacing the yearly emissions due to wildfires with the Natural Disturbance Background Level.The Technical Correction was calculated using the CARBINE model (**Annex 3.4.1).** It is assumed that current management practices are continued into the future, and no allowance is made in the projection for changes in management practice, e.g. due to increased demand for bioenergy feedstock (which might involve shorter rotations or more intensive management of woodlands) or more widespread application of continuous cover management (which might

involve longer rotations). This also factors out the effects of post-2009 changes to policies affecting forest management. The proportion of harvested wood products assigned to the HWP categories is fixed at the 2009 level to factors out the effects of post-2009 changes to policies affecting HWP.

The following pools and gases are included in the corrected FMRL: carbon stock changes in above and below ground biomass, litter, deadwood, mineral and organic soils and harvested wood products, and $CO_2$, $CH_4$ and $N_2O$ emissions from biomass burning in wildfires. Further details are given in **Annex 3.4.** No pools are omitted from the reference level construction and there is no double counting. The pools included in the reference level are consistent with those reported in the KP and UNFCCC LULUCF inventories.

Historical and projected emissions and removals from 1990 to 2020 are shown in Table 11.7. These are consistent with the national GHGI in the latest submission, as they are based on the same activity data and use the same methods. Wildfire emissions are also shown, both historical and projected, as described in **Chapter 6** and **Annex 3.4**. Projections are based upon business as usual assumptions and are consistent with the approach taken in calculating the original FMRL. Projected estimates rely on the same methodology as that used for estimating historical emissions and removals.

**Table 11.7**      **Area under forest management and emissions/removals from forest management 1990-2020 (UK only, based on the latest inventory submission)**[*]

| Year | Area of FM land, kha | Net $CO_2$ emissions/ removals from carbon stock changes, Gg $CO_2$ | Natural disturbance background level, Gg $CO_2$eq | Emissions/ removals from HWP, Gg $CO_2$ | Net emissions/ removals, Gg $CO_2$eq |
|---|---|---|---|---|---|
| 1990 | 3032 | -15499 | 270 | -2017 | -17246 |
| 1991 | 3031 | -16173 | 270 | -1806 | -17709 |
| 1992 | 3030 | -16694 | 270 | -1823 | -18248 |
| 1993 | 3029 | -17113 | 270 | -1905 | -18748 |
| 1994 | 3028 | -17248 | 270 | -2071 | -19050 |
| 1995 | 3028 | -17625 | 270 | -2109 | -19465 |

| Year | Area of FM land, kha | Net $CO_2$ emissions/ removals from carbon stock changes, Gg $CO_2$ | Natural disturbance background level, Gg $CO_2$eq | Emissions/ removals from HWP, Gg $CO_2$ | Net emissions/ removals, Gg $CO_2$eq |
|------|------|------|------|------|------|
| **1996** | **3027** | **-18090** | **270** | **-2055** | **-19875** |
| **1997** | **3026** | **-18302** | **270** | **-2244** | **-20276** |
| **1998** | **3025** | **-18750** | **270** | **-2161** | **-20642** |
| **1999** | **3024** | **-18874** | **270** | **-2372** | **-20977** |
| **2000** | **3021** | **-19214** | **270** | **-2402** | **-21346** |
| **2001** | **3017** | **-19513** | **270** | **-2343** | **-21586** |
| **2002** | **3014** | **-19702** | **270** | **-2324** | **-21757** |
| **2003** | **3009** | **-19718** | **270** | **-2396** | **-21844** |
| **2004** | **3006** | **-19560** | **270** | **-2565** | **-21855** |
| **2005** | **3002** | **-19694** | **270** | **-2411** | **-21836** |
| **2006** | **3000** | **-19708** | **270** | **-2277** | **-21715** |

| Year | Area of FM land, kha | Net $CO_2$ emissions/ removals from carbon stock changes, Gg $CO_2$ | Natural disturbance background level, Gg $CO_2$eq | Emissions/ removals from HWP, Gg $CO_2$ | Net emissions/ removals, Gg $CO_2$eq |
|---|---|---|---|---|---|
| 2007 | 2996 | -19479 | 270 | -2344 | -21553 |
| 2008 | 2993 | -19809 | 270 | -2010 | -21549 |
| 2009 | 2990 | -19566 | 270 | -1919 | -21215 |
| 2010 | 2987 | -19297 | 270 | -2044 | -21071 |
| 2011 | 2984 | -18755 | 270 | -2348 | -20833 |
| 2012 | 2981 | -17443 | 270 | -3069 | -20241 |
| 2013 | 2979 | -17264 | 270 | -2703 | -19697 |
| 2014 | 2976 | -16861 | 270 | -2529 | -19120 |
| 2015 | 2973 | -16351 | 270 | -2511 | -18592 |
| 2016 | 2970 | -16184 | 270 | -2332 | -18246 |
| 2017 | 2967 | -15862 | 270 | -2172 | -17764 |

| Year | Area of FM land, kha | Net $CO_2$ emissions/ removals from carbon stock changes, Gg $CO_2$ | Natural disturbance background level, Gg $CO_2$eq | Emissions/ removals from HWP, Gg $CO_2$ | Net emissions/ removals, Gg $CO_2$eq |
|---|---|---|---|---|---|
| **2018** | **2964** | **-15484** | **270** | **-2113** | **-17327** |
| **2019** | **2961** | **-14995** | **270** | **-2094** | **-16819** |
| **2020** | **2959** | **-14543** | **270** | **-2109** | **-16382** |

[*] The OTs & CDs were not included in the original FMRL or the Technical Correction but would have an insignificant impact on the totals, with an increase of 13.5 kha, -33.6 Gg $CO_2$e from carbon stock changes, 3 Gg $CO_2$e from wildfires and -0.05 Gg $CO_2$ from HWP

For the business-as-usual projection standard management regimes (rotation lengths and thinning regime and felling regimes) are rolled forward, with the effect that harvesting rates are largely driven by historical planting rates. The pre-2010 policies included are the same as for the original FMRL submission. It is assumed that there were no significant effects from post-2009 policies in the area and age distribution.

The Technical Correction was calculated as $FMRL_{corr}$ - $FMRL_{orig}$ and is shown in Table 11.8.

**Table 11.8** **Forest Management Reference Levels and Technical Correction for the period 2013-2020.**

| | Assuming instantaneous Oxidation, Gg $CO_2$eq | With emissions/removals from HWP using first order decay functions, Gg $CO_2$eq |
|---|---|---|
| **Submitted FMRL (FMRL$_{orig}$)** | -3442 | -8268 |
| **Corrected FMRL (FMRL$_{corr}$)** | -15673 | -17993 |
| **Technical Correction** | -12231 | -9725 |

**11.5.2.4 Information related to the natural disturbances provision under Article 3.4**

The information in section 11.4.4 also applies here.

**11.5.2.5 Information on Harvested Wood Products under Article 3.4**

Carbon stock changes in the HWP pool are calculated on a first-order decay function basis for AR and FM forests and on an instantaneous oxidation basis for Deforestation (since 1990), in accordance with the 2013 Kyoto Protocol Supplementary Guidance (see **Annex 3.4** for details).

HWP are included in Forest Management in the second commitment period as the UK's FMRL was based on a projection.

Carbon stocks in HWP are estimated by CARBINE based on the time of planting, species yield class and management regime (**Annex 3.4.1**). HWPs are generated for all woodland that has been harvested since 1990. HWPs for land deforested before 1990 are not modelled and therefore not included, HWPs for land deforested since 1990 are accounted for on the basis of instantaneous oxidation.

### 11.5.3 Information relating to Cropland Management, Grazing Land Management and Revegetation, Wetland Drainage and Rewetting, if elected, for the base year

The UK has elected three additional Article 3.4 activities: Cropland Management, Grazing Land Management and Wetland Drainage and Rewetting. Emissions and removals from soils and biomass as a result of land-use change, management activities and wildfires are reported for both Cropland Management and Grazing Land Management.

The UK is not yet in a position to report emissions and removals from soils as a result of grassland management or from drainage of semi-natural Grazing Land on organic soils. Nor is it yet able to report on emissions and removals from other Wetland Drainage and Rewetting activities. The UK has a programme in progress to enable full reporting of these actvitities by the end of the commitment period (see box in section 6.5.8).

## 11.6    OTHER INFORMATION

### 11.6.1 Key category analysis for Article 3.3 activities and any elected activities under Article 3.4

Five categories are considered to be key: Article 3.3 Afforestation and Reforestation ($CO_2$), Article 3.3 Deforestation ($CO_2$), Article 3.4 Forest Management ($CO_2$), Article 3.4 Cropland Management ($CO_2$), and Article 3.4 Grazing Land Management ($CO_2$). These have been assessed according to the IPCC 2013 Kyoto Protocol Supplement Section 2.3.6. The numbers have been compared with key category analysis for the latest reported year based on level of emissions (including LULUCF).

*Article 3.3 Afforestation and Reforestation ($CO_2$)*: The associated UNFCCC category 4A (-18 365 Gg $CO_2$) is a key category and the AR component (i.e. its category contribution (-2 970 Gg $CO_2$) is also larger than the smallest UNFCCC key category (5B Biological treatment of solid waste). Removals from this category are also predicted to increase over time as a result of tree planting schemes partially focussed on climate change mitigation.

*Article 3.3 Deforestation ($CO_2$)*: The associated UNFCCC categories (4B, 4C and 4E) are key categories (11 080, -9 005 and 6 677 Gg $CO_2$ respectively), although the Deforestation category contribution (1 561 Gg $CO_2$) is not key on its own.

*Article 3.4 Forest Management ($CO_2$)*: The associated UNFCCC category 4A is a key category (-18 365 Gg $CO_2$). The Forest Management category contribution (-17 606 Gg $CO_2$) is also greater than other categories in the UNFCCC key category analysis.

*Article 3.4 Cropland Management ($CO_2$):* The associated UNFCCC category 4B is a key category (11 080 Gg $CO_2$e). The Cropland Management category contribution (11 872 Gg $CO_2$e) is also greater than the smallest UNFCCC key category.

*Article 3.4 Grazing Land Management ($CO_2$):* The associated UNFCCC category 4C is a key category (-9 005 Gg $CO_2$e). The Grazing Land Management category contribution (-6 289 Gg $CO_2$e) is also greater than the smallest UNFCCC key category.

## 11.6.2 Information relating to Article 6

Not applicable in the United Kingdom.

# 12  Information on Accounting of Kyoto Units

## 12.1  BACKGROUND INFORMATION

The UK's Standard Electronic Format report for 2019 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_2019_2_2.xls for commitment period 2.f

## 12.2  SUMMARY OF INFORMATION REPORTED IN THE SEF TABLES

### 12.2.1 Commitment Period 2

At the end of 2019, the total CP2 holdings for the UK Registry was 18,891,680 CERs, of which 3,259,735 were in the voluntary cancellation account. There was also a total of 2,903,076 ERUs.

In total for 2019, the UK Registry received 2,950,043 CERs and 4,844,889 ERUs. Conversely, 9,998,274 CERs and 92,579,904 ERUs were externally transferred to other national registries. No other CP2 units were transferred or acquired.

1,977,216 CERs and 1,771,612 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://unionregistry.ec.europa.eu/euregistry/GB/public/reports/publicReports.xhtml

| Annual Submission Item | Reporting Guidance |
|---|---|
| 15/CMP.1 annex I.E paragraph 11:<br><br>Standard electronic format (SEF) | UK's Standard Electronic Format report for 2019 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.<br><br>SEF_RREG1_GB_2019_2_2.xlsx (Commitment Period 2 only). |

## 12.3  DISCREPANCIES AND NOTIFICATIONS

| Annual Submission Item | Reporting Guidance |
|---|---|
| 15/CMP.1 annex I.E paragraph 12:<br><br>List of discrepant transactions | No discrepant transactions occurred in 2019.<br><br>This is confirmed in the table named "R2" in the Excel file included, |

| | SIAR Reports 2019-GB v1.0.xls |
|---|---|
| 15/CMP.1 annex I.E paragraph 13 & 14:<br><br>List of CDM notifications | No CDM notifications occurred in 2019.<br><br>Refer to Separate Electronic Attachment "SIAR Reports 2019-GB v1.0.xls" Worksheet R3. |
| 15/CMP.1 annex I.E paragraph 15:<br><br>List of non-replacements | No non-replacements occurred in 2019.<br><br>Refer to Separate Electronic Attachment "SIAR Reports 2019-GB v1.0.xls" Worksheet R4. |
| 15/CMP.1 annex I.E paragraph 16:<br><br>List of invalid units | No invalid units exist as at 31 December 2019.<br><br>Refer to Separate Electronic Attachment "SIAR Reports 2019-GB v1.0.xls" Worksheet R5. |
| 15/CMP.1 annex I.E paragraph 17<br><br>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<br><br>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://unionregistry.ec.europa.eu/euregistry/GB/public/reports/publicReports.xhtml<br><br>In accordance with the requirements of Annex E to Decision 13/CMP.1, all required information for a Party with an active Kyoto registry is provided with the exceptions as outlined below. |
| | Account Information (Paragraph 45)<br><br>In line with the data protection requirements of Regulation (EC) No 45/2001 and Directive 95/46/EC and in accordance with Article 110 of Commission Regulation (EU) no 389/2013, the information on account representatives, account holdings, account numbers, all transactions made and carbon unit identifiers, held in the EUTL, the Union Registry and any other KP registry (required by paragraph 45) is considered confidential.<br><br>JI projects in UK (Paragraph 46)<br><br>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://unionregistry.ec.europa.eu/euregistry/GB/public/reports/publicReports.xhtml<br><br>Paragraph 47 a/d/f - Holding and transaction information of units<br><br>Holding and transaction information is provided on a holding type level, due to more detailed information being declared confidential by EU Regulation. |

| Annual Submission Item | Reporting Guidance |
|---|---|
| | Article 110 of Commission Regulation (EU) 389/2013, provides that "Information, including the holdings of all accounts, all transactions made, the unique unit identification code of the allowances and the unique numeric value of the unit serial number of the Kyoto units held or affected by a transaction, held in the EUTL, the Union Registry and any other KP registry shall be considered confidential except as otherwise required by Union law, or by provisions of national law that pursue a legitimate objective compatible with this Regulation and are proportionate.." <br><br> Paragraph 47c <br><br> The United Kingdom is not hosting domestic JI projects as per paragraph 46 above. |
| | Paragraph 47e <br><br> The United Kingdom is currently not participating in any LULUCF projects for 2019. <br><br> Paragraph 47g <br><br> No ERUs, CERs, AAUs and RMUs have been cancelled on the basis of activities under Article 3, paragraphs 3 and 4 to date. <br><br> Paragraph 47h <br><br> 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. <br><br> Paragraph 47j <br><br> No ERUs and CERs have been retired in 2019 for CP2. <br><br> Paragraph 47k <br><br> 85,302,015 ERUs and 25,882,305 CERs were carried over from CP1 to CP2 in 2018. <br><br> Account holders authorised to hold Kyoto units in their account (Paragraph 48) <br><br> In line with the data protection requirements of Regulation (EC) No 45/2001 and Directive 95/46/EC and in accordance with Article 110 and Annex III of the Commission Regulation (EU) no 389/2013, the legal entity contact information (required by paragraph 48) is considered confidential. |

## 12.5 CALCULATION OF THE COMMITMENT PERIOD RESERVE (CPR)

| 15/CMP.1 annex I.E paragraph 18 <br><br> CPR Calculation | The Annex to Decision 11/CMP.1 (paragraph 6) specifies that: 'each Party included in Annex I shall maintain, in its national registry, a commitment period reserve which should not drop below 90 per cent of the Party's assigned amount calculated pursuant to Article 3, paragraphs 7 and 8 of the Kyoto Protocol, or 100 per cent of eight times its most recently reviewed inventory, whichever is lowest'. <br><br> 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

2017 Total Emissions*     **x**     Total years of the second commitment period

469,983,808     **x**     8

= 3,759,870,467

*Emissions total is taken the 2019 submission, including KP LULUCF.

Our rationale for using this figure is that the Report on the individual review of the annual submission of the United Kingdom of Great Britain and Northern Ireland submitted in 2016, para G.11 on page 19 states:

"The ERT recommends that the United Kingdom, when preparing the NIR, compare the 90 per cent of assigned amount value against the total GHG emissions, excluding LULUCF, in the most recent year."

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

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

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

# 14  Information on Changes to the National Registry

The following changes to the national registry of United Kingdom of Great Britain and Northern Ireland have occurred in 2019. Note that the 2019 SIAR confirms that previous recommendations have been implemented and included in the annual report.

| Reporting Item | Description |
|---|---|
| 15/CMP.1 annex II.E paragraph 32.(a)<br><br>Change of name or contact | None |
| 15/CMP.1 annex II.E paragraph 32.(b)<br><br>Change regarding cooperation arrangement | No change of cooperation arrangement occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(c)<br><br>Change to database structure or the capacity of national registry | There have been no new EUCR releases after version 8.2.2 (the production version at the time of the last Chapter 14 submission).<br><br>No change was therefore required to the database and application backup plan or to the disaster recovery plan. The database model is provided in Annex A.<br><br>No change to the capacity of the national registry occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(d)<br><br>Change regarding conformance to technical standards | No changes have been introduced since version 8.2.2 of the national registry (Annex B).<br><br>It is to be noted that each release of the registry is subject to both regression testing and tests related to new functionality. These tests also include thorough testing against the DES and are carried out prior to the relevant major release of the version to Production (see Annex B).<br><br>No other change in the registry's conformance to the technical standards occurred for the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(e)<br><br>Change to discrepancies procedures | No change of discrepancies procedures occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(f)<br><br>Change regarding security | No changes regarding security occurred during the reported period. |

| Reporting Item | Description |
|---|---|
| 15/CMP.1 annex II.E paragraph 32.(g)<br><br>Change to list of publicly available information | No change to the list of publicly available information occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(h)<br><br>Change of Internet address | The EUTL Public internet address changed during the reported period. The new URL is<br><br>https://ec.europa.eu/clima/ets/ |
| 15/CMP.1 annex II.E paragraph 32.(i)<br><br>Change regarding data integrity measures | No change of data integrity measures occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(j)<br><br>Change regarding test results | No change during the reported period. |

# 15 Information on minimization of adverse impacts in accordance with Article 3, paragraph 14

## 15.1 GENERAL OVERVIEW

The UK is committed to action aimed at minimising the impacts from climate change, including any adverse impacts resulting from action taken to mitigate climate change as outlined in Article 3, paragraph 14 of the Kyoto Protocol.

We continue to play a key role at the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC), and in December 2019 were formally appointed as the President for COP26, to be held in Glasgow in November 2020.

Central to our commitment to effective climate action is a continuation of the UK's ambitious domestic record of reducing our emissions while growing our economy, as well as our world-leading support for developing countries as they look to pursue low greenhouse gas emissions and climate resilient development.

In June 2019, the UK government set a legally binding target to achieve net zero greenhouse gas emissions from across the UK economy by 2050. We are the first major economy in the world to legislate for a net zero target, which will end the UK's contribution to climate change. Since setting a net zero target, the Government has committed around £2 billion to support clean growth in a range of sectors from transport to industry. In July, we published our landmark Green Finance Strategy, setting out our approach to catalysing the investment in green infrastructure, technologies and services that will be needed to deliver net zero.

As well as seeking to prevent further climate change, we continue to help those already most affected by it. At the UN Climate Action Summit, the Prime Minister announced that the UK will be doubling its International Climate Finance (ICF) to £11.6 billion between 2021-2025 to help countries cut emissions, improve resilience, and reduce deforestation.

The UK's ICF portfolio has already: helped 57m people cope with the impacts of climate change; provided 26m people with improved access to clean energy; reduced/avoided 16m tonnes of GHG emissions ($tCO_2e$); and supported the installation of 1600 MW of clean energy capacity. [86]

Whilst the UK is unwavering in our commitment to climate action, we look to implement policies and measures in such a way as to maximise the positive and minimise the negative impact on our international partners – in line with obligations under Article 3, paragraph 14 of the Kyoto Protocol, and consistent with paragraph 4.15 of the Paris Agreement. This chapter sets out the steps we take in this regard.

This chapter has been updated for the 2019 NIR submission. Changes include:

- An update on research programmes in 15.2.1;
- An update on International Climate Finance in 15.2.3;
- An update on Knowledge Transfer in 15.2.4;
- An update on Research Collaboration in 15.2.5;

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[86]https://www.gov.uk/guidance/international-climate-finance#our-results

- An update on Capacity Building and Technology Transfer projects on Renewable Energy and Energy Efficiency in 15.2.6;
- An update on capacity building projects on adapting to climate change in 15.2.7; and
- An update on Energy Market Reforms in 15.2.8;

## 15.2   UNDERSTANDING IMPACTS OF RESPONSE MEASURES

Understanding the impacts of response measures is a key step to minimising the adverse impacts. The UK continues to undertake assessments, reviews, and analysis to better understand the impacts its policies could have on developing countries, and how they could be addressed. Consequently, the UK takes these findings and seeks to apply them in the UK and through our international engagement to minimise adverse impacts, in accordance with article 3, paragraph 14. Recent examples of areas where ongoing research and action is taking place are outlined below.

### 15.2.1 UK research, reports, and analysis

The UK has undertaken research to determine the extent of impacts of response measures and uses this information to implement policies in a way that takes into account the impacts of response measures on all developing countries. Examples of ongoing work are listed below.

- BEIS recently published a review of the available scientific evidence to assess the co-benefits and possible adverse side effects of climate change mitigation[87].BEIS recently funded two major programmes of research to produce research to feed into the IPCC Special Report on Global Warming of 1.5°C. This included analysis of 1.5-degree pathways and the limitations and possible impacts of 1.5-degree consistent mitigation options (for example widespread deployment of Bioenergy and Carbon Capture and Storage[88]). The UK continues to fund a major programme of research into greenhouse gas removal technologies, which includes an exploration of the challenges and limitations of such technologies[89].

To support the UK 2050 Pathways Analysis the Department for Business, Energy, and Industrial Strategy (BEIS) developed a 2050 Energy and Emissions Calculator model. The Calculator is an award-winning, user-friendly model that allows the user to create their own UK emissions reduction pathway, and see the impact using real scientific data. This model is currently being updated and will have new functionality added. Over the last five years, BEIS has supported countries around the world to develop their own calculators to explore their options to reduce greenhouse gas emissions and help tackle energy challenges.

- An International Climate Finance programme has directly supported teams in India, Indonesia, Brazil, Mexico, Colombia, Nigeria, South Africa, Vietnam, Thailand, and Bangladesh. These ten countries have now published finished calculators online. Many other countries have also adopted the model, for example China, Japan, and Austria.
- There is evidence that the models have had a policy impact. For example, four countries (India, Colombia, Vietnam, and Nigeria) used their calculators to help develop

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[87] https://www.gov.uk/government/publications/climate-change-mitigation-the-co-benefits-and-possible-adverse-side-effects

[88] http://iopscience.iop.org/article/10.1088/1748-9326/aaaa02/meta

[89] https://nerc.ukri.org/research/funded/programmes/ggr/

their Intended Nationally-Determined Contributions (INDCs) for the UNFCCC conference in Paris.

- BEIS is now extending this programme, providing an additional £3.5 million over three years. This will allow a further five countries to create their own Calculator models, and support updates to Calculators in developing countries that have already been developed.
- BEIS, working in collaboration with a number of other organisations, built a Global Calculator in 2015, which enables users to explore the options for reducing global emissions, and the impacts of climate change associated with them.[90]

Following on from the Gallagher review in 2008, the UK Department for Transport (DfT) has and continues to lead work into understanding Indirect Land-Use Change (ILUC) impacts from biofuels. For example, on the basis of the review and emerging evidence, the UK decided to promote the transition from crop-based to waste-derived biofuels, including double rewards for waste-based biofuels and a cap on crop-based biofuels. DfT continues to review evidence and support research into the area to ensure we promote biofuels with the highest possible greenhouse gas savings, including when indirect land-use change impacts are taken into account.

The UK Department for the Environment, Food and Rural Affairs (Defra) has funded and continues to fund research looking at embedded emissions and sustainable production and consumption, in particular:

- The development of an embedded carbon emissions indicator. The aim of this project is to monitor greenhouse gas emissions associated with UK consumption, including those relating to trade flows. This work will provide a high level analysis of the UK national "carbon footprint", and in particular will assess the emissions which are embedded in products which the UK imports and exports[91].

## 15.2.2 Actions to minimise adverse impacts in accordance with Article 3, paragraph 14

The UK Government supports the historic agreement reached in the 21st UNFCCC Conference of Parties in Paris in December 2015. The Paris Agreement is a significant step forward on our path to limiting global temperature rises to below 2°C, and agrees to pursue efforts towards 1.5°C. The Agreement also recognises the role of both developed and emerging economies in helping the poorest and most vulnerable to curb emissions whilst developing and to protect themselves from the worst effects of climate change. The transition to a low carbon world requires support to developing countries in their domestic efforts to mitigate and adapt to climate change and to develop their own low carbon economies.

The UK has taken action to minimise adverse impacts in accordance with article 3, paragraph 14 through its International Climate Finance (ICF) and other international action.

## 15.2.3 International Climate Finance

Recognising the growing importance and urgency of tackling climate change and its impact on growth and poverty reduction, the UK committed to provide at least £5.8 billion of International Climate Finance from 2015/16 to 2020/21 and in September 2019 announced a further doubling to £11.6 billion from 2021/22 to 2025/26. At the UN Climate Action Summit in

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[90] http://tool.globalcalculator.org

[91] http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=17729&FromSearch=Y&Publisher=1&SearchText=emissions&GridPage=7&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

September 2019, the Prime Minister announced that the UK will be doubling its International Climate Finance (ICF) to £11.6 billion between 2021-2025 to help countries cut emissions, improve resilience and reduce deforestation. Recognising that adaptation is a priority for many developing countries, the UK aims for an even split in its adaptation and mitigation spend. This commitment reflects our view that climate change is the biggest threat to the long-term eradication of global poverty, and that the impacts of climate change will hit the poorest hardest. At the Summit we announced major new investments in both clean energy and a range of actions and investments to strengthen resilience and adaptation.

The UK's ICF is supporting a portfolio of investments managed by the Department for International Development (DFID), BEIS, and Defra. It aims to support international poverty eradication now and in the future by helping developing countries to manage risk and build resilience to the impacts of climate change, take up low-carbon development at scale, and manage natural resources sustainably.

To achieve this, the UK ICF delivers transformational change through well-targeted finance. For example, it helps to pay the incremental cost of making infrastructure investments climate smart and avoid lock-in of high carbon technologies, supports agriculture which is more resilient in the face of climate events such as drought and also incentivises countries to reduce deforestation and promote sustainable land-use. This demonstrates that low-carbon, climate resilient development paths are viable and compatible with economic growth and poverty alleviation.

Cumulative data that we collect show that, between 2011/12 and 2018/19, UK ICF programmes have[92]:

- Supported 57 million people to cope with the effects of climate change;
- Provided 26 million people with improved access to clean energy;
- Reduced or avoided 16 million tonnes of greenhouse gas (GHG) emissions ($tCO_2e$);
- Installed 1,600 MW of clean energy capacity; and
- Mobilised £3.8 billion public and £1.4 billion private finance for climate change purposes in developing countries.

Through its ICF, the UK is supporting a number of bilateral and multilateral programmes, including (but not limited to) the following examples:

**The Green Climate Fund –** Since becoming operational in 2015 the Green Climate Fund (GCF) has become the key multilateral climate fund with a mandate to make 'an ambitious contribution to the global efforts towards attaining the goals set by the international community to combat climate change'. The UK is a strong supporter of the GCF, having committed £720 million for the initial resource mobilisation period, and is committed to ensuring that the GCF delivers maximum impacts in the developing countries it supports. The GCF is now entering into its first replenishment period (2020-2023). In 2019, the UK has committed to double its contribution to the GCF to £1.44 billion making it the fund's lead donor and demonstrating our ongoing commitment to the GCF over the coming four years (2020-2023).

The GCF funds transformational projects with a strong focus on leveraging private finance, with a commitment to provide 50% of its resources for mitigation and 50% for adaptation. At least 50% of its adaptation support will be provided to particularly vulnerable countries including Least Developed Countries (LDCs), Small Island Developing States (SIDS) and African States. In the past year, the GCF has made significant progress in terms of programming, tightening its policy framework, and building the Secretariat's capacity. So far,

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[92] https://www.gov.uk/guidance/international-climate-finance#our-results

the GCF has committed $55.6 billion of funding to 124 projects, representing a balanced geographical and thematic split, and has a dedicated private sector facility.

Projects approved by the GCF, including $833 million to Small Island Developing States, are expected to increase the resilience of 348 million beneficiaries. **The Nationally Appropriate Mitigation Action (NAMA) Facility** is a multi-donor programme supported by the UK, working in partnership with the German Federal Ministry for the Environment (BMUB), Denmark and the European Commission. **NAMAs** refer to any action that reduces emissions in developing countries and is prepared under the umbrella of a national governmental initiative and are often the building blocks to achieving NDCs. They can be policies directed at transformational change within an economic sector, or actions across sectors for a broader national focus. The Facility seeks to support and fund the implementation of the most transformational parts of the NAMAs. It has an open application process, welcoming projects across a diverse range of sectors and geographies.

Since 2012, 20 climate mitigation projects across 16 countries have been supported, with each project chosen for its ability to catalyse change in the sector. To support this demand the UK has committed over £245 million into the Facility.

**Climate Investment Funds (CIF)** The UK is the largest investor in the $8.5 billion Climate Investment Funds (CIFs), having invested over $2.5 billion since 2008, to demonstrate low-emission and climate resilient development through projects implemented by the multilateral development banks. The CIFs now operate across 72 countries and have a total portfolio of 310 projects. CIF finance is enabling the construction of the equivalent of over a quarter of the current globally installed geothermal and concentrated solar power. The projects are unlocking finance flows in the green markets of developing countries and are expected to generate $58 billion of co-financing.

**The Clean Technology Fund (CTF)** Of the four funds that sit under the Climate Investment Fund, the UK has contributed £900 million, between 2011/12 and 2018/19, to the Clean Technology Fund (CTF). The CTF provides concessional finance and technical assistance delivering significant development benefits, such as increased energy security, reduced local air pollution, and job opportunities. It has supported national governments to identify and implement ambitious low carbon investment plans and helped demonstrate technologies and create markets. South Africa's KaXu Solar One Concentrated Solar Power project, with funding from the Clean Technology Fund, has recently been awarded a *Momentum for Change Award* by the UNFCCC for its innovative and game-changing approach to climate change and wider economic, social and environmental challenges.

**The Scaling up Renewable Energy Programme (SREP)** is another of the four Climate Investment Funds. The UK has provided £268m to SREP, which aims to stimulate energy access and economic activity by working with governments to build renewable energy markets and support productive uses of energy at the household level. As of June 2019, SREP had endorsed investment plans for 2219 pilot countries. Expected results under approved projects, and the Fund's Private Sector Set Aside, include an estimated 3.3 gigawatt hours (GWh) of electricity to be generated annually from renewable energy sources (equivalent to the annual electricity production of Armenia) and new or improved access to clean, modern energy services for 8.4 million people (approximately the population of Malawi). The total estimated greenhouse gas (GHG) emissions to be avoided are approximately 2.4 million tons $CO_2e$/yr.

**Pilot Programme for Climate Resilience (PPCR)** The UK is the largest contributor to the $1.2 billion Pilot Programme for Climate Resilience (PPCR), one of the four Funds that sit under the CIF. The PPCR assists governments with the integration of climate resilience into development planning and pilots innovative public and private solutions to climate-related risks, primarily in Least Developed Countries or Small Island Developing States. For example, a $15.75 million project in Mozambique will develop climate resilient infrastructure to improve the ability of 8,200 farming families to withstand extreme weather events.

**Least Developed Countries Fund (LDCF)** The UK has been a long-standing contributor to LDCF, which supports LDCs in developing their National Adaptation Programmes of Action (NAPAs) and funding the resultant programming. Since inception the UK, through DFID has contributed £122m to LDCF. The most recent contribution was £30 million from December 2016 to March 2019. The Project Completion Report in 2019 demonstrated LDCF had performed well. Cumulative results achieved under the LDCF portfolio, since inception i.e. including projects completed before FY18, comprise more than 15.5 million direct beneficiaries, over 1.75 million hectares of land under more climate-resilient management, and some 420,000 people trained in aspects of planning and implementing resilience strengthening activities.

**The Global Environment Facility (GEF)** The GEF is the principal multilateral agency supporting developing countries in tackling major environmental problems and supporting implementation of the international agreements covering biodiversity (including wildlife loss), land degradation, deforestation, chemical pollution, marine and freshwater degradation – including marine plastic - **and climate change**. Since its inception in 1991 the GEF has supported management of more than 3,300 protected areas covering 860 million hectares (an area larger than Brazil), 790 climate change mitigation projects contributing to 2.7 billion tonnes of greenhouse gas emission reductions, sustainable management of 34 of the world's major river basins, and provided $131m to the Global Wildlife Programme to tackle the illegal wildlife trade.

GEF supported activities will achieve outputs across a range of environmental sectors. The GEF is financed through 4-yearly replenishments. The current, seventh replenishment started in 2018 and will end in June 2022 and is funded by DFID and Defra . The GEF7 replenishment period has a total donor endorsement of $4.1 billion (UK has 10.07% burden share of the total). Of this total, the UK is contributing up to £250m (£100m/40% Defra and £150m/60% DFID); 20% of which will attract payment by results.

The expected direct results from GEF 7 include, 200 million hectares of terrestrial protected areas created or under improved management for conservation and sustainable use; 8 million hectares of marine protected areas created or under improved management; 6 million hectares of degraded land restored; 1,500 million metric tons of $CO_2e$ of greenhouse gas emissions mitigated; and 100 thousand metric tons of toxic chemicals of global concern reduced. GEF funded projects seek to provide broader transformative effect through demonstrating approaches that can be replicated and scaled up elsewhere.

**Reduce Emissions from Deforestation and forest Degradation (REDD+)** is a framework agreed under the UNFCCC to *Reduce Emissions from Deforestation and forest Degradation* and enhance forest carbon stocks (+) in developing countries. It aims to demonstrate the potential of a land-use paradigm that delivers large-scale forest protection alongside sustainable agricultural practises. The UK will continue to support "jurisdictional" REDD+ results-based finance that unlocks key barriers in the enabling environment and mobilises private finance, including the examples below:

- The UK has committed £141.5 million to the Forest Carbon Partnership Facility Carbon Fund, the world's biggest fund for forest carbon. It is a payment for results mechanism, designed to incentivise ambitious actions to reduce deforestation through payments for verified emission reductions generated by jurisdictional REDD+ programmes. There are 18 country programmes in the Carbon Fund portfolio.
- The UK also supports the BioCarbon Fund with £115 million. This fund combines upfront technical assistance with results-based finance, rewarding countries which implement landscape-level approaches that reduce emissions from agriculture, forests and other land-use. It also aims to catalyse investments from the private sector, recognising that many companies along the supply chain of commodities (such as palm oil) have committed to zero-deforestation sourcing.

**REDD for Early Movers** The UK has committed £73 million to the **REDD Early Movers** programme which is an accelerator for the most ambitious and committed countries to reduce emissions from deforestation. REM rewards countries that are already successful in driving down deforestation trends, with finance re-invested in agreed activities to deliver further results. UK support focusses on Colombia's goal to stabilise deforestation in its Amazon region, as well as programmes to decouple increases in production from forest loss in two Brazilian States – Acre and Mato Grosso.

The £104 million **Partnerships for Forests** (**P4F**) programme, focusing in South America, West, Central and East Africa, and Southeast Asia, brings together the private sector, governments, and local communities to create market-ready partnerships for sustainable forestry and land-use P4F provides seed grant finance to early stage businesses to help accelerate the commercial scale up of sustainable farming and forestry enterprises. It supports businesses where the private sector, public sector and communities work together to protect forests while providing sustainable livelihoods. This works alongside BEIS' other climate finance support for governance and policy implementation through REDD+ and climate partnerships with key countries; to build the business conditions to grow sustainable rural economies in areas affected by deforestation.

**The Sustainable Infrastructure Programme** In 2017 the UK established the Sustainable Infrastructure Programme (SIP) in Latin America in partnership with the Inter-American Development Bank. The purpose of the programme is to enable and accelerate the implementation of the Nationally Determined Contributions in Latin America, initially Brazil, Colombia, Mexico and Peru, focusing on supporting and catalysing private sector investments in low carbon infrastructure. The UK will provide up to £177.5 million from its ICF budget over 5 years to provide technical and financial support. This can include technical assistance to governments to help them shape their regulatory frameworks in a way that is attractive to private investors, support the development of local capital markets, while also investing in a few demonstration projects to showcase the commercial viability of sustainable infrastructure.

**UK Climate Investments (UKCI)** UKCI is a joint venture between the Green Investment Group and the UK Government Department for Business, Energy and Industrial Strategy. UKCI invests in renewable energy and energy efficiency projects across sub-Saharan Africa and India to demonstrate that low carbon development is possible, replicable at scale, commercially viable and capable of supporting economic growth, poverty reduction and lowering carbon emissions. UKCI is mandated to invest up to £200m of UK International Climate Finance over an initial investment period of 2015-2019.The fund provides late-stage minority equity investments on a commercial basis to help get projects off the ground that would not otherwise reach financial close.

Completed investments to date include:

- 50GW utility-scale solar project in Maharashtra, India
- India's first renewable yield company (or yieldco), an innovative financial structure that pools solar energy assets to provide secondary market funding and free up developers' capital for new renewable energy projects.
- The financing of two wind projects and one small-hydro project in South Africa via the participation of a Black Economic Empowerment (BEE) party.

**The Renewable Energy Performance Platform (REPP)** - REPP seeks to mobilise private sector development activity and investment in small and medium scale renewable energy projects (up to 25MW, or up to 50MW for wind power) in sub-Saharan Africa. REPP aims to increase the number of sound 'bankable' smaller renewable energy projects by assisting project proponents throughout the project development stage by providing technical assistance, access to risk mitigation instruments, and pre-construction finance, and providing

post-construction finance where needed. The UK has committed £148m to the programme to 2023.

**The Climate Public Private Partnership (CP3)** a £130 million programme that aims to support clean energy and demonstrate the commercial viability of investments in climate-related businesses in emerging markets. By anchoring two private equity funds – i.e. providing committed investment into these funds to help attract additional investors – the programme has so far mobilised private climate finance of $103 million (attributable to the UK). The funds have so far invested in 102 investments and renewable energy developers across developing countries in Asia, Africa and South and Central America. CP3 is expected to avoid 8 million tonnes of $CO_2$ equivalent over its lifetime (to 2026).

**The Climate Leadership in Cities (CLIC) Programme** is a £27.5 million UK Government initiative launched at the end of 2017, which supports developing country cities to unlock ambitious climate action. The programme was developed in recognition of the fact that, with the majority of the world's population living in urban areas, and cities accounting for more than 70% of global $CO_2$ emissions, climate leadership in cities is critical in delivering the Paris Agreement. The programme contains three components:

- Technical assistance for 15 megacities in Latin America and Asia to develop ambitious climate action plans consistent with the Paris Agreement, delivered by C40.
- Expanding the C40 Cities Finance Facility, jointly implemented by C40 and GIZ, through which cities bid for technical assistance to develop investable business cases for climate action.
- Global research and national advocacy (with country programmes in China and Mexico, and a global workstream) to help remove barriers to city action, delivered by the Coalition for Urban Transitions.

The **Global Climate Partnership Fund (GCPF)** uses a £49 million investment by the UK, combined with investments from other donor governments, as a risk cushion so that it can raise capital from development institutions, institutional investors and the private sector. To date it has raised over $600 million. The GCPF then provides lines of credit to local banks in developing countries so they can on-lend to their clients for renewable energy and energy efficiency investments. The clients are small and medium-sized enterprises and households and their investments range from high-efficiency household appliances to light industrial equipment. GCPF can also invest directly in larger sale projects.

The UK also funds the GCPF's technical assistance facility with £6m, which supports the local banks to open up new green lending markets, establish $CO_2$ reporting facilities and so on. The GCPF has now invested in over 20 countries in Latin America, Africa and Asia. Its partners have issued over 55,000 sub-loans, amounting to over 10 million tonnes of $CO_2$ saved over the lifetime of the loans.

The **Market Accelerator for Green Construction (MAGC)** is a £106.1 million global programme launched at the end of 2018 in partnership with the International Finance Corporation. The Fund aims to drive the financing and construction of more energy efficient buildings in emerging economies. Buildings account for around a fifth of global greenhouse gas emissions and improving building design and construction will play an important role in avoiding climate change and meeting our Paris Agreement goals.

By providing a package of technical assistance and blended finance, the programme will work with banks to establish new green construction finance services that will help crowd in private finance while encouraging developers to adopt greener construction practices, thereby developing clean growth markets in emerging economies. A significant research component will also aim to develop a robust evidence base that can be used to further enhance green building standards and motivate the wider uptake of greener construction over existing approaches.

**The Climate Finance Accelerator (CFA)** is a £10m technical assistance programme which supports developing countries to translate their Nationally Determined Contributions (NDCs) – commitments made under the Paris Agreement – into 'climate investment plans', which consist of a pipeline of bankable, low-carbon projects. It does this by bringing together policy makers, project developers and capital market players from developing countries with green finance experts from the City of London to learn from each other in workshops. Participants take low-carbon project ideas, identify barriers to finance, find potential solutions, and turn them into investable proposals. By finding ways to improve the enabling environment for private finance, countries can then unlock flows of capital at the scale required to meet their NDC targets. The CFA was tested in series of successful pilot activities, involving Colombia, Mexico and Nigeria, which took place between 2017 and 2019. The full programme was announced in January 2020, with activities set to commence later in the year.

**The NDC Partnership (NDCP)** is a coalition of countries and institutions working to turn countries' NDCs into specific strategies and measures, as well as achieving greater harmonisation between development assistance and NDC implementation efforts. The Partnership adopts a flexible, country-driven approach that helps governments set out priorities and connect them to available resources across its membership. BEIS has provided £2m of funding in the past. BEIS recently extended our contribution by providing between £11m and £17m to the NDCP. £4m of this will be spent directly on the Climate Action Enhancement Package (CAEP). CAEP was launched at the UNCAS and is directly funding and mobilising funding for projects that help countries update and implement their NDCs in 2020. Demand for NDCP's services is now outstripping supply – originally the Support Unit planned to work in 38 countries at a time. They are currently working in over 40 with plans to expand to 60 in the coming year.

**UK PACT (Partnering for Accelerated Climate Transitions) -** Set up in 2018, **UK PACT** is a £60 million technical assistance programme designed to support clean growth transitions in developing countries. Through demand-driven technical assistance projects, long term secondments and short-term skill shares, the programme works to increase capacity and capability in partner countries to reduce carbon emissions in line with their commitments under the Paris Agreement. UK PACT works in areas of UK low-carbon expertise, including green finance, climate legislation, and energy market reform. The programme is currently working in Colombia and Mexico across multiple demand-led areas, as well as in China (solely on green finance). UK PACT plans to expand to four new countries in Africa and Asia in the next two years.

In addition to the direct assistance the UK provides to developing countries through our climate finance programmes listed above, the UK recognises that **the scale of the challenge will require a broader effort at all levels to align financial flows with the goals of the Paris Agreement**. Ensuring climate and environmental factors are fully integrated into mainstream financial decision making across all sectors and asset classes is essential to achieving this.

**In July 2019 the UK published its Green Finance Strategy**. This sets out how we will be driving the growth of Green Finance, by aligning private sector financial flows with clean, environmentally sustainable and resilient growth. This includes for example:

- committing to align all UK ODA with the Paris Agreement
- setting out an expectation for all listed companies and large asset owners to disclose in line with the TCFD recommendations by 2022
- CDC and UK Export Finance will make climate-related financial disclosures in their accounts in line with the TCFD recommendations as soon as practicable, following the close of the 2020/21 financial year

- working with industry and the British Standards Institution to develop a set of Sustainable Finance Standards, and chairing a new International Organisation for Standardisation (ISO) Technical Committee on Sustainable Finance

The UK will use its global influence to explore and accelerate approaches to the alignment of financial flows, including through our role as founding members of the Coalition of Finance Ministers for Climate Action, and the milestones of COP26 and our subsequent G7 presidency.

## 15.2.4 Knowledge transfer

Knowledge transfer can help accelerate the development and deployment of low-carbon and climate resilient technologies to help developing countries mitigate and adapt to climate change.

The UK supports the Technology Mechanism (TM), as agreed at COP16 in Cancun 2010, and we are already involved with several knowledge transfer initiatives. In addition to the UK's long-standing involvement in initiatives such as the Climate Technology Initiative, recent actions in this area include:

- The UK-funded Global Network of Climate Innovation Centres programme, which provides funding to the World Bank's Climate Technology Programme (CTP) to support the design, implementation, and international coordination of Climate Innovation Centres (CICs) in developing countries. The programme assists local entrepreneurs to develop innovative technology and business solutions to domestic energy, resource and environmental challenges.

The UK also supports CICs in Ethiopia and Vietnam through bi-lateral programmes, while there are additional non-DFID supported CICs in South Africa, the Caribbean, Ghana and Morocco. The programme helps gather evidence on climate technology innovation in developing countries, enabling national CICs to respond to technology trends.

- DFID has committed approximately £103m to the Climate and Development Knowledge Network (CDKN) which is generating and sharing knowledge and building the capacity of developing country decision-makers to design and deliver climate-compatible development policies and programmes. The CDKN does this by providing access to high quality, demand-led technical assistance, research, capacity building, knowledge management and climate negotiation support to support policy and implementation processes at the country and regional level. CDKN has four priority thematic areas which helps prioritise its work across its three focus regions (Africa, Asia and Latin America). These are:
  - o Climate compatible development (CCD) strategies and plans;
  - o Improving developing countries' access to climate finance;
  - o Strengthening resilience through climate-related disaster risk management (DRM); and
  - o Supporting climate negotiators from the Least Developed Countries.

- The UK has a detailed monitoring system in place for capturing results delivered through the ICF portfolio. ICF has a Monitoring, Evaluation and Learning programme that aims to further enhance the monitoring system and generate evidence and knowledge from the portfolio.

## 15.2.5 Research collaboration

Enhancing global collaboration on research, development and demonstration (RD&D) will be essential to ensure innovation and take-up of climate technologies in developing countries. The UK is cooperating in the technological development of non-energy uses of fossil fuels and doing so in partnership and supporting developing countries. We are exploring opportunities

to support RD&D 'gap-filling' activity on climate technologies (both for mitigation/low carbon development and adaptation activities).

The UK will continue to play a leading role in international research efforts to reduce the costs of low carbon energy, working with other countries to strengthen collaboration and transparency in clean energy research, development, and demonstration.

Since 2015, the UK has played a leading role in Mission Innovation, an international initiative which aims to accelerate clean energy investment and innovation in order to provide reliable and affordable energy for all. In line with the Mission Innovation pledge, the Government committed to double the UK's energy innovation spend, such that by 2021 it will have doubled to over £400m per year.

The UK is participating in all seven of the Mission Innovation "Innovation Challenges" and co-leads the affordable heating and cooling of Buildings Innovation Challenge alongside the European Commission and United Arab Emirates. These challenges are aimed at catalysing global research efforts in areas that could provide significant benefits in reducing greenhouse gas emissions, increasing energy security, and creating new opportunities for clean economic growth.

At the UN Climate Action Summit in New York, the Prime Minister announced a £1bn Ayrton Fund for clean energy research development and demonstration (RD&D) from 2021-26. The Ayrton Fund will almost double the Official Development Assistance (ODA) investment across UK Government in clean energy innovation and will enhance the UK's global leadership in this area. Emerging technology areas to be supported include, for example energy storage, new sustainable cooling technologies, next generation solar, and technologies for industrial decarbonisation.

International engagement is a significant part of the Avoiding Dangerous Climate Change Research Programme (AVOID). For example, the first phase of the programme investigated technology options for reducing $CO_2$ emissions from the energy sector in India and China to meet national 2050 emissions targets consistent with limiting global temperature rise to below 2°C. It then shared these results with Indian and Chinese officials at international workshops. The second phase of AVOID involved extensive engagement with international researchers and officials on a range of issues, including regional climate impacts, feasibility of energy sector decarbonisation, and the potential role of land-use in both mitigating and contributing to climate change.

The UK is playing a leading role in providing technical assistance on Carbon Capture, Usage & Storage (CCUS) to developing countries and emerging economies. The UK has committed up to £70 million of International Climate Finance since 2012 to raise the technical and institutional level of understanding of CCUS within fossil fuel-intensive countries, such as Mexico, South Africa, China and Indonesia. UK funding is provided through the World Bank CCUS Trust Fund (£35 million) and the Asian Development Bank CCUS Fund (£35 million), and the UK is the largest ODA donor to CCUS globally. This funding is supporting the establishment of the necessary regulatory and policy frameworks, technical knowledge and incentive structures to enable demonstration and ultimately accelerate the deployment of CCUS. It has supported activities such as feasibility studies, pilot projects, CCUS Centres of Excellence, running training workshops, and facilitating knowledge-sharing activities.

The UK is an active member of key international CCUS fora: the CCUS Initiative under the Clean Energy Ministerial, the Carbon Sequestration Leadership Forum (CSLF), the IEA Greenhouse Gas R&D programme, and co-leads the CCUS Challenge under Mission Innovation (alongside Mexico and Saudi Arabia). The UK co-hosted the International CCUS Summit and Conference with the IEA in November 2018, hosted a CCUS side event in the UK Pavilion at COP24 and COP25, and actively participates in COP events on CCUS.

The UK provided £35m in 2015/16 to the CGIAR consortium of 15 agriculture research centres. Research conducted by the CGIAR has underpinned global agriculture development since the green revolution. Over 60% of modern plant varieties grown in developing countries have CGIAR ancestry and 30% of global yield growth between 1965 and 1998 can be attributed to plant genetic improvement by the CGIAR. A significant part of the UK support to the CGIAR will develop the next generation of agricultural technology which has the potential to lead to further increases in agricultural productivity, improve the resilience of small-holder agriculture and improve the nutrition and food security of poor people in developing countries.

## 15.2.6 Capacity Building and Technology Transfer projects on Renewable Energy and Energy Efficiency

The world needs increasing energy supplies to sustain economic growth and development. However, energy resources are under pressure and $CO_2$ emissions from today's energy use are already changing the climate. It is necessary to accelerate the deployment of low carbon energy technologies and increase energy efficiency to address the global challenges of energy security, climate change and economic development. The following are some examples of the technology transfer activities that the UK undertakes (not an exhaustive list):

- **Carbon Capture, Usage and Storage (CCUS)**: Since 2012, the UK has provided £70 million to support developing countries and emerging economies to build the technical and institutional knowledge necessary to enable the deployment of CCUS technologies. CCUS development and deployment is crucial for meeting the 'well-below' 2°C target set out under the Paris Agreement. The programme aims to raise the level of knowledge of CCUS in key countries, such as Mexico, South Africa, China and Indonesia, leading to the establishment of the necessary regulatory and policy frameworks to support CCUS demonstration and ultimately accelerate the deployment of CCUS.
- **The Clean Technology Fund (CTF)**, to which the UK is the largest contributor (providing £701 million), has demonstrated and deployed low carbon technologies at scale. Examples include supporting the first generation of utility scale Concentrated Solar Power (CSP) plants to be built in developing countries, with the plant in South Africa now providing power to 80,000 people and winning a Momentum for Change award from the UNFCCC. CTF finance for the Noor CSP complex in Morocco has helped to bring down technology costs and overall CTF has supported around a fifth of global CSP deployment to date. The fund has dramatically scaled up geothermal development across multiple countries, as well as a wide range of other renewable and clean transport technologies.
- **Capacity Building and Transparency**: As agreed by COP21, the Capacity Building Initiative for Transparency (CBIT) was established by the Global Environment Facility (GEF) in 2015 to support developing countries to meet new reporting requirements under the enhanced transparency framework of the Paris Agreement. The UK is the second largest donor (behind the US) to CBIT to date, committing £10 million from the ICF and £1 million from the Scottish Government.
- **Asian Development Bank (ADB)'s Clean Energy Fund** was set up to improve energy access, energy security and the transition to low-carbon technologies through cost-effective investments. The UK's contribution of £19.5 million is specifically used to fund the technical assistance elements of the fund across the Asia-Pacific region.
- **Results Based Financing for Low Carbon Energy Access (RBF)** aims to pilot and demonstrate payment by results to increase sustainable energy access for people in developing countries using market-based renewable energy and energy efficiency approaches. The £40m programme, funded by the UK and implemented by Energising Development, is about establishing markets through a range of different approaches, utilising decentralised low carbon technologies, such as solar mini-grids and electric

cookstoves. The programme has improved energy access for over 4 million people to-date through the sale of over 1 million low carbon technologies in 17 projects across 14 countries.

o **The Africa Clean Energy (ACE)** programme aims to increase access to modern, clean, affordable energy for low-income households in Africa by providing up to £65m UK funding to promote a market-based approach for private sector delivery of off-grid energy services including standalone solar household systems and mini-grids. ACE focuses on seven of the countries with the lowest access to electricity rates in Sub-Saharan Africa.

The UK has continued to leverage the collective commitment of the international community in other key fora and institutions to deliver policy interventions and high-level actions that encourage the promotion of low carbon technologies, including:

**International Renewable Energy Agency (IRENA)** - The UK supports IRENA's mission to promote widespread and sustainable use of renewable energy through its role as a centre of excellence for energy transformation, a global voice for renewables, a network hub for international collaboration, and a source of support and advice. The UK has been an IRENA Council member for 2016-2017 and has helped to drive forward IRENA's medium-term strategy which is consistent with UK government objectives regarding energy security and decarbonisation.

**International Partnership for Energy Efficiency Co-operation (IPEEC)** - The UK is working in the International Partnership for Energy Efficiency Co-operation (IPEEC),) with key developed and developing countries, to share experience and learn from each other's policy successes and failures. This identifies opportunities for collaborative work to address issues of mutual interest or concern, where such international action can add value to domestic efforts/expertise. A work programme has been developed encompassing a range of activities including appliance standards and labels, sustainable buildings, financing, data collection and indicators, energy management, transport, and capacity building activities. Much of this work is also being taken forward within the G20's Energy Efficiency Leading programme which IPEEC is co-ordinating. The UK is also working with members of the G20, IPEEC and the International Energy Agency (IEA) to establish an "Energy Efficiency Hub", to help coordinate international efforts to drive forward energy efficiency improvements.

## 15.2.7 Capacity building projects on adapting to climate change

UK ICF investments aim to support international poverty reduction now and in the future by helping developing countries manage risk and build resilience to the impacts of climate change, take up low-carbon development at scale, and manage natural resources sustainably. The poorest and most vulnerable people in the world will be hit first and hardest by the impacts of climate change. This is why the UK aims to spend half of its climate finance on adaptation.

We support capacity-building to assist developing countries to better:

**Adapt** to long-term impacts well in advance, for example by changing or diversifying livelihoods and ensuring infrastructure are fit for purpose.
**Anticipate** and reduce the impact of climate variability and extremes, , and longer-term climate change for example through effective forecasting and preparedness measures.
**Absorb** the effects of climate extremes and disasters - for example through effective and rapid response that enables people to cope with disaster and recover quickly.

Adapt

• The Blue Forest programme is introducing models for the sustainable management of mangroves in Madagascar and scaling these models in Indonesia and South East Asia to help increase coastal adaptation and resilience. The £10.1 million project, involving

fisheries management and mangrove livelihood diversification, is expected to protect 20,000 hectares of mangrove forests and benefit over 100,000 people. Key progress made on livelihood adaptation includes the creation and implementation of 11 sustainable community-owned mangrove forestry management plans, and the development and integration of multiple alternative livelihoods, including bee keeping and sea cucumber farming.

Anticipate

- UK Aid funds the Weather and Climate Information and Services for Africa (WISER) programme and the Asia Regional Resilience to a Changing Climate (ARRCC) programme. Their missions are to deliver transformational change in the quality, accessibility and use of weather and climate information services at all levels of decision making for sustainable development in Africa and South Asia, respectively. These programmes strengthen the capacity of the national and regional mandated organisations and channels in order to deliver weather and climate services which support poverty reduction, directed by user needs.
- UK ICF also funds the Future Climate for Africa (FCFA) research programme, which aims to enhance the scientific understanding and prediction of climate variability and change in Africa and, at the same time, is working with stakeholders to bring this information into use in adaptation planning. FCFA includes 11 pilot studies, building capacity across sub-Saharan Africa in using climate information to inform decisions, including infrastructure development, climate-smart agriculture, and urban and national planning.
- The UK is a convening partner of the Risk-Informed Early Action Partnership (REAP), a new global partnership convening the humanitarian, development and climate communities, drawing on data, evidence and best practice to drive up and unify standards, and increase targets for forecast-based action and investment. By bringing together partners working on climate risk, early warning, and anticipatory and early action, and focusing on the communities most at risk from climate shocks, REAP will drive a systemic shift towards anticipatory action that will save lives and protect livelihoods now and in the future, making 1 billion people safer from disaster by 2025.[93] On launch at the UN Climate Action Summit in September 2019, the UK made commitments of £175 million to the targets of REAP. The partnership now has 15 country members across donors, LDCs and SIDS, and 22 organisational members. The partnership will grow significantly in 2020 and bring a comprehensive plan to meet 2025 targets to COP26 in Glasgow.

Absorb

- The UK is a major contributor to African Risk Capacity (ARC) which strengthens African governments' understanding of drought risk and enables them to buy insurance that will pay out after harvest failures due to droughts. Senegal, Mauritania and Niger received payments totalling $26.5 million after poor rains in 2014, providing food aid, animal fodder and other assistance to 1.3 million people. Malawi received a payment

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[93] Specifically, REAP will work to these targets by 2025:

**1. 50 countries** *have reviewed and integrated their crisis/disaster risk management and climate adaptation laws, policies and/or plans to ensure that they reduce climate change impacts and exposure on people and the environment.* **2. 1 billion** *more people are covered by financing and delivery mechanisms connected to effective early action plans, ensuring they can act ahead of predicted disasters and crises.* **3. $500 million** *invested in early warning system infrastructure and institutions to target early action in 'last/first mile' communities, building on existing initiatives such as DFID's WISER, ARRCC & the CREWS programmes.* **4. 1 billion** *more people are covered by new or improved early warning systems, including heatwave early warning, connected to longer-term risk management systems and supported by public awareness campaigns.*

of $8.1 million in 2016, which they have used for emergency cash transfers to affected people and to replenish the national strategic grain reserve. Five countries are currently insured

## 15.2.8 Energy Market Reforms – responding to energy market imperfections

Launched in 2013, Electricity Market Reform (EMR) introduced two key mechanisms – Contracts for Difference (CfD) and the Capacity Market, designed to incentivise the investment required in the UK's energy infrastructure and deliver low carbon electricity and reliable supplies, while minimising costs to consumers.

CfDs are long term (15-year) contracts between low carbon electricity generators and the Low Carbon Contracts Company (LCCC), a government-owned company. The scheme was designed to provide a degree of income stabilisation for new projects by reducing their exposure to volatile wholesale prices, making projects that have high up-front costs but long lifetimes and low running costs attractive to investors. It also protects consumers when electricity prices are high.

Contracts are awarded in a series of competitive auctions, driving efficiency and cost-reduction. Generators receive revenue from selling their electricity into the market as usual. However, when the 'market reference price' (a measure of the average market price for electricity) is below the 'strike price' (a price for electricity reflecting the cost of investing in a particular low carbon technology), generators receive a top-up payment for the additional amount. Conversely if the reference price is above the strike price, the generator must pay back the difference.

Investment contracts (an early form of CfD) were awarded to eight projects in 2014, and three competitive allocation rounds have been held since then in 2015, 2017 and 2019. Projects currently supported by the CfD scheme, together with bespoke contracts signed in the early days of the scheme are expected to provide around 16GW of new renewable electricity capacity by 2025. So far, 20 of these projects have been commissioned, providing a combined capacity of over 4.2GW of renewable electricity. Details of CfD projects are available on the CfD Register published by the LCCC at www.lowcarboncontracts.uk.

Our sustained support for clean electricity has led to dramatic falls in the costs of some renewable technologies. For example, the costs of offshore wind are now around 30% lower than the second auction held in 2017 and 65% lower than the first auction held in 2015. In July 2018 the government announced its intention to hold a CfD auction approximately every two years, to provide industry with the certainty to invest in new renewable projects. The next auction is planned to open in 2021.

Four main Capacity Market auctions have been completed so far. These auctions have secured supplies up to 2021/22. However, the Capacity Market is currently standstill, following the judgment of the General Court of the Court of Justice of the European Union in Case T-793/14. The UK government is working closely with the European Commission on the necessary steps for the GB Capacity Market (CM) scheme to be reinstated as quickly as possible. During this standstill period no further auctions can take place, nor any capacity payments made.

The most recent main auction concluded in February 2018, for delivery in 2021/22. This secured 50.4GW of capacity.

The UK is continuing to reduce its reliance on coal and is bringing innovative and low-carbon technologies into its energy mix, as part of a cleaner, more flexible energy system. The Government has confirmed plans to close all unabated coal power stations by 2025

# 16  Other Information

There is no additional information to include in this chapter.

# 17 References

References for the main chapters and the annexes are listed here and are organised by chapter and annex. References in this document refer to correct name at the time of original publication.

## 17.1 CHAPTER 1 [INTRODUCTION]

Baggott SL, Lelland A, Passant NP, and Watterson J (2004) Review of Carbon Emission Factors in the UK Greenhouse Gas Inventory. AEA Energy and Environment, The Gemini Building, Fermi Avenue, Didcot, Oxfordshire, OX11 0QR, UK. November 2004. AEA report number AEAT/ENV/R/2347. Report prepared for UK Defra under contract RMP/2106.

BEIS (2019), Digest of United Kingdom Energy Statistics 2019, London, The Stationery Office.

BEIS (2019a), National Forestry Accounting Plan of the United Kingdom. Forest Reference Level for the Period 2021-2015. BEIS Research paper Number 050/1819.

IPCC (1996) Climate Change 1995 – The science of climate change. Contribution of Working Group 1 to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Ed. Houghton, JT., Cambridge University Press.

IPCC (1997a), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 1, Greenhouse Gas Inventory Reporting Instructions, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (1997b), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 2, Greenhouse Gas Inventory Workbook, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (1997c), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 3, Greenhouse Gas Inventory Reference Manual, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (2000), Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, ed. Penman, J, Kruger, D, Galbally, I, et al., IPCC National Greenhouse Gas Inventories Programme, Technical Support Programme Technical Support Unit, Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan.

IPCC (2001), Climate change 2001 – The scientific basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

IPCC (2003), Good Practice Guidance for Land Use, Land-Use Change and Forestry. Institute for Global Environmental strategies (IGES) for the Intergovernmental Panel on Climate Change, Kanagawa, Japan.

IPCC (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories

http://www.ipcc-nggip.iges.or.jp/public/2006gl/

IPCC (2007), Climate change 2007 – The scientific basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm

Scarbrough, T., Tsagatakis, I., Smith, K., Wakeling, D. (Ricardo), Smith, T., O'Keeffe, E., Hauerhoff, E. (UCL Consultants, U-MAS). (2017). A Review of the NAEI Shipping Emissions Methodology. Ricardo Energy & Environment. https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1712140936_ED61406_NAEI_shipping_report_12Dec2017.pdf

## 17.2   CHAPTER 3 [ENERGY (CRF SECTOR 1)]

Airtricity (2019). Gas demand, gas compositional analysis and leakage information for Northern Ireland gas provision by Airtricity in 2018, personal communication from James Archer, July 2019.

Baggott SL, Lelland A, Passant NP, and Watterson J (2004) Review of Carbon Emission Factors in the UK Greenhouse Gas Inventory. AEA Energy and Environment, The Gemini Building, Fermi Avenue, Didcot, Oxfordshire, OX11 0QR, UK. November 2004. AEA report number AEAT/ENV/R/2347. Report prepared for UK Defra under contract RMP/2106.

Barty, R (1995), Energy Policy and Analysis Unit, DTI, Personal Communication.

Bennet, S, Kershaw, S & Burrell, R, (1995), Control Measures for Methane Emissions from Coal Production, ETSU N/01/00006/REP.

BEIS (2019a), Digest of United Kingdom Energy Statistics 2019, London, The Stationery Office.

BEIS (2019b). EU ETS data for all UK installations, as provided by the UK regulators to BEIS

BEIS OPRED (2019). EEMS data from upstream oil and gas installations, personal communication from Michelle McDade, BEIS, 2019.

BP Chemicals (2015), Personal Communication, David Ingram, BP Chemicals, May 2015.

BGS (2018) British Geological Survey (2018), UK Minerals Yearbook 2017

British Steel (2019). Emissions and activity data by sub-source within integrated steelworks in 2018. Personal communication from Lee Adcock, British Steel, July 2019.

Brown, P, Wakeling, D, Pang, Y and Murrells TP (2018). "Methodology for the UK's Road Transport Emissions Inventory". Task 53/54 of the 2015 GHG Improvement Programme, Report by Ricardo Energy & Environment for the Department for Business, Energy & Industrial Strategy, Report ED59803130, 2018.

CAA (2019a), UK Airport data 2018 – Annual data from 2018. Table 3.1 Airport data 2018

http://www.caa.co.uk/uploadedFiles/CAA/Content/Standard_Content/Data_and_analysis/Datasets/Airport_stats/Airport_data_2016_annual/Table_03_1_Aircraft_Movements.csv

CAA (2019b), personal communication with Jouse Grant, records of individual air transport movements operations between UK and worldwide destinations for all reporting airports.

Cadent Gas (2019). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by Cadent Gas, personal communication from Matt Marshall, August 2019.

Cayman Islands Government (2019), The Cayman Islands' Compendium of Statistics 2018

CLG (Communities and Government) (2016), Table 401, Household projections, United Kingdom, 1961-2039

https://www.gov.uk/government/statistical-data-sets/live-tables-on-household-projections [Accessed on 22/08/2016].

Coal Authority (2019), Production and manpower returns for 2018 annual data. Personal communication from Helen Day, the Coal Authority, July 2019.

CPL (2015), Information about petroleum coke uses, Personal Communication from Trevor Roberts, Coal Products Limited (CPL), June 2015.

Department for Infrastructure, Northern Ireland (2018). Travel Survey for Northern Ireland (TSNI) 2015-2017. Personal communication from Carrie Taggart, DfINI, September 2018.

DfT (2018a), Transport Statistics Great Britain, The Stationery Office. https://www.gov.uk/government/statistics/transport-statistics-great-britain-2018including road traffic statistics to 2017:

https://www.gov.uk/government/statistics/road-traffic-estimates-in-great-britain-2017 [Accessed on 12/12/2018].

DfT (2019b), Vehicle Licensing Statistics: 2018, Department for Transport, https://www.gov.uk/government/statistics/vehicle-licensing-statistics-2018

DfT (2019c) Maritime and Shipping Statistics. Downloaded from https://www.gov.uk/government/collections/maritime-and-shipping-statistics

DfT (2019d), private communication, Barinder Hundle, DfT Maritime Statistics, September 2019

EMEP (2009b). EMEP/EEA air pollutant emission inventory guidebook — 2009. Part B, Section 1A4 Other Mobile. http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-4-other-mobile-tfeip-endorsed-draft.pdf

EMEP/EEA (2009). http://www.eea.europa.eu/themes/air/emep-eea-air-pollutant-emission-inventory-guidebook/emep

EMEP/EEA, (2016), EMEP/EEA air pollutant emission inventory guidebook 2016; Updated in July 2018. https://www.eea.europa.eu/publications/emep-eea-guidebook-2016

Emisia (2018), COPERT 5 "Computer Programme to Calculate Emissions from Road Transport" http://emisia.com/products/copert/copert-5

Entec (2010). UK Ship Emissions Inventory. Final Report to Defra, November 2010. http://uk-air.defra.gov.uk/reports/cat15/1012131459_21897_Final_Report_291110.pdf

Environment Agency (2019), Pollution Inventory, Personal Communication from Alison Issit, the Environment Agency, June 2019.

Fynes, G and Sage, PW, (1994), Emissions of Greenhouse Gases from Coal Fired Plant, British Coal, Coal Research Establishment, CERCHAR, DMT, Delft University of Technology, TPS Termiska Processor AB, CONTRACT NO JOUF 0047-C(SMA)

Government of Bermuda Department of Statistics (2018), 2018 Environmental Statistics Compendium

Hedmark (2015). Clarifications regarding the completeness and detail of reporting of several EU ETS installations in Scotland, for sites using the "fall-back" reporting approach. Personal communication from Asa Hedmark of SEPA, October 2015.

IMO (2010). MEPC 61/4, 16 February 2010, Sulphur monitoring for 2009

IMO (2015) Third IMO Greenhouse Gas 2014 study. Smith, T. W. P.; Jalkanen, J. P.; Anderson, B. A.; Corbett, J. J.; Faber, J.; Hanayama, S.; O'Keeffe, E.; Parker, S.; Johansson, L.; Aldous, L.; Raucci, C.; Traut, M.; Ettinger, S.; Nelissen, D.; Lee, D. S.; Ng, S.; Agrawal, A.; Winebrake, J. J.; Hoen, M.; Chesworth, S.; Pandey, A.

IPCC (1997), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 3, Greenhouse Gas Inventory Reference Manual, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories

http://www.ipcc-nggip.iges.or.jp/public/2006gl/

Isle of Man Government (2019), Isle of Man in Numbers 2018

ISSB (2019), Personal Communication from Abbie Connolly, Iron & Steel Statistics Bureau, July 2019

IVL (2004) Cooper, D., Gustafsson, T., Methodology for calculating emissions from ships: 1. Update of emission factors, IVL (Swedish Environmental Research Institute).

Kershaw (2005), "Projected Methane Emissions from Abandoned Coal Mines in the UK", White Young Green report to Defra, 2005.

Lakhani (2015). Updated estimates of natural gas use in gas compressors, and in upstream oil and gas sector were confirmed by Shyam Lakhani of DECC energy statistics, to clarify that the UK GHGI should deviate from DUKES 2015 data for these sources. Personal communication, October 2015.

Leng (2019). UK ammonia production data estimates, 2018. Personal communication, Darren Leng, Environment Agency, July 2019.

Livingston (2011), Personal Communication, Fiona Livingston (DECC Offshore Inspectorate)

MPA (2019), UK cement clinker production, emissions, and fuel consumption data for all sites in 2018. Personal communication from Diana Casey, 2019.

MMO (2018) UK Sea Fisheries Statistics 2017, Marine Management Organisation. https://www.gov.uk/government/statistics/uk-sea-fisheries-annual-statistics-report-2017MoD (2019), personal communication with MoD, Whitehall, London, September 2019.

Murrells et al. (2011). Murrells T, John Norris, Glen Thistlethwaite, Neil Passant, Helen Walker, Nikki Webb (2011). Definitions of Gas Oil and DERV and Allocations to Sectors in the UK Greenhouse Gas Inventory. AEA Report for DECC under Task 5 of the 2011 UK GHG Inventory Improvement Programme. AEAT/ENV/R/3234, November 2011.

National Grid (2019). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by National Grid, including updated releases from venting on the NTS and LNG terminals, personal communication from Matt Williams, July 2019.

Netcen (2004), "Non-Road Mobile Machinery Usage, Life and Correction Factors", Report to the Department for Transport, AEAT/ENV/R/1895, November 2004, www.airquality.co.uk/archive/reports/reports.php?report_id=304

NIEA (2019). Northern Ireland Pollution Inventory (NIPI), personal communication from Hugh McGinn, Northern Ireland Environment Agency, July 2019.

Northern Gas Networks (2019). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by NGN, personal communication from Dean Pearson, July 2019.

NRW (2019), Welsh Emissions Inventory, Personal Communication from Susan Freeman, Natural Resources Wales, August 2019.

Off Highway Research Ltd (2000), International Database Service, March 2000

ORR (2019) Office of Rail & Road, National Rail Trends Data Portal, https://dataportal.orr.gov.uk/browsereports/9

PRI (1995), Communication from Precision Research International.

PRI (1998), Communication from Precision Research International. Samaras, Z & Zierock

Resource Futures, Biodegradability of municipal solid waste (WR1003), 2012

Ricardo-AEA (2014a), GHG Inventory Research: Use of EU ETS Data - Iron and Steel Sector: Review of UK data on emissions of GHGs from the Iron and Steel sector to utilise EU ETS data in the national inventory

Ricardo-AEA (2014b), GHG Inventory Research: Non-Energy Use of Fuels: Review of UK data on emissions of GHGs from Process Feedstock and other non-energy uses of fossil fuels.

Ricardo (2016). "Updated Emission and Fuel Consumption Factors for Road Transport in the UK Greenhouse Gas Inventory. Report on the 2015 GHG Improvement Programme by Ricardo Energy & Environment to DECC, January 2016

RSSB, Personal Communication, 2019

Rypdal et al.. (2000), Kristin Rypdal and Ketil Flugsrud (Statistics Norway), and William Irving (USEPA). Good Practice – Methodological Choice, Good Practice – Methodological Choice – background paper

Salway, (1998), Comparison between the IPCC default and UK Detailed Inventories 1990-1996, National Environmental Technology Centre, AEA Technology, AEAT-4457

Samaras Z & Zierock KH (1993). Notes on the assessment of the emissions of off-road mobile machinery in the European Community

Samaras, Z & Zierock, KH, (1994), Supplement to above.

Samaras, Z (1996), Personal Communication

Scarbrough, T. Tsagatakis, I., Smith, K. et al. (2017) A review of the NAEI shipping emissions methodology. Report for the Department for Business, Energy & Industrial Strategy. Published 12/12/2017. Available from: http://naei.beis.gov.uk/reports/reports?report_id=950

SEPA (2019), Scottish Pollutant Release Inventory, Scottish Environment Protection Agency, Personal Communication from Bob Boyce, August 2019

SGN (2018). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by SGN, personal communication from Fay Tester, July 2018.

SMMT (2019). Personal communication with Tim Bruin, Society of Motor Manufacturers and Traders, August 2019.

SSI Steel (2015). Emissions and activity data by sub-source within integrated steelworks in 2014. Personal communication from Darren Anderson, Sahaviriya Steel, June 2015.

Tata Steel (2018). Emissions and activity data by sub-source within integrated steelworks in 2017. Personal communication from Neil Haines, July 2018.

UK Coal (2018), UK production and manpower data from open-cast and deep mines during 2017. Personal communication from Brian Dobbin, UK Coal, July 2018.

UKPIA (2004), United Kingdom Petroleum Industry Association, Malcolm Watson communication on properties of UK fuels in 2004 (and correspondence in earlier years).

UKPIA (2019a), Refinery production & emissions data in 2018, carbon emission factors, petroleum products data from the United Kingdom Petroleum Industry Association, Personal Communication from Andy Roberts, UKPIA, October 2019.

UKPIA (2019b), United Kingdom Petroleum Industry Association, Hugh Tucker communication on properties of UK fuels in 2018, June 2019.

UK Statistics Authority (2019). Code of Practice for Statistics. ISBN 978-1-85774-902-1. UKSA, London, UK. https://www.statisticsauthority.gov.uk/wp-content/uploads/2018/02/Code-of-Practice-for-Statistics.pdf

Wales & West Utilities (2018). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by W&W, personal communication from Catherine Litster, August 2018.

Walker, H., Chris Conolly, John Norris and Tim Murrells. Greenhouse Gas Emissions from Inland Waterways and Recreational Craft in the UK. AEAT/ENV/R/3175, Task 25 of the 2010 DA / UK GHG Inventory Improvement Programme, June 2011. http://uk-air.defra.gov.uk/reports/cat07/1106231031_IP_Task_25_Inland_Waterways_Issue_1.pdf

Williams, A. (1993), *Methane Emissions*, Watt Committee Report Number 28, The Watt Committee on Energy, London, 1993.

WSP (2011) Update of Estimated Methane Emissions from UK Abandoned Coal Mines. http://www.decc.gov.uk/assets/decc/publications/1775-ghg-improvement-project-wsp-report.pdf

## 17.3    CHAPTER 4 [INDUSTRIAL PROCESSES (CRF SECTOR 2)]

8 Squadron (2012), The NATO Airborne Early Warning and Control Force (NAEW&CF). http://www.8squadron.co.uk/sqn_naewf.php. Last Updated 6th September, 2012. Accessed 9th December, 2013.

AEA (2004), Emissions and Projections of HFCs, PFCs and $SF_6$ for the UK and Constituent Countries. Final Report prepared for the Department for Environment, Food and Rural Affairs, 2nd Edition, June 2004, AEA Technology, Oxfordshire, UK.

AEA (2005), Judith Bates, Martin Adams, and Stephen Pye. Evaluation of Policies and Measures to Reduce F Gas Emissions. A report produced for Department for Environment, Food and Rural Affairs. July 2005. AEAT/48209407. Issue 3. AEA, The Gemini Building, Fermi Avenue, Harwell, Didcot, OX11 0QR.

AEA (2008), UK emissions of HFCs, PFCs and $SF_6$. 2008 update. Report to DECC/Defra (for external release). Issue 1. December 2008. AEA/ED05478/Issue 1. AEA, The Gemini Building, Fermi Avenue, Harwell, Didcot, OX11 0QR.

AEA (2008b), Implementation scoping review of the 2006 IPCC Guidelines on the UK GHG inventory. Prepared for Defra (CEOSA). October 2008

AEA (2010), UK HFC consumption and emissions forecasting. Report prepared for the Department for Environment, Food and Rural Affairs, 2010, AEA, Oxfordshire, UK.

AEA (2013), UK Greenhouse Gas Inventory, 1990-2011 Annual Report for Submission under the Framework Convention on Climate Change. Prepared for Department of Energy and Climate Change. April 2013.

Alexander (2019). Information on the abatement technologies and performance of UK nitric acid plant. Personal communication, Ian Alexander, Environment Agency, February 2019.

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). 1995. Standard 110-1995 – Method of Testing Performance of Laboratory Fume Hoods.

ASSURE (2013), ASSURE note on UK F-Gas emissions for the Fire Protection Sector. Provided by Peter Woodman on 1st and 6th November 2013.

BEIS (2019a), Digest of United Kingdom Energy Statistics 2018, London, The Stationery Office.

BEIS (2010b). EU ETS data for all UK installations, as provided by the UK regulators to BEIS

BOC (2013), Personal Communication with Gemma Hill of BOC on 26 and 27 November 2013.

British Ceramic Confederation (2014). Personal Communication with Andrew McDermott, 2 October 2014

British Coatings Federation (20189. Personal communication with John Dixon, July 2019.

British Geological Survey (2018), UK Minerals Yearbook 2017

British Glass (2001), Emissions from the UK Glass Industry, Report for AEA Technology

British Glass (2018), UK glass production and recycling data in 2017, Personal Communication from Holly Feeney, British Glass, July 2018.

British Photovoltaic Association (2013), Personal communications with Reza Shaybani. 4 November 2013.

British Steel (2019). Emissions and activity data by sub-source within integrated steelworks in 2018. Personal communication from Lee Adcock, British Steel, July 2019.

British Sugar (2013), Personal Communication (Richard Cogman)

British Refrigeration Association (2018), UK Market Statistics 2017 Refrigeration Equipment and Components, personal communication Bruce Wright, August 2018.

California Air Resource Board (2009). The Adoption of a regulation to reduce sulphur hexafluoride emissions in non-semiconductor and non-utility applications, 2009.

California Air Resources Board (2011), Lifecycle Analysis of High-Global Warming Potential Greenhouse Gas Destruction. Prepared by ICF International under Contract Number 07-330, October 2011. Available at: http://www.arb.ca.gov/research/apr/past/07-330.pdf.

CF Fertilisers (2018). Emissions and production data for ammonia and nitric acid plant in 2017. Personal Communication from Caroline Thomson, July 2018.

Chemical Industries Association (2014), Personal Communication (Nick Sturgeon)

CIS (1991), Chem-Facts UK, Chemical Intelligence Services, Reed Telepublishing, Dunstable, Beds, UK.

Cockcroft Institute (2013), Personal communications with Swapan Chattopadhyay, November 2013.

CORINAIR (1989), CORINAIR Inventory, Commission of the European Community, Default Emission Factors Handbook, 1st edition, CITEPA, Paris.

Corus (2005), Personal Communication, Mick Briggs

Crowthorne Hi-Tec Services Limited (2013). Personal communications with Steve Robertson. November 15, 2013.

CSIRO (2005). Article "Metal Technologies: A Green Winner". Solve, Journal of the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). Issue 3, May 05. http://solve.csiro.au/0505/article1.htm

Dale Flow (2013). Personal communications with Howard Westerdale. November 14, 2013.

Defra (2008), Impact Assessment of the Fluorinated Greenhouse Gases Regulations 2009. Available                                                                                                          at: http://archive.defra.gov.uk/environment/quality/air/fgas/documents/impact-assessment.pdf.

Defra (2012), General Guidance: F Gas and Ozone Regulations Information Sheet GEN 3: Markets & Equipment. April 2012. Available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/182572/fgas-gen3-markets-equipment.pdf.

Defra (2019), Latest statistics on milk utilisation by dairies - national statistics, including data on cream production to 2018, September 2019. Available at https://www.gov.uk/government/statistics/milk-utilisation-by-dairies-in-england-and-wales.

(ECCP, 2001). Final Report on the European Climate Change Programme. Working Group Industry. Work Item Fluorinated Gases. Prepared on behalf of the European Commission (DG ENV and DG ENTR) by Jochen Harnisch (Ecofys) and Ray Gluckman (Enviros). June 18, 2001.

Ecofys (2009a), Costs and the impact on emissions of potential regulatory framework for reducing emissions of hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. Draft report. September 2002.

Ecofys (2009b), Methodology for the free allocation of emission allowances in the EU ETS post 2012, November 2009

ECOWORLD (2002), Gasfüllungen in Schallschutzfenstern und Autoreifen fördern Treibhauseffekt. http://www.eco-world.de/scripts/basics/econews/basics.prg?a_no=6747&main=drucken citing original source Umweltbundesamt für Mensch und Umwelt.

EEA (2013), Fluorinated greenhouse gases 2012: Data reported by companies on the production, import and export of fluorinated greenhouse gases in the European Union. Available at: http://www.eea.europa.eu/publications/fluorinated-greenhouse-gases-2012

EEA (2019), Fluorinated greenhouse gases 2018: Data reported by companies on the production, import and export of fluorinated greenhouse gases in the European Union. Available at: https://www.eea.europa.eu//publications/fluorinated-greenhouse-gases-2018

EIPPCB (2000), Reference Document on Best Available Techniques in the Glass Manufacturing Industry, October 2000

Environment Agency (2018), Pollution Inventory, Personal Communication from Alison Issit, the Environment Agency, June 2018.

Enviros Consulting Limited (2008), Assessment of the Costs & Implication on Emissions of Potential Regulatory Frameworks for Reducing Emissions of HFCs, PFCs & $SF_6$. Available at: http://ec.europa.eu/clima/policies/eccp/docs/eccp_containment_measures_en.pdf.

Eurostat (2019), GDP and main components (output, expenditure and income) [nama_10_gdp]. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_gdp&lang=en

FEICA (2013), Personal Communication with Bernard Ghyoot of FEICA on 5 November 2013.

FIA (2014), Personal Communication with Robert Thilthorpe of FIA on 7 February 2014.

Glass and Glazing Federation (2013), Personal Communications with Russell Day, Technical Officer. 27 November 2013.

Gluckman (2013). NAEI – Report on F-Gases. Report on Programme of Work on F-Gases, Financial Year 2013/14. Version 2, November 11th 2013. Report prepared by Ray Gluckman, SKM Enviros, Sinclair Knight Merz, New City Court, 20 St Thomas Street, London, SE1 9R, UK.

Gluckman (2015), NAEI F-Gas Inventory Improvement Revision to ICF Model for Refrigeration, air-conditioning and heat pumps.

Groves and Sasonow (2010). Michael C.E. Groves & Alexander Sasonow. Uhde EnviNO$_x$® technology for NO$_X$ and N$_2$O abatement: a contribution to reducing emissions from nitric acid plants, Journal ofIntegrative Environmental Sciences, 7:S1, 211-222, DOI: 10.1080/19438151003621334

https://doi.org/10.1080/19438151003621334

Growhow (2015). Emissions data and plant design, abatement and flue gas measurement information for ammonia and nitric acid production units in 2014, Personal Communication from Peter Rees, February 2015.

GTS (2008), UK Glass Manufacture 2008: A Mass Balance Study, Report for British Glass

Harnisch, J & Schwarz, W (2003), Costs and the impact on emissions of potential regulatory framework for reducing emissions of hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. Prepared on behalf of EC (DG ENV).

Harp International (2013), Personal Communication with Bryan Davies of Harp International on 14 November 2013.

Hjelgaard (2015). Personal communication from Katja Hjelgaard, regarding the development of methodologies to estimate N$_2$O emissions from squirty cream, within the Danish inventory. Outcome from the UK-Denmark bilateral review in 2015.

Home Office (2018), Drug Misuse: findings from 2017 to 2018 CSEW, July 2018, https://www.gov.uk/government/statistics/drug-misuse-findings-from-the-2017-to-2018-csew

ICF, (2011) DEVELOPMENT OF THE GHG REFRIGERATION AND AIR CONDITIONING MODEL, http://www.decc.gov.uk/assets/decc/11/cutting-emissions/3844-greenhouse-gas-inventory-improvement-project-deve.pdf

Invent-UK (2013). Personal communications with Dr. Ali Bicen. October 30, 2013.

Invista (2010), Plant-specific emissions and abatement details, Personal communication (Bill Longley-Cook).

IPCC (1997), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 3, Greenhouse Gas Inventory Reference Manual, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (2000), Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, ed. Penman, J, Kruger, D, Galbally, I, et al., IPCC National Greenhouse Gas Inventories Programme, Technical Support Unit, Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan.

IPCC (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories, edited by Eggleston, S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., IPCC National Greenhouse Gas Inventories Programme, Technical Support Unit, Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan.

ICF (2011), Development of the GHG Refrigeration and Air Conditioning Model.

ICF (2014), Review of data and methodologies used in the calculation of UK emissions from F-Gases

Iron & Steel Statistics Bureau (2018), Personal Communication, Abbie Conolly, June 2018.

March (1999), UK Emissions of HFCs, PFCs and SF$_6$ and Potential Emission Reduction Options, March Consulting Group.

Mineral Products Association (2019), UK cement clinker production, emissions, and fuel consumption data for all sites in 2018. Personal communication from Diana Casey, 2019.

MOD (2012), Statistical Series 4 – Equipment Bulletin 4.01 – Formations, Vessels, and Aircraft. Annual: 2012 edition.

Munday, PK (1990) UK Emissions of Air Pollutants 1970-1988, Warren Spring Laboratory, LR 764.

National Microelectronics Institute (2013), Personal Communications with Derek Boyd. 11 November 2013.

NHS England (2013) Carbon Footprint from Anaesthetic gas use, Sustainable Development Unit, http://www.sduhealth.org.uk/documents/publications/Anaesthetic_gases_research_v1.pdf [accessed August 2014]

NIEA (2019). Northern Ireland Pollution Inventory (NIPI), personal communication from Hugh McGinn, Northern Ireland Environment Agency, July 2019.

NM (2014), Personal communication with Derek Boyd. 4 February 2014.

NRW (2019), Welsh Emissions Inventory, Personal Communication from Susan Freeman, Natural Resources Wales, August 2019.

NSAA (2003), Sulphuric acid plant emissions data for 2002, Personal Communication

Office of National Statistics (2019), Index of Production, Index of Output, Population Statistics and Prodcom data for 1990-2018, www.statistics.gov.uk

OriGen Biomedical (2013), Personal Communication with Shanna Seigel of OriGen Biomedical on 12 November 2013.

PWC. 2012. Faster, greener, smarter – reaching beyond the horizon in the world of semiconductors. Available online at: http://www.pwc.com/en_GX/gx/technology/publications/assets/pwc-faster-greener-smarter.pdf

Quest Biomedical (2013), Personal Communication with Gary Cavanagh of Quest Biomedical on 14 November 2013.

RAF (2013), E-3D Sentry AEW1. http://www.raf.mod.uk/equipment/sentry.cfm. Last Updated 2013. Accessed 9th December, 2013.

RioTintoAlcan (2019). Aluminium smelter site emissions for all UK primary aluminium production sites in 2018, and clarifications regarding higher reported PFC emissions at one site. Personal communication from Jodie Innes, July 2019.

Ricardo-AEA (2014b), GHG Inventory Research: Non-Energy Use of Fuels: Review of UK data on emissions of GHGs from Process Feedstock and other non-energy uses of fossil fuels.

Ricardo (2016), GHG Inventory F-gas Improvements 2015.

Rudd, HJ, Mikkelsen, M, (1996), Emissions of Volatile Organic Compounds from Ship Purging in the UK, AEA Technology Plc, Report No AEAT/20034001/REMA-208/Issue 2.

Schwartz, W (2005), Emissions, Activity Data, and Emission Factors of Fluorinated Greenhouse Gases (F-Gases) in Germany 1995-2002. Research Report 201 41 261/01.

Scotch Whisky Association (2018), Statistical Report 2017, personal communication, Jennifer Brown, September 2018.

Sellafield Ltd (2013). Personal communications with Dr. Trish Dunlop. December 3, 2013.

SEPA (2019), Scottish Pollutant Release Inventory, Scottish Environment Protection Agency, Personal Communication from Bob Boyce, July 2018.

SKM Enviros (1999), "UK Emissions of HFCs, PFCs, and $SF_6$ and Potential Emission Reduction Options". March Consulting Group, 1999.

SKM Enviros (2014), Personal Communication with Ray Gluckman of SKM Enviros on 29 January 2014.

Springfields Fuels Limited (2013) Personal Communication with Andrew Parkinson of Springfields Fuels Limited on 28 November 2013.

SSI Steel (2015). Emissions and activity data by sub-source within integrated steelworks in 2014. Personal communication from Darren Anderson, Sahaviriya Steel, June 2015.

STFC (2013), http://nicolas.delerue.free.fr/accelerateurs/accelerators_uk.php, obtained via personal communications with Gareth Baker – Environment Officer at STFC. November 2013.

Tata Steel (2019). Emissions and activity data by sub-source within integrated steelworks in 2018. Personal communication from Neil Haines, July 2018.

TSO (2009), Annual Abstract of Statistics, 2009.

URENCO (2013), Personal Communication with Michael Peers on 21 November 2013.

US EPA (2015). Compilation of Air Emission Factors. http://www.epa.gov/ttnchie1/ap42/ Accessed in 2015.

US EPA (2011), Confidentiality Determinations for Eight Subparts of the GHGRP. Docket ID EPA-HQ-OAR-2011-0028.

US EPA (2012). Global Anthropogenic Non-$CO_2$ Greenhouse Gas Emissions: 1990 – 2030. Available Online at http://www.epa.gov/climatechange/Downloads/EPAactivities/EPA_Global_NonCO_2_Projections_Dec2012.pdf. December 2012.

## 17.4   CHAPTER 5 [AGRICULTURE (CRF SECTOR 3)]

ADAS (1995). Personal communication to A. Croxford (MAFF). Linseed burning data.

AFRC (1993). Energy and protein requirements of ruminants. AFRC Technical Committee on Responses to Nutrients, CAB International, Wallingford, UK, 159 pp.

Agnew, R. E., Yan, T., France, J., Kebreab, E. and Thomas, C. (2004). Energy requirement and supply. In: ed. C. Thomas, Feed into milk: a new applied feeding system for dairy cows, pp.11-20. Nottingham University Press, Nottingham, UK.

Anthony et al. (2016). Spatial Extent of Cultivated Organic (Histosol) Soils. Report to Defra as part of AC0114.

Anthony, S. (2017). Greenhouse Gas Emissions from the United Kingdom Grassland Sector: Disaggregation and Method of Calculation Including the UPCYCLE Model. Defra Project AC0114, Draft Methodology Report, 140 pp.

Anthony et al. (2018). Sheep sector methodology. Report to Defra as part of AC0114.

Bell, M.J., Hinton, N.J., Cloy, J.M., Topp, C.F.E., Rees, R.M., Williams, J.R., Misselbrook, T.H., Chadwick, D.R., (2016a). How do emission rates and emission factors for nitrous oxide and ammonia vary with manure type and time of application in a Scottish farmland? Geoderma 264, 81–93.

Bell M.J., Cloy J.M., Topp C.F.E., Ball B., Bagnall A., Rees R.M., Chadwick D.R. (2016b) Quantifying $N_2O$ emissions from intensive grassland production: the role of synthetic fertilizer type, application rate, timing and nitrification inhibitors. J Agric Sci: 5: 812-827. doi:10.1017/S0021859615000945

Bell, M.J., Hinton, N., Cloy, J.M., Topp, C.F.E., Rees, R.M., Cardenas, L., Scott, T., Webster, C., Ashton, R.W., Whitmore, A.P., Williams, J.R., Balshaw, H., Paine, F., Goulding, K.W.T. & Chadwick, D.R. (2015) Nitrous oxide emissions from fertilised UK arable soils: Fluxes, emission factors and mitigation. Agriculture, Ecosystems & Environment, 212, 134-147.

BSFP (2017). British Survey of Fertiliser Practice: Fertiliser Use on Farm Crops for Crop Year 2015, The BSFP Authority, Peterborough. Data for preceding years comes from earlier versions of the same publication.

Cardenas, L.M.; Gooday, R., Brown, L., Scholefield, D., Cuttle, S., Gilhespy, S., Matthews, R., Misselbrook, T., Wang, J., Li, C., Hughes, G., Lord, E. 2013. Towards an improved inventory of $N_2O$ from Agriculture: Model evaluation of $N_2O$ emission factors and N fraction leached from different sources in UK agriculture. Atmospheric Environment. 79, 340-348.

Cayman Islands Government (2019), The Cayman Islands' Compendium of Statistics 2018

Coffey, M.P., Hickey, J., Brotherstone, S. (2006). Genetic aspects of growth of Holstein-Friesian dairy cows from birth to maturity. J. Dairy Sci. 89, 322-329.

Conen, F., et al. (2000). "Predicting $N_2O$ emissions from agricultural land through related soil parameters." Global Change Biology 6(4): 417-426.

Cooper, A. and T. McCann. (2002). Technical Report of the Northern Ireland Countryside Survey, University of Ulster.

Cooper, A., McCann, T. and Rogers, D. (2009). Northern Ireland Countryside Survey 2007.

Cottrill, B.R. and Smith, K.A. (2007). Nitrogen output of livestock excreta. Final report DefraProject WT0715NVZ, June 2007. Available via Defra website [www.defra.gov.uk/](www.defra.gov.uk/)

DAERA (2019). Agricultural Census in Northern Ireland for 2018, DAERA, [https://www.daera-ni.gov.uk/articles/agricultural-census-northern-ireland](https://www.daera-ni.gov.uk/articles/agricultural-census-northern-ireland)

Defra (2019). June Agricultural Census, DEFRA. Structure of the agricultural industry in England and the UK at June, [https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june](https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june)

Defra (2019). British Survey of Fertiliser Practice 2018: Fertiliser Use on Farm Crops for Crop Year. Data for preceding years comes from earlier versions of the same publication. [https://www.gov.uk/government/collections/fertiliser-usage](https://www.gov.uk/government/collections/fertiliser-usage)

Defra AC0115: Improvements of $CH_4$ emission factors from agriculture. Report available on request.

Defra AC0114: Synthesis of data. Report available on request.

De Klein, C.A.M., Harvey, M.J. (2012). Nitrous oxide chamber methodology guidelines. Global Research Alliance. Ministry of Primary Industries, New Zealand, pp. 1–146 (Available via: www.globalresearchalliance.org/research/livestock/activities/nitrousoxide-chamber-methodology-guidelines/).

Dragosits, U. (2017). Composition of holding level data on livestock numbers and crop areas. Report to Defra as part of AC0114.

Ewing, W.N. (1998) The feeds directory. Vol. 1, Commodity products, Context Publishing, Heather, Leicestershire.

Farm Business Survey for Northern Ireland, DAERA, [https://www.daera-ni.gov.uk/articles/farm-business-data](https://www.daera-ni.gov.uk/articles/farm-business-data)

Haines-Young, R. H., C. J. Barr, et al. (2000). Accounting for nature: assessing habitats in the UK countryside. London, DETR Countryside Survey 2000. [http://www.countrysidesurvey.org.uk/archiveCS2000/report.htm](http://www.countrysidesurvey.org.uk/archiveCS2000/report.htm)

Hulin, A., Bellamy, P., Corstanje, R., Keatley, P., Caskie, P., Williams, A. Anthony, S. (2015) Disaggregation of fertiliser practice data for the improved UK agricultural greenhouse gas inventory WP3 of project AC0114

Hough, M. and Jones, R. (1997) The United Kingdom Meteorological Office rainfall and evaporation calculation system: MORECS version 2.0 – an overview. Hydrology and Earth System Sciences, 1, 2, 227-239.

IPCC (Intergovernmental Panel on Climate Change) (1997). Greenhouse gas emissions from agricultural soils. In: Houghton, J.T. et al. (Eds.), Greenhouse Gas Inventory Reference Manual. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.

IPCC/OECD/IES. UK Meteorological Office, Bracknell, UK.

IPCC (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Eggleston H.S. et al. (eds.) IPCC National Greenhouse Gas Inventories Programme Technical Support Unit. Volume 4: Agriculture, Forestry and Other Land Use.

Jenkins, G., Perry, M. and Prior, J. (2008) The climate of the United Kingdom and recent trends. Hadley Centre, Met Office, Exeter, 122 pp.

Lopez, S., France, J., Gerrits, W.J.J., Dhanoa, M.S., Humphries, D.J., Dijkstra, J. (2000). A generalized Michaelis-Menten equation for the analysis of growth. J. Anim. Sci. 78, 1816-1828.

MAFF (1992). Feed composition: U.K. tables of feed composition and nutritive value for ruminants. Ministry of Agriculture, Fisheries and Food (MAFF) Standing Committee on Tables of Feed Composition.

MAFF (1995). Straw Disposal Survey. Data for earlier years taken from previous editions of the survey. Contact: Government Buildings, Epsom Rd., Guildford, Surrey, GU1 2LD for copies.

MAFF (2000) Fertiliser recommendations for agricultural and horticultural crops (RB209). The Stationery Office, London, 177 pp.

March, M.D., Haskell, M.J., Chagunda, M.G.G., Langford, F.M., Roberts, D.J. (2014). Current trends in British dairy management regimens. J. Dairy Sci. 97, 7985-7994.

Misselbrook et al. (2018). Dairy sector methodology; Report to Defra as part of project AC0114

National Bovine Data Centre (previously the Centre for Dairy Information) http://nbdc.uk/

Nicholson, F., Rollett, A. and Chambers, B. (2011). Review of pollutant losses from solid manures stored in temporary field heaps. Defra project WT1006, 2011, ADAS, 56 pp

NIEA (2008). Broad Habitat Change 1998- 2007. Northern Ireland Environment Agency Research and Development Series No. 09/06, http://www.ni-environment.gov.uk/biodiversity/nhresearch/nicountrysidesurvey-2/nics_2007_results.htm

Nix, J. (2011) Farm management pocketbook, 41st edition. Agro Business Consultants, Melton Mowbray, UK.

Parsons, D.J.; Williams, A.G. (2015) Analysis of Farm Business Survey (FBS) module data on livestock productivity, practices and greenhouse gas emissions. Report for Defra on project DO0148. https://tinyurl.com/defra-DO0148

Pollott, G.E., Stone D.G. (2003) The breeding structure of the British sheep industry 2003. Defra report
http://webarchive.nationalarchives.gov.uk/20110318142020/http://www.defra.gov.uk/evidence/economics/foodfarm/reports/documents/pollott2003.pdf

Reed et al (2015). Reed, K.F., Moraes, L.E., Casper, D.P., Kebreab, E., 2015. Predicting nitrogen excretion from cattle. J. Dairy Sci. 98, 3025-3035.

Roderick, S. (2001). An epidemiological survey of vitamin E deficiency in the UK sheep flock. A report to Defra as part of project LS3401

Scottish Government (2019). June Scottish Agricultural Census for 2018, Scottish Government, http://www.gov.scot/Topics/Statistics/Browse/Agriculture-Fisheries/PubFinalResultsJuneCensus

Smart, S.M.; Allen, D.; Murphy, J.; Carey, P.D.; Emmett, B.A.; Reynolds, B.; Simpson, I.C.; Evans, R.A.; Skates, J.; Scott, W.A.; Maskell, L.C.; Norton, L.R.; Rossall, M.J.; Wood, C. (2009). Countryside Survey: Wales Results from 2007. NERC/Centre for Ecology & Hydrology, Welsh Assembly Government, Countryside Council for Wales, 94pp.

Smith, K. A., Brewer, A. J., Dauven, A. and Wilson, D. W. (2000). A survey of the production and use of animal manures in England and Wales. I. Pig manure. Soil Use and Management 16, 124-132.

Smith, K. A., Brewer, A. J., Crabb, J. and Dauven, A. (2001a). A survey of the production and use of animal manures in England and Wales. II. Poultry manure. Soil Use and Management 17, 48-56.

Smith, K. A., Brewer, A. J., Crabb, J. and Dauven, A. (2001b). A survey of the production and use of animal manures in England and Wales. III. Cattle manures. Soil Use and Management 17, 77-87.

Smith et al. (2015) Predicting the effect of rotation design on N, P, K balances on organic farms using the NDICEA model, Renewable Agriculture and Food Systems, available online.

Smith, K.A., Williams, A.G. (2016), Production and management of cattle manure in the UK and implications for land application practice. Soil Use and Management 32, 73–82. https://doi.org/10.1111/sum.12247

States of Guernsey (2019), Guernsey Facts and Figures 2018

States of Jersey (2018), Agricultural Statistics 2018

Thomas, C. (2004) Feed into Milk: A New Applied Feeding System for Dairy Cows. Nottingham University Press. ISBN-10: 1904761267. ISBN-13: 978-1904761266

Topp, C. F. E., Anthony, S., Smith, K.E., Thorman, R.E., Cardenas, L., Chadwick, D., Rees, R.M., Misselbrook, T. (2018). The development of the UK country specific emission factors for $N_2O$ emissions from agricultural soils. Report to Defra as part of project AC0114

UKCIP, http://www.ukcip.org.uk/

UK Informative Inventory Report, DEFRA, https://uk-air.defra.gov.uk/

USEPA (1997). Compilation of Air Pollutant Emission Factors, volume 1, 5th ed., AP-42, United States Environmental Protection Agency, North Carolina.

van der Burgt, G.J.H.M., Oomen, G.J.M., Habets, A.S.J., Rossing, W.A.H. (2006). The NDICEA model, a tool to improve nitrogen use efficiency in cropping systems. Nutrient Cycling in Agroecosystems 74, 275–294. doi:10.1007/s10705-006-9004-3

Wall, E. and Pritchard, T. (2017). Analysis of large scale slaughter statistics, SRUC, internal report.

Webb, J., Misselbrook, T.H. (2004). A mass-flow model of ammonia emissions from UK livestock production. Atmos. Environ. 38, 2163-2176.

Welsh Government (2019). Survey of agriculture and horticulture for 2018, Welsh Government, http://gov.wales/statistics-and-research/survey-agricultural-horticulture/?lang=enWheeler,

Wheeler, K., Wright, N. and Phillips, K. (2012) More robust evidence on the average age of UK lambs at slaughter. ADAS, Report to Defra, 23 pp.

Williams, A.G.; Goglio, P. (2017). Crop Residues Management. Appendix F to Crop Sector Methods for the Enhanced GHG Inventory. Document produced under Defra project SCF0102 at Cranfield University. Access by request to adrian.williams@cranfield.ac.uk

Williams et al. (2018). Crop sector methodology. Report to Defra as part of AC0114.

Wright & Phillips (2012). More robust evidence on the average age of OK lambs at slaughter. ADAS report, 2012.

## 17.5 CHAPTER 6 [LAND-USE CHANGE AND FORESTRY (CRF SECTOR 4)]

Anthony, S. (2013) Spatial Extent of Cultivated Organic (Histosol) Soils personal communication.

Ashman, M., Falloon, P., Coleman, K and Smith, P (2000) Size and rate of change of carbon density due to changes in agricultural activity. In Carbon sequestration in vegetation and soils, Contract report to the Department of the Environment, Transport and the Regions. Contract DETR EPG1/1/39

Barraclough, D., Smith, P., Worrall, F., Black, H.I.J. & Bhogal, A. (2015). Is there an impact of climate change on soil carbon contents in England and Wales? *European Journal of Soil Science.* 66: 451–462. DOI: 10.1111/ejss.12253

Bellamy, P., P. Loveland, et al. (2005). Carbon losses from all soils across England and Wales 1978-2003. Nature 437: 245-248.

Bellamy, P and Rivas-Casado, M. (2009). Statistical analysis of NSI soil carbon changes in relation to climate and land management changes. K.E. Dyson (ed.), Inventory and projections of UK emissions by sources and removals by sinks due to land-use, land-use change and forestry. Annual report July 2009. Centre for Ecology and Hydrology.

Bradley, R. I., R. Milne, et al. (2005). A soil carbon and land-use database for the United Kingdom. Soil Use and Management 21(004): 363-369.

Chapman, S.J., Campbell, C.D., Puri, G., 2003. Native woodland expansion: soil chemical and microbiological indicators of change. Soil Biol Biochem 35, 753-764.

Cooper, A. and T. McCann (2002). Technical Report of the Northern Ireland Countryside Survey, University of Ulster.

Cooper, A., McCann, T. and Rogers, D. (2009) Northern Ireland Countryside Survey 2007: Broad Habitat Change 1998- 2007. *Northern Ireland Environment Agency Research and Development Series* No. 09/06

Cruikshank, M.M., Tomlinson, R.W., Bond, D., Devine, P.M., and Edwards, C.J.W. (1995) Peat extraction, conservation and the rural economy in Northern Ireland, Applied Geography 15(4): 365-383.

Cruickshank, M. M., and R. W. Tomlinson (1997), Carbon loss from UK peatlands for fuel and horticulture, in Carbon Sequestration in Vegetation and Soils, edited by M. G. R. Cannell, Department on Environment, London.

Cruickshank, M. and R. Tomlinson (2000). Changes in soil carbon storage in Northern Ireland: estimated by the IPCC default and matrix methods. Carbon Sequestration in Vegetation and Soils. R. Milne. London, Department of Environment.

Cruickshank, M. M., R. W. Tomlinson, et al. (1998). Carbon in the vegetation and soils of Northern Ireland. Biology and Environment-Proceedings of the Royal Irish Academy 98B(1): 9-21.

DAERA (2019) Agricultural Census in Northern Ireland 2018 https://www.daera-ni.gov.uk/articles/agricultural-census-northern-ireland

DECC (2011) Submission of information on forest management reference levels by United Kingdom of Great Britain and Northern Ireland in accordance with Decision 2/CMP.6. Available at: http://unfccc.int/bodies/awg-kp/items/5896.php?middle=j

DECC (2016) The United Kingdom's Initial Report under the Second Commitment Period of the Kyoto Protocol.

Defra, (2015a), Structure of the agricultural industry in England and the UK at June. https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june

Defra (2019). British Survey of Fertiliser Practice 2018: Fertiliser Use on Farm Crops for Crop Year. Data for preceding years comes from earlier versions of the same publication. https://www.gov.uk/government/collections/fertiliser-usage

Dewar, R.C. and M.G.R. Cannell (1992). Carbon sequestration in the trees, products and soils of forest plantations - an analysis using UK examples. Tree Physiology 11: 49-71.

Directory of Mines and Quarries (5-yearly, latest 2014) http://www.bgs.ac.uk/mineralsUK/mines/dmq.html

Evans, C., Artz, R., Moxley, J., Smyth, M-A., Taylor, E., Archer, N., Burden, A., Williamson, J., Donnelly, D., Thomson, A., Buys, G., Malcolm, H., Wilson, D., Renou-Wilson, F., Potts J. (2017). *Implementation of an emission inventory for UK peatlands*. Report to the Department for Business, Energy and Industrial Strategy, Centre for Ecology and Hydrology, Bangor. Available at: https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1904111135_UK_peatland_GHG_emissions.pdf

FAO (2005). Global Forest Resources Assessment 2005. United Kingdom of Great Britain and Northern Ireland. Country report. Global Forest Resources Assessment 2005. Rome, Forestry Department, Food and Agriculture Organization of the United Nations: 64.

FAO (2010). Global Forest Resources Assessment 2010. United Kingdom of Great Britain and Northern Ireland. Country report. Global Forest Resources Assessment 2010. Rome, Forestry Department, Food and Agriculture Organization of the United Nations: 73.

FAO (2018). FAOSTAT database for GHG emissions. http://www.fao.org/faostat/en/#data/GL Data for Cayman Islands accessed and reviewed. Zero net emissions of LULUCF emissions.

FAO/ECE (2002). Forest Fire Statistics 1999-2001. Timber Bulletin. Geneva, Switzerland, Food and Agriculture Organization of the United Nations/United Nations Economic Commission for Europe.

Forest Service (2002). Facts and Figures 2001/02., Forest Service, Department of Agriculture and Rural Development.

Forestry Commission (1996). Water storage of timber: Experience in Britain. Bulletin 117.

Forestry Commission (2011) NFI Method Statement. https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/Forestry Commission (2016) Preliminary estimates of the changes in canopy cover in British woodlands between 2006 and 2015.

https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/what-our-woodlands-and-tree-cover-outside-woodlands-are-like-today-8211-nfi-inventory-reports-and-woodland-map-reportsForestry Commission (yearly, latest 2017) Forestry Statistics. http://www.forestry.gov.uk/statistics

Forestry Commission (2017) "Tree cover outside woodland in Great Britain report" https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/what-our-woodlands-and-tree-cover-outside-woodlands-are-like-today-8211-nfi-inventory-reports-and-woodland-map-reports/

Guo, L. B. and R. M. Gifford (2002). Soil carbon stocks and land-use change: a meta-analysis. Global Change Biology 8: 345-360.

Haines-Young, R. H., C. J. Barr, et al. (2000). Accounting for nature: assessing habitats in the UK countryside. London, DETR Countryside Survey 2000. http://www.countrysidesurvey.org.uk/content/reports-previous-surveys

Hartley McMaster Limited (2015). Review of the Quality Assurance Framework of the National Atmospheric Emissions Inventory, Pollution Climate Mapping and Impact Pathway Model, Report prepared for Defra under Contract 21366. Available at: http://uk-air.defra.gov.uk/assets/documents/reports/cat09/1511251152_AQ0962_Review_of_Quality_Assurance_framework_for_models-Final_report.pdf

Howard, D. C., C. J. Barr, et al. (2003). Countryside Survey 2000. Module 17 - Finding out causes and understanding significance (CS2000 Focus). Final report. Volume 2: Technical Annexes, NERC/Centre for Ecology and Hydrology. UKCEH: Project Report Number C01916.

IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Eggleston H.S. et al. (eds.) IPCC National Greenhouse Gas Inventories Programme Technical Support Unit. Volume 4: Agriculture, Forestry and Other Land Use.

IPCC (2013a) Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetlands Supplement).

IPCC (2013b) Revised supplementary methods and good practice guidance arising from the Kyoto Protocol. IPCC National Greenhouse Gas Inventories Programme Technical Support Unit.

Jackson, D.L (2000) Guidance on the interpretation of the Biodiversity Broad Habitat Classification (terrestrial and freshwater types): Definitions and the relationship with other classifications. JNCC Report 307. http://jncc.defra.gov.uk/page-2433

Jones, D.L., Nguyen, C., Finlay, R.D., 2009. Carbon flow in the rhizosphere: Carbon trading at the soil-root interface. Plant Soil 321, 5–33. doi:10.1007/s11104-009-9925-0

Jurn, K, Lavallee, J, and King, L. 2018. Environmental destruction in the new economy: Offshore finance and mangrove forest clearance in Grand Cayman. Geoforum 97, 155-168. https://doi.org/10.1016/j.geoforum.2018.10.019

Kirk, G., Bellamy, P., Emmett, B. and Scott, A. (2011). Comparison of topsoil carbon changes across England and Wales estimated in the Countryside Survey and the National Soil Inventory. Contract Report prepared for the Department for Environment, Food and Rural Affairs Project SP1101.

Kurz, W.A., Beukema, S.J., 1996. Estimation of root biomass and dynamics for the carbon budget model of the Canadian forest sector. Can. J. For. Res. 26, 1973–1979. doi:10.1139/x26-223

Laganiere, J., Angers, D.A., Pare, D., 2010. Carbon accumulation in agricultural soils after afforestation: a meta-analysis. Global Change Biol 16, 439-453.

Levy, P. and A. Clark (2009). Modelling the impact of climate, $CO_2$ and land-use change on the carbon balance of terrestrial ecosystems in Great Britain. K. E. Dyson (ed.), Inventory and projections of UK emissions by sources and removals by sinks due to land use, land-use change and forestry. Annual report July 2009. Centre for Ecology and Hydrology.

Levy, P. E. and R. Milne (2004). Estimation of deforestation rates in Great Britain. Forestry 77(1): 9-16.

Levy and Rowland (2011). A further review of data sets and models relevant to the LULUCF inventory methodology. Unpublished UKCEH report to DECC.

Levy, P., Van Oijen, M., Buys, G., and Tomlinson, S. (2018). Estimation of gross land-use change and its uncertainty using a Bayesian data assimilation approach. Biogeosciences, 15(5), 1497-1513.

Li, Z., Kurz, W. a, Apps, M.J., Beukema, S.J. (2003). Below ground biomass dynamics in the Carbon Budget Model of the Canadian Forest Sector: recent improvements and implications for the estimation of NPP and NEP. Can. J. For. Res. 33, 126–136. doi:10.1139/x02-165

Liski, J., Perruchoud, D. and Karjalainen, T. (2002). Increasing carbon stocks in the forest soils of Western Europe. Forest Ecology and Management, 169, 159–175.

Magnani, F., M. Mencuccini, et al. (2007). The human footprint in the carbon cycle of temperate and boreal forests. Nature 447(7146): 848-850.

Matthews, R., Malcolm, H., Buys, G., Henshall, P., Moxley, J., Morris, A. and Mackie, E. (2014) Changes to the representation of Forest Land and associated land-use changes in the 1990-2012 UK Greenhouse Gas Inventory. Forest Research and Centre for Ecology and Hydrology (DECC Contract GA0510, UKCEH Contract no. NEC0376)

Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016a). Forest Yield: A handbook on forest growth and yield tables for British forestry. Forestry Commission, Edinburgh.

Matthews, R.W., Henshall, P.A., Duckworth, R.R., Jenkins, T.A.R., Mackie, E.D, and Dick, E.C. (2016b) Forest Yield: a PC-Based yield model for forest management in Britain. Forestry Commission, Edinburgh

Milne, R. and T. A. Brown (1997). Carbon in the vegetation and soils of Great Britain. Journal of Environmental Management 49(4): 413-433.

Milne, R. and T. A. Brown (1999). Methods and data for Land-Use Change and Forestry Section in the 1997 IPCC Greenhouse Gas Inventory. In carbon sequestration in vegetation and soils. UKCEH/ITE report to the Department of the Environment, Transport and the Regions. DETR contract EPG1/1/19.

Mitchell, R.J., Campbell, C.D., Chapman, S.J., Osler, G.H.R., Vanbergen, A.J., Ross, L.C., Cameron, C.M., Cole, L. (2007). The cascading effects of birch on heather moorland: a test for the top-down control of an ecosystem engineer. J Ecol 95, 540-554.

MLC (1986). Monitoring Landscape Change, Report prepared by Hunting Surveys & Consultants Ltd for Department of the Environment and the Countryside Commission.

Moxley, J., Anthony, S., Begum, K., Bhogal, A., Buckingham, S., Christie, P., Datta, A., Ulrike Dragosits, U., Fitton, N., Higgins, A., Myrgiotis, V., Kuhnert, M., Laidlaw, S., Malcolm, H., Rees. B., Smith, P., Tomlinson, S., Topp, K., Watterson. J., Webb. J., Yeluripati, J. (2014a) Capturing Cropland and Grassland Management Impacts on Soil Carbon in the UK LULUCF Inventory Contract Report prepared for the Department for Environment, Food and Rural Affairs Project SP1113.

Moxley, J., Angelopoulos, N., Buckingham, S., Laidlaw, S,. Malcolm. H., Norton, L., Olave, R., Rees, R., Rowe, R., Tomlinson, S., Thomson, A., and Topp., K. (2014b) Capturing the effect of Cropland and Grassland Management on biomass carbon stocks in the UK LULUCF inventory. Unpublished report by UKCEH for Department of Energy and Climate Change contract TRN265/09/2011

http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=18355

Office for National Statistics. (latest 2017). UK Standard Area Measurements. http://www.ons.gov.uk/ons/guide-method/geography/products/other/uk-standard-area-measurements--sam-/index.html

Office of National Statistics (annual, latest 2014). Mineral Extraction in Great Britain. https://www.gov.uk/government/collections/minerals

Perruchoud, D., Joos, F., Fischlin, A., Hajdas, I. and Bonani, G. (1999). Evaluating timescales of carbon turnover in temperate forest soils with radiocarbon data. Global Biogeochemical Cycles, 13, 555–573.

Poeplau, C., Don, A., Vesterdal, L., Leifeld, J., Van Wesemael, B.A.S., Schumacher, J., Gensior, A. (2011). Temporal dynamics of soil organic carbon after land-use change in the temperate zone – carbon response functions as a model approach. Global Change Biol 17, 2415-2427.

Reay, D.S., Radajewski, S., Murrell, J.C., McNamara, N., Nedwell, D.B., (2001). Effects of land-use on the activity and diversity of methane oxidizing bacteria in forest soils. Soil Biol Biochem 33, 1613-1623.

Reynolds, B *et al.* (2013) Countryside Survey: national "soil change" 1978-2007 for topsoils in Great Britain - acidity, carbon, and total nitrogen status. *Vadose Zone Journal*, 12 (2), vzj2012.0114. 15, pp.

Rollinson, T.J.D and Gay, J.M. (1983). Assortment Forecasting Service, Volume 77 of Research information note. Forestry Commission, Research Division.

Ruddock, K. (2007). UK Overseas Territories and Crown Dependencies: Emissions by sources and removals by sinks due to activities in the Land Use, Land-Use Change and Forestry sector, University of Edinburgh. MSc in Environmental Sustainability.

Salway, A.G; Murrells, T.P; Milne, R and Ellis (2001) S UK Greenhouse Gas Inventory 1990 – 1999, Appendix 6 AEA Technology report reference AEAT/R/ENV/0524 https://uk-air.defra.gov.uk/assets/documents/reports/empire/ghg/ukghgi_90-99_append_5-6.pdf

Saxton, K. and Rawls, W. (2006) Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. Soil Science Society of America Journal, 70, 1569–1578.

Sayle, T., Lamb, J., Colvin, A. and Harris, B. (1995) Isle of Man: Ecological Habitat Survey: Phase 1 1991-1994 Final Report. Isle of Man Government, Department of Agriculture, Fisheries and Forestry.

Scottish Government (annual, latest 2018) Results from the June Agricultural Census. http://www.scotland.gov.uk/Topics/Statistics/Browse/Agriculture-Fisheries/PubFinalResultsJuneCensus

Skiba, U. (2007). N fertilisation of UK forests. Personal communication.

Smart, S.M.; Allen, D.; Murphy, J.; Carey, P.D.; Emmett, B.A.; Reynolds, B.; Simpson, I.C.; Evans, R.A.; Skates, J.; Scott, W.A.; Maskell, L.C.; Norton, L.R.; Rossall, M.J.; Wood, C. (2009) Countryside Survey: Wales Results from 2007. NERC/Centre for Ecology & Hydrology, Welsh Assembly Government, Countryside Council for Wales, 94pp.

Smith, J., Gottschalk, P., Bellarby, J., Richards, M., Nayak, D., Coleman, K., Hillier, J., Flynn, H., Wattenbach, M., Aitkenhead, M., Yeluripurti, J., Farmer, J. and Smith, P. (2011). Model to Estimate Carbon in Organic Soils – Sequestration and Emissions (ECOSSE): User Manual. University of Aberdeen: Aberdeen, 77pp.

Smith, P., Chapman, S.J., Scott, W.A., Black, H.I.J., Wattenbach, M., Milne, R., Campbell, C.D., Lilly, A., Ostle, N., Levy, P.E., Lumsdon, D.G., Millard, P., Towers, W., Zaehle, S., Smith, J.U., 2007. Climate change cannot be entirely responsible for soil carbon loss observed in England and Wales, 1978-2003. Global Change Biol., 13, 2605-2609.

Sutton, M. A., D. Simpson, et al. (2008). Uncertainties in the relationship between atmospheric nitrogen deposition and forest carbon sequestration. Global Change Biology 14(9): 2057-2063.

Taylor, C. M. A. (1991). Forest fertilisation in Britain. Forestry Commission Bulletin 95.

Ťupek, B., Mäkipää, R., Heikkinen, J., Peltoniemi, M., Ukonmaanaho, L., Hokkanen, T., Nöjd, P., Nevalainen, S., Lindgren, M., Lehtonen, A., 2015. Foliar turnover rates in Finland — comparing estimates from needle-cohort and litterfall-biomass methods. Boreal Environ. Res. 20, 283–304.

Thomson *et al.* (2011) Defra project SP1105 Scoping Study to Determine Feasibility of Populating the Land Use Component of the LULUCF-GHG Inventory. http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=17144&FromSearch=Y&Publisher=1&SearchText=SP1105&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

Tomlinson, R. W. (2010). Changes in the extent of peat extraction in Northern Ireland 1990–2008 and associated changes in carbon loss. Applied Geography, 30: 294-301.

UKCEH Land Cover Map 2015 https://www.ceh.ac.uk/services/land-cover-map-2015

van Oijen, M. and Thomson, A. (2010) Toward Bayesian uncertainty quantification for forestry models used in the United Kingdom Greenhouse Gas Inventory for Land Use, Land-Use change, and forestry. Climatic Change, 103(1-2): 55-67.

Welsh Government (annual, latest 2015) Survey of Agricultural and Horticulture. http://wales.gov.uk/statistics-and-research/survey-agricultural-horticulture/?lang=en#/statistics-and-research/survey-agricultural-horticulture/?tab=previous&lang=en

Yamulki, S. And Broadmeadow, S. (2012). Revised nitrous oxide emission estimates from forest soils in England, Scotland and Wales for the LULUCF inventory sector. Personal communication.

Zerva, A., Mencuccini, M., 2005. Carbon stock changes in a peaty gley soil profile after afforestation with Sitka spruce (Picea sitchensis). Ann Forest Sci 62, 873-880..

## 17.6   CHAPTER 7 [WASTE (CRF SECTOR 5)]

AEA Technology (2002), Atmospheric Emissions from Small Carcass Incinerators, Report produced for the Department for Environment, Food and Rural Affairs by AEA Technology Environment, Culham Science Centre, Abingdon, Oxon. OX14 3ED, August 2002. Report AEAT/ENV/R/0920. http://www.airquality.co.uk/archive/reports/cat07/aeat-env-r-0920.pdf

The Association for Organics Recycling (2006 to 2008). "Market survey of the UK organics recycling industry". http://www.organics-recycling.org.uk/page.php?article=1746&name=Survey+of+the+UK+Organics+Recycling+Industry+2008%2F09, http://www.organics-recycling.org.uk/uploads/article1769/WRAP_AFOR_Report_0708_-_FINAL_AFOR__3__cg.pdf, http://www.organics-recycling.org.uk/uploads/article1769/The_State_of_Composting_and_Biological_Waste_Treatment_in_the_UK_2006-7.pdf

BEIS (2019). Digest of United Kingdom Energy Statistics 2019, London, The Stationery Office.

Biogas, 2016. The Official Information Portal on Anaerobic Digestion: Biogas Map. Biogas. http://www.biogas-info.co.uk/resources/biogas-map/. (Accessed September 2016).

Broomfield M, Davies J, Furmston P, Levy L, Pollard SJT, Smith R (2010). "*Exposure Assessment of Landfill Sites Volume 1: Main report.*" Environment Agency, Bristol. Report: P1-396/R.

Brown, KA and Leech, A (2008) Revision of UK model for predicting methane emissions from landfills. Task 3 report – Review of methodology, data quality & scope for improvement. Final Report to Defra, October 2008.

Brown, KA, Smith, A, Burnley, SJ, Campbell, DJV, King, K & Milton, MJT (1999), Methane Emissions from UK Landfills, AEA Technology, AEAT-5217, Culham.

Cardenas L., Gilhespy S. and Misselbrook T. (2015) Inventory of UK emissions of methane and nitrous oxide from agricultural sources for the year 2014. MS EXCEL spreadsheet. Rothamsted Research, North Wyke, Devon.

Chartered Institute of Waste Management (2013), "Commercial and Industrial Waste in the UK and Republic of Ireland," President's Report prepared by Ricardo-AEA, Report Ref. Ricardo-AEA/R/ED58810, Issue Number 4, Date 15/10/2013.

Chemical Industries Association (2014). Qualitative information regarding activity and emissions in the chemical industry. Personal communication from Nick Sturgeon, CIA, 2014.

The Composting Association (1998-2005). "The State of Composting and Biological Waste Treatment in the UK". http://www.organics-recycling.org.uk/uploads/article1769/Compost_Survey_2005-06.pdf, http://www.organics-recycling.org.uk/uploads/article1769/Compost_Survey_2004-05.pdf, http://www.organics-recycling.org.uk/uploads/article1769/Compost_Survey_2001-02.pdf, http://www.organics-recycling.org.uk/uploads/article1769/Compost_Survey_2001-02.pdf, http://www.organics-recycling.org.uk/uploads/article1769/Compost_Survey_1999.pdf, http://www.organics-recycling.org.uk/uploads/article1769/Compost_Survey_1998.pdf

The Cremation Society of Great Britain (2018), Table of Cremations 2018, 1960-2018.

DAERA (2019). Statistics on waste disposal in Northern Ireland in 2018. Personal communication, Adrian Gregory, DAERA, September 2019.

DECC (2015a) "UK Greenhouse Gas and Air Quality Pollutant Inventory Improvement Programme: Analysis of volumes of landfill gas flared in the UK between 1990 and 2013," Report prepared by Ricardo-AEA and CRA Europe.

DECC (2015b) "Emissions estimation for IPCC 2006 Guidelines Compliance in the UK Waste Sector," Report prepared by Ricardo-AEA and Aether.

Defra (2011). Government Review of Waste Policy in England 2011. http://www.defra.gov.uk/publications/files/pb13540-waste-policy-review110614.pdf

Defra (2011b), "Survey of Commercial and Industrial Waste Arisings 2010 – Revised Final Results," Statistical Release, 13 June 2011.

Defra (2010) UK meets 2010 Landfill Directive target and responds to landfill consultations Published by the Department for Environment, Food and Rural Affairs on 8th September 2010. http://ww2.defra.gov.uk/news/2010/09/08/landfill-directive-target/

Defra (2018), Expenditure and Food Survey Report. https://www.gov.uk/government/statistical-data-sets/family-food-datasets

Defra (2007) Waste Strategy for England 2007. Published by Defra.

http://www.defra.gov.uk/environment/waste/strategy/strategy07/documents/waste07-strategy.pdf

Defra EPSIM data, (2006).

http://www.defra.gov.uk/environment/statistics/waste/wrsewage.htm

Defra (2004), The National Food Survey 1990-03.

DCLG (2014), Fire Statistics Great Britain.

https://www.gov.uk/government/collections/fire-statistics-great-britain Checked in 2014.

DOENI (2006) Towards Resource Management – The Northern Ireland Waste Strategy 2006-2020. Published by the Northern Ireland Department of the Environment. http://www.doeni.gov.uk/niea/de/wms.17.pdf

Entec (2003). Entec UK Ltd, Development of UK Cost Curves for Abatement of Dioxin Emissions to Air, Final Report for Consultation, November 2003.

Environment Agency (2018), Pollution Inventory to 2017. Personal communication from Alison Issitt, the Environment Agency, June 2018.

Eunomia Consulting and Research (2011), Inventory Improvement Project – UK Landfill Methane Emissions Model" – Final Report to Defra. http://randd.defra.gov.uk/Document.aspx?Document=9887_WR1124Finalreportincludingappendices.pdf

Golder Associates (2005), UK Landfill Methane Emissions: Evaluation and Appraisal of Waste Policies and Projections to 2050. Report version A.2, November 2005. Report for the UK Department of Environment, Food and Rural Affairs. Authors: Arnold, S. and Yang. Z. Report number 05529424.500.

Golder Associates (2014) for Defra, "Review of landfill methane emissions monitoring," R Gregory, J Stalleicken, R Lane, S Arnold and D Hall, Report Ref. 13514290381.504/A.1. http://randd.defra.gov.uk/Document.aspx?Document=12439_WR1908ReviewofMethaneEmissionsModelling.pdf

Government of Bermuda Department of Statistics (2017), 2017 Environmental Statistics Compendium

HMIP (1995), A Review of Dioxin Emissions in the UK, Report No HMIP/CPR2/41/1/38, October 1995.

Home Office (2019). Fire Statistics Great Britain, from the Home Office Incident Reporting System, last updated 19 August 2019.

IPCC (1997), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 3, Greenhouse Gas Inventory Reference Manual, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (2000), Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, ed. Penman, J, Kruger, D, Galbally, I, *et al.*, IPCC National Greenhouse Gas Inventories Programme, Technical Support Programme Technical Support Unit, Institute for Global Environmental Strategies, Hayama, Kanegawa, Japan.

IPCC (2006) Guidelines for National Greenhouse Gas Inventories, ed. Eggleston, S, Buendia, L, Miwa, Kyoko, Ngara, Todd, Tanabe, Kiyoto. IPCC National Greenhouse Gas Inventories Programme, Technical Support Programme Technical Support Unit, Institute for Global Environmental Strategies, Hayama, Kanegawa, Japan.

Jacobs Engineering UK Ltd (2010) Final report to the Environment Agency: Categories of Landfills for Methane Emissions.

Jacobs Engineering UK Ltd (2011) for Defra, "Commercial and Industrial Waste Survey 2009: Final Report," May 2011.

LQM (2003), Methane emissions from landfill sites in the UK. Final report. January 2003. Report for the UK Department for Environment, Food and Rural Affairs. Authors: Gregory, RG, Gillett, AG, Bradley, D, LQM report 443/1. Defra contract EPG 1/1/145.

Local authority collected waste for England: quarterly estimates. https://www.gov.uk/government/statistics/local-authority-collected-waste-for-england-quarterly-estimates

NIEA (2018). Northern Ireland Pollution Inventory (NIPI) for 2017. Personal communication from Michael Moody, Northern Ireland Environment Agency, August 2018.

NNFCC (2017), National Non-Food Crops Centre Anaerobic Digestion Deployment in the United Kingdom. http://www.nnfcc.co.uk/publications/report-anaerobic-digestion-deployment-in-the-uk (Accessed July 2017).

NRW (2019), Welsh Emissions Inventory, waste interrogator data and landfill gas use data. Personal communication from Susan Freeman, Natural Resources Wales, August 2019.

ONS (2018), Office of National Statistics Population Estimates for UK, England and Wales, Scotland and Northern Ireland. https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/bulletins/annualmidyearpopulationestimates/mid2017

Parfitt, J. (2009) Home Composting Diversion: District Level Analysis. Waste & Resources Action Programme. http://www.wrap.org.uk/sites/files/wrap/Home%20Composting%20Diversion%20District%20Level%20Analysis.pdf

Resource Futures (2012) for Defra, "Biodegradability of municipal solid waste," Report Ref. WR1003.

RCEP (Royal Commission on Environmental Protection), 17th Report - Incineration of Waste, 1993.

Scottish Government (2010) Scotland's Zero Waste Plan. Published by the Scottish Government, Edinburgh 2010. http://www.scotland.gov.uk/Publications/2010/06/08092645/11

SEPA (2015). Waste data reporting. http://www.sepa.org.uk/environment/waste/waste-data/waste-data-reporting/

SEPA (2015). Statistics on waste disposal by incineration in Scotland in 2014. Personal communication.

SEPA (2019). Statistics on waste disposal in Scotland in 2018. Personal communication, Peter Ferrett, SEPA, September 2019.

States of Guernsey (2018), Guernsey Facts and Figures 2018

StatsWales. https://statswales.wales.gov.uk/Catalogue/Environment-and-Countryside/Waste-Management/Local-Authority-Municipal-Waste/Annual

StatsWales. https://statswales.wales.gov.uk/Catalogue/Environment-and-Countryside/Waste-Management/Recycling-Destinations/Recycling-Tonnages-by-Material-FacilityType

UKCEH (2019). Data on composting and anaerobic digestion to 2018, based on UKCEH analysis of resources such as the NNFCC database. Personal communication from Ulli Dragosits, 2019.

UKWIR (2019). UK Water Industry Research data provision from UK water companies to provide estimated emissions and activity for methane and nitrous oxide emissions from water treatment, sludge treatment and sludge disposal activities in 2018. Data provided for: Anglian,

Dwr Cymru, Scottish Water, Severn Trent, South West Water, Southern Water, Thames Water, Unitied Utilities , Wessex Water, Yorkshire Water.

US EPA (2008), AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume I, Stationary Point and Area Sources. US EPA website, 2008: http://www.epa.gov/ttn/chief/ap42/index.html

US EPA (2015), US EPA, AP 42 Compilation of Air Pollutant Emission Factors, 5th Edition, Section 2.5 http://www.epa.gov/ttnchie1/ap42/ Checked in 2015.

WRAP (2009 to 2014). "A survey of the UK organics recycling industry". http://www.wrap.org.uk/content/organics-recycling-survey-2012, http://www.wrap.org.uk/sites/files/wrap/ASORI%20Final%20Report%202010%20v2.pdf, http://www.organics-recycling.org.uk/dmdocuments/2009_Organics_Report_Final.pdf

WRAP (2013) A survey of the UK organics recycling industry in 2012 [online]. Available from: http://www.wrap.org.uk/content/organics-recycling-survey-2012

WRAP (2014) A survey of the UK Anaerobic Digestion industry in 2013 [online]. Available from: http://www.wrap.org.uk/sites/files/wrap/A_survey_of_the_UK_Anaerobic_Digestion_industry_ in_2013.pdf

WRAP 2016. Operational Anaerobic Digestion sites. Waste and Resources Action Programme. http://www.wrap.org.uk/content/operational-ad-sites. (Accessed September 2016).

WRAP 2017. Organics recycling industry status report 2015. A report on the status of composting and Anaerobic Digestion sectors in UK (England, Wales, Scotland and Northern Ireland). http://www.wrap.org.uk/sites/files/wrap/asori%202015.pdf (Accessed October 2017).

Welsh Assembly Government (2009), Waste Strategy 2009-2050: Towards Zero Waste Consultation document published by the Welsh Assembly Government. http://wales.gov.uk/consultations/environmentandcountryside/wastestrategy/?lang=en

Wenborn, M.J., Coleman, P.J., Passant, N.R., Salway, A.G. & Lymberidi, E., Future UK Emissions of Persistent Organic Pollutants, Cadmium, Lead and Mercury, AEA Technology, Report No AEAT-3171/20531001/Issue 1, June 1998.

## 17.7   CHAPTER 10 [RECALCULATIONS AND IMPROVEMENTS]

BEIS (2019a), Digest of United Kingdom Energy Statistics 2019, London, The Stationery Office.

FCCC ERT (2017). Framework Convention on Climate Change – Expert Review Team. Report on the individual review of the annual submission of the United Kingdom of Great Britain and Northern Ireland submitted in 2017. FCCC/ARR/2017/GBR. United Nations Framework Convention on Climate Change, Haus Carstanjen, Martin-Luther-King-Strasse 8, D-53175 Bonn, Germany.

IPCC (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories

http://www.ipcc-nggip.iges.or.jp/public/2006gl/

Ricardo-AEA, 2014 UK GHG Inventory Improvements: Industrial Process Sector Compliance with IPCC 2006 Guidelines, a report to DECC by Ricardo-AEA, December 2014.

## 17.8 ANNEX 2 [UNCERTAINTIES]

AEA (2008) UK emissions of HFCs, PFCs and $SF_6$ 2008 update. Final Report prepared for the Department for Environment, Food and Rural Affairs, December 2008, AEA, Oxfordshire, UK.

Abbott et al. (2007). Internal review of uncertainties. 2007.

BEIS (2018a), Digest of United Kingdom Energy Statistics 2018, London, The Stationery Office.

Bennet et al. (1995). Bennet, S, Kershaw, S, Burrell, R (1995), Control Measures for Methane Emissions from Coal Production, ETSU N/01/00006/REP

Brown et al. (1999). Brown, KA, Smith, A, Burnley, SJ, Campbell, DJV, King, K, Milton, MJT, (1999) Methane Emissions from UK Landfills, AEA Technology, AEAT-5217, Culham.

Eggleston et al. (1998). Eggleston, HS, Salway, AG, Charles, D, Jones, BMR, Milne, R (1998), Treatment of Uncertainties for National Estimates of Greenhouse Gas Emissions, National Environmental Technology Centre, AEA Technology, Report AEAT - 2688.

Hobson et al. (1996). Hobson, J, Palfrey, R, Sivil, D, Palfrey, E, Day, M (1996), Control Measures to Limit Methane Emissions from Sewage and Sludge Treatment and Disposal, WRc, Report No DOE 4118.

ICF (2014), Review of data and methodologies used in the calculation of UK emissions from F-GasesIPCC (2000), Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, ed. Penman, J, Kruger, D, Galbally, I, *et al.*, IPCC National Greenhouse Gas Inventories Programme, Technical Support Programme Technical Support Unit, Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan.

IPCC (2006) Guidelines for National Greenhouse Gas Inventories, ed. Eggleston, S, Buendia, L, Miwa, Kyoko, Ngara, Todd, Tanabe, Kiyoto. IPCC National Greenhouse Gas Inventories Programme, Technical Support Programme Technical Support Unit, Institute for Global Environmental Strategies, Hayama, Kanegawa, Japan.

Milne (2018). Alice E. Milne, Tom Misselbrook, Sarah Gilhespy, Steve Anthony, Adrian Williams. Analysis of uncertainties in the estimates of nitrous oxide and methane emissions in the UK's greenhouse gas inventory for agriculture.

Milne, R (2006), Centre for Ecology and Hydrology, (Edinburgh), Personal Communication.

Thomson (2008) Centre for Ecology and Hydrology, (Edinburgh), Personal Communication.

Williams, A (1993), Methane Emissions, Watt Committee Report Number 28, The Watt Committee on Energy, London.

## 17.9 ANNEX 3, SECTOR 1, 1A

AEP (2004), Joslin, A, Rodgers I, Salway G, Tabberer R, Relating fuel consumption to $CO_2$ emissions: Review and recommendations for power station fuel and plant parameters for use in the DTI power station model.

Airtricity (2018). Gas demand, gas compositional analysis and leakage information for Northern Ireland gas provision by Airtricity in 2017. Personal communication from Valerie Hazlett, November 2018.

Baggott SL, Lelland A, Passant NP, and Watterson J (2004) Review of Carbon Emission Factors in the UK Greenhouse Gas Inventory. AEA Energy and Environment, The Gemini Building, Fermi Avenue, Didcot, Oxfordshire, OX11 0QR, UK. November 2004. AEA report number AEAT/ENV/R/2347. Report prepared for UK Defra under contract RMP/2106.

BEIS (2019a), Digest of United Kingdom Energy Statistics 2019, London, The Stationery Office.

BEIS (2019b). EU ETS data for all UK installations, as provided by the UK regulators to BEIS. Personal communication, Sam Bradley, BEIS, April 2019.

BEIS OPRED (2019). EEMS data from upstream oil and gas installations. Personal communication from CMichelle McDade, BEIS, 2019.

Betwys (2000), Personal Communication

BITOR (1995), Manufacturer's specification for Orimulsion®

BLF/UKPIA/CORA (1994), The Use and Fate of Lubricants and Used Oils.

Brain, SA, Carr, CE, Davies, M, Rantell, T & Stokes, BJ (1994), Emission of Volatile Organic Compounds (VOCs) from Coal-Fired Appliances, DTI, Coal R&D, Report No COAL R033.

British Gas (1992,) Personal Communication from FE Shephard, Gas Research Centre, Loughborough, Leics.

British Gas (1994), Personal Communication from S Pearson, Gas Research Centre, Loughborough, Leics.

BP Chemicals (2015), Personal Communication, David Ingram, BP Chemicals, May 2015.

BR (1994), Research Report "Determination of Diesel Exhaust emissions on British Rail" Jan 1994.

British Steel (2019). Emissions and activity data by sub-source within integrated steelworks in 2018. Personal communication from Lee Adcock, British Steel, October 2019.

CAA (2019), UK Airport Statistics: 2018 – annual. Table 08 Air Passengers by Type and Nat of Operator 2019.

Cadent Gas (2018). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by Cadent Gas. Personal communication from Matt Marshall, August 2018.

Carslaw, D., Beevers, S., Westmoreland, E., Williams M., Tate, J., Murrells, TP., Stedman, J., Li, Y., Grice, S., Kent, A and Tsagatakis I (2011) Trends in $NO_x$ and $NO_2$ emissions and ambient measurements in the UK. Report prepared for Defra, July 2011. http://uk-air.defra.gov.uk/reports/cat05/1108251149_110718_AQ0724_Final_report.pdf

Celtic Energy (2006) Personal Communication (Richard Morris).

CLG (2010) . See http://www.communities.gov.uk/housing/housingresearch/housingstatistics/housingstatisticsby/householdestimates/livetables-households/, table 401

CONCAWE (1986), Hydrocarbon Emissions from Gasoline Storage and Distribution Systems, Report No 85/54

CORINAIR (1992) CORINAIR Inventory, Commission of the European Community, Default Emission Factors Handbook, 2nd ed, CITEPA, Paris.

DfT (2001), New Car Fuel Consumption and Emission Figures, Vehicle Certification Agency, July 2001

DfT (2004b), Transport, Environment and Taxation Division communication (C Parkin), February 2004

DfT (2007a), Road Statistics 2006: Traffic, Speeds and Congestion, Transport Statistics Bulletin SB(07) 20, 2007

DfT(2007b), National Travel Survey: 2006, Transport Statistics Bulletin, SB(07) 21, 2007

DfT (2008a), English Regional Traffic Growth and Speed Forecasts, Rev 1.1 April 2008, personal communication with Malcolm Jay, ITEA Division, DfT, April 2008

DfT (2008b), personal communication with Nick Barter, DfT, April 2008.

DfT (2008c), Transport Statistics Report, Maritime Statistics 2007. Department for Transport. Available from http://www.dft.gov.uk/pgr/statistics

DfT (2009a), personal communication with Annie Sorbie, Transport Statistics, DfT, November 2009

DfT (2009b), Transport Statistics Great Britain: 2009 edition, The Stationery Office. http://www.dft.gov.uk/pgr/statistics/datatablespublications/tsgb/

DfT (2009c), personal communication with Chris Parkin, Cleaner Fuels and Vehicles, Transport Statistics, DfT, March 2009

DfT (2011a), Road Freight Statistics 2010, October 2011 Release, Department for Transport. http://www.dft.gov.uk/statistics/releases/road-freight-statistics-2010/

DfT (2012b), personal communication with Alberto Pompermaier, Department for Transport, 2012

DfT (2013a), personal communication with Matthew Tranter, Bus Service Operators Grant system, DfT, August 2013

DfT (2014a), personal communication, Road Traffic Statistics, DfT. See also

https://www.gov.uk/government/statistics/road-traffic-estimates-in-great-britain-2013. August 2014

DfT (2014b), personal communication, Vehicle Licensing Statistics, Department for Transport, August 2014

DfT (2014c), Vehicle Licensing Statistics: 2013, Department for Transport, https://www.gov.uk/government/statistics/vehicle-licensing-statistics-2013

Drax Power Ltd (2019). Environmental Performance Review 2018.

DRDNI (2013), personal communication with Karol Shields, Transport NI - Roads Service, Department for Regional Development, Northern Ireland, October 2013

DRDNI (2014), personal communication with Manny Fitzpatrick, DVA Statistics Branch, Department of Environment, August 2014

DTI (1998), Digest of United Kingdom Energy Statistics 1997, London, The Stationery Office.

EMEP (1990), European Monitoring and Evaluation Programme. Proceedings of the EMEP Workshop on Emissions from Ships. State Pollution Control Authority, Norway.

EMEP/EEAEMEP/EEAEMEP/EEAEMEP/EEA (2009). http://www.eea.europa.eu/themes/air/emep-eea-air-pollutant-emission-inventory-guidebook/emep

EMEP (2009b). EMEP/EEA air pollutant emission inventory guidebook — 2009. Part B, Section 1A4 Other Mobile. http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-4-other-mobile-tfeip-endorsed-draft.pdf

EMEP/EEA (2016), Atmospheric Emission Inventory Guidebook, 2016 Edition.

Entec (2002), Quantification of emissions from ships associated with ship movements between ports in the European Community", Report for European Commission, DG ENV. Belgium; Main

Contributors Chris Whall, Karen Archer, Layla Twigger, Neil Thurston, David Ockwell, Alun McIntyre, Alistair Ritchie (Entec) and David Cooper (IVL).

Entec (2005). Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments. Task 1 - Preliminary Assignment of Ship Emissions to European Countries. Final Report to European Commission Directorate General Environment, Entec UK Limited, August 2005. http://ec.europa.eu/environment/air/pdf/task1_asign_report.pdf

Entec (2010). UK Ship Emissions Inventory. Final Report to Defra, November 2010. http://uk-air.defra.gov.uk/reports/cat15/1012131459_21897_Final_Report_291110.pdf

ERM (2008). Waste Oil Technical Advisory Group, Final Report, February 2008

Environment Agency (1997), Chemical Release Inventory 1996, Personal Communication.

Environment Agency (2019), Pollution Inventory. Personal communication from Alison Issitt, the Environment Agency, June 2019.

Fynes, G & Sage, PW (1994), Emissions of Greenhouse Gases from Coal Fired Plant, British Coal, Coal Research Establishment, CERCHAR, DMT, Delft University of Technology, TPS Termiska Processer AB, CONTRACT NO JOUF 0047-C(SMA).

Hawkins & Coad (2004), Personal communication. John Hawkins & Nick Coad from the Association of Train Operating Companies (ATOC).

Hedmark (2015). Clarifications regarding the completeness and detail of reporting of several EU ETS installations in Scotland, for sites using the "fall-back" reporting approach. Personal communication from Asa Hedmark of SEPA, October 2015.

IPCC (1997a), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 1, Greenhouse Gas Inventory Reporting Instructions, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (1997b), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 2, Greenhouse Gas Inventory Workbook, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (1997c), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 3, Greenhouse Gas Inventory Reference Manual, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (2000), Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, ed. Penman, J, Kruger, D, Galbally, I, et al., IPCC National Greenhouse Gas Inventories Programme, Technical Support Programme Technical Support Unit, Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan.

IPCC (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories http://www.ipcc-nggip.iges.or.jp/public/2006gl/

Iron & Steel Statistics Bureau (2019), Iron and Steel Industry, Annual Statistics for the UK, 2018. ISSB Limited.

Lakhani (2015). Updated estimates of natural gas use in gas compressors, and in upstream oil and gas sector were confirmed by Shyam Lakhani of DECC energy statistics, to clarify that the UK GHGI should deviate from DUKES 2015 data for these sources. Personal communication, October 2015.

LRC (1998), London Research Centre, UK Emission Factor Database.

MoD (2019), personal communication with Ray Dickinson, MoD, August 2019.

Murrells et al. (2011). Murrells T, John Norris, Glen Thistlethwaite, Neil Passant, Helen Walker, Nicola Webb (2011). Definitions of Gas Oil and DERV and Allocations to Sectors in the UK

Greenhouse Gas Inventory. AEA Report for DECC under Task 5 of the 2011 UK GHG Inventory Improvement Programme. AEAT/ENV/R/3234, November 2011

National Grid (2019). Natural gas leakage estimates and gas compositional analysis for all gas transmission and distribution infrastructure operated by National Grid, including updated emissions from 2011 onwards from venting and LNG terminals. Personal communications from Matt Williams, July 2019.

Netcen (2004a), "Non-Road Mobile Machinery Usage, Life and Correction Factors", Report to the Department for Transport, AEAT/ENV/R/1895, November 2004, www.airquality.co.uk/archive/reports/reports.php?report_id=304

Netcen (2004b), "Emission factors programme Task 8c – emissions from non-road mobile machinery in the lawn and garden sector", Report to Defra, AEAT/ENV/R/1719, April 2004.

Northern Gas Networks (2019). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by NGN, personal communication from Dean Pearson, July 2019.

Northern Ireland Environment Agency (2018). Northern Ireland Pollution Inventory (NIPI). Personal communication from M Moody, NIEA, August 2018.

NRW (2019), Welsh Emissions Inventory, waste interrogator data and landfill gas use data, Natural Resources Wales. Personal communication from Susan Freeman, August 2018.

Off Highway Research Ltd (2000), International Database Service, March 2000

Oil & Gas UK (1998). UKOOA, Internal UKOOA study to determine pre-EEMS emissions totals and trends, 1990-1995, via Personal Communication (Peter Russell, Granherne)

ORR (2010) National Rail Trends Year Book (2010). http://www.rail-reg.gov.uk/upload/pdf/nrt-yearbook-2009-10.pdf

ORR (2018) National Rail Trends Data Portal http://dataportal.orr.gov.uk/

Passant, NR (2004), Emission factors programme Task 1 – Summary of simple desk studies (2003/4), AEA Technology Plc, Report No AEAT/ENV/R/1715/Issue 1, March 2004.

Passant, Watterson and Jackson. (2007) Review of the Treatment of Stored Carbon and the Non Energy Uses of Fuel in the UK Greenhouse Gas Inventory. AEA Energy and Environment, The Gemini Building, Fermi Avenue, Harwell, Didcot, Oxfordshire, OX11 0QR, UK. Report to Defra CESA for contract RMP/2106.

PRI (1995), Communication from Precision Research International.

PRI (1998), Communication from Precision Research International.

Quick, W (2004) – Power Tech – Personal correspondence

Samaras, Z & Zierock, KH (1993), Notes on the Assessment of the Emissions of Off-Road Mobile Machinery in the European Community.

Samaras, Z & Zierock, KH, (1994), Supplement to above.

Samaras, Z (1996), Personal Communication.

SGN (2018). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by SGN. Personal communication from Faye Tester, July 2018.

Scottish Coal (2006), Coal sales and elemental content data. Personal communication (Louis Suffredini).

SEPA (2019), Scottish Pollutant Release Inventory, Scottish Environment Protection Agency. Personal communication from Bob Boyce, October 2019.

SMMT (1999), Society of Motor Manufacturers and Traders, communication, November 1999.

Stewart, R & Walker, D (1996), Emissions to Atmosphere from Fossil Fuel Power Generation in the United Kingdom, AEAT-0746, ISBN 0-7058-1753-3.

Tata Steel (2019). Emissions and activity data by sub-source within integrated steelworks in 2018. Personal communication from Neil Haines, August 2019.

Tower (2006), Personal Communication

Transco (2008) – Measurement and process report MPR046: Estimation of Carbon Dioxide emission factors for UK Natural Gas 1990-2004

UK Coal (2019), UK production and manpower data from open-cast and deep mines during 2018. Personal communication from Brian Dobbin, UK Coal, July 2019.

UKPIA (1989), United Kingdom Petroleum Industry Association, Personal Communication.

UKPIA (2004), United Kingdom Petroleum Industry Association, Malcolm Watson communication on properties of UK fuels in 2004 (and correspondence in earlier years).

UKPIA (2019a), Refinery production & emissions data in 2018, carbon emission factors, petroleum products data from the United Kingdom Petroleum Industry Association, Personal Communication from Andy Roberts, UKPIA, August 2019.

UKPIA (2019b), United Kingdom Petroleum Industry Association, Hugh Tucker communication on properties of UK fuels in 2018, June 2019.

USEPA (1997), United States Environmental Protection Agency, Compilation of Air Pollutant Emission Factors, Vol 1, 5th Edition, AP-42, North Carolina.

US EPA (2010), Compilation of Air Pollutant Emission Factors, AP-42, via the internet at: www.epa.gov, 2010

Wales & West Utilities (2019). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by W&W, personal communication from Catherine Lister, July 2019.

Walker, H., Chris Conolly, John Norris and Tim Murrells. Greenhouse Gas Emissions from Inland Waterways and Recreational Craft in the UK. AEAT/ENV/R/3175, Task 25 of the 2010 DA / UK GHG Inventory Improvement Programme, June 2011. http://uk-air.defra.gov.uk/reports/cat07/1106231031_IP_Task_25_Inland_Waterways_Issue_1.pdf

Watterson, JD, Walker, C and Eggleston, S (2004) Revision to the Method of Estimating Emissions from Aircraft in the UK Greenhouse Gas Inventory. Report to Global Atmosphere Division, UK Defra. Report number ED47052, July 2004. netcen, The Gemini Building, Harwell, Didcot, Oxfordshire, OX11 0QR, UK.

Zachariadis, Th. & Samaras, Z, (1997), Int. J. of Vehicle Design, 18, 312.

## 17.10  ANNEX 3, SECTOR 1, 1B

Airtricity (2018). Gas demand, gas compositional analysis and leakage information for Northern Ireland gas provision by Airtricity in 2017. Personal communication from Valerie Hazlett, November 2018.

Barty, R (1995), Energy Policy and Analysis Unit, DTI, Personal Communication.

BEIS (2019a), Digest of United Kingdom Energy Statistics 2019, London, The Stationery Office.

BEIS (2019b). EU ETS data for all UK installations, as provided by the UK regulators to BEIS. Personal communication, Sam Bradley, BEIS, April 2018.

BEIS OPRED (2019). EEMS data from upstream oil and gas installations. Personal communication from CMichelle McDade, BEIS, 2019.

Bennet, S, Kershaw, S & Burrell, R, (1995), Control Measures for Methane Emissions from Coal Production, ETSU N/01/00006/REP.

British Gas (1993), Personal communication from C Rose, Regional Services Engineering Dept, London.

British Gas (1994), Personal communication from S Pearson, Gas Research Centre, Loughborough, Leics.

British Steel (2019). Emissions and activity data by sub-source within integrated steelworks in 2018. Personal communication from Lee Adcock, British Steel, October 2019.

Cadent Gas (2018). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by Cadent Gas. Personal communication from Matt Marshall, August 2018.

CONCAWE (1986), Hydrocarbon Emissions from Gasoline storage and distribution systems. Report No 85/54.

CORINAIR (1999), CORINAIR Inventory, Commission of the European Community, Default Emission Factors Handbook, 1st ed, CITEPA, Paris.

DTI (1997), The Energy Report 2, Oil and Gas Resources of the United Kingdom, Department of Trade and Industry, The Stationery Office.

DTI (1998), Digest of United Kingdom Energy Statistics 1998, London, The Stationery Office.

DTI (1998a), The Energy Report 2, Oil and Gas Resources of the United Kingdom, Department of Trade and Industry, The Stationery Office.

EIPPCB (2000), European Integrated Pollution Prevention and Control Bureau, Best Available Techniques reference Document on the Production of Iron and Steel.

Environment Agency (2019), Pollution Inventory. Personal communication from Alison Issitt, the Environment Agency, June 2019.

IPCC (1997), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 3, Greenhouse Gas Inventory Reference Manual, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (2000), Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, ed. Penman, J, Kruger, D, Galbally, I, et al., IPCC National Greenhouse Gas Inventories Programme, Technical Support Programme Technical Support Unit, Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan.

IPCC (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories

http://www.ipcc-nggip.iges.or.jp/public/2006gl/

Kershaw (2005), "Development of a Methodology for Estimating Methane Emissions from Abandoned Coal Mines in the UK", White Young Green report to Defra, 2005.

Petroleum Review (2000), 2000 UK Retail Marketing Survey. A special Supplement to Petroleum Review, Institute of Petroleum, March 2000.

National Grid (2019). Natural gas leakage estimates and gas compositional analysis for all gas transmission and distribution infrastructure operated by National Grid, including updated

emissions from 2011 onwards from venting and LNG terminals. Personal communications from Matt Williams, July 2019.

Northern Gas Networks (2019). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by NGN. Personal communication from Dean Pearson, July 2019.

Northern Ireland Environment Agency (2019). Northern Ireland Pollution Inventory (NIPI). Personal communication from M Moody, NIEA, August 2019.

NRW (2019), Welsh Emissions Inventory, waste interrogator data and landfill gas use data, Natural Resources Wales. Personal communication from Susan Freeman, August 2019.

Pheonix National Gas (2019) Gas leakage, annual gas demand data for 2018. Personal Communication from David Carson, June 2019.

SGN (2019). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by SGN, personal communication from Faye Tester, July 2019.

SEPA (2019), Scottish Pollutant Release Inventory, Scottish Environment Protection Agency. Personal communication from Bob Boyce, October 2019.

Tata Steel (2019). Emissions and activity data by sub-source within integrated steelworks in 2018. Personal communication from Neil Haines, August 2019.

UK Coal (2019), UK production and manpower data from open-cast and deep mines during 2018. Personal communication from Brian Dobbin, UK Coal, July 2019.

UKOOA (1998), Internal UKOOA study to determine pre-EEMS emissions totals and trends, 1990-1995, via personal communication (Peter Russell, Granherne)

UKOOA (2005), EEMS Environmental Database for Emissions and Discharges from Offshore Installations, Atmospheric Emissions Inventory, 2003 data. Personal communication from UKOOA via Peter Russell at Granherne.

UKPIA (2019a), Refinery production & emissions data in 2018, carbon emission factors, petroleum products data from the United Kingdom Petroleum Industry Association. Personal communication from Andy Roberts, UKPIA, August 2019.

UKPIA (2019b), United Kingdom Petroleum Industry Association, Hugh Tucker communication on properties of UK fuels in 2018, June 2019.

USEPA (2004), United States Environmental Protection Agency, Compilation of Air Pollutant Emission Factors. Vol 1, 5th Edition, AP-42, North Carolina. www.epa.gov

Wales & West Utilities (2019). Natural gas leakage estimates and gas compositional analysis for all gas distribution infrastructure operated by W&W. Personal communication from Catherine Litster, August 2019.

Williams, A. (1993), Methane Emissions, Watt Committee Report Number 28, The Watt Committee on Energy, London, 1993.

WSP (2011) Update of Estimated Methane Emissions from UK Abandoned Coal Mines. http://www.decc.gov.uk/assets/decc/publications/1775-ghg-improvement-project-wsp-report.

## 17.11  ANNEX 3, SECTOR 3

See references under **Chapter 5**

## 17.12 ANNEX 3, SECTOR 4

See references under **Chapter 6**

## 17.13 ANNEX 3, SECTOR 5

BEIS (2019a), Digest of United Kingdom Energy Statistics 2019, London, The Stationery Office.

Environment Agency and Scottish Environment Protection Agency (2002) Guidance of landfill gas flaring"

Environment Agency and Scottish Environment Protection Agency (2004) Guidance on the management of landfill gas.

Defra (2019), Expenditure and Food Survey Report providing data to 2018.

DOE (1993), UK Sewage Sludge Survey, CES Limited, HMSO.

Golder Associates (2005), UK Landfill Methane Emissions: Evaluation and Appraisal of Waste Policies and Projections to 2050. Report version A.2, November 2005. Report for the UK Department of Environment, Food and Rural Affairs. Authors: Arnold, S. and Yang. Z. Report number 05529424.500

LQM (2003), Methane emissions from landfill sites in the UK. Final report. January 2003. Report for the UK Department for Environment, Food and Rural Affairs. Authors: Gregory, RG, Gillett, AG, Bradley, D, LQM report 443/1. Defra contract EPG 1/1/145.

Ofgem (Office for Gas and Electricity Markets) . http://www.ofgem.gov.uk/Sustainability/Environment/Pages/Environment.aspx

## 17.14 ANNEX 4 [NATIONAL ENERGY BALANCE FOR THE MOST RECENT INVENTORY YEAR]

BEIS (2019a), Digest of United Kingdom Energy Statistics 2019, London, The Stationery Office.

Murrells et al. (2011). Murrells T, John Norris, Glen Thistlethwaite, Neil Passant, Helen Walker, Nikki Webb (2011). Definitions of Gas Oil and DERV and Allocations to Sectors in the UK Greenhouse Gas Inventory. AEA Report for DECC under Task 5 of the 2011 UK GHG Inventory Improvement Programme. AEAT/ENV/R/3234, November 2011.

## 17.15 ANNEX 6 [VERIFICATION]

Arnold, T., A. J. Manning, J. Kim, S. Li, H. Webster, D. Thompson, J. Muhle, R. Weiss, S. Park, and S. O'Doherty; Inverse modelling of CF4 and $NF_3$ emissions in East Asia; Atmos. Chem. Phys., 18, 13305-13320, 2018, https://doi.org/10.5194/acp-18-13305-2018

Bergamaschi et al. (2005). Bergamaschi, P., M. Krol, F. Dentener, A. Vermeulen, F. Meinhardt, R. Graul, M. Ramonet, W. Peters, and E. J. Dlugokencky, Inverse modelling of national and European $CH_4$ emissions using the atmospheric zoom model TM5, *Atmos. Chem. Phys.,* 5, 2431-2460.

Jones et al. (2007). Jones A.R., Thomson D.J., Hort M. and Devenish B., 'The U.K. Met Office's next-generation atmospheric dispersion model, NAME III', in Borrego C. and Norman A.-L. (Eds) Air Pollution Modelling and its Application XVII (Proceedings of the 27th NATO/CCMS

International Technical Meeting on Air Pollution Modelling and its Application), Springer, pp. 580-589

Lawson, C. L. and Hanson, R. J. (1974) Solving Least Squares Problems, Classics in Applied Mathematics, 1974 Manning et al. (2003). Manning A.J., Ryall D.B., Derwent R.G., Simmonds P.G. and O'Doherty S., 'Estimating European emissions of ozone-depleting and greenhouse gases using observations and a modelling back-attribution technique', *J. Geophys. Res.,* 108, 4405.

Manning et al. (2011). Manning, A. J., O'Doherty S., Jones, A. R. Simmonds, P. G. and Derwent R. G., Estimating UK methane and nitrous oxide emissions from 1990 to 2007 using an inversion modelling approach, *J. Geophys. Res.*, 116, D02305, doi:10.1029/2010JD014763.

Nilsson et al. (2001). Nilsson, M., C. Mikkela, I. Sundh, G. Granberg, B. H. Svensson, and B. Ranneby, Methane emission from Swedish mires: Natural and regional budgets and dependence on mire vegetation, *J. Geophys. Res.,* 106, 20847-20860.

O'Doherty et al. (2004). O'Doherty S., Cunnold D.M., Manning A.J., Miller B.R., Wang R.H.J., Krummel P.B., Fraser P.J., Simmonds P.G., McCulloch A., Weiss R.F., Salameh P.K., Porter L.W., Prinn R.G., Huang J., Sturrock G., Ryall D.B., Derwent R.G. and Montzka S., Rapid growth of HFC-134a, HCFC-141b, HCFC-142b and HCFC-22 from AGAGE observations at Cape Grim, Tasmania and Mace Head, Ireland during 1997-2002, *J. Geophys. Res.*, 109.

O'Doherty et al. (2014). O'Doherty, S., Rigby, M., Mühle, J., Ivy, D. J., Miller, B. R., Young, D., Simmonds, P. G., Reimann, S., Vollmer, M. K., Krummel, P. B., Fraser, P. J., Steele, L. P., Dunse, B., Salameh, P. K., Harth, C. M., Arnold, T., Weiss, R. F., Kim, J., Park, S., Li, S., Lunder, C., Hermansen, O., Schmidbauer, N., Zhou, L. X., Yao, B., Wang, R. H. J., Manning, A., and Prinn, R. G.: Global emissions of HFC-143a ($CH_3CF_3$) and HFC-32 ($CH_2F_2$) from in situ and air archive atmospheric observations, *Atmos. Chem. Phys.*, 14, 9429-9258, doi:10.5194/acp-14-9249-2014

Prinn, R. G., Weiss, R. F., Arduini, J., Arnold, T., DeWitt, H. L., Fraser, P. J., Ganesan, A. L., Gasore, J., Harth, C. M., Hermansen, O., Kim, J., Krummel, P. B., Li, S., Loh, Z. M., Lunder, C. R., Maione, M., Manning, A. J., Miller, B. R., Mitrevski, B., Mühle, J., O'Doherty, S., Park, S., Reimann, S., Rigby, M., Saito, T., Salameh, P. K., Schmidt, R., Simmonds, P. G., Steele, L. P., Vollmer, M. K., Wang, R. H., Yao, B., Yokouchi, Y., Young, D., and Zhou, L.: History of chemically and radiatively important atmospheric gases from the Advanced Global Atmospheric Gases Experiment (AGAGE), Earth Syst. Sci. Data, 10, 985-1018, 10.5194/essd-10-985-2018, 2018.

Simmonds, P. G., Rigby, M., Manning, A. J., Lunt, M. F., O'Doherty, S., McCulloch, A., Fraser, P., Henne, S., Vollmer, M. K., Muhle, J., Weiss, R., Salameh, P, Young, D., Reimann, S., Wenger, A., Arnold, A., Harth, C., et al, Global and regional emissions estimates of HFC-152a from in situ and air archive observations, Atmos. Chem. Phys., 16, pp. 365-382, 2016.

Stanley, K. M., Grant, A., O'Doherty, S., Young, D., Manning, A. J., Stavert, A. R., Spain, T. G., Salameh, P. K., Harth, C. M., Simmonds, P. G., Sturges, W. T., Oram, D. E., and Derwent, R. G.: Greenhouse gas measurements from a UK network of tall towers: technical description and first results, Atmos. Meas. Tech., 11, 1437-1458, 10.5194/amt-11-1437-2018, 2018.

Stavert A. R., S. O'Doherty, K. Stanley, D. Young, A. J. Manning, M. F. Lunt, C. Rennick, T. Arnold.: UK greenhouse gas measurements at two new tall towers for aiding emissions verification, Atmos. Meas. Tech., 12, 1103-1121, https://doi.org/10.5194/amt-12-1103-2019, 2019

## 17.16  ANNEX 7 [ANALYSIS OF EU ETS DATA]

Baggott et al. (2004). Baggott SL, Lelland A, Passant NP, and Watterson J (2004) Review of Carbon Emission Factors in the UK Greenhouse Gas Inventory. AEA Energy and Environment, November 2004.

BEIS (2019a), Digest of United Kingdom Energy Statistics 2019, London, The Stationery Office.

BEIS (2019b). EU ETS data for all UK installations, as provided by the UK regulators to BEIS, personal communication, Sam Bradley, BEIS, April 2019.

BEIS (2019c). Autogenerator gas consumption by refineries and other sectors, as reflected in DUKES. Personal Communication (James Halliwell), 2019.

BEIS OPRED (2019), spreadsheet of emissions data from the EU ETS reporting system of site operator annual returns to BEIS OPRED for 2018. Personal Communication from Michelle McDade.

British Steel (2019). Emissions and activity data by sub-source within integrated steelworks in 2018. Personal communication from Lee Adcock, British Steel, October 2019.

DECC (2010), email response to EU ETS-DUKES discrepancy issues, Personal Communication (Warren Evans), 2010

Hedmark (2015). Clarifications regarding the completeness and detail of reporting of several EU ETS installations in Scotland, for sites using the "fall-back" reporting approach. Personal communication from Asa Hedmark of SEPA, October 2015.

Tata Steel (2019). Emissions and activity data by sub-source within integrated steelworks in 2018. Personal communication from Neil Haines, August 2019.

UKPIA (2019a), Refinery production & emissions data in 2018, carbon emission factors, petroleum products data from the United Kingdom Petroleum Industry Association, Personal Communication from Andy Roberts, UKPIA, August 2019.

# 18 Acknowledgements

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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[94]. Lead Author. Author of uncertainty and key category analysis annexes. Reviewed f-gas sections. |
| Cardenas, Laura[95] | Sector expert for agriculture; author of sections of the NIR and other reporting requirements on agriculture. |
| Choudrie, Sarah | Inventory compilation lead; contribution to other chapters. |
| Jones, Luke | Contributor to Cpts 1, 3, 4, 5, 7, Annexes 1, 2, 4, 7, and 9. Compiled attached emission factors tables. |
| Karagianni, Eirini | Author of road transport, off-road machinery. |
| MacCarthy, Joanna | NAEI Contract Manager, contributor to Cpts 10 and annex 3 |
| Passant, Neil | Author of most sections on energy and industry and waste incineration; contributions to most chapters. |
| Richmond, Ben | Contributions of Cpt 2 |
| Smith, Harry | Contributor to Cpts 3 and 10. |
| Thomson, Amanda[96] | Sector expert for LULUCF and KP-LULUCF. Main author of LULUCF Cpt 6 and Cpt 11, Annex 3.5. Contributor to compilation of Sector 4. |
| Turtle, Lara | UK Greenhouse Gas Inventory Report Manager. Author of executive summary, Cpt 1, Cpt 2 and Annex 8. |
| Wakeling, Daniel | Author of road transport, off-road machinery, shipping and fishing. |
| *Contributors* | |
| Bradley, Sam | BEIS GHGI improvement programme lead |
| Broomfield, Mark | Sector expert for solid waste disposal on land. Author of landfill, biological treatment of waste, and sections within Annex 3. |

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[95]    Rothamsted Research

[96]    Centre for Ecology & Hydrology

| Person | Technical work area and responsibility |
|---|---|
| Buys, Gwen[96] | Data and QA/QC manager for LULUCF and KP-LULUCF sectors. Author of sections in Cpt 1 and Cpt 2. Compilation of Sector 4 of the CRF. |
| Clilverd, Hannah[96] | LULUCF contributing author for Cpt 6 and Annex 3.5. Contributor to compilation of sector 4. |
| Gibbs, Mark | Compilation of rail emissions estimates and text for this sector |
| Gilhespy, Sarah[95] | Contributions to agriculture inventory compilation and text |
| Glendining, Margaret[95] | Contributions to agriculture inventory compilation and text |
| Gluckman, Ray[97] | Author of the section on f-gases in Cpt 4. |
| Henshall, Paul[80] | CARBINE modelling for LULUCF inventory for 4A Forestry, 4G Harvested Wood Products and KP, contributions to text for sections in Cpt 6, Cpt 11 and Annex 3.5. |
| Hobson, Melanie[98] | Compilation of rail emissions estimates and text for this sector |
| Malcolm, Heath[96] | UKCEH project manager for the LULUCF inventory team. Contribution to LULUCF QA/QC. |
| Manning, Alistair[99] | Verification of the UK greenhouse gas inventory (Annex 6) |
| Neil Lambert | BEIS GHGI Contract Manager |
| Matthews, Robert[100] | CARBINE modelling for LULUCF inventory for 4A Forestry, 4G Harvested Wood Products and KP, contributions to text sections in Cpt 6, Cpt 11 and Annex 3.5 |
| May, Kirsten[98] | Responsible for compilation of emission estimates for the OTs and CDs, and report text relating to this |
| Milne, Alice[75] | Contributions to agriculture inventory compilation and text |
| Misselbrook, Tom[95] | Contributions to agriculture inventory compilation and text |
| Murrells, Tim | NAEI transport manager. Technical Director of NAEI Programme. Contributing author to all sections on transport |
| Pearson, Ben | Methodological development of the Monte Carlo model |
| Raoult, Justine[98] | Responsible for compilation of emission estimates for the OTs and CDs, and report text relating to this |
| Thistlethwaite, Glen | Inventory QA/QC manager. Author of QA/QC section. |
| Walker, Charles | Sector expert for aviation in the NAEI. Author of aviation sections. |
| Watterson, John | Review of LULUCF chapters and Annex. Contribution to Cpt 10. |
| Eleanor Webster | BEIS GHGI and statistics lead |
| Zhang, Holly[98] | Responsible for updating the OTs and CDs Annex tables for this report text |
| *Additional assistance* | |
| Aston, Clare | Data acquisition, report printing |
| National Inventory Steering Committee | Suggestions and improvements to draft versions of the NIR |
| Richardson, Joe Roberts Webb, Nicola | NAEI compilation |

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[97] Gluckman Consulting

[98] Aether

[99] The Met Office

[100] Forest Research

**Table 18.2    Key Data Providers to the Greenhouse Gas Inventory**

| Organisation | Summary of Data Provided |
| --- | --- |
| BEIS | Energy statistics (DUKES) including fuel activity and GCVs;<br>Oil and gas production, flaring and venting statistics;<br>Upstream oil and gas emissions data (EEMS). |
| Defra | Solid waste disposal / fate statistics;<br>Waste-water treatment activity data;<br>Food and protein survey data;<br>Agricultural survey data, activity statistics (livestock, crops). |
| DfT | Road traffic statistics;<br>Marine transport statistics;<br>Rail activity and emission estimates (REM);<br>Aviation movement statistics. |
| ONS | PRODCOM statistics (industrial production data);<br>Housing and population data;<br>Economic activity statistics (GDP, GVA); |
| Environment Agency<br>SEPA<br>NIEA<br>NRW | Industrial activity and emissions data (EU ETS);<br>Industrial emissions data from IPPC/EPR regulation;<br>Waste management and disposal statistics, including incineration data; |
| UKPIA | Refinery emissions data by source;<br>Oil products characteristics (RVP, sulphur content) |
| Mineral Products Association | Mineral processing activity and emissions data; fuel quality data; |
| UK Gas Distribution Networks | Natural gas compositional analysis (annual for each LDZ);<br>Gas leakage estimates from transmission and distribution network; |
| ISSB | Iron and steel production statistics, by technology;<br>Iron and steel fuel use, by fuel, by source; |
| Tata Steel<br>British Steel | Iron and steel facility emissions by source for integrated works;<br>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<br>BP Chemicals<br>Kemira GrowHow<br>SABIC<br>Shell | Facility emissions data by source, aligned to specific inventory reporting requirements. |