Annexes

Table of Tables:

Table of Figures:

ANNEX 1: Key Categories

This annex contains the key category analysis for the latest GHG inventory[1]. It contains:

- A description of the methodology used for identifying key categories
- Information on the level of disaggregation
- Information to fulfil the reporting requirements of Tables 4.2 and 4.3 of Volume 1 of the 2006 IPCC Guidelines, including and excluding land use, land-use change and forestry (LULUCF).

The annex also contains information relevant to the requirements of reporting under the Kyoto Protocol (KP). The table below contains the additional KP information that Annex 1 needs to contain, and the locations of this information in the Annex[2].

Requirements	**Locations of the relevant information in this Annex**
Description of methodology used for identifying key categories, *including KP-LULUCF*	See sections immediately below including "*General approach used to identify Key Categories*" and "*Approach used to identify KP-LULUCF Key Categories*".
Reference to the key category tables in the CRF	This Annex of the NIR presents detailed tables of information of the data derived from the key category analysis. These data are used to create the key category tables (Table 7) in the CRF.
Reference to the key category tables in the CRF, *including in the KP-LULUCF CRF tables*	This Annex of the NIR presents detailed tables of information of the data derived from the key category analysis. These data are used to create the key category KP-LULUCF tables (Table NIR 3) in the CRF.
Information on the level of disaggregation	The tables in this Annex contain information on the level of disaggregation used. The level of disaggregation follows IPCC 2006 Guidelines.
Tables 4.2 to 4.4 of Volume 4 the 2006 IPCC guidelines	The data requested in the 2006 Guidelines tables, including and excluding LULUCF, are provided in **Table A 1.3.1** to **Table A 1.4.6** and **Table 1.7** to **Table 1.10**.
Table NIR.3, as contained in the annex to decision 6/CMP.3	A facsimile of Table NIR 3, provided in the CRF, is given in **Table A 1.8.1**.

A 1.1 GENERAL APPROACH USED TO IDENTIFY KEY CATEGORIES

In the UK inventory, certain source categories are particularly significant in terms of their contribution to the overall uncertainty of the inventory. These key source categories have been identified so that

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[1] Following the requirements to report information about uncertainties as set out in FCCC/CP/2013/10/Add.3. Report of the Conference of the Parties on its nineteenth session, held in Warsaw from 11 to 23 November 2013. Addendum Part two: Action taken by the Conference of the Parties at its nineteenth session.

[2] The information in this table has been taken directly from the UNFCCC document "Annotated outline of the National Inventory Report including reporting elements under the Kyoto Protocol".

the resources available for inventory preparation may be prioritised, and the best possible estimates prepared for the most significant source categories.

The UK completes both quantitative and qualitative Key Category Analyses (KCAs).

The UK has used the method set out in Section 4.3.1 and Section 4.3.2 of the 2006 IPCC Guidelines Volume 1 General Guidance and Reporting (*Approach 1 to identify key categories,* and *Approach 2 to identify key categories* respectively) to quantitatively determine the key source categories.

A 1.2 QUALITATIVE ANALYSIS USED TO IDENTIFY KEY CATEGORIES

Following IPCC good practice, a qualitative analysis of the inventory has been made to identify any additional key source categories, which may not have been identified using the quantitative analysis. The approach set out in Section 4.3.3 of the IPCC 2006 Guidelines has been applied, using the four criteria set out in the guidance, to judge whether a category is a key category. The criteria are:

1. (Use of) mitigation techniques and technologies;
2. Emissions growth (increase or decrease);
3. No quantitative assessment of uncertainties performed;
4. Completeness (examine qualitatively potential key categories that are not yet estimated quantitatively by applying the qualitative considerations above).

In addition, additional criteria have also been taken in account

5. High uncertainty (links to point 3 above);
6. Unexpectedly low or high emissions;
7. External recommendation has also been used as an additional criterion to identify key categories.

The results of the qualitative analysis did not identify any categories that were not already identified by the quantitative key category analysis.

A 1.3 QUANTITATIVE APPROACH 1 KCA FOLLOWING IPCC 2006 GUIDELINES

A key category analysis has been completed for both level and trend. This KCA has been created using the 2006 IPCC Guidelines Approach 1 methodology. The factors that make a source a key category are:

- A high contribution to the level of emissions; and
- A high contribution to the trend;

For example, transport fuel (1A3b) is a key category for carbon dioxide because it is a large source of emissions and nitric acid production (2B2) because it shows a significant trend.

The category groupings are largely aligned to those suggested in Tables 4.5 and 4.6 in Volume 1, Chapter 4 of the 2006 IPCC guidelines, although we deviate in a number of cases, in particular:

- **Agriculture and LULUCF**. In the 2006 guidelines a different nomenclature for categorising agriculture and LULUCF sources and sinks was used compared to the adopted nomenclature, which means that it would be challenging and confusing to retain this categorisation when sources are grouped differently in the adopted nomenclature. The UK Inventory Agency considers that the level of aggregation used in the UK method for the KCA is sufficiently detailed to target inventory improvements whilst not introducing unnecessary computational difficulties (e.g. use of “miscellaneous” categories to mop up the remainder within a sector). Further, the level of source/sink category aggregations in the KCA are aligned to how individual methods or models are used to derive the UK inventory estimates, and are therefore at an appropriate level of detail for the UK inventory
- **Fugitive Emissions**. The suggested categories are at a much more granular level (e.g. 1B2aii) than other sectors. We considered that this would lead to an undue diminishing of these sectors, decreasing their likelihood of being considered key, so have adopted a level of aggregation more consistent with other sectors
- **Miscellaneous emissions**. The suggested approach was to group a large number of small sources into one category. We considered that this would lead to an undue increase in the significance of these sources, increasing their likelihood of being considered key, so have adopted a level of aggregation more consistent with other sectors

The results of the key category analysis with and without LULUCF, for the base year and the latest reported year and for both Approaches 1 and 2 KCA, are summarised by sector and gas in **Section 1.5.1**. The tables indicate whether a key category arises from the level (L1) assessment or the trend (T1) assessment.

The results of the **level assessment** (based on Approach 1) with and without LULUCF for the base year and the latest reported year are shown **Table A 1.3.1** to **Table A 1.3.4.** The key source categories are highlighted by the shaded cells in the table. The source categories (i.e. rows of the table) were sorted in descending order of magnitude based on the results of the “Level Parameter”, and then the cumulative total was included in the final column of the table. The key source categories are those whose contributions add up to 95% of the sum of the level parameters in the final column after this sorting process, which according to the 2006 IPCC guidelines, should account for 90% of the uncertainty in level.

The results of the **trend assessment** (based on Approach 1) with and without LULUCF for the base year to the latest reported year are shown in **Table A 1.3.5** and **Table A 1.3.6.** The key source categories are highlighted by the shaded cells in the table. The trend parameter was calculated using the absolute value of the result; an absolute function is used since Land Use, Land Use Change and Forestry contains negative sources (sinks) and the absolute function is necessary to produce positive uncertainty contributions for these sinks. The source categories (i.e. rows of the table) were sorted in descending order of the “Trend parameter”, and then the cumulative total was included in the final column of the table. The key source categories are those whose contributions add up to 95% of the sum of the trend parameters in the final column after this sorting process, which according to the 2006 IPCC guidelines, should account for 90% of the uncertainty in trend.

An additional assessment has been undertaken for the inventory submitted under Kyoto Protocol geographical scope. For clarity, the outcomes of this analysis are not presented in this Annex: results are very similar to those from the submission under the Convention (UNFCCC scope), and any differences are documented in **Chapter 1.5** of the main document.

Note that the tables in chapter 1 of the NIR summarise the key categories from both the approach 1 and approach 2 key categories analyses and the aggregations used are slightly different for the two approaches. For example, the category "3A" is therefore total emissions from category 3A, whilst categories 3A1 and 3A2 have also been identified as key categories in their own right.

Table A 1.3.1 Approach 1 Key Category Analysis for the base year based on level of emissions (including LULUCF) – UNFCCC scope

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
1A1	Energy industries: solid fuels	CO_2	185,488.39	185,488.39	0.2194	0.2194
1A3b	Road transportation: liquid fuels	CO_2	108,573.17	108,573.17	0.1284	0.3478
1A4	Other sectors: gaseous fuels	CO_2	70,371.86	70,371.86	0.0832	0.4310
5A	Solid waste disposal	CH_4	60,389.54	60,389.54	0.0714	0.5024
1A1	Energy industries: liquid fuels	CO_2	40,386.62	40,386.62	0.0478	0.5502
1A2	Manufacturing industries and construction: liquid fuels	CO_2	29,443.87	29,443.87	0.0348	0.5850
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	27,291.16	27,291.16	0.0323	0.6173
2C1	Iron and steel production	CO_2	23,628.28	23,628.28	0.0279	0.6453
1B1	Coal mining and handling	CH_4	21,826.68	21,826.68	0.0258	0.6711
1A2	Manufacturing industries and construction: solid fuels	CO_2	20,241.37	20,241.37	0.0239	0.6950
2B3	Adipic acid production	N_2O	19,934.61	19,934.61	0.0236	0.7186
1A4	Other sectors: solid fuels	CO_2	19,824.90	19,824.90	0.0234	0.7420
1A4	Other sectors: liquid fuels	CO_2	19,350.38	19,350.38	0.0229	0.7649
3A1	Enteric fermentation from Cattle	CH_4	18,866.76	18,866.76	0.0223	0.7872
2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3	17,784.67	17,784.67	0.0210	0.8083
4B	Cropland	CO_2	15,947.46	15,947.46	0.0189	0.8271
3D	Agricultural soils	N_2O	14,552.30	14,552.30	0.0172	0.8443
4A	Forest land	CO_2	-13,992.50	13,992.50	0.0165	0.8609
1B2	Oil and gas extraction	CH_4	12,342.11	12,342.11	0.0146	0.8755
1A1	Energy industries: gaseous fuels	CO_2	11,939.20	11,939.20	0.0141	0.8896
1A3d	Domestic Navigation: liquid fuels	CO_2	7,611.13	7,611.13	0.0090	0.8986
2A1	Cement production	CO_2	7,295.26	7,295.26	0.0086	0.9072
4E	Settlements	CO_2	5,427.63	5,427.63	0.0064	0.9137
1A5	Other: liquid fuels	CO_2	5,293.44	5,293.44	0.0063	0.9199
3A2	Enteric fermentation from Sheep	CH_4	5,231.18	5,231.18	0.0062	0.9261
1B2	Oil and gas extraction	CO_2	5,088.52	5,088.52	0.0060	0.9321

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
2B8	Petrochemical and carbon black production	CO_2	4,751.56	4,751.56	0.0056	0.9377
3B1	Manure management from Cattle	CH_4	4,158.78	4,158.78	0.0049	0.9427
2B2	Nitric acid production	N_2O	3,860.26	3,860.26	0.0046	0.9472
3B2	Manure management from Sheep	N_2O	3,433.79	3,433.79	0.0041	0.9513
4C	Grassland	CH_4	2,385.87	2,385.87	0.0028	0.9541
5D	Wastewater treatment and discharge	CH_4	2,284.15	2,284.15	0.0027	0.9568
4G	Harvested wood products	CO_2	-2,087.72	2,087.72	0.0025	0.9593
4D	Wetlands	CH_4	1,961.70	1,961.70	0.0023	0.9616
2B1	Ammonia production	CO_2	1,895.00	1,895.00	0.0022	0.9638
1A3a	Domestic aviation: liquid fuels	CO_2	1,869.71	1,869.71	0.0022	0.9661
1B1	Coal mining and handling solid fuels	CO_2	1,698.56	1,698.56	0.0020	0.9681
1A3c	Railways: liquid fuels	CO_2	1,471.82	1,471.82	0.0017	0.9698
5C	Incineration and open burning of waste	CO_2	1,360.37	1,360.37	0.0016	0.9714
2C6	Zinc production	CO_2	1,350.65	1,350.65	0.0016	0.9730
2A2	Lime production	CO_2	1,328.60	1,328.60	0.0016	0.9746
1A3b	Road transportation: liquid fuels	N_2O	1,313.56	1,313.56	0.0016	0.9761
1A4	Other sectors: solid fuels	CH_4	1,286.45	1,286.45	0.0015	0.9777
1A3b	Road transportation: liquid fuels	CH_4	1,253.75	1,253.75	0.0015	0.9791
2A4	Other process uses of carbonates	CO_2	1,097.09	1,097.09	0.0013	0.9804
1A1	Energy industries: solid fuels	N_2O	1,056.46	1,056.46	0.0012	0.9817
3G	Liming	CO_2	1,016.78	1,016.78	0.0012	0.9829
5D	Wastewater treatment and discharge	N_2O	893.23	893.23	0.0011	0.9839
2G1	Electrical equipment	HFCs, PFCs, SF_6 and NF_3	797.11	797.11	0.0009	0.9849
4A	Forest land	N_2O	752.90	752.90	0.0009	0.9858
4B	Cropland	N_2O	734.60	734.60	0.0009	0.9866
4D	Wetlands	CO_2	571.12	571.12	0.0007	0.9873
2G3	N_2O from product uses	N_2O	554.92	554.92	0.0007	0.9880
2D	Non-energy products from fuels and solvent use	CO_2	552.81	552.81	0.0007	0.9886
2C3	Aluminium production	CO_2	450.32	450.32	0.0005	0.9892
2F4	Aerosols	HFCs, PFCs, SF_6 and NF_3	448.15	448.15	0.0005	0.9897

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
4E	Settlements	N_2O	441.11	441.11	0.0005	0.9902
2A3	Glass production	CO_2	412.37	412.37	0.0005	0.9907
2C4	Magnesium production	HFCs, PFCs, SF_6 and NF_3	387.17	387.17	0.0005	0.9912
1A4	Other sectors: peat	CO_2	372.48	372.48	0.0004	0.9916
2C3	Aluminium production	HFCs, PFCs, SF_6 and NF_3	333.43	333.43	0.0004	0.9920
3H	Urea application to land	CO_2	327.68	327.68	0.0004	0.9924
4	Indirect N_2O emissions from LULUCF	N_2O	305.49	305.49	0.0004	0.9927
3A4	Enteric fermentation from Other livestock	CH_4	302.02	302.02	0.0004	0.9931
4B	Cropland	CH_4	291.94	291.94	0.0003	0.9935
3A3	Enteric fermentation from Swine	CH_4	283.06	283.06	0.0003	0.9938
3J	Agriculture activities in OTs and CDs	CH_4	270.85	270.85	0.0003	0.9941
1A1	Energy industries: gaseous fuels	N_2O	261.00	261.00	0.0003	0.9944
1A4	Other sectors: solid fuels	N_2O	245.31	245.31	0.0003	0.9947
1A1	Energy industries: other fuels	CO_2	244.26	244.26	0.0003	0.9950
1A3e	Other transportation: liquid fuels	CO_2	224.74	224.74	0.0003	0.9953
2B7	Soda ash production	CO_2	224.40	224.40	0.0003	0.9955
2F1	Refrigeration and air conditioning	HFCs, PFCs, SF_6 and NF_3	215.00	215.00	0.0003	0.9958
2G2	SF_6 and PFCs from other product use	HFCs, PFCs, SF_6 and NF_3	202.72	202.72	0.0002	0.9960
4C	Grassland	N_2O	202.42	202.42	0.0002	0.9963
2B10	Other Chemical Industry	CH_4	191.21	191.21	0.0002	0.9965
3F	Field burning of agricultural residues	CH_4	187.03	187.03	0.0002	0.9967
2F2	Foam blowing agents	HFCs, PFCs, SF_6 and NF_3	184.62	184.62	0.0002	0.9969
3J	Agriculture activities in OTs and CDs	N_2O	178.70	178.70	0.0002	0.9971
1A4	Other sectors: gaseous fuels	CH_4	157.65	157.65	0.0002	0.9973
1A2	Manufacturing industries and construction: solid fuels	N_2O	141.45	141.45	0.0002	0.9975
1A2	Manufacturing industries and construction: liquid fuels	N_2O	137.23	137.23	0.0002	0.9977

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
5C	Incineration and open burning of waste	CH_4	136.32	136.32	0.0002	0.9978
1A1	Energy industries: gaseous fuels	CH_4	128.80	128.80	0.0002	0.9980
4C	Grassland	CO_2	114.65	114.65	0.0001	0.9981
1A1	Energy industries: liquid fuels	N_2O	112.43	112.43	0.0001	0.9982
1A3d	Domestic Navigation: liquid fuels	N_2O	105.00	105.00	0.0001	0.9984
2B6	Titanium dioxide production	CO_2	104.63	104.63	0.0001	0.9985
1A4	Other sectors: liquid fuels	N_2O	101.77	101.77	0.0001	0.9986
1A4	Other sectors: biomass	CH_4	90.07	90.07	0.0001	0.9987
4A	Forest land	CH_4	87.54	87.54	0.0001	0.9988
1A2	Manufacturing industries and construction: other fuels	CO_2	70.70	70.70	0.0001	0.9989
3F	Field burning of agricultural residues	N_2O	57.80	57.80	0.0001	0.9990
1A4	Other sectors: liquid fuels	CH_4	56.96	56.96	0.0001	0.9990
1A5	Other: liquid fuels	N_2O	56.12	56.12	0.0001	0.9991
5C	Incineration and open burning of waste	N_2O	50.93	50.93	0.0001	0.9992
1A1	Energy industries: solid fuels	CH_4	50.88	50.88	0.0001	0.9992
1A2	Manufacturing industries and construction: solid fuels	CH_4	44.77	44.77	0.0001	0.9993
1B2	Oil and gas extraction	N_2O	44.69	44.69	0.0001	0.9993
1A2	Manufacturing industries and construction: liquid fuels	CH_4	43.87	43.87	0.0001	0.9994
2G4	Other product manufacture and use	N_2O	41.00	41.00	0.0000	0.9994
2C1	Iron and steel production	CH_4	39.22	39.22	0.0000	0.9995
1A4	Other sectors: gaseous fuels	N_2O	37.58	37.58	0.0000	0.9995
2F6	Other product uses as substitutes for ODS	HFCs, PFCs, SF_6 and NF_3	37.10	37.10	0.0000	0.9996
1A1	Energy industries: liquid fuels	CH_4	34.49	34.49	0.0000	0.9996
2A4	Other process uses of carbonates	CH_4	31.11	31.11	0.0000	0.9996
2B8	Petrochemical and carbon black production	CH_4	30.17	30.17	0.0000	0.9997
1A4	Other sectors: peat	CH_4	26.35	26.35	0.0000	0.9997
1A2	Manufacturing industries and construction: biomass	N_2O	21.79	21.79	0.0000	0.9997
4D	Wetlands	N_2O	21.29	21.29	0.0000	0.9998
2C1	Iron and steel production	N_2O	20.73	20.73	0.0000	0.9998

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
1A1	Energy industries: other fuels	CH_4	18.54	18.54	0.0000	0.9998
5B	Biological treatment of solid waste	CH_4	18.13	18.13	0.0000	0.9998
1A3a	Domestic aviation: liquid fuels	N_2O	17.70	17.70	0.0000	0.9998
4E	Settlements	CH_4	16.31	16.31	0.0000	0.9999
1A2	Manufacturing industries and construction: gaseous fuels	N_2O	14.57	14.57	0.0000	0.9999
1A2	Manufacturing industries and construction: biomass	CH_4	13.71	13.71	0.0000	0.9999
1A4	Other sectors: biomass	N_2O	13.54	13.54	0.0000	0.9999
2E1	Integrated circuit or semiconductor	HFCs, PFCs, SF_6 and NF_3	13.22	13.22	0.0000	0.9999
5B	Biological treatment of solid waste	N_2O	12.97	12.97	0.0000	0.9999
1A2	Manufacturing industries and construction: gaseous fuels	CH_4	12.22	12.22	0.0000	1.0000
1A3a	Domestic aviation: liquid fuels	CH_4	6.87	6.87	0.0000	1.0000
1A1	Energy industries: other fuels	N_2O	6.70	6.70	0.0000	1.0000
1A3d	Domestic Navigation: liquid fuels	CH_4	3.66	3.66	0.0000	1.0000
1A5	Other: liquid fuels	CH_4	3.56	3.56	0.0000	1.0000
1A3c	Railways: liquid fuels	N_2O	3.30	3.30	0.0000	1.0000
1A3e	Other transportation: liquid fuels	N_2O	2.79	2.79	0.0000	1.0000
1A3c	Railways: liquid fuels	CH_4	2.46	2.46	0.0000	1.0000
2B8	Petrochemical and carbon black production	N_2O	2.21	2.21	0.0000	1.0000
1A4	Other sectors: peat	N_2O	1.47	1.47	0.0000	1.0000
2F3	Fire protection	HFCs, PFCs, SF_6 and NF_3	1.42	1.42	0.0000	1.0000
1A1	Energy industries: biomass	CH_4	0.47	0.47	0.0000	1.0000
1A2	Manufacturing industries and construction: other fuels	N_2O	0.34	0.34	0.0000	1.0000
2B1	Ammonia production	N_2O	0.31	0.31	0.0000	1.0000
1A3e	Other transportation: liquid fuels	CH_4	0.29	0.29	0.0000	1.0000
2B1	Ammonia production	CH_4	0.26	0.26	0.0000	1.0000
1A1	Energy industries: biomass	N_2O	0.25	0.25	0.0000	1.0000
1A2	Manufacturing industries and construction: other fuels	CH_4	0.15	0.15	0.0000	1.0000
1B1	Coal mining and handling biomass	CH_4	0.10	0.10	0.0000	1.0000

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
1B1	Coal mining and handling solid fuels	N_2O	0.09	0.09	0.0000	1.0000
1B1	Coal mining and handling solid fuels	CH_4	0.08	0.08	0.0000	1.0000
Total			**813,352.09**	**845,512.52**	**1.0000**	

Table A 1.3.2 Approach 1 Key Category Analysis for the base year based on level of emissions (excluding LULUCF) – UNFCCC scope

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
1A1	Energy industries: solid fuels	CO_2	185,488.39	185,488.39	0.2318	0.3675
1A3b	Road transportation: liquid fuels	CO_2	108,573.17	108,573.17	0.1357	0.3675
1A4	Other sectors: gaseous fuels	CO_2	70,371.86	70,371.86	0.0879	0.4554
5A	Solid waste disposal	CH_4	60,389.54	60,389.54	0.0755	0.5309
1A1	Energy industries: liquid fuels	CO_2	40,386.62	40,386.62	0.0505	0.5814
1A2	Manufacturing industries and construction: liquid fuels	CO_2	29,443.87	29,443.87	0.0368	0.6182
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	27,291.16	27,291.16	0.0341	0.6523
2C1	Iron and steel production	CO_2	23,628.28	23,628.28	0.0295	0.6818
1B1	Coal mining and handling	CH_4	21,826.68	21,826.68	0.0273	0.7091
1A2	Manufacturing industries and construction: solid fuels	CO_2	20,241.37	20,241.37	0.0253	0.7344
2B3	Adipic acid production	N_2O	19,934.61	19,934.61	0.0249	0.7593
1A4	Other sectors: solid fuels	CO_2	19,824.90	19,824.90	0.0248	0.7841
1A4	Other sectors: liquid fuels	CO_2	19,350.38	19,350.38	0.0242	0.8083
3A1	Enteric fermentation from Cattle	CH_4	18,866.76	18,866.76	0.0236	0.8318
2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3	17,784.67	17,784.67	0.0222	0.8541
3D	Agricultural soils	N_2O	14,552.30	14,552.30	0.0182	0.8723
1B2	Oil and gas extraction	CH_4	12,342.11	12,342.11	0.0154	0.8877
1A1	Energy industries: gaseous fuels	CO_2	11,939.20	11,939.20	0.0149	0.9026
1A3d	Domestic Navigation: liquid fuels	CO_2	7,611.13	7,611.13	0.0095	0.9121
2A1	Cement production	CO_2	7,295.26	7,295.26	0.0091	0.9212
1A5	Other: liquid fuels	CO_2	5,293.44	5,293.44	0.0066	0.9278
3A2	Enteric fermentation from Sheep	CH_4	5,231.18	5,231.18	0.0065	0.9344
1B2	Oil and gas extraction	CO_2	5,088.52	5,088.52	0.0064	0.9407

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
2B8	Petrochemical and carbon black production	CO_2	4,751.56	4,751.56	0.0059	0.9467
3B1	Manure management from Cattle	CH_4	4,158.78	4,158.78	0.0052	0.9519
2B2	Nitric acid production	N_2O	3,860.26	3,860.26	0.0048	0.9567
3B2	Manure management from Sheep	N_2O	3,433.79	3,433.79	0.0043	0.9610
5D	Wastewater treatment and discharge	CH_4	2,284.15	2,284.15	0.0029	0.9638
2B1	Ammonia production	CO_2	1,895.00	1,895.00	0.0024	0.9662
1A3a	Domestic aviation: liquid fuels	CO_2	1,869.71	1,869.71	0.0023	0.9686
1B1	Coal mining and handling solid fuels	CO_2	1,698.56	1,698.56	0.0021	0.9707
1A3c	Railways: liquid fuels	CO_2	1,471.82	1,471.82	0.0018	0.9725
5C	Incineration and open burning of waste	CO_2	1,360.37	1,360.37	0.0017	0.9742
2C6	Zinc production	CO_2	1,350.65	1,350.65	0.0017	0.9759
2A2	Lime production	CO_2	1,328.60	1,328.60	0.0017	0.9776
1A3b	Road transportation: liquid fuels	N_2O	1,313.56	1,313.56	0.0016	0.9792
1A4	Other sectors: solid fuels	CH_4	1,286.45	1,286.45	0.0016	0.9808
1A3b	Road transportation: liquid fuels	CH_4	1,253.75	1,253.75	0.0016	0.9824
2A4	Other process uses of carbonates	CO_2	1,097.09	1,097.09	0.0014	0.9838
1A1	Energy industries: solid fuels	N_2O	1,056.46	1,056.46	0.0013	0.9851
3G	Liming	CO_2	1,016.78	1,016.78	0.0013	0.9863
5D	Wastewater treatment and discharge	N_2O	893.23	893.23	0.0011	0.9875
2G1	Electrical equipment	HFCs, PFCs, SF_6 and NF_3	797.11	797.11	0.0010	0.9885
2G3	N_2O from product uses	N_2O	554.92	554.92	0.0007	0.9891
2D	Non-energy products from fuels and solvent use	CO_2	552.81	552.81	0.0007	0.9898
2C3	Aluminium production	CO_2	450.32	450.32	0.0006	0.9904
2F4	Aerosols	HFCs, PFCs, SF_6 and NF_3	448.15	448.15	0.0006	0.9910
2A3	Glass production	CO_2	412.37	412.37	0.0005	0.9915
2C4	Magnesium production	HFCs, PFCs, SF_6 and NF_3	387.17	387.17	0.0005	0.9920
1A4	Other sectors: peat	CO_2	372.48	372.48	0.0005	0.9924
2C3	Aluminium production	HFCs, PFCs, SF_6 and NF_3	333.43	333.43	0.0004	0.9928
3H	Urea application to land	CO_2	327.68	327.68	0.0004	0.9933
3A4	Enteric fermentation from Other livestock	CH_4	302.02	302.02	0.0004	0.9936

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
3A3	Enteric fermentation from Swine	CH_4	283.06	283.06	0.0004	0.9940
3J	Agriculture activities in OTs and CDs	CH_4	270.85	270.85	0.0003	0.9943
1A1	Energy industries: gaseous fuels	N_2O	261.00	261.00	0.0003	0.9946
1A4	Other sectors: solid fuels	N_2O	245.31	245.31	0.0003	0.9950
1A1	Energy industries: other fuels	CO_2	244.26	244.26	0.0003	0.9953
1A3e	Other transportation: liquid fuels	CO_2	224.74	224.74	0.0003	0.9955
2B7	Soda ash production	CO_2	224.40	224.40	0.0003	0.9958
2F1	Refrigeration and air conditioning	HFCs, PFCs, SF_6 and NF_3	215.00	215.00	0.0003	0.9961
2G2	SF_6 and PFCs from other product use	HFCs, PFCs, SF_6 and NF_3	202.72	202.72	0.0003	0.9963
2B10	Other Chemical Industry	CH_4	191.21	191.21	0.0002	0.9966
3F	Field burning of agricultural residues	CH_4	187.03	187.03	0.0002	0.9968
2F2	Foam blowing agents	HFCs, PFCs, SF_6 and NF_3	184.62	184.62	0.0002	0.9970
3J	Agriculture activities in OTs and CDs	N_2O	178.70	178.70	0.0002	0.9973
1A4	Other sectors: gaseous fuels	CH_4	157.65	157.65	0.0002	0.9975
1A2	Manufacturing industries and construction: solid fuels	N_2O	141.45	141.45	0.0002	0.9976
1A2	Manufacturing industries and construction: liquid fuels	N_2O	137.23	137.23	0.0002	0.9978
5C	Incineration and open burning of waste	CH_4	136.32	136.32	0.0002	0.9980
1A1	Energy industries: gaseous fuels	CH_4	128.80	128.80	0.0002	0.9981
1A1	Energy industries: liquid fuels	N_2O	112.43	112.43	0.0001	0.9983
1A3d	Domestic Navigation: liquid fuels	N_2O	105.00	105.00	0.0001	0.9984
2B6	Titanium dioxide production	CO_2	104.63	104.63	0.0001	0.9986
1A4	Other sectors: liquid fuels	N_2O	101.77	101.77	0.0001	0.9987
1A4	Other sectors: biomass	CH_4	90.07	90.07	0.0001	0.9988
1A2	Manufacturing industries and construction: other fuels	CO_2	70.70	70.70	0.0001	0.9989
3F	Field burning of agricultural residues	N_2O	57.80	57.80	0.0001	0.9990
1A4	Other sectors: liquid fuels	CH_4	56.96	56.96	0.0001	0.9990
1A5	Other: liquid fuels	N_2O	56.12	56.12	0.0001	0.9991
5C	Incineration and open burning of waste	N_2O	50.93	50.93	0.0001	0.9992
1A1	Energy industries: solid fuels	CH_4	50.88	50.88	0.0001	0.9992

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
1A2	Manufacturing industries and construction: solid fuels	CH_4	44.77	44.77	0.0001	0.9993
1B2	Oil and gas extraction	N_2O	44.69	44.69	0.0001	0.9993
1A2	Manufacturing industries and construction: liquid fuels	CH_4	43.87	43.87	0.0001	0.9994
2G4	Other product manufacture and use	N_2O	41.00	41.00	0.0001	0.9994
2C1	Iron and steel production	CH_4	39.22	39.22	0.0000	0.9995
1A4	Other sectors: gaseous fuels	N_2O	37.58	37.58	0.0000	0.9995
2F6	Other product uses as substitutes for ODS	HFCs, PFCs, SF_6 and NF_3	37.10	37.10	0.0000	0.9996
1A1	Energy industries: liquid fuels	CH_4	34.49	34.49	0.0000	0.9996
2A4	Other process uses of carbonates	CH_4	31.11	31.11	0.0000	0.9997
2B8	Petrochemical and carbon black production	CH_4	30.17	30.17	0.0000	0.9997
1A4	Other sectors: peat	CH_4	26.35	26.35	0.0000	0.9997
1A2	Manufacturing industries and construction: biomass	N_2O	21.79	21.79	0.0000	0.9998
2C1	Iron and steel production	N_2O	20.73	20.73	0.0000	0.9998
1A1	Energy industries: other fuels	CH_4	18.54	18.54	0.0000	0.9998
5B	Biological treatment of solid waste	CH_4	18.13	18.13	0.0000	0.9998
1A3a	Domestic aviation: liquid fuels	N_2O	17.70	17.70	0.0000	0.9999
1A2	Manufacturing industries and construction: gaseous fuels	N_2O	14.57	14.57	0.0000	0.9999
1A2	Manufacturing industries and construction: biomass	CH_4	13.71	13.71	0.0000	0.9999
1A4	Other sectors: biomass	N_2O	13.54	13.54	0.0000	0.9999
2E1	Integrated circuit or semiconductor	HFCs, PFCs, SF_6 and NF_3	13.22	13.22	0.0000	0.9999
5B	Biological treatment of solid waste	N_2O	12.97	12.97	0.0000	0.9999
1A2	Manufacturing industries and construction: gaseous fuels	CH_4	12.22	12.22	0.0000	1.0000
1A3a	Domestic aviation: liquid fuels	CH_4	6.87	6.87	0.0000	1.0000
1A1	Energy industries: other fuels	N_2O	6.70	6.70	0.0000	1.0000
1A3d	Domestic Navigation: liquid fuels	CH_4	3.66	3.66	0.0000	1.0000
1A5	Other: liquid fuels	CH_4	3.56	3.56	0.0000	1.0000
1A3c	Railways: liquid fuels	N_2O	3.30	3.30	0.0000	1.0000
1A3e	Other transportation: liquid fuels	N_2O	2.79	2.79	0.0000	1.0000
1A3c	Railways: liquid fuels	CH_4	2.46	2.46	0.0000	1.0000

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
2B8	Petrochemical and carbon black production	N_2O	2.21	2.21	0.0000	1.0000
1A4	Other sectors: peat	N_2O	1.47	1.47	0.0000	1.0000
2F3	Fire protection	HFCs, PFCs, SF_6 and NF_3	1.42	1.42	0.0000	1.0000
1A1	Energy industries: biomass	CH_4	0.47	0.47	0.0000	1.0000
1A2	Manufacturing industries and construction: other fuels	N_2O	0.34	0.34	0.0000	1.0000
2B1	Ammonia production	N_2O	0.31	0.31	0.0000	1.0000
1A3e	Other transportation: liquid fuels	CH_4	0.29	0.29	0.0000	1.0000
2B1	Ammonia production	CH_4	0.26	0.26	0.0000	1.0000
1A1	Energy industries: biomass	N_2O	0.25	0.25	0.0000	1.0000
1A2	Manufacturing industries and construction: other fuels	CH_4	0.15	0.15	0.0000	1.0000
1B1	Coal mining and handling biomass	CH_4	0.10	0.10	0.0000	1.0000
1B1	Coal mining and handling solid fuels	N_2O	0.09	0.09	0.0000	1.0000
1B1	Coal mining and handling solid fuels	CH_4	0.08	0.08	0.0000	1.0000
Total			**800,170.27**	**800,170.27**	**1.0000**	

Table A 1.3.3 Approach 1 Key Category Analysis for the latest reported year based on level of emissions (including LULUCF) – UNFCCC scope

IPCC Code	IPCC Category	GHG	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
1A3b	Road transportation: liquid fuels	CO_2	88,729.89	88,729.89	0.1957	0.1957
1A4	Other sectors: gaseous fuels	CO_2	72,648.22	72,648.22	0.1602	0.3559
1A1	Energy industries: gaseous fuels	CO_2	52,284.86	52,284.86	0.1153	0.4712
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	21,595.59	21,595.59	0.0476	0.5189
4A	Forest land	CO_2	-17,933.72	17,933.72	0.0396	0.5584
3A1	Enteric fermentation from Cattle	CH_4	16,130.21	16,130.21	0.0356	0.5940
4B	Cropland	CO_2	14,403.93	14,403.93	0.0318	0.6258
1A2	Manufacturing industries and construction: liquid fuels	CO_2	13,420.69	13,420.69	0.0296	0.6554
1A4	Other sectors: liquid fuels	CO_2	13,328.52	13,328.52	0.0294	0.6848
5A	Solid waste disposal	CH_4	12,912.14	12,912.14	0.0285	0.7133
3D	Agricultural soils	N_2O	11,648.42	11,648.42	0.0257	0.7389
1A1	Energy industries: liquid fuels	CO_2	11,638.01	11,638.01	0.0257	0.7646

IPCC Code	IPCC Category	GHG	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
2C1	Iron and steel production	CO_2	10,617.87	10,617.87	0.0234	0.7880
2F1	Refrigeration and air conditioning	HFCs, PFCs, SF_6 and NF_3	10,219.79	10,219.79	0.0225	0.8106
1A1	Energy industries: other fuels	CO_2	6,257.60	6,257.60	0.0138	0.8244
1A1	Energy industries: solid fuels	CO_2	5,908.93	5,908.93	0.0130	0.8374
1A3d	Domestic Navigation: liquid fuels	CO_2	4,777.23	4,777.23	0.0105	0.8479
1B2	Oil and gas extraction	CH_4	4,208.76	4,208.76	0.0093	0.8572
3A2	Enteric fermentation from Sheep	CH_4	4,153.77	4,153.77	0.0092	0.8664
4E	Settlements	CO_2	4,032.04	4,032.04	0.0089	0.8753
2A1	Cement production	CO_2	3,899.69	3,899.69	0.0086	0.8839
3B1	Manure management from Cattle	CH_4	3,812.01	3,812.01	0.0084	0.8923
1A2	Manufacturing industries and construction: solid fuels	CO_2	3,281.12	3,281.12	0.0072	0.8995
1B2	Oil and gas extraction	CO_2	3,245.49	3,245.49	0.0072	0.9067
3B2	Manure management from Sheep	N_2O	2,813.54	2,813.54	0.0062	0.9129
2B8	Petrochemical and carbon black production	CO_2	2,592.13	2,592.13	0.0057	0.9186
4C	Grassland	CH_4	2,420.90	2,420.90	0.0053	0.9239
4G	Harvested wood products	CO_2	-2,128.72	2,128.72	0.0047	0.9286
4D	Wetlands	CH_4	2,043.62	2,043.62	0.0045	0.9332
1A4	Other sectors: solid fuels	CO_2	1,993.13	1,993.13	0.0044	0.9375
4C	Grassland	CO_2	-1,873.95	1,873.95	0.0041	0.9417
5D	Wastewater treatment and discharge	CH_4	1,711.17	1,711.17	0.0038	0.9455
2B1	Ammonia production	CO_2	1,644.56	1,644.56	0.0036	0.9491
1A5	Other: liquid fuels	CO_2	1,403.89	1,403.89	0.0031	0.9522
1A3c	Railways: liquid fuels	CO_2	1,399.64	1,399.64	0.0031	0.9553
5B	Biological treatment of solid waste	CH_4	1,216.79	1,216.79	0.0027	0.9579
2F4	Aerosols	HFCs, PFCs, SF_6 and NF_3	1,193.09	1,193.09	0.0026	0.9606
5D	Wastewater treatment and discharge	N_2O	1,016.77	1,016.77	0.0022	0.9628
2A2	Lime production	CO_2	1,000.31	1,000.31	0.0022	0.9650
3G	Liming	CO_2	950.29	950.29	0.0021	0.9671
1A3b	Road transportation: liquid fuels	N_2O	891.99	891.99	0.0020	0.9691
5B	Biological treatment of solid waste	N_2O	715.01	715.01	0.0016	0.9707
4A	Forest land	N_2O	712.25	712.25	0.0016	0.9722
1A3a	Domestic aviation: liquid fuels	CO_2	687.75	687.75	0.0015	0.9738

IPCC Code	IPCC Category	GHG	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
2G3	N_2O from product uses	N_2O	665.41	665.41	0.0015	0.9752
1A2	Manufacturing industries and construction: other fuels	CO_2	648.84	648.84	0.0014	0.9767
4D	Wetlands	CO_2	605.99	605.99	0.0013	0.9780
1A3e	Other transportation: liquid fuels	CO_2	560.00	560.00	0.0012	0.9792
1B1	Coal mining and handling	CH_4	470.90	470.90	0.0010	0.9803
3A4	Enteric fermentation from Other livestock	CH_4	463.55	463.55	0.0010	0.9813
2A4	Other process uses of carbonates	CO_2	435.86	435.86	0.0010	0.9822
2F2	Foam blowing agents	HFCs, PFCs, SF_6 and NF_3	402.00	402.00	0.0009	0.9831
4B	Cropland	N_2O	398.47	398.47	0.0009	0.9840
2D	Non-energy products from fuels and solvent use	CO_2	379.49	379.49	0.0008	0.9849
2G1	Electrical equipment	HFCs, PFCs, SF_6 and NF_3	329.32	329.32	0.0007	0.9856
2A3	Glass production	CO_2	323.35	323.35	0.0007	0.9863
2F3	Fire protection	HFCs, PFCs, SF_6 and NF_3	310.84	310.84	0.0007	0.9870
4E	Settlements	N_2O	293.94	293.94	0.0006	0.9876
4B	Cropland	CH_4	279.33	279.33	0.0006	0.9882
1A1	Energy industries: gaseous fuels	N_2O	278.33	278.33	0.0006	0.9889
1A4	Other sectors: biomass	CH_4	264.11	264.11	0.0006	0.9894
5C	Incineration and open burning of waste	CO_2	248.95	248.95	0.0005	0.9900
3H	Urea application to land	CO_2	234.27	234.27	0.0005	0.9905
1A1	Energy industries: biomass	N_2O	218.58	218.58	0.0005	0.9910
1A3b	Road transportation: biomass	CO_2	214.55	214.55	0.0005	0.9915
3J	Agriculture activities in OTs and CDs	CH_4	193.22	193.22	0.0004	0.9919
3A3	Enteric fermentation from Swine	CH_4	190.07	190.07	0.0004	0.9923
4C	Grassland	N_2O	184.75	184.75	0.0004	0.9927
4	Indirect N_2O emissions from LULUCF	N_2O	171.77	171.77	0.0004	0.9931
1A4	Other sectors: gaseous fuels	CH_4	162.07	162.07	0.0004	0.9934
1A4	Other sectors: solid fuels	CH_4	151.94	151.94	0.0003	0.9938
1B1	Coal mining and handling solid fuels	CO_2	148.67	148.67	0.0003	0.9941
2B7	Soda ash production	CO_2	141.86	141.86	0.0003	0.9944
1A1	Energy industries: biomass	CH_4	138.31	138.31	0.0003	0.9947

IPCC Code	IPCC Category	GHG	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
2B6	Titanium dioxide production	CO_2	134.87	134.87	0.0003	0.9950
1A1	Energy industries: other fuels	CH_4	131.45	131.45	0.0003	0.9953
2G2	SF_6 and PFCs from other product use	HFCs, PFCs, SF_6 and NF_3	129.56	129.56	0.0003	0.9956
1A2	Manufacturing industries and construction: biomass	N_2O	127.36	127.36	0.0003	0.9959
1A1	Energy industries: other fuels	N_2O	119.47	119.47	0.0003	0.9961
3J	Agriculture activities in OTs and CDs	N_2O	113.40	113.40	0.0003	0.9964
4A	Forest land	CH_4	103.13	103.13	0.0002	0.9966
1A1	Energy industries: gaseous fuels	CH_4	102.93	102.93	0.0002	0.9969
2G4	Other product manufacture and use	N_2O	87.24	87.24	0.0002	0.9970
1A2	Manufacturing industries and construction: biomass	CH_4	80.38	80.38	0.0002	0.9972
1A4	Other sectors: liquid fuels	N_2O	79.30	79.30	0.0002	0.9974
2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3	76.13	76.13	0.0002	0.9976
1A2	Manufacturing industries and construction: liquid fuels	N_2O	75.43	75.43	0.0002	0.9977
1A3b	Road transportation: liquid fuels	CH_4	68.55	68.55	0.0002	0.9979
1A3d	Domestic Navigation: liquid fuels	N_2O	62.81	62.81	0.0001	0.9980
2B10	Other Chemical Industry	CH_4	55.75	55.75	0.0001	0.9981
1A1	Energy industries: liquid fuels	N_2O	55.28	55.28	0.0001	0.9983
2C3	Aluminium production	CO_2	55.06	55.06	0.0001	0.9984
2B2	Nitric acid production	N_2O	49.35	49.35	0.0001	0.9985
1B1	Coal mining and handling liquid fuels	CO_2	48.45	48.45	0.0001	0.9986
2F6	Other product uses as substitutes for ODS	HFCs, PFCs, SF_6 and NF_3	40.86	40.86	0.0001	0.9987
1A4	Other sectors: biomass	N_2O	40.50	40.50	0.0001	0.9988
1A4	Other sectors: gaseous fuels	N_2O	38.64	38.64	0.0001	0.9989
1A3c	Railways: solid fuels	CO_2	36.22	36.22	0.0001	0.9989
1A4	Other sectors: liquid fuels	CH_4	33.13	33.13	0.0001	0.9990
1B2	Oil and gas extraction	N_2O	30.89	30.89	0.0001	0.9991
4E	Settlements	CH_4	30.19	30.19	0.0001	0.9992
1A1	Energy industries: solid fuels	N_2O	29.42	29.42	0.0001	0.9992
1A2	Manufacturing industries and construction: liquid fuels	CH_4	29.16	29.16	0.0001	0.9993

IPCC Code	IPCC Category	GHG	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
2C4	Magnesium production	HFCs, PFCs, SF_6 and NF_3	28.92	28.92	0.0001	0.9993
1A4	Other sectors: solid fuels	N_2O	26.61	26.61	0.0001	0.9994
5C	Incineration and open burning of waste	N_2O	26.37	26.37	0.0001	0.9995
1A2	Manufacturing industries and construction: solid fuels	N_2O	25.95	25.95	0.0001	0.9995
4D	Wetlands	N_2O	24.81	24.81	0.0001	0.9996
2E1	Integrated circuit or semiconductor	HFCs, PFCs, SF_6 and NF_3	24.78	24.78	0.0001	0.9996
2F5	Solvents	HFCs, PFCs, SF_6 and NF_3	16.34	16.34	0.0000	0.9997
1A5	Other: liquid fuels	N_2O	14.79	14.79	0.0000	0.9997
1A2	Manufacturing industries and construction: gaseous fuels	N_2O	11.49	11.49	0.0000	0.9997
2B8	Petrochemical and carbon black production	CH_4	11.19	11.19	0.0000	0.9997
2C1	Iron and steel production	CH_4	10.93	10.93	0.0000	0.9998
1A2	Manufacturing industries and construction: other fuels	N_2O	10.40	10.40	0.0000	0.9998
1A2	Manufacturing industries and construction: gaseous fuels	CH_4	9.64	9.64	0.0000	0.9998
1A2	Manufacturing industries and construction: solid fuels	CH_4	8.64	8.64	0.0000	0.9998
1A1	Energy industries: liquid fuels	CH_4	7.84	7.84	0.0000	0.9999
5C	Incineration and open burning of waste	CH_4	7.39	7.39	0.0000	0.9999
2C1	Iron and steel production	N_2O	7.12	7.12	0.0000	0.9999
1A3e	Other transportation: liquid fuels	N_2O	6.93	6.93	0.0000	0.9999
1A3a	Domestic aviation: liquid fuels	N_2O	6.51	6.51	0.0000	0.9999
1A2	Manufacturing industries and construction: other fuels	CH_4	6.34	6.34	0.0000	0.9999
1A3d	Domestic Navigation: liquid fuels	CH_4	6.26	6.26	0.0000	0.9999
1A4	Other sectors: peat	CO_2	4.83	4.83	0.0000	1.0000
2C3	Aluminium production	HFCs, PFCs, SF_6 and NF_3	4.28	4.28	0.0000	1.0000
1B1	Coal mining and handling biomass	CH_4	3.78	3.78	0.0000	1.0000
1A3c	Railways: liquid fuels	N_2O	3.14	3.14	0.0000	1.0000
2A4	Other process uses of carbonates	CH_4	2.62	2.62	0.0000	1.0000
1A1	Energy industries: solid fuels	CH_4	1.53	1.53	0.0000	1.0000

IPCC Code	IPCC Category	GHG	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
2B8	Petrochemical and carbon black production	N_2O	1.41	1.41	0.0000	1.0000
1A5	Other: liquid fuels	CH_4	0.93	0.93	0.0000	1.0000
1A3c	Railways: solid fuels	CH_4	0.83	0.83	0.0000	1.0000
1A3c	Railways: liquid fuels	CH_4	0.44	0.44	0.0000	1.0000
1A3a	Domestic aviation: liquid fuels	CH_4	0.42	0.42	0.0000	1.0000
1A4	Other sectors: peat	CH_4	0.34	0.34	0.0000	1.0000
2B1	Ammonia production	N_2O	0.32	0.32	0.0000	1.0000
2B1	Ammonia production	CH_4	0.27	0.27	0.0000	1.0000
1A3e	Other transportation: liquid fuels	CH_4	0.22	0.22	0.0000	1.0000
1A3c	Railways: solid fuels	N_2O	0.08	0.08	0.0000	1.0000
1A4	Other sectors: peat	N_2O	0.02	0.02	0.0000	1.0000
1B1	Coal mining and handling solid fuels	N_2O	0.02	0.02	0.0000	1.0000
1B1	Coal mining and handling solid fuels	CH_4	0.01	0.01	0.0000	1.0000
Total			**409,523.61**	**453,396.39**	**1.0000**	

Table A 1.3.4 Approach 1 Key Category Analysis for the latest reported year based on level of emissions (excluding LULUCF) – UNFCCC scope

IPCC Code	IPCC Category	GHG	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
1A3b	Road transportation: liquid fuels	CO_2	88,729.89	88,729.89	0.2187	0.2187
1A4	Other sectors: gaseous fuels	CO_2	72,648.22	72,648.22	0.1790	0.3977
1A1	Energy industries: gaseous fuels	CO_2	52,284.86	52,284.86	0.1289	0.5266
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	21,595.59	21,595.59	0.0532	0.5798
3A1	Enteric fermentation from Cattle	CH_4	16,130.21	16,130.21	0.0398	0.6196
1A2	Manufacturing industries and construction: liquid fuels	CO_2	13,420.69	13,420.69	0.0331	0.6526
1A4	Other sectors: liquid fuels	CO_2	13,328.52	13,328.52	0.0328	0.6855
5A	Solid waste disposal	CH_4	12,912.14	12,912.14	0.0318	0.7173
3D	Agricultural soils	N_2O	11,648.42	11,648.42	0.0287	0.7460
1A1	Energy industries: liquid fuels	CO_2	11,638.01	11,638.01	0.0287	0.7747
2C1	Iron and steel production	CO_2	10,617.87	10,617.87	0.0262	0.8009
2F1	Refrigeration and air conditioning	HFCs, PFCs, SF_6 and NF_3	10,219.79	10,219.79	0.0252	0.8261
1A1	Energy industries: other fuels	CO_2	6,257.60	6,257.60	0.0154	0.8415

IPCC Code	IPCC Category	GHG	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
1A1	Energy industries: solid fuels	CO_2	5,908.93	5,908.93	0.0146	0.8560
1A3d	Domestic Navigation: liquid fuels	CO_2	4,777.23	4,777.23	0.0118	0.8678
1B2	Oil and gas extraction	CH_4	4,208.76	4,208.76	0.0104	0.8782
3A2	Enteric fermentation from Sheep	CH_4	4,153.77	4,153.77	0.0102	0.8884
2A1	Cement production	CO_2	3,899.69	3,899.69	0.0096	0.8980
3B1	Manure management from Cattle	CH_4	3,812.01	3,812.01	0.0094	0.9074
1A2	Manufacturing industries and construction: solid fuels	CO_2	3,281.12	3,281.12	0.0081	0.9155
1B2	Oil and gas extraction	CO_2	3,245.49	3,245.49	0.0080	0.9235
3B2	Manure management from Sheep	N_2O	2,813.54	2,813.54	0.0069	0.9304
2B8	Petrochemical and carbon black production	CO_2	2,592.13	2,592.13	0.0064	0.9368
1A4	Other sectors: solid fuels	CO_2	1,993.13	1,993.13	0.0049	0.9417
5D	Wastewater treatment and discharge	CH_4	1,711.17	1,711.17	0.0042	0.9460
2B1	Ammonia production	CO_2	1,644.56	1,644.56	0.0041	0.9500
1A5	Other: liquid fuels	CO_2	1,403.89	1,403.89	0.0035	0.9535
1A3c	Railways: liquid fuels	CO_2	1,399.64	1,399.64	0.0034	0.9569
5B	Biological treatment of solid waste	CH_4	1,216.79	1,216.79	0.0030	0.9599
2F4	Aerosols	HFCs, PFCs, SF_6 and NF_3	1,193.09	1,193.09	0.0029	0.9629
5D	Wastewater treatment and discharge	N_2O	1,016.77	1,016.77	0.0025	0.9654
2A2	Lime production	CO_2	1,000.31	1,000.31	0.0025	0.9678
3G	Liming	CO_2	950.29	950.29	0.0023	0.9702
1A3b	Road transportation: liquid fuels	N_2O	891.99	891.99	0.0022	0.9724
5B	Biological treatment of solid waste	N_2O	715.01	715.01	0.0018	0.9741
1A3a	Domestic aviation: liquid fuels	CO_2	687.75	687.75	0.0017	0.9758
2G3	N_2O from product uses	N_2O	665.41	665.41	0.0016	0.9775
1A2	Manufacturing industries and construction: other fuels	CO_2	648.84	648.84	0.0016	0.9791
1A3e	Other transportation: liquid fuels	CO_2	560.00	560.00	0.0014	0.9805
1B1	Coal mining and handling	CH_4	470.90	470.90	0.0012	0.9816
3A4	Enteric fermentation from Other livestock	CH_4	463.55	463.55	0.0011	0.9828
2A4	Other process uses of carbonates	CO_2	435.86	435.86	0.0011	0.9838
2F2	Foam blowing agents	HFCs, PFCs, SF_6 and NF_3	402.00	402.00	0.0010	0.9848
2D	Non-energy products from fuels and solvent use	CO_2	379.49	379.49	0.0009	0.9858

IPCC Code	IPCC Category	GHG	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
2G1	Electrical equipment	HFCs, PFCs, SF_6 and NF_3	329.32	329.32	0.0008	0.9866
2A3	Glass production	CO_2	323.35	323.35	0.0008	0.9874
2F3	Fire protection	HFCs, PFCs, SF_6 and NF_3	310.84	310.84	0.0008	0.9881
1A1	Energy industries: gaseous fuels	N_2O	278.33	278.33	0.0007	0.9888
1A4	Other sectors: biomass	CH_4	264.11	264.11	0.0007	0.9895
5C	Incineration and open burning of waste	CO_2	248.95	248.95	0.0006	0.9901
3H	Urea application to land	CO_2	234.27	234.27	0.0006	0.9907
1A1	Energy industries: biomass	N_2O	218.58	218.58	0.0005	0.9912
1A3b	Road transportation: biomass	CO_2	214.55	214.55	0.0005	0.9917
3J	Agriculture activities in OTs and CDs	CH_4	193.22	193.22	0.0005	0.9922
3A3	Enteric fermentation from Swine	CH_4	190.07	190.07	0.0005	0.9927
1A4	Other sectors: gaseous fuels	CH_4	162.07	162.07	0.0004	0.9931
1A4	Other sectors: solid fuels	CH_4	151.94	151.94	0.0004	0.9934
1B1	Coal mining and handling solid fuels	CO_2	148.67	148.67	0.0004	0.9938
2B7	Soda ash production	CO_2	141.86	141.86	0.0003	0.9942
1A1	Energy industries: biomass	CH_4	138.31	138.31	0.0003	0.9945
2B6	Titanium dioxide production	CO_2	134.87	134.87	0.0003	0.9948
1A1	Energy industries: other fuels	CH_4	131.45	131.45	0.0003	0.9952
2G2	SF_6 and PFCs from other product use	HFCs, PFCs, SF_6 and NF_3	129.56	129.56	0.0003	0.9955
1A2	Manufacturing industries and construction: biomass	N_2O	127.36	127.36	0.0003	0.9958
1A1	Energy industries: other fuels	N_2O	119.47	119.47	0.0003	0.9961
3J	Agriculture activities in OTs and CDs	N_2O	113.40	113.40	0.0003	0.9964
1A1	Energy industries: gaseous fuels	CH_4	102.93	102.93	0.0003	0.9966
2G4	Other product manufacture and use	N_2O	87.24	87.24	0.0002	0.9968
1A2	Manufacturing industries and construction: biomass	CH_4	80.38	80.38	0.0002	0.9970
1A4	Other sectors: liquid fuels	N_2O	79.30	79.30	0.0002	0.9972
2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3	76.13	76.13	0.0002	0.9974
1A2	Manufacturing industries and construction: liquid fuels	N_2O	75.43	75.43	0.0002	0.9976
1A3b	Road transportation: liquid fuels	CH_4	68.55	68.55	0.0002	0.9978

IPCC Code	IPCC Category	GHG	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
1A3d	Domestic Navigation: liquid fuels	N_2O	62.81	62.81	0.0002	0.9979
2B10	Other Chemical Industry	CH_4	55.75	55.75	0.0001	0.9981
1A1	Energy industries: liquid fuels	N_2O	55.28	55.28	0.0001	0.9982
2C3	Aluminium production	CO_2	55.06	55.06	0.0001	0.9983
2B2	Nitric acid production	N_2O	49.35	49.35	0.0001	0.9985
1B1	Coal mining and handling liquid fuels	CO_2	48.45	48.45	0.0001	0.9986
2F6	Other product uses as substitutes for ODS	HFCs, PFCs, SF_6 and NF_3	40.86	40.86	0.0001	0.9987
1A4	Other sectors: biomass	N_2O	40.50	40.50	0.0001	0.9988
1A4	Other sectors: gaseous fuels	N_2O	38.64	38.64	0.0001	0.9989
1A3c	Railways: solid fuels	CO_2	36.22	36.22	0.0001	0.9990
1A4	Other sectors: liquid fuels	CH_4	33.13	33.13	0.0001	0.9990
1B2	Oil and gas extraction	N_2O	30.89	30.89	0.0001	0.9991
1A1	Energy industries: solid fuels	N_2O	29.42	29.42	0.0001	0.9992
1A2	Manufacturing industries and construction: liquid fuels	CH_4	29.16	29.16	0.0001	0.9993
2C4	Magnesium production	HFCs, PFCs, SF_6 and NF_3	28.92	28.92	0.0001	0.9993
1A4	Other sectors: solid fuels	N_2O	26.61	26.61	0.0001	0.9994
5C	Incineration and open burning of waste	N_2O	26.37	26.37	0.0001	0.9995
1A2	Manufacturing industries and construction: solid fuels	N_2O	25.95	25.95	0.0001	0.9995
2E1	Integrated circuit or semiconductor	HFCs, PFCs, SF_6 and NF_3	24.78	24.78	0.0001	0.9996
2F5	Solvents	HFCs, PFCs, SF_6 and NF_3	16.34	16.34	0.0000	0.9996
1A5	Other: liquid fuels	N_2O	14.79	14.79	0.0000	0.9997
1A2	Manufacturing industries and construction: gaseous fuels	N_2O	11.49	11.49	0.0000	0.9997
2B8	Petrochemical and carbon black production	CH_4	11.19	11.19	0.0000	0.9997
2C1	Iron and steel production	CH_4	10.93	10.93	0.0000	0.9997
1A2	Manufacturing industries and construction: other fuels	N_2O	10.40	10.40	0.0000	0.9998
1A2	Manufacturing industries and construction: gaseous fuels	CH_4	9.64	9.64	0.0000	0.9998
1A2	Manufacturing industries and construction: solid fuels	CH_4	8.64	8.64	0.0000	0.9998

IPCC Code	IPCC Category	GHG	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
1A1	Energy industries: liquid fuels	CH_4	7.84	7.84	0.0000	0.9998
5C	Incineration and open burning of waste	CH_4	7.39	7.39	0.0000	0.9999
2C1	Iron and steel production	N_2O	7.12	7.12	0.0000	0.9999
1A3e	Other transportation: liquid fuels	N_2O	6.93	6.93	0.0000	0.9999
1A3a	Domestic aviation: liquid fuels	N_2O	6.51	6.51	0.0000	0.9999
1A2	Manufacturing industries and construction: other fuels	CH_4	6.34	6.34	0.0000	0.9999
1A3d	Domestic Navigation: liquid fuels	CH_4	6.26	6.26	0.0000	0.9999
1A4	Other sectors: peat	CO_2	4.83	4.83	0.0000	0.9999
2C3	Aluminium production	HFCs, PFCs, SF_6 and NF_3	4.28	4.28	0.0000	1.0000
1B1	Coal mining and handling biomass	CH_4	3.78	3.78	0.0000	1.0000
1A3c	Railways: liquid fuels	N_2O	3.14	3.14	0.0000	1.0000
2A4	Other process uses of carbonates	CH_4	2.62	2.62	0.0000	1.0000
1A1	Energy industries: solid fuels	CH_4	1.53	1.53	0.0000	1.0000
2B8	Petrochemical and carbon black production	N_2O	1.41	1.41	0.0000	1.0000
1A5	Other: liquid fuels	CH_4	0.93	0.93	0.0000	1.0000
1A3c	Railways: solid fuels	CH_4	0.83	0.83	0.0000	1.0000
1A3c	Railways: liquid fuels	CH_4	0.44	0.44	0.0000	1.0000
1A3a	Domestic aviation: liquid fuels	CH_4	0.42	0.42	0.0000	1.0000
1A4	Other sectors: peat	CH_4	0.34	0.34	0.0000	1.0000
2B1	Ammonia production	N_2O	0.32	0.32	0.0000	1.0000
2B1	Ammonia production	CH_4	0.27	0.27	0.0000	1.0000
1A3e	Other transportation: liquid fuels	CH_4	0.22	0.22	0.0000	1.0000
1A3c	Railways: solid fuels	N_2O	0.08	0.08	0.0000	1.0000
1A4	Other sectors: peat	N_2O	0.02	0.02	0.0000	1.0000
1B1	Coal mining and handling solid fuels	N_2O	0.02	0.02	0.0000	1.0000
1B1	Coal mining and handling solid fuels	CH_4	0.01	0.01	0.0000	1.0000
Total			**405,754.88**	**405,754.88**	**1.0000**	

Table A 1.3.5 Approach 1 Key Category Analysis based on trend in emissions (from base year to latest reported year, including LULUCF) – UNFCCC scope

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Latest reported year (LY) emissions (Gg CO_2e)	Trend Assessment	Contribution to Trend	Cumulative Total
1A1	Energy industries: solid fuels	CO_2	185,488.39	5,908.93	0.1035	0.2420	0.2420
1A1	Energy industries: gaseous fuels	CO_2	11,939.20	52,284.86	0.0547	0.1280	0.3700
1A4	Other sectors: gaseous fuels	CO_2	70,371.86	72,648.22	0.0440	0.1029	0.4729
1A3b	Road transportation: liquid fuels	CO_2	108,573.17	88,729.89	0.0403	0.0942	0.5672
5A	Solid waste disposal	CH_4	60,389.54	12,912.14	0.0207	0.0484	0.6155
1B1	Coal mining and handling	CH_4	21,826.68	470.90	0.0124	0.0291	0.6446
2F1	Refrigeration and air conditioning	HFCs, PFCs, SF_6 and NF_3	215.00	10,219.79	0.0120	0.0280	0.6726
2B3	Adipic acid production	N_2O	19,934.61	-	0.0119	0.0278	0.7004
2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3	17,784.67	76.13	0.0105	0.0246	0.7249
1A1	Energy industries: liquid fuels	CO_2	40,386.62	11,638.01	0.0103	0.0241	0.7490
1A4	Other sectors: solid fuels	CO_2	19,824.90	1,993.13	0.0094	0.0221	0.7711
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	27,291.16	21,595.59	0.0093	0.0217	0.7928
1A2	Manufacturing industries and construction: solid fuels	CO_2	20,241.37	3,281.12	0.0082	0.0191	0.8119
3A1	Enteric fermentation from Cattle	CH_4	18,866.76	16,130.21	0.0078	0.0183	0.8303
4B	Cropland	CO_2	15,947.46	14,403.93	0.0075	0.0176	0.8479
1A1	Energy industries: other fuels	CO_2	244.26	6,257.60	0.0073	0.0170	0.8649
3D	Agricultural soils	N_2O	14,552.30	11,648.42	0.0051	0.0120	0.8768
1A4	Other sectors: liquid fuels	CO_2	19,350.38	13,328.52	0.0042	0.0099	0.8867
4A	Forest land	CO_2	-13,992.50	-17,933.72	0.0036	0.0083	0.8951
1B2	Oil and gas extraction	CH_4	12,342.11	4,208.76	0.0024	0.0055	0.9006
4C	Grassland	CO_2	114.65	-1,873.95	0.0023	0.0053	0.9060
2B2	Nitric acid production	N_2O	3,860.26	49.35	0.0022	0.0052	0.9112
3B1	Manure management from Cattle	CH_4	4,158.78	3,812.01	0.0020	0.0048	0.9159
3A2	Enteric fermentation from Sheep	CH_4	5,231.18	4,153.77	0.0018	0.0042	0.9202

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Latest reported year (LY) emissions (Gg CO_2e)	Trend Assessment	Contribution to Trend	Cumulative Total
1A2	Manufacturing industries and construction: liquid fuels	CO_2	29,443.87	13,420.69	0.0017	0.0039	0.9240
4E	Settlements	CO_2	5,427.63	4,032.04	0.0015	0.0036	0.9276
2C1	Iron and steel production	CO_2	23,628.28	10,617.87	0.0015	0.0035	0.9312
1A5	Other: liquid fuels	CO_2	5,293.44	1,403.89	0.0015	0.0035	0.9347
4C	Grassland	CH_4	2,385.87	2,420.90	0.0014	0.0034	0.9380
5B	Biological treatment of solid waste	CH_4	18.13	1,216.79	0.0014	0.0033	0.9414
3B2	Manure management from Sheep	N_2O	3,433.79	2,813.54	0.0013	0.0030	0.9444
4D	Wetlands	CH_4	1,961.70	2,043.62	0.0012	0.0029	0.9473
4G	Harvested wood products	CO_2	-2,087.72	-2,128.72	0.0012	0.0028	0.9500
2F4	Aerosols	HFCs, PFCs, SF_6 and NF_3	448.15	1,193.09	0.0011	0.0027	0.9527
1A3d	Domestic Navigation: liquid fuels	CO_2	7,611.13	4,777.23	0.0011	0.0026	0.9553
5B	Biological treatment of solid waste	N_2O	12.97	715.01	0.0008	0.0020	0.9573
1B1	Coal mining and handling solid fuels	CO_2	1,698.56	148.67	0.0008	0.0020	0.9592
2B1	Ammonia production	CO_2	1,895.00	1,644.56	0.0008	0.0019	0.9612
1B2	Oil and gas extraction	CO_2	5,088.52	3,245.49	0.0008	0.0019	0.9630
2C6	Zinc production	CO_2	1,350.65	-	0.0008	0.0019	0.9649
1A3c	Railways: liquid fuels	CO_2	1,471.82	1,399.64	0.0008	0.0018	0.9668
1A2	Manufacturing industries and construction: other fuels	CO_2	70.70	648.84	0.0007	0.0017	0.9684
5D	Wastewater treatment and discharge	N_2O	893.23	1,016.77	0.0007	0.0016	0.9700
1A3b	Road transportation: liquid fuels	CH_4	1,253.75	68.55	0.0007	0.0016	0.9716
5D	Wastewater treatment and discharge	CH_4	2,284.15	1,711.17	0.0007	0.0016	0.9731
1A1	Energy industries: solid fuels	N_2O	1,056.46	29.42	0.0006	0.0014	0.9745
1A4	Other sectors: solid fuels	CH_4	1,286.45	151.94	0.0006	0.0014	0.9759
1A3e	Other transportation: liquid fuels	CO_2	224.74	560.00	0.0005	0.0012	0.9771
3G	Liming	CO_2	1,016.78	950.29	0.0005	0.0012	0.9783
5C	Incineration and open burning of waste	CO_2	1,360.37	248.95	0.0005	0.0012	0.9795

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Latest reported year (LY) emissions (Gg CO_2e)	Trend Assessment	Contribution to Trend	Cumulative Total
2G3	N_2O from product uses	N_2O	554.92	665.41	0.0005	0.0011	0.9806
4A	Forest land	N_2O	752.90	712.25	0.0004	0.0009	0.9815
2A2	Lime production	CO_2	1,328.60	1,000.31	0.0004	0.0009	0.9824
4D	Wetlands	CO_2	571.12	605.99	0.0004	0.0009	0.9833
3A4	Enteric fermentation from Other livestock	CH_4	302.02	463.55	0.0004	0.0009	0.9842
2F3	Fire protection	HFCs, PFCs, SF_6 and NF_3	1.42	310.84	0.0004	0.0009	0.9850
2F2	Foam blowing agents	HFCs, PFCs, SF_6 and NF_3	184.62	402.00	0.0004	0.0009	0.9859
1A3a	Domestic aviation: liquid fuels	CO_2	1,869.71	687.75	0.0003	0.0007	0.9866
1A3b	Road transportation: liquid fuels	N_2O	1,313.56	891.99	0.0003	0.0006	0.9872
2A1	Cement production	CO_2	7,295.26	3,899.69	0.0003	0.0006	0.9879
1A4	Other sectors: biomass	CH_4	90.07	264.11	0.0003	0.0006	0.9885
1A1	Energy industries: biomass	N_2O	0.25	218.58	0.0003	0.0006	0.9891
1A3b	Road transportation: biomass	CO_2	-	214.55	0.0003	0.0006	0.9897
2B8	Petrochemical and carbon black production	CO_2	4,751.56	2,592.13	0.0002	0.0006	0.9902
1A4	Other sectors: peat	CO_2	372.48	4.83	0.0002	0.0005	0.9907
2C3	Aluminium production	CO_2	450.32	55.06	0.0002	0.0005	0.9912
2C4	Magnesium production	HFCs, PFCs, SF_6 and NF_3	387.17	28.92	0.0002	0.0005	0.9917
2C3	Aluminium production	HFCs, PFCs, SF_6 and NF_3	333.43	4.28	0.0002	0.0005	0.9921
1A1	Energy industries: gaseous fuels	N_2O	261.00	278.33	0.0002	0.0004	0.9925
1A1	Energy industries: biomass	CH_4	0.47	138.31	0.0002	0.0004	0.9929
4B	Cropland	CH_4	291.94	279.33	0.0002	0.0004	0.9933
1A1	Energy industries: other fuels	CH_4	18.54	131.45	0.0001	0.0003	0.9936
2A4	Other process uses of carbonates	CO_2	1,097.09	435.86	0.0001	0.0003	0.9939
1A2	Manufacturing industries and construction: biomass	N_2O	21.79	127.36	0.0001	0.0003	0.9943
1A1	Energy industries: other fuels	N_2O	6.70	119.47	0.0001	0.0003	0.9946

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Latest reported year (LY) emissions (Gg CO_2e)	Trend Assessment	Contribution to Trend	Cumulative Total
2A3	Glass production	CO_2	412.37	323.35	0.0001	0.0003	0.9949
2D	Non-energy products from fuels and solvent use	CO_2	552.81	379.49	0.0001	0.0003	0.9952
1A4	Other sectors: solid fuels	N_2O	245.31	26.61	0.0001	0.0003	0.9954
3F	Field burning of agricultural residues	CH_4	187.03	-	0.0001	0.0003	0.9957
4C	Grassland	N_2O	202.42	184.75	0.0001	0.0002	0.9959
1A4	Other sectors: gaseous fuels	CH_4	157.65	162.07	0.0001	0.0002	0.9962
2B6	Titanium dioxide production	CO_2	104.63	134.87	0.0001	0.0002	0.9964
1A2	Manufacturing industries and construction: biomass	CH_4	13.71	80.38	0.0001	0.0002	0.9966
2G1	Electrical equipment	HFCs, PFCs, SF_6 and NF_3	797.11	329.32	0.0001	0.0002	0.9968
4E	Settlements	N_2O	441.11	293.94	0.0001	0.0002	0.9970
3H	Urea application to land	CO_2	327.68	234.27	0.0001	0.0002	0.9972
2G4	Other product manufacture and use	N_2O	41.00	87.24	0.0001	0.0002	0.9974
5C	Incineration and open burning of waste	CH_4	136.32	7.39	0.0001	0.0002	0.9975
4A	Forest land	CH_4	87.54	103.13	0.0001	0.0002	0.9977
3J	Agriculture activities in OTs and CDs	CH_4	270.85	193.22	0.0001	0.0002	0.9979
1B1	Coal mining and handling liquid fuels	CO_2	-	48.45	0.0001	0.0001	0.9980
3A3	Enteric fermentation from Swine	CH_4	283.06	190.07	0.0001	0.0001	0.9981
1A2	Manufacturing industries and construction: solid fuels	N_2O	141.45	25.95	0.0001	0.0001	0.9982
2B10	Other Chemical Industry	CH_4	191.21	55.75	0.0000	0.0001	0.9984
1A1	Energy industries: gaseous fuels	CH_4	128.80	102.93	0.0000	0.0001	0.9985
1A3c	Railways: solid fuels	CO_2	-	36.22	0.0000	0.0001	0.9986
1A4	Other sectors: biomass	N_2O	13.54	40.50	0.0000	0.0001	0.9987
3F	Field burning of agricultural residues	N_2O	57.80	-	0.0000	0.0001	0.9987
2B7	Soda ash production	CO_2	224.40	141.86	0.0000	0.0001	0.9988
4B	Cropland	N_2O	734.60	398.47	0.0000	0.0001	0.9989
1A4	Other sectors: liquid fuels	N_2O	101.77	79.30	0.0000	0.0001	0.9990

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Latest reported year (LY) emissions (Gg CO_2e)	Trend Assessment	Contribution to Trend	Cumulative Total
2G2	SF_6 and PFCs from other product use	HFCs, PFCs, SF_6 and NF_3	202.72	129.56	0.0000	0.0001	0.9990
1A1	Energy industries: solid fuels	CH_4	50.88	1.53	0.0000	0.0001	0.9991
3J	Agriculture activities in OTs and CDs	N_2O	178.70	113.40	0.0000	0.0001	0.9992
2F6	Other product uses as substitutes for ODS	HFCs, PFCs, SF_6 and NF_3	37.10	40.86	0.0000	0.0001	0.9992
4E	Settlements	CH_4	16.31	30.19	0.0000	0.0001	0.9993
1A4	Other sectors: gaseous fuels	N_2O	37.58	38.64	0.0000	0.0001	0.9994
2E1	Integrated circuit or semiconductor	HFCs, PFCs, SF_6 and NF_3	13.22	24.78	0.0000	0.0001	0.9994
4	Indirect N_2O emissions from LULUCF	N_2O	305.49	171.77	0.0000	0.0000	0.9995
2F5	Solvents	HFCs, PFCs, SF_6 and NF_3	-	16.34	0.0000	0.0000	0.9995
4D	Wetlands	N_2O	21.29	24.81	0.0000	0.0000	0.9995
1A2	Manufacturing industries and construction: solid fuels	CH_4	44.77	8.64	0.0000	0.0000	0.9996
1A5	Other: liquid fuels	N_2O	56.12	14.79	0.0000	0.0000	0.9996
2A4	Other process uses of carbonates	CH_4	31.11	2.62	0.0000	0.0000	0.9997
1A4	Other sectors: peat	CH_4	26.35	0.34	0.0000	0.0000	0.9997
1A2	Manufacturing industries and construction: other fuels	N_2O	0.34	10.40	0.0000	0.0000	0.9997
1A3d	Domestic Navigation: liquid fuels	N_2O	105.00	62.81	0.0000	0.0000	0.9997
1A1	Energy industries: liquid fuels	CH_4	34.49	7.84	0.0000	0.0000	0.9998
2C1	Iron and steel production	CH_4	39.22	10.93	0.0000	0.0000	0.9998
1B2	Oil and gas extraction	N_2O	44.69	30.89	0.0000	0.0000	0.9998
1A2	Manufacturing industries and construction: liquid fuels	CH_4	43.87	29.16	0.0000	0.0000	0.9998
1A2	Manufacturing industries and construction: liquid fuels	N_2O	137.23	75.43	0.0000	0.0000	0.9999
1A2	Manufacturing industries and construction: other fuels	CH_4	0.15	6.34	0.0000	0.0000	0.9999

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Latest reported year (LY) emissions (Gg CO_2e)	Trend Assessment	Contribution to Trend	Cumulative Total
1A3e	Other transportation: liquid fuels	N_2O	2.79	6.93	0.0000	0.0000	0.9999
1A4	Other sectors: liquid fuels	CH_4	56.96	33.13	0.0000	0.0000	0.9999
1A3d	Domestic Navigation: liquid fuels	CH_4	3.66	6.26	0.0000	0.0000	0.9999
1A2	Manufacturing industries and construction: gaseous fuels	N_2O	14.57	11.49	0.0000	0.0000	0.9999
2B8	Petrochemical and carbon black production	CH_4	30.17	11.19	0.0000	0.0000	0.9999
1B1	Coal mining and handling biomass	CH_4	0.10	3.78	0.0000	0.0000	0.9999
1A2	Manufacturing industries and construction: gaseous fuels	CH_4	12.22	9.64	0.0000	0.0000	1.0000
2C1	Iron and steel production	N_2O	20.73	7.12	0.0000	0.0000	1.0000
1A3a	Domestic aviation: liquid fuels	CH_4	6.87	0.42	0.0000	0.0000	1.0000
1A3a	Domestic aviation: liquid fuels	N_2O	17.70	6.51	0.0000	0.0000	1.0000
1A3c	Railways: liquid fuels	N_2O	3.30	3.14	0.0000	0.0000	1.0000
1A1	Energy industries: liquid fuels	N_2O	112.43	55.28	0.0000	0.0000	1.0000
1A5	Other: liquid fuels	CH_4	3.56	0.93	0.0000	0.0000	1.0000
1A3c	Railways: solid fuels	CH_4	-	0.83	0.0000	0.0000	1.0000
1A3c	Railways: liquid fuels	CH_4	2.46	0.44	0.0000	0.0000	1.0000
5C	Incineration and open burning of waste	N_2O	50.93	26.37	0.0000	0.0000	1.0000
1A4	Other sectors: peat	N_2O	1.47	0.02	0.0000	0.0000	1.0000
2B8	Petrochemical and carbon black production	N_2O	2.21	1.41	0.0000	0.0000	1.0000
2B1	Ammonia production	N_2O	0.31	0.32	0.0000	0.0000	1.0000
2B1	Ammonia production	CH_4	0.26	0.27	0.0000	0.0000	1.0000
1A3c	Railways: solid fuels	N_2O	-	0.08	0.0000	0.0000	1.0000
1A3e	Other transportation: liquid fuels	CH_4	0.29	0.22	0.0000	0.0000	1.0000
1B1	Coal mining and handling solid fuels	N_2O	0.09	0.02	0.0000	0.0000	1.0000
1B1	Coal mining and handling solid fuels	CH_4	0.08	0.01	0.0000	0.0000	1.0000
Total			**813,352.09**	**409,523.61**	**0.4276**	**1.0000**	

Table A 1.3.6 Approach 1 Key Category Analysis based on trend in emissions (from base year to latest reported year, excluding LULUCF) – UNFCCC scope

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Latest reported year (LY) emissions (Gg CO_2e)	Trend Assessment	Contribution to Trend	Cumulative Total
1A1	Energy industries: solid fuels	CO_2	185,488.39	5,908.93	0.1035	0.2539	0.2539
1A1	Energy industries: gaseous fuels	CO_2	11,939.20	52,284.86	0.0547	0.1343	0.3882
1A4	Other sectors: gaseous fuels	CO_2	70,371.86	72,648.22	0.0440	0.1080	0.4962
1A3b	Road transportation: liquid fuels	CO_2	108,573.17	88,729.89	0.0403	0.0989	0.5951
5A	Solid waste disposal	CH_4	60,389.54	12,912.14	0.0207	0.0508	0.6459
1B1	Coal mining and handling	CH_4	21,826.68	470.90	0.0124	0.0305	0.6764
2F1	Refrigeration and air conditioning	HFCs, PFCs, SF_6 and NF_3	215.00	10,219.79	0.0120	0.0293	0.7057
2B3	Adipic acid production	N_2O	19,934.61	-	0.0119	0.0291	0.7349
2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3	17,784.67	76.13	0.0105	0.0258	0.7606
1A1	Energy industries: liquid fuels	CO_2	40,386.62	11,638.01	0.0103	0.0252	0.7859
1A4	Other sectors: solid fuels	CO_2	19,824.90	1,993.13	0.0094	0.0232	0.8091
1A2	Manufacturing industries and construction: gaseous fuels	CO_2	27,291.16	21,595.59	0.0093	0.0228	0.8318
1A2	Manufacturing industries and construction: solid fuels	CO_2	20,241.37	3,281.12	0.0082	0.0201	0.8519
3A1	Enteric fermentation from Cattle	CH_4	18,866.76	16,130.21	0.0078	0.0192	0.8712
1A1	Energy industries: other fuels	CO_2	244.26	6,257.60	0.0073	0.0178	0.8890
3D	Agricultural soils	N_2O	14,552.30	11,648.42	0.0051	0.0125	0.9015
1A4	Other sectors: liquid fuels	CO_2	19,350.38	13,328.52	0.0042	0.0104	0.9119
1B2	Oil and gas extraction	CH_4	12,342.11	4,208.76	0.0024	0.0058	0.9177
2B2	Nitric acid production	N_2O	3,860.26	49.35	0.0022	0.0055	0.9232
3B1	Manure management from Cattle	CH_4	4,158.78	3,812.01	0.0020	0.0050	0.9282
3A2	Enteric fermentation from Sheep	CH_4	5,231.18	4,153.77	0.0018	0.0044	0.9326
1A2	Manufacturing industries and construction: liquid fuels	CO_2	29,443.87	13,420.69	0.0017	0.0041	0.9367
2C1	Iron and steel production	CO_2	23,628.28	10,617.87	0.0015	0.0037	0.9404
1A5	Other: liquid fuels	CO_2	5,293.44	1,403.89	0.0015	0.0037	0.9441

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Latest reported year (LY) emissions (Gg CO_2e)	Trend Assessment	Contribution to Trend	Cumulative Total
5B	Biological treatment of solid waste	CH_4	18.13	1,216.79	0.0014	0.0035	0.9476
3B2	Manure management from Sheep	N_2O	3,433.79	2,813.54	0.0013	0.0031	0.9507
2F4	Aerosols	HFCs, PFCs, SF_6 and NF_3	448.15	1,193.09	0.0011	0.0028	0.9535
1A3d	Domestic Navigation: liquid fuels	CO_2	7,611.13	4,777.23	0.0011	0.0027	0.9563
5B	Biological treatment of solid waste	N_2O	12.97	715.01	0.0008	0.0021	0.9583
1B1	Coal mining and handling solid fuels	CO_2	1,698.56	148.67	0.0008	0.0021	0.9604
2B1	Ammonia production	CO_2	1,895.00	1,644.56	0.0008	0.0020	0.9624
1B2	Oil and gas extraction	CO_2	5,088.52	3,245.49	0.0008	0.0020	0.9644
2C6	Zinc production	CO_2	1,350.65	-	0.0008	0.0020	0.9663
1A3c	Railways: liquid fuels	CO_2	1,471.82	1,399.64	0.0008	0.0019	0.9683
1A2	Manufacturing industries and construction: other fuels	CO_2	70.70	648.84	0.0007	0.0018	0.9700
5D	Wastewater treatment and discharge	N_2O	893.23	1,016.77	0.0007	0.0016	0.9717
1A3b	Road transportation: liquid fuels	CH_4	1,253.75	68.55	0.0007	0.0016	0.9733
5D	Wastewater treatment and discharge	CH_4	2,284.15	1,711.17	0.0007	0.0016	0.9749
1A1	Energy industries: solid fuels	N_2O	1,056.46	29.42	0.0006	0.0015	0.9764
1A4	Other sectors: solid fuels	CH_4	1,286.45	151.94	0.0006	0.0014	0.9778
1A3e	Other transportation: liquid fuels	CO_2	224.74	560.00	0.0005	0.0013	0.9791
3G	Liming	CO_2	1,016.78	950.29	0.0005	0.0013	0.9804
5C	Incineration and open burning of waste	CO_2	1,360.37	248.95	0.0005	0.0013	0.9817
2G3	N_2O from product uses	N_2O	554.92	665.41	0.0005	0.0011	0.9828
2A2	Lime production	CO_2	1,328.60	1,000.31	0.0004	0.0010	0.9838
3A4	Enteric fermentation from Other livestock	CH_4	302.02	463.55	0.0004	0.0009	0.9847
2F3	Fire protection	HFCs, PFCs, SF_6 and NF_3	1.42	310.84	0.0004	0.0009	0.9856
2F2	Foam blowing agents	HFCs, PFCs, SF_6 and NF_3	184.62	402.00	0.0004	0.0009	0.9865

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Latest reported year (LY) emissions (Gg CO_2e)	Trend Assessment	Contribution to Trend	Cumulative Total
1A3a	Domestic aviation: liquid fuels	CO_2	1,869.71	687.75	0.0003	0.0007	0.9872
1A3b	Road transportation: liquid fuels	N_2O	1,313.56	891.99	0.0003	0.0007	0.9879
2A1	Cement production	CO_2	7,295.26	3,899.69	0.0003	0.0007	0.9885
1A4	Other sectors: biomass	CH_4	90.07	264.11	0.0003	0.0006	0.9892
1A1	Energy industries: biomass	N_2O	0.25	218.58	0.0003	0.0006	0.9898
1A3b	Road transportation: biomass	CO_2	-	214.55	0.0003	0.0006	0.9904
2B8	Petrochemical and carbon black production	CO_2	4,751.56	2,592.13	0.0002	0.0006	0.9910
1A4	Other sectors: peat	CO_2	372.48	4.83	0.0002	0.0005	0.9915
2C3	Aluminium production	CO_2	450.32	55.06	0.0002	0.0005	0.9920
2C4	Magnesium production	HFCs, PFCs, SF_6 and NF_3	387.17	28.92	0.0002	0.0005	0.9925
2C3	Aluminium production	HFCs, PFCs, SF_6 and NF_3	333.43	4.28	0.0002	0.0005	0.9930
1A1	Energy industries: gaseous fuels	N_2O	261.00	278.33	0.0002	0.0004	0.9934
1A1	Energy industries: biomass	CH_4	0.47	138.31	0.0002	0.0004	0.9938
1A1	Energy industries: other fuels	CH_4	18.54	131.45	0.0001	0.0004	0.9942
2A4	Other process uses of carbonates	CO_2	1,097.09	435.86	0.0001	0.0003	0.9945
1A2	Manufacturing industries and construction: biomass	N_2O	21.79	127.36	0.0001	0.0003	0.9948
1A1	Energy industries: other fuels	N_2O	6.70	119.47	0.0001	0.0003	0.9952
2A3	Glass production	CO_2	412.37	323.35	0.0001	0.0003	0.9955
2D	Non-energy products from fuels and solvent use	CO_2	552.81	379.49	0.0001	0.0003	0.9958
1A4	Other sectors: solid fuels	N_2O	245.31	26.61	0.0001	0.0003	0.9961
3F	Field burning of agricultural residues	CH_4	187.03	-	0.0001	0.0003	0.9964
1A4	Other sectors: gaseous fuels	CH_4	157.65	162.07	0.0001	0.0002	0.9966
2B6	Titanium dioxide production	CO_2	104.63	134.87	0.0001	0.0002	0.9968
1A2	Manufacturing industries and construction: biomass	CH_4	13.71	80.38	0.0001	0.0002	0.9970
2G1	Electrical equipment	HFCs, PFCs, SF_6 and NF_3	797.11	329.32	0.0001	0.0002	0.9973

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Latest reported year (LY) emissions (Gg CO_2e)	Trend Assessment	Contribution to Trend	Cumulative Total
3H	Urea application to land	CO_2	327.68	234.27	0.0001	0.0002	0.9975
2G4	Other product manufacture and use	N_2O	41.00	87.24	0.0001	0.0002	0.9976
5C	Incineration and open burning of waste	CH_4	136.32	7.39	0.0001	0.0002	0.9978
3J	Agriculture activities in OTs and CDs	CH_4	270.85	193.22	0.0001	0.0002	0.9980
1B1	Coal mining and handling liquid fuels	CO_2	-	48.45	0.0001	0.0001	0.9981
3A3	Enteric fermentation from Swine	CH_4	283.06	190.07	0.0001	0.0001	0.9983
1A2	Manufacturing industries and construction: solid fuels	N_2O	141.45	25.95	0.0001	0.0001	0.9984
2B10	Other Chemical Industry	CH_4	191.21	55.75	0.0000	0.0001	0.9985
1A1	Energy industries: gaseous fuels	CH_4	128.80	102.93	0.0000	0.0001	0.9986
1A3c	Railways: solid fuels	CO_2	-	36.22	0.0000	0.0001	0.9987
1A4	Other sectors: biomass	N_2O	13.54	40.50	0.0000	0.0001	0.9988
3F	Field burning of agricultural residues	N_2O	57.80	-	0.0000	0.0001	0.9989
2B7	Soda ash production	CO_2	224.40	141.86	0.0000	0.0001	0.9990
1A4	Other sectors: liquid fuels	N_2O	101.77	79.30	0.0000	0.0001	0.9991
2G2	SF_6 and PFCs from other product use	HFCs, PFCs, SF_6 and NF_3	202.72	129.56	0.0000	0.0001	0.9992
1A1	Energy industries: solid fuels	CH_4	50.88	1.53	0.0000	0.0001	0.9992
3J	Agriculture activities in OTs and CDs	N_2O	178.70	113.40	0.0000	0.0001	0.9993
2F6	Other product uses as substitutes for ODS	HFCs, PFCs, SF_6 and NF_3	37.10	40.86	0.0000	0.0001	0.9994
1A4	Other sectors: gaseous fuels	N_2O	37.58	38.64	0.0000	0.0001	0.9994
2E1	Integrated circuit or semiconductor	HFCs, PFCs, SF_6 and NF_3	13.22	24.78	0.0000	0.0001	0.9995
2F5	Solvents	HFCs, PFCs, SF_6 and NF_3	-	16.34	0.0000	0.0000	0.9995
1A2	Manufacturing industries and construction: solid fuels	CH_4	44.77	8.64	0.0000	0.0000	0.9996
1A5	Other: liquid fuels	N_2O	56.12	14.79	0.0000	0.0000	0.9996
2A4	Other process uses of carbonates	CH_4	31.11	2.62	0.0000	0.0000	0.9996

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Latest reported year (LY) emissions (Gg CO_2e)	Trend Assessment	Contribution to Trend	Cumulative Total
1A4	Other sectors: peat	CH_4	26.35	0.34	0.0000	0.0000	0.9997
1A2	Manufacturing industries and construction: other fuels	N_2O	0.34	10.40	0.0000	0.0000	0.9997
1A3d	Domestic Navigation: liquid fuels	N_2O	105.00	62.81	0.0000	0.0000	0.9997
1A1	Energy industries: liquid fuels	CH_4	34.49	7.84	0.0000	0.0000	0.9998
2C1	Iron and steel production	CH_4	39.22	10.93	0.0000	0.0000	0.9998
1B2	Oil and gas extraction	N_2O	44.69	30.89	0.0000	0.0000	0.9998
1A2	Manufacturing industries and construction: liquid fuels	CH_4	43.87	29.16	0.0000	0.0000	0.9998
1A2	Manufacturing industries and construction: liquid fuels	N_2O	137.23	75.43	0.0000	0.0000	0.9998
1A2	Manufacturing industries and construction: other fuels	CH_4	0.15	6.34	0.0000	0.0000	0.9999
1A3e	Other transportation: liquid fuels	N_2O	2.79	6.93	0.0000	0.0000	0.9999
1A4	Other sectors: liquid fuels	CH_4	56.96	33.13	0.0000	0.0000	0.9999
1A3d	Domestic Navigation: liquid fuels	CH_4	3.66	6.26	0.0000	0.0000	0.9999
1A2	Manufacturing industries and construction: gaseous fuels	N_2O	14.57	11.49	0.0000	0.0000	0.9999
2B8	Petrochemical and carbon black production	CH_4	30.17	11.19	0.0000	0.0000	0.9999
1B1	Coal mining and handling biomass	CH_4	0.10	3.78	0.0000	0.0000	0.9999
1A2	Manufacturing industries and construction: gaseous fuels	CH_4	12.22	9.64	0.0000	0.0000	1.0000
2C1	Iron and steel production	N_2O	20.73	7.12	0.0000	0.0000	1.0000
1A3a	Domestic aviation: liquid fuels	CH_4	6.87	0.42	0.0000	0.0000	1.0000
1A3a	Domestic aviation: liquid fuels	N_2O	17.70	6.51	0.0000	0.0000	1.0000
1A3c	Railways: liquid fuels	N_2O	3.30	3.14	0.0000	0.0000	1.0000
1A1	Energy industries: liquid fuels	N_2O	112.43	55.28	0.0000	0.0000	1.0000
1A5	Other: liquid fuels	CH_4	3.56	0.93	0.0000	0.0000	1.0000
1A3c	Railways: solid fuels	CH_4	-	0.83	0.0000	0.0000	1.0000
1A3c	Railways: liquid fuels	CH_4	2.46	0.44	0.0000	0.0000	1.0000
5C	Incineration and open burning of waste	N_2O	50.93	26.37	0.0000	0.0000	1.0000

IPCC Code	IPCC Category	GHG	Base year emissions (Gg CO_2e)	Latest reported year (LY) emissions (Gg CO_2e)	Trend Assessment	Contribution to Trend	Cumulative Total
1A4	Other sectors: peat	N_2O	1.47	0.02	0.0000	0.0000	1.0000
2B8	Petrochemical and carbon black production	N_2O	2.21	1.41	0.0000	0.0000	1.0000
2B1	Ammonia production	N_2O	0.31	0.32	0.0000	0.0000	1.0000
2B1	Ammonia production	CH_4	0.26	0.27	0.0000	0.0000	1.0000
1A3c	Railways: solid fuels	N_2O	-	0.08	0.0000	0.0000	1.0000
1A3e	Other transportation: liquid fuels	CH_4	0.29	0.22	0.0000	0.0000	1.0000
1B1	Coal mining and handling solid fuels	N_2O	0.09	0.02	0.0000	0.0000	1.0000
1B1	Coal mining and handling solid fuels	CH_4	0.08	0.01	0.0000	0.0000	1.0000
Total			**800,170.27**	**405,754.88**	**0.4075**	**1.0000**	

A 1.4 QUANTITATIVE APPROACH 2 KCA FOLLOWING IPCC 2006 GUIDELINES

Following the 2006 IPCC Guidelines, the UK has also completed an Approach 2 KCA for both level and trend, which takes into account uncertainties, using the Approach 1 method for uncertainty estimates. This analysis has been performed using the data shown in **Table A 1.4.1** to **Table A 1.4.4**using the same categorisation and the same estimates of uncertainty.

The results of the level assessment (based on Approach 2) with and without LULUCF for the base year and the latest reported year are shown in **Table A 1.4.1** to **Table A 1.4.4**.The key source categories are highlighted by the shaded cells in the table. The source categories (i.e. rows of the table) were sorted in descending order of magnitude based on the results of the “Level Parameter”, and then the cumulative total was included in the final column of the table. The key source categories are those whose contributions add up to 90% of the sum of the level parameter in the final column after this sorting process, which accounts for 90% of the uncertainty in level.

The results of the trend assessment (based on Approach 2) with and without LULUCF for the base year to the latest reported year, are shown in **Table A 1.4.5** to **Table A 1.4.6.**

The key source categories are highlighted by the shaded cells in the table. The trend parameter was calculated using the absolute value of the result; an absolute function is used since Land Use, Land Use Change and Forestry contains negative sources (sinks) and the absolute function is necessary to produce positive uncertainty contributions for these sinks. The source categories (i.e. rows of the table) were sorted in descending order of magnitude based on the results of the trend parameter, and then the cumulative total was included in the final column of the table. The key source categories are those whose contributions add up to 90% of the sum of the level parameter in the final column after this sorting process, which accounts for 90% of the uncertainty in trend.

Any methodological improvements to the uncertainty analysis are discussed in **ANNEX 2:**.

Table A 1.4.1 Approach 2 Level Assessment for Base year (including LULUCF) with Key Categories Shaded in Grey – UNFCCC scope

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
5A	5A Solid Waste Disposal	CH_4	60389.54	60389.54	0.2831	0.2831
1A	1A Coal	CO_2	225554.66	225554.66	0.0801	0.3633
1A	1A (Stationary) Oil	CO_2	94431.33	94431.33	0.0563	0.4196
1B2	1B2 Natural Gas Transmission	CH_4	10600.72	10600.72	0.0516	0.4712
1B1	1B1 Coal Mining	CH_4	21826.68	21826.68	0.0425	0.5137
5C	5C Waste Incineration	CO_2	1360.37	1360.37	0.0399	0.5536
3A	3A Enteric Fermentation	CH_4	24683.01	24683.01	0.0329	0.5864
4B	4B Cropland	CO_2	15947.46	15947.46	0.0309	0.6174
3D	3D Agricultural Soils	N_2O	14552.30	14552.30	0.0306	0.6480
4E	4E Settlements	CO_2	5427.63	5427.63	0.0237	0.6717
2B	2B Chemical industries	N_2O	23797.38	23797.38	0.0232	0.6949
1A	1A Natural Gas	CO_2	109602.22	109602.22	0.0214	0.7162
4A	4A Forest Land	CO_2	-13992.50	13992.50	0.0204	0.7366
5D	5D Wastewater Handling	N_2O	893.23	893.23	0.0188	0.7554
2B	2B Chemical industry	HFCs	17670.77	17670.77	0.0171	0.7726
2C	2C Metal Industries	CO_2	25429.25	25429.25	0.0169	0.7894
1A3b	1A3b Gasoline/ LPG	CO_2	75562.66	75562.66	0.0163	0.8057
1B2	1B2 Upstream Oil & Gas	CH_4	1741.39	1741.39	0.0148	0.8205
1A1 & 1A2 & 1A4 & 1A5	1A1 & 1A2 & 1A4 & 1A5 Other Combustion	N_2O	2208.02	2208.02	0.0143	0.8348
1A3d	1A3d Marine fuel	CO_2	7611.13	7611.13	0.0133	0.8481
2B	2B Chemical industries	CO_2	6975.59	6975.59	0.0118	0.8599
5D	5D Wastewater Handling	CH_4	2284.15	2284.15	0.0110	0.8709
4C	4C Grassland	CH_4	2385.87	2385.87	0.0093	0.8801
1A3b	1A3b Gasoline/ LPG	CH_4	1166.71	1166.71	0.0085	0.8886
2G	2G Other Product Manufacture and Use	N_2O	595.92	595.92	0.0082	0.8968
1A3b	1A3b Gasoline/ LPG	N_2O	996.92	996.92	0.0072	0.9040
1A3b	1A3b DERV	CO_2	33008.88	33008.88	0.0072	0.9111
4D	4D Wetland	CH_4	1961.70	1961.70	0.0067	0.9178
4A	4A Forest land	N_2O	752.90	752.90	0.0062	0.9240
1A1 & 1A2 & 1A4 & 1A5	1A1 & 1A2 & 1A4 & 1A5 Other Combustion	CH_4	1968.95	1968.95	0.0062	0.9302

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
3B	3B Manure Management	N_2O	3433.79	3433.79	0.0058	0.9360
4E	4E Settlements	N_2O	441.11	441.11	0.0056	0.9415
4	4 Indirect LULUCF Emissions	N_2O	305.49	305.49	0.0049	0.9464
3B	3B Manure Management	CH_4	4158.78	4158.78	0.0042	0.9506
1A3b	1A3b DERV	N_2O	316.64	316.64	0.0040	0.9546
1A3a	1A3a Aviation Fuel	CO_2	1869.71	1869.71	0.0036	0.9582
1B2	1B2 Oil & Natural Gas	CO_2	5088.52	5088.52	0.0031	0.9613
4G	4G Other Activities	CO_2	-2087.72	2087.72	0.0030	0.9644
2D	2D Non Energy Products from Fuels and Solvent Use	CO_2	552.81	552.81	0.0030	0.9674
4B	4B Cropland	CH_4	291.94	291.94	0.0025	0.9699
4B	4B Cropland	N_2O	734.60	734.60	0.0025	0.9724
2A	2A Mineral Industries	CO_2	10133.32	10133.32	0.0023	0.9748
1A3	1A3 Other diesel	CO_2	1696.57	1696.57	0.0022	0.9770
3G	3G Liming	CO_2	1016.78	1016.78	0.0021	0.9791
3J	3J OT & CD Agriculture	CH_4	270.85	270.85	0.0019	0.9809
3H	3H Urea application to agriculture	CO_2	327.68	327.68	0.0016	0.9825
3J	3J OT & CD Agriculture	N_2O	178.70	178.70	0.0012	0.9838
1A3d	1A3d Marine fuel	N_2O	105.00	105.00	0.0012	0.9850
1A4	1A4 Peat	CO_2	372.48	372.48	0.0011	0.9861
5C	5C Waste Incineration	N_2O	50.93	50.93	0.0011	0.9872
1B1	1B1 Solid Fuel Transformation	CO_2	1698.56	1698.56	0.0011	0.9884
4D	4D Wetland	CO_2	571.12	571.12	0.0011	0.9895
1A3b	1A3b DERV	CH_4	87.05	87.05	0.0011	0.9906
2F	2F Product Uses as Substitutes for ODS	HFCs	885.83	885.83	0.0010	0.9916
4C	4C Grassland	N_2O	202.42	202.42	0.0009	0.9925
4A	4A Forest Land	CH_4	87.54	87.54	0.0007	0.9932
5C	5C Waste Incineration	CH_4	136.32	136.32	0.0007	0.9939
2G	2G Other Product Manufacture and Use	PFCs	141.67	141.67	0.0006	0.9945
2C	2C Metal Industries	PFCs	333.43	333.43	0.0006	0.9951
2G	2G Other Product Manufacture and Use	SF_6	858.16	858.16	0.0005	0.9956
3F	3F Field Burning	CH_4	187.03	187.03	0.0005	0.9961
1B2	1B2 Oil & Natural Gas	N_2O	44.69	44.69	0.0004	0.9965
2B	2B Chemical Industry	CH_4	221.63	221.63	0.0004	0.9969

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
1A	1A Other (waste)	CO_2	245.26	245.26	0.0003	0.9973
2A	2A Mineral Industries	CH_4	31.11	31.11	0.0003	0.9976
1A4	1A4 Petroleum Coke	CO_2	114.30	114.30	0.0003	0.9979
2C	2C Metal Industries	SF_6	387.17	387.17	0.0003	0.9981
2C	2C Iron & Steel	N_2O	20.73	20.73	0.0002	0.9984
4C	4C Grassland	CO_2	114.65	114.65	0.0002	0.9986
1A3a	1A3a Aviation Fuel	N_2O	17.70	17.70	0.0002	0.9988
4D	4D Wetland	N_2O	21.29	21.29	0.0002	0.9990
5B	5B Biological treatment of solid waste	CH_4	18.13	18.13	0.0002	0.9991
2C	2C Iron & Steel Production	CH_4	39.22	39.22	0.0002	0.9993
3F	3F Field Burning	N_2O	57.80	57.80	0.0001	0.9994
5B	5B Biological treatment of solid waste	N_2O	12.97	12.97	0.0001	0.9996
2B	2B Chemical industry	PFCs	113.90	113.90	0.0001	0.9997
1A3	1A3 Other diesel	N_2O	6.09	6.09	0.0001	0.9998
4E	4E Settlements	CH_4	16.31	16.31	0.0001	0.9998
2E	2E Electronics Industry	HFCs	12.94	12.94	0.0001	0.9999
1A3d	1A3d Marine fuel	CH_4	3.66	3.66	0.0000	0.9999
1A3a	1A3a Aviation Fuel	CH_4	6.87	6.87	0.0000	1.0000
1A3	1A3 Other diesel	CH_4	2.75	2.75	0.0000	1.0000
2E	2E Electronics Industry	NF_3	0.27	0.27	0.0000	1.0000
2F	2F Product Uses as Substitutes for ODS	PFCs	0.44	0.44	0.0000	1.0000
1B1	1B1 Fugitive Emissions from Solid Fuels	N_2O	0.09	0.09	0.0000	1.0000
1B1	1B1 Solid Fuel Transformation	CH_4	0.18	0.18	0.0000	1.0000
1A3	1A3 Natural Gas	CO_2	0.00	0.00	0.0000	1.0000
1A3c	1A3c Coal	CO_2	0.00	0.00	0.0000	1.0000
1B2	1B2 Other Energy Industries	CO_2	0.00	0.00	0.0000	1.0000
4F	4F Other Land	CO_2	0.00	0.00	0.0000	1.0000
1A3	1A3 Natural Gas	CH_4	0.00	0.00	0.0000	1.0000
1A3c	1A3c Coal	CH_4	0.00	0.00	0.0000	1.0000
2D	2D Non-energy Products from Fuels and Solvent Use	CH_4	0.00	0.00	0.0000	1.0000
2C	2C Metal Industries	HFCs	0.00	0.00	0.0000	1.0000
Total			**813,352.09**	**845,512.52**	**1**	

Table A 1.4.2 Approach 2 Level Assessment for the latest reported year (including LULUCF) with Key Categories Shaded in Grey – UNFCCC scope

IPCC Code	IPCC Category	Gas	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
5A	5A Solid Waste Disposal	CH_4	12912.14	12912.14	0.1236	0.1236
1A	1A Natural Gas	CO_2	146528.67	146528.67	0.0583	0.1819
4B	4B Cropland	CO_2	14403.93	14403.93	0.0571	0.2390
3A	3A Enteric Fermentation	CH_4	20937.60	20937.60	0.0569	0.2959
4A	4A Forest Land	CO_2	-17933.72	17933.72	0.0533	0.3493
3D	3D Agricultural Soils	N_2O	11648.42	11648.42	0.0500	0.3993
1A	1A (Stationary) Oil	CO_2	39351.88	39351.88	0.0479	0.4472
5D	5D Wastewater Handling	N_2O	1016.77	1016.77	0.0437	0.4909
4E	4E Settlements	CO_2	4032.04	4032.04	0.0359	0.5268
1B2	1B2 Natural Gas Transmission	CH_4	3337.33	3337.33	0.0332	0.5600
2F	2F Product Uses as Substitutes for ODS	HFCs	12182.92	12182.92	0.0288	0.5888
1A3b	1A3b DERV	CO_2	61012.20	61012.20	0.0270	0.6157
5B	5B Biological treatment of solid waste	CH_4	1216.79	1216.79	0.0250	0.6408
1A3b	1A3b DERV	N_2O	819.98	819.98	0.0211	0.6619
2G	2G Other Product Manufacture and Use	N_2O	752.65	752.65	0.0211	0.6829
4C	4C Grassland	CH_4	2420.90	2420.90	0.0192	0.7021
1A	1A Other (waste)	CO_2	6706.96	6706.96	0.0186	0.7207
1A3d	1A3d Marine fuel	CO_2	4777.23	4777.23	0.0171	0.7378
5D	5D Wastewater Handling	CH_4	1711.17	1711.17	0.0168	0.7546
2B	2B Chemical industries	CO_2	4513.43	4513.43	0.0156	0.7702
1A1 & 1A2 & 1A4 & 1A5	1A1 & 1A2 & 1A4 & 1A5 Other Combustion	N_2O	1151.56	1151.56	0.0152	0.7854
1B2	1B2 Upstream Oil & Gas	CH_4	871.43	871.43	0.0151	0.8005
5C	5C Waste Incineration	CO_2	248.95	248.95	0.0149	0.8154
2C	2C Metal Industries	CO_2	10672.94	10672.94	0.0145	0.8299
4D	4D Wetland	CH_4	2043.62	2043.62	0.0142	0.8441
5B	5B Biological treatment of solid waste	N_2O	715.01	715.01	0.0134	0.8575
1A3b	1A3b Gasoline/ LPG	CO_2	27660.36	27660.36	0.0122	0.8696
4A	4A Forest land	N_2O	712.25	712.25	0.0120	0.8816
3B	3B Manure Management	N_2O	2813.54	2813.54	0.0096	0.8913
1A	1A Coal	CO_2	11183.18	11183.18	0.0081	0.8994

IPCC Code	IPCC Category	Gas	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
3B	3B Manure Management	CH_4	3812.01	3812.01	0.0079	0.9073
4E	4E Settlements	N_2O	293.94	293.94	0.0076	0.9148
4C	4C Grassland	CO_2	-1873.95	1873.95	0.0074	0.9222
1A1 & 1A2 & 1A4 & 1A5	1A1 & 1A2 & 1A4 & 1A5 Other Combustion	CH_4	1128.74	1128.74	0.0073	0.9295
4G	4G Other Activities	CO_2	-2128.72	2128.72	0.0063	0.9358
1A3	1A3 Other diesel	CO_2	2174.19	2174.19	0.0059	0.9417
4	4 Indirect LULUCF Emissions	N_2O	171.77	171.77	0.0056	0.9473
4B	4B Cropland	CH_4	279.33	279.33	0.0050	0.9523
2D	2D Non Energy Products from Fuels and Solvent Use	CO_2	379.49	379.49	0.0042	0.9565
1B2	1B2 Oil & Natural Gas	CO_2	3221.84	3221.84	0.0040	0.9605
3G	3G Liming	CO_2	950.29	950.29	0.0039	0.9645
1A4	1A4 Petroleum Coke	CO_2	639.08	639.08	0.0032	0.9676
4B	4B Cropland	N_2O	398.47	398.47	0.0028	0.9704
1A3a	1A3a Aviation Fuel	CO_2	687.75	687.75	0.0027	0.9731
3J	3J OT & CD Agriculture	CH_4	193.22	193.22	0.0027	0.9758
2A	2A Mineral Industries	CO_2	5659.21	5659.21	0.0027	0.9785
4D	4D Wetland	CO_2	605.99	605.99	0.0024	0.9809
3H	3H Urea application to agriculture	CO_2	234.27	234.27	0.0023	0.9832
1B1	1B1 Coal Mining	CH_4	470.90	470.90	0.0019	0.9851
4A	4A Forest Land	CH_4	103.13	103.13	0.0017	0.9868
4C	4C Grassland	N_2O	184.75	184.75	0.0016	0.9885
3J	3J OT & CD Agriculture	N_2O	113.40	113.40	0.0016	0.9901
1A3d	1A3d Marine fuel	N_2O	62.81	62.81	0.0015	0.9915
5C	5C Waste Incineration	N_2O	26.37	26.37	0.0012	0.9927
1A3b	1A3b Gasoline/ LPG	N_2O	71.98	71.98	0.0011	0.9938
1A3b	1A3b Gasoline/ LPG	CH_4	60.90	60.90	0.0009	0.9947
2G	2G Other Product Manufacture and Use	PFCs	79.38	79.38	0.0007	0.9954
1B2	1B2 Oil & Natural Gas	N_2O	30.89	30.89	0.0006	0.9960
4D	4D Wetland	N_2O	24.81	24.81	0.0004	0.9965
2G	2G Other Product Manufacture and Use	SF_6	379.50	379.50	0.0004	0.9969
1B2	1B2 Other Energy Industries	CO_2	23.65	23.65	0.0003	0.9972
1B1	1B1 Solid Fuel Transformation	CO_2	197.11	197.11	0.0003	0.9975

IPCC Code	IPCC Category	Gas	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
2B	2B Chemical Industry	CH_4	67.21	67.21	0.0003	0.9978
1A3	1A3 Other diesel	N_2O	10.07	10.07	0.0003	0.9980
4E	4E Settlements	CH_4	30.19	30.19	0.0002	0.9983
2E	2E Electronics Industry	HFCs	24.42	24.42	0.0002	0.9985
2C	2C Iron & Steel	N_2O	7.12	7.12	0.0002	0.9986
1A3b	1A3b DERV	CH_4	6.29	6.29	0.0002	0.9988
1A3d	1A3d Marine fuel	CH_4	6.26	6.26	0.0002	0.9990
2B	2B Chemical industry	PFCs	76.13	76.13	0.0002	0.9991
1A3c	1A3c Coal	CO_2	36.22	36.22	0.0001	0.9993
1A3a	1A3a Aviation Fuel	N_2O	6.51	6.51	0.0001	0.9994
2B	2B Chemical industries	N_2O	51.08	51.08	0.0001	0.9995
2C	2C Iron & Steel Production	CH_4	10.93	10.93	0.0001	0.9996
5C	5C Waste Incineration	CH_4	7.39	7.39	0.0001	0.9997
1A3	1A3 Natural Gas	CO_2	56.98	56.98	0.0001	0.9997
2A	2A Mineral Industries	CH_4	2.62	2.62	0.0001	0.9998
2C	2C Metal Industries	SF_6	27.44	27.44	0.0000	0.9998
1B1	1B1 Solid Fuel Transformation	CH_4	3.80	3.80	0.0000	0.9999
1A3	1A3 Natural Gas	CH_4	1.35	1.35	0.0000	0.9999
1A4	1A4 Peat	CO_2	4.83	4.83	0.0000	0.9999
1A3c	1A3c Coal	CH_4	0.83	0.83	0.0000	1.0000
1A3	1A3 Other diesel	CH_4	0.66	0.66	0.0000	1.0000
2C	2C Metal Industries	PFCs	4.28	4.28	0.0000	1.0000
1A3a	1A3a Aviation Fuel	CH_4	0.42	0.42	0.0000	1.0000
2E	2E Electronics Industry	NF_3	0.36	0.36	0.0000	1.0000
2C	2C Metal Industries	HFCs	1.48	1.48	0.0000	1.0000
1A3c	1A3c Coal	N_2O	0.08	0.08	0.0000	1.0000
1A3	1A3 Natural Gas	N_2O	0.03	0.03	0.0000	1.0000
1B1	1B1 Fugitive Emissions from Solid Fuels	N_2O	0.02	0.02	0.0000	1.0000
4F	4F Other Land	CO_2	0.00	0.00	0.0000	1.0000
2D	2D Non-energy Products from Fuels and Solvent Use	CH_4	0.00	0.00	0.0000	1.0000
3F	3F Field Burning	N_2O	0.00	0.00	0.0000	1.0000
2B	2B Chemical industry	HFCs	0.00	0.00	0.0000	1.0000

IPCC Code	IPCC Category	Gas	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
2F	2F Product Uses as Substitutes for ODS	PFCs	0.00	0.00	0.0000	1.0000
Total			**409,523.61**	**453,396.39**	**1**	

Table A 1.4.3 Approach 2 Level Assessment for Base year (not including LULUCF) with Key Categories Shaded in Grey – UNFCCC scope

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
5A	5A Solid Waste Disposal	CH_4	60389.54	60389.54	0.3213	0.3213
1A	1A Coal	CO_2	225554.66	225554.66	0.0910	0.4123
1A	1A (Stationary) Oil	CO_2	94431.33	94431.33	0.0639	0.4761
1B2	1B2 Natural Gas Transmission	CH_4	10600.72	10600.72	0.0586	0.5347
1B1	1B1 Coal Mining	CH_4	21826.68	21826.68	0.0482	0.5830
5C	5C Waste Incineration	CO_2	1360.37	1360.37	0.0453	0.6282
3A	3A Enteric Fermentation	CH_4	24683.01	24683.01	0.0373	0.6655
3D	3D Agricultural Soils	N_2O	14552.30	14552.30	0.0347	0.7002
2B	2B Chemical industries	N_2O	23797.38	23797.38	0.0263	0.7266
1A	1A Natural Gas	CO_2	109602.22	109602.22	0.0243	0.7508
5D	5D Wastewater Handling	N_2O	893.23	893.23	0.0214	0.7722
2B	2B Chemical industry	HFCs	17670.77	17670.77	0.0194	0.7916
2C	2C Metal Industries	CO_2	25429.25	25429.25	0.0192	0.8108
1A3b	1A3b Gasoline/ LPG	CO_2	75562.66	75562.66	0.0185	0.8292
1B2	1B2 Upstream Oil & Gas	CH_4	1741.39	1741.39	0.0168	0.8461
1A1 & 1A2 & 1A4 & 1A5	1A1 & 1A2 & 1A4 & 1A5 Other Combustion	N_2O	2208.02	2208.02	0.0162	0.8622
1A3d	1A3d Marine fuel	CO_2	7611.13	7611.13	0.0151	0.8774
2B	2B Chemical industries	CO_2	6975.59	6975.59	0.0134	0.8908
5D	5D Wastewater Handling	CH_4	2284.15	2284.15	0.0124	0.9032
1A3b	1A3b Gasoline/ LPG	CH_4	1166.71	1166.71	0.0096	0.9128
2G	2G Other Product Manufacture and Use	N_2O	595.92	595.92	0.0093	0.9221
1A3b	1A3b Gasoline/ LPG	N_2O	996.92	996.92	0.0082	0.9303
1A3b	1A3b DERV	CO_2	33008.88	33008.88	0.0081	0.9384
1A1 & 1A2 & 1A4 & 1A5	1A1 & 1A2 & 1A4 & 1A5 Other Combustion	CH_4	1968.95	1968.95	0.0070	0.9454

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
3B	3B Manure Management	N_2O	3433.79	3433.79	0.0065	0.9519
3B	3B Manure Management	CH_4	4158.78	4158.78	0.0048	0.9567
1A3b	1A3b DERV	N_2O	316.64	316.64	0.0045	0.9613
1A3a	1A3a Aviation Fuel	CO_2	1869.71	1869.71	0.0041	0.9654
1B2	1B2 Oil & Natural Gas	CO_2	5088.52	5088.52	0.0035	0.9689
2D	2D Non Energy Products from Fuels and Solvent Use	CO_2	552.81	552.81	0.0034	0.9723
2A	2A Mineral Industries	CO_2	10133.32	10133.32	0.0027	0.9750
1A3	1A3 Other diesel	CO_2	1696.57	1696.57	0.0025	0.9775
3G	3G Liming	CO_2	1016.78	1016.78	0.0023	0.9799
3J	3J OT & CD Agriculture	CH_4	270.85	270.85	0.0021	0.9820
3H	3H Urea application to agriculture	CO_2	327.68	327.68	0.0018	0.9838
3J	3J OT & CD Agriculture	N_2O	178.70	178.70	0.0014	0.9852
1A3d	1A3d Marine fuel	N_2O	105.00	105.00	0.0014	0.9865
1A4	1A4 Peat	CO_2	372.48	372.48	0.0013	0.9878
5C	5C Waste Incineration	N_2O	50.93	50.93	0.0013	0.9891
1B1	1B1 Solid Fuel Transformation	CO_2	1698.56	1698.56	0.0013	0.9904
1A3b	1A3b DERV	CH_4	87.05	87.05	0.0012	0.9916
2F	2F Product Uses as Substitutes for ODS	HFCs	885.83	885.83	0.0012	0.9928
5C	5C Waste Incineration	CH_4	136.32	136.32	0.0008	0.9936
2G	2G Other Product Manufacture and Use	PFCs	141.67	141.67	0.0007	0.9943
2C	2C Metal Industries	PFCs	333.43	333.43	0.0007	0.9950
2G	2G Other Product Manufacture and Use	SF_6	858.16	858.16	0.0005	0.9956
3F	3F Field Burning	CH_4	187.03	187.03	0.0005	0.9961
1B2	1B2 Oil & Natural Gas	N_2O	44.69	44.69	0.0005	0.9966
2B	2B Chemical Industry	CH_4	221.63	221.63	0.0005	0.9971
1A	1A Other (waste)	CO_2	245.26	245.26	0.0004	0.9974
2A	2A Mineral Industries	CH_4	31.11	31.11	0.0003	0.9978
1A4	1A4 Petroleum Coke	CO_2	114.30	114.30	0.0003	0.9981
2C	2C Metal Industries	SF_6	387.17	387.17	0.0003	0.9984
2C	2C Iron & Steel	N_2O	20.73	20.73	0.0003	0.9987
1A3a	1A3a Aviation Fuel	N_2O	17.70	17.70	0.0002	0.9989
5B	5B Biological treatment of solid waste	CH_4	18.13	18.13	0.0002	0.9991
2C	2C Iron & Steel Production	CH_4	39.22	39.22	0.0002	0.9993

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	Absolute value of Base year emissions (Gg CO_2e)	Level Assessment	Cumulative Total
3F	3F Field Burning	N_2O	57.80	57.80	0.0002	0.9994
5B	5B Biological treatment of solid waste	N_2O	12.97	12.97	0.0001	0.9996
2B	2B Chemical industry	PFCs	113.90	113.90	0.0001	0.9997
1A3	1A3 Other diesel	N_2O	6.09	6.09	0.0001	0.9998
2E	2E Electronics Industry	HFCs	12.94	12.94	0.0001	0.9999
1A3d	1A3d Marine fuel	CH_4	3.66	3.66	0.0001	0.9999
1A3a	1A3a Aviation Fuel	CH_4	6.87	6.87	0.0000	1.0000
1A3	1A3 Other diesel	CH_4	2.75	2.75	0.0000	1.0000
2E	2E Electronics Industry	NF_3	0.27	0.27	0.0000	1.0000
2F	2F Product Uses as Substitutes for ODS	PFCs	0.44	0.44	0.0000	1.0000
1B1	1B1 Fugitive Emissions from Solid Fuels	N_2O	0.09	0.09	0.0000	1.0000
1B1	1B1 Solid Fuel Transformation	CH_4	0.18	0.18	0.0000	1.0000
1A3	1A3 Natural Gas	CO_2	0.00	0.00	0.0000	1.0000
1A3c	1A3c Coal	CO_2	0.00	0.00	0.0000	1.0000
1B2	1B2 Other Energy Industries	CO_2	0.00	0.00	0.0000	1.0000
1A3	1A3 Natural Gas	CH_4	0.00	0.00	0.0000	1.0000
1A3c	1A3c Coal	CH_4	0.00	0.00	0.0000	1.0000
2D	2D Non-energy Products from Fuels and Solvent Use	CH_4	0.00	0.00	0.0000	1.0000
2C	2C Metal Industries	HFCs	0.00	0.00	0.0000	1.0000
Total			**800,170.27**	**800,170.27**	**1**	

Table A 1.4.4 Approach 2 Level Assessment for the latest reported year (not including LULUCF) with Key Categories Shaded in Grey – UNFCCC scope

IPCC Code	IPCC Category	Gas	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
5A	5A Solid Waste Disposal	CH_4	12912.14	12912.14	0.1611	0.1611
1A	1A Natural Gas	CO_2	146528.67	146528.67	0.0760	0.2371
3A	3A Enteric Fermentation	CH_4	20937.60	20937.60	0.0742	0.3113
3D	3D Agricultural Soils	N_2O	11648.42	11648.42	0.0652	0.3765
1A	1A (Stationary) Oil	CO_2	39351.88	39351.88	0.0624	0.4389
5D	5D Wastewater Handling	N_2O	1016.77	1016.77	0.0570	0.4959
1B2	1B2 Natural Gas Transmission	CH_4	3337.33	3337.33	0.0432	0.5392

IPCC Code	IPCC Category	Gas	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
2F	2F Product Uses as Substitutes for ODS	HFCs	12182.92	12182.92	0.0375	0.5766
1A3b	1A3b DERV	CO_2	61012.20	61012.20	0.0352	0.6118
5B	5B Biological treatment of solid waste	CH_4	1216.79	1216.79	0.0326	0.6444
1A3b	1A3b DERV	N_2O	819.98	819.98	0.0275	0.6719
2G	2G Other Product Manufacture and Use	N_2O	752.65	752.65	0.0274	0.6994
1A	1A Other (waste)	CO_2	6706.96	6706.96	0.0243	0.7237
1A3d	1A3d Marine fuel	CO_2	4777.23	4777.23	0.0223	0.7460
5D	5D Wastewater Handling	CH_4	1711.17	1711.17	0.0219	0.7678
2B	2B Chemical industries	CO_2	4513.43	4513.43	0.0203	0.7881
1A1 & 1A2 & 1A4 & 1A5	1A1 & 1A2 & 1A4 & 1A5 Other Combustion	N_2O	1151.56	1151.56	0.0198	0.8079
1B2	1B2 Upstream Oil & Gas	CH_4	871.43	871.43	0.0197	0.8277
5C	5C Waste Incineration	CO_2	248.95	248.95	0.0194	0.8471
2C	2C Metal Industries	CO_2	10672.94	10672.94	0.0189	0.8660
5B	5B Biological treatment of solid waste	N_2O	715.01	715.01	0.0175	0.8834
1A3b	1A3b Gasoline/ LPG	CO_2	27660.36	27660.36	0.0159	0.8993
3B	3B Manure Management	N_2O	2813.54	2813.54	0.0126	0.9119
1A	1A Coal	CO_2	11183.18	11183.18	0.0106	0.9224
3B	3B Manure Management	CH_4	3812.01	3812.01	0.0103	0.9327
1A1 & 1A2 & 1A4 & 1A5	1A1 & 1A2 & 1A4 & 1A5 Other Combustion	CH_4	1128.74	1128.74	0.0095	0.9422
1A3	1A3 Other diesel	CO_2	2174.19	2174.19	0.0077	0.9498
2D	2D Non Energy Products from Fuels and Solvent Use	CO_2	379.49	379.49	0.0055	0.9554
1B2	1B2 Oil & Natural Gas	CO_2	3221.84	3221.84	0.0052	0.9606
3G	3G Liming	CO_2	950.29	950.29	0.0051	0.9657
1A4	1A4 Petroleum Coke	CO_2	639.08	639.08	0.0041	0.9698
1A3a	1A3a Aviation Fuel	CO_2	687.75	687.75	0.0036	0.9734
3J	3J OT & CD Agriculture	CH_4	193.22	193.22	0.0035	0.9769
2A	2A Mineral Industries	CO_2	5659.21	5659.21	0.0035	0.9804
3H	3H Urea application to agriculture	CO_2	234.27	234.27	0.0030	0.9834
1B1	1B1 Coal Mining	CH_4	470.90	470.90	0.0024	0.9859
3J	3J OT & CD Agriculture	N_2O	113.40	113.40	0.0021	0.9879
1A3d	1A3d Marine fuel	N_2O	62.81	62.81	0.0019	0.9898

IPCC Code	IPCC Category	Gas	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
5C	5C Waste Incineration	N_2O	26.37	26.37	0.0016	0.9914
1A3b	1A3b Gasoline/ LPG	N_2O	71.98	71.98	0.0014	0.9928
1A3b	1A3b Gasoline/ LPG	CH_4	60.90	60.90	0.0012	0.9939
2G	2G Other Product Manufacture and Use	PFCs	79.38	79.38	0.0010	0.9949
1B2	1B2 Oil & Natural Gas	N_2O	30.89	30.89	0.0008	0.9957
2G	2G Other Product Manufacture and Use	SF_6	379.50	379.50	0.0005	0.9963
1B2	1B2 Other Energy Industries	CO_2	23.65	23.65	0.0004	0.9967
1B1	1B1 Solid Fuel Transformation	CO_2	197.11	197.11	0.0003	0.9970
2B	2B Chemical Industry	CH_4	67.21	67.21	0.0003	0.9974
1A3	1A3 Other diesel	N_2O	10.07	10.07	0.0003	0.9977
2E	2E Electronics Industry	HFCs	24.42	24.42	0.0003	0.9980
2C	2C Iron & Steel	N_2O	7.12	7.12	0.0002	0.9982
1A3b	1A3b DERV	CH_4	6.29	6.29	0.0002	0.9984
1A3d	1A3d Marine fuel	CH_4	6.26	6.26	0.0002	0.9987
2B	2B Chemical industry	PFCs	76.13	76.13	0.0002	0.9988
1A3c	1A3c Coal	CO_2	36.22	36.22	0.0002	0.9990
1A3a	1A3a Aviation Fuel	N_2O	6.51	6.51	0.0002	0.9992
2B	2B Chemical industries	N_2O	51.08	51.08	0.0001	0.9994
2C	2C Iron & Steel Production	CH_4	10.93	10.93	0.0001	0.9995
5C	5C Waste Incineration	CH_4	7.39	7.39	0.0001	0.9996
1A3	1A3 Natural Gas	CO_2	56.98	56.98	0.0001	0.9997
2A	2A Mineral Industries	CH_4	2.62	2.62	0.0001	0.9997
2C	2C Metal Industries	SF_6	27.44	27.44	0.0001	0.9998
1B1	1B1 Solid Fuel Transformation	CH_4	3.80	3.80	0.0000	0.9998
1A3	1A3 Natural Gas	CH_4	1.35	1.35	0.0000	0.9999
1A4	1A4 Peat	CO_2	4.83	4.83	0.0000	0.9999
1A3c	1A3c Coal	CH_4	0.83	0.83	0.0000	0.9999
1A3	1A3 Other diesel	CH_4	0.66	0.66	0.0000	1.0000
2C	2C Metal Industries	PFCs	4.28	4.28	0.0000	1.0000
1A3a	1A3a Aviation Fuel	CH_4	0.42	0.42	0.0000	1.0000
2E	2E Electronics Industry	NF_3	0.36	0.36	0.0000	1.0000
2C	2C Metal Industries	HFCs	1.48	1.48	0.0000	1.0000
1A3c	1A3c Coal	N_2O	0.08	0.08	0.0000	1.0000

IPCC Code	IPCC Category	Gas	Latest reported year (LY) emissions (Gg CO_2e)	Absolute value of LY emissions (Gg CO_2e)	Level Assessment	Cumulative Total
1A3	1A3 Natural Gas	N_2O	0.03	0.03	0.0000	1.0000
1B1	1B1 Fugitive Emissions from Solid Fuels	N_2O	0.02	0.02	0.0000	1.0000
2D	2D Non-energy Products from Fuels and Solvent Use	CH_4	0.00	0.00	0.0000	1.0000
3F	3F Field Burning	N_2O	0.00	0.00	0.0000	1.0000
2B	2B Chemical industry	HFCs	0.00	0.00	0.0000	1.0000
2F	2F Product Uses as Substitutes for ODS	PFCs	0.00	0.00	0.0000	1.0000
Total			**405,754.88**	**405,754.88**	**1**	

Table A 1.4.5 Approach 2 Assessment for Trend (including LULUCF) with Key Categories Shaded in Grey – UNFCCC scope

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	LY emissions (Gg CO_2e)	Trend Assessment with Uncertainty	% Contribution to Trend Uncertainty	Cumulative Total
5A	5A Solid Waste Disposal	CH_4	60389.54	12912.14	0.0100	21.8%	0.2182
1A	1A Coal	CO_2	225554.66	11183.18	0.0044	9.7%	0.3149
1B1	1B1 Coal Mining	CH_4	21826.68	470.90	0.0025	5.4%	0.3694
1A	1A Natural Gas	CO_2	109602.22	146528.67	0.0022	4.7%	0.4168
2F	2F Product Uses as Substitutes for ODS	HFCs	885.83	12182.92	0.0017	3.6%	0.4529
5C	5C Waste Incineration	CO_2	1360.37	248.95	0.0016	3.4%	0.4869
4B	4B Cropland	CO_2	15947.46	14403.93	0.0015	3.3%	0.5198
5B	5B Biological treatment of solid waste	CH_4	18.13	1216.79	0.0015	3.2%	0.5521
5D	5D Wastewater Handling	N_2O	893.23	1016.77	0.0015	3.2%	0.5839
2B	2B Chemical industries	N_2O	23797.38	51.08	0.0014	3.1%	0.6148
3A	3A Enteric Fermentation	CH_4	24683.01	20937.60	0.0014	3.0%	0.6450
1B2	1B2 Natural Gas Transmission	CH_4	10600.72	3337.33	0.0012	2.6%	0.6709
1A3b	1A3b DERV	CO_2	33008.88	61012.20	0.0012	2.6%	0.6965
3D	3D Agricultural Soils	N_2O	14552.30	11648.42	0.0011	2.4%	0.7206
1A	1A Other (waste)	CO_2	245.26	6706.96	0.0011	2.4%	0.7445
2B	2B Chemical industry	HFCs	17670.77	0.00	0.0011	2.3%	0.7674
1A3b	1A3b DERV	N_2O	316.64	819.98	0.0010	2.2%	0.7895
5B	5B Biological treatment of solid waste	N_2O	12.97	715.01	0.0008	1.7%	0.8069

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	LY emissions (Gg CO_2e)	Trend Assessment with Uncertainty	% Contribution to Trend Uncertainty	Cumulative Total
2G	2G Other Product Manufacture and Use	N_2O	595.92	752.65	0.0008	1.6%	0.8234
4E	4E Settlements	CO_2	5427.63	4032.04	0.0007	1.5%	0.8384
1A	1A (Stationary) Oil	CO_2	94431.33	39351.88	0.0006	1.3%	0.8514
4C	4C Grassland	CH_4	2385.87	2420.90	0.0006	1.3%	0.8640
4A	4A Forest Land	CO_2	-13992.50	-17933.72	0.0005	1.2%	0.8756
1A3b	1A3b Gasoline/ LPG	CH_4	1166.71	60.90	0.0005	1.0%	0.8858
4C	4C Grassland	CO_2	114.65	-1873.95	0.0005	1.0%	0.8958
4D	4D Wetland	CH_4	1961.70	2043.62	0.0004	1.0%	0.9053
1A3b	1A3b Gasoline/ LPG	N_2O	996.92	71.98	0.0004	0.8%	0.9136
4A	4A Forest land	N_2O	752.90	712.25	0.0003	0.7%	0.9209
5D	5D Wastewater Handling	CH_4	2284.15	1711.17	0.0003	0.7%	0.9280
1A3b	1A3b Gasoline/ LPG	CO_2	75562.66	27660.36	0.0003	0.6%	0.9340
3B	3B Manure Management	N_2O	3433.79	2813.54	0.0002	0.5%	0.9388
1A3	1A3 Other diesel	CO_2	1696.57	2174.19	0.0002	0.5%	0.9435
3B	3B Manure Management	CH_4	4158.78	3812.01	0.0002	0.5%	0.9481
2B	2B Chemical industries	CO_2	6975.59	4513.43	0.0002	0.5%	0.9526
1A3d	1A3d Marine fuel	CO_2	7611.13	4777.23	0.0002	0.4%	0.9570
4G	4G Other Activities	CO_2	-2087.72	-2128.72	0.0002	0.4%	0.9609
2C	2C Metal Industries	CO_2	25429.25	10672.94	0.0002	0.4%	0.9646
1A4	1A4 Petroleum Coke	CO_2	114.30	639.08	0.0002	0.4%	0.9684
4B	4B Cropland	CH_4	291.94	279.33	0.0001	0.3%	0.9715
4E	4E Settlements	N_2O	441.11	293.94	0.0001	0.2%	0.9739
3G	3G Liming	CO_2	1016.78	950.29	0.0001	0.2%	0.9762
4D	4D Wetland	CO_2	571.12	605.99	0.0001	0.2%	0.9779
1A4	1A4 Peat	CO_2	372.48	4.83	0.0001	0.1%	0.9794
2D	2D Non Energy Products from Fuels and Solvent Use	CO_2	552.81	379.49	0.0001	0.1%	0.9808
1A3a	1A3a Aviation Fuel	CO_2	1869.71	687.75	0.0001	0.1%	0.9821
4A	4A Forest Land	CH_4	87.54	103.13	0.0001	0.1%	0.9834
1A3b	1A3b DERV	CH_4	87.05	6.29	0.0001	0.1%	0.9847
1B1	1B1 Solid Fuel Transformation	CO_2	1698.56	197.11	0.0001	0.1%	0.9859

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	LY emissions (Gg CO_2e)	Trend Assessment with Uncertainty	% Contribution to Trend Uncertainty	Cumulative Total
1A1 & 1A2 & 1A4 & 1A5	1A1 & 1A2 & 1A4 & 1A5 Other Combustion	CH_4	1968.95	1128.74	0.0001	0.1%	0.9870
1B2	1B2 Oil & Natural Gas	CO_2	5088.52	3221.84	0.0000	0.1%	0.9881
3J	3J OT & CD Agriculture	CH_4	270.85	193.22	0.0000	0.1%	0.9891
4C	4C Grassland	N_2O	202.42	184.75	0.0000	0.1%	0.9901
3H	3H Urea application to agriculture	CO_2	327.68	234.27	0.0000	0.1%	0.9910
2C	2C Metal Industries	PFCs	333.43	4.28	0.0000	0.1%	0.9918
5C	5C Waste Incineration	CH_4	136.32	7.39	0.0000	0.1%	0.9926
4	4 Indirect LULUCF Emissions	N_2O	305.49	171.77	0.0000	0.1%	0.9934
1A1 & 1A2 & 1A4 & 1A5	1A1 & 1A2 & 1A4 & 1A5 Other Combustion	N_2O	2208.02	1151.56	0.0000	0.1%	0.9941
3F	3F Field Burning	CH_4	187.03	0.00	0.0000	0.1%	0.9947
1B2	1B2 Other Energy Industries	CO_2	0.00	23.65	0.0000	0.0%	0.9951
3J	3J OT & CD Agriculture	N_2O	178.70	113.40	0.0000	0.0%	0.9955
2A	2A Mineral Industries	CO_2	10133.32	5659.21	0.0000	0.0%	0.9959
2A	2A Mineral Industries	CH_4	31.11	2.62	0.0000	0.0%	0.9962
4D	4D Wetland	N_2O	21.29	24.81	0.0000	0.0%	0.9965
2C	2C Metal Industries	SF_6	387.17	27.44	0.0000	0.0%	0.9968
1A3d	1A3d Marine fuel	N_2O	105.00	62.81	0.0000	0.0%	0.9971
4B	4B Cropland	N_2O	734.60	398.47	0.0000	0.0%	0.9974
1A3	1A3 Other diesel	N_2O	6.09	10.07	0.0000	0.0%	0.9976
2B	2B Chemical Industry	CH_4	221.63	67.21	0.0000	0.0%	0.9979
4E	4E Settlements	CH_4	16.31	30.19	0.0000	0.0%	0.9981
2E	2E Electronics Industry	HFCs	12.94	24.42	0.0000	0.0%	0.9983
1B2	1B2 Oil & Natural Gas	N_2O	44.69	30.89	0.0000	0.0%	0.9985
1A3c	1A3c Coal	CO_2	0.00	36.22	0.0000	0.0%	0.9987
3F	3F Field Burning	N_2O	57.80	0.00	0.0000	0.0%	0.9989
1A3d	1A3d Marine fuel	CH_4	3.66	6.26	0.0000	0.0%	0.9991
1B2	1B2 Upstream Oil & Gas	CH_4	1741.39	871.43	0.0000	0.0%	0.9992
2C	2C Iron & Steel	N_2O	20.73	7.12	0.0000	0.0%	0.9993
2C	2C Iron & Steel Production	CH_4	39.22	10.93	0.0000	0.0%	0.9994

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	LY emissions (Gg CO_2e)	Trend Assessment with Uncertainty	% Contribution to Trend Uncertainty	Cumulative Total
2G	2G Other Product Manufacture and Use	PFCs	141.67	79.38	0.0000	0.0%	0.9995
1A3	1A3 Natural Gas	CO_2	0.00	56.98	0.0000	0.0%	0.9996
2G	2G Other Product Manufacture and Use	SF_6	858.16	379.50	0.0000	0.0%	0.9996
1A3a	1A3a Aviation Fuel	N_2O	17.70	6.51	0.0000	0.0%	0.9997
1A3a	1A3a Aviation Fuel	CH_4	6.87	0.42	0.0000	0.0%	0.9998
2B	2B Chemical industry	PFCs	113.90	76.13	0.0000	0.0%	0.9998
1B1	1B1 Solid Fuel Transformation	CH_4	0.18	3.80	0.0000	0.0%	0.9999
1A3	1A3 Natural Gas	CH_4	0.00	1.35	0.0000	0.0%	0.9999
5C	5C Waste Incineration	N_2O	50.93	26.37	0.0000	0.0%	0.9999
1A3	1A3 Other diesel	CH_4	2.75	0.66	0.0000	0.0%	1.0000
1A3c	1A3c Coal	CH_4	0.00	0.83	0.0000	0.0%	1.0000
2C	2C Metal Industries	HFCs	0.00	1.48	0.0000	0.0%	1.0000
2E	2E Electronics Industry	NF_3	0.27	0.36	0.0000	0.0%	1.0000
1A3c	1A3c Coal	N_2O	0.00	0.08	0.0000	0.0%	1.0000
2F	2F Product Uses as Substitutes for ODS	PFCs	0.44	0.00	0.0000	0.0%	1.0000
1A3	1A3 Natural Gas	N_2O	0.00	0.03	0.0000	0.0%	1.0000
1B1	1B1 Fugitive Emissions from Solid Fuels	N_2O	0.09	0.02	0.0000	0.0%	1.0000
4F	4F Other Land	CO_2	0.00	0.00	0.0000	0.0%	1.0000
2D	2D Non-energy Products from Fuels and Solvent Use	CH_4	0.00	0.00	0.0000	0.0%	1.0000
2D	2D Non-energy Products from Fuels and Solvent Use	N_2O	0.00	0.00	0.0000	0.0%	1.0000
Total			**813,352.09**	**409,523.61**		**1**	

Table A 1.4.6 Approach 2 Assessment for Trend (not including LULUCF) with Key Categories Shaded in Grey – UNFCCC scope

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	LY emissions (Gg CO_2e)	Trend Assessment with Uncertainty	% Contribution to Trend Uncertainty	Cumulative Total
5A	5A Solid Waste Disposal	CH_4	60389.54	12912.14	0.0100	24.6%	0.2462
1A	1A Coal	CO_2	225554.66	11183.18	0.0044	10.9%	0.3554
1B1	1B1 Coal Mining	CH_4	21826.68	470.90	0.0025	6.1%	0.4169
1A	1A Natural Gas	CO_2	109602.22	146528.67	0.0022	5.3%	0.4703

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	LY emissions (Gg CO_2e)	Trend Assessment with Uncertainty	% Contribution to Trend Uncertainty	Cumulative Total
2F	2F Product Uses as Substitutes for ODS	HFCs	885.83	12182.92	0.0017	4.1%	0.5110
5C	5C Waste Incineration	CO_2	1360.37	248.95	0.0016	3.8%	0.5494
5B	5B Biological treatment of solid waste	CH_4	18.13	1216.79	0.0015	3.7%	0.5859
5D	5D Wastewater Handling	N_2O	893.23	1016.77	0.0015	3.6%	0.6218
2B	2B Chemical industries	N_2O	23797.38	51.08	0.0014	3.5%	0.6567
3A	3A Enteric Fermentation	CH_4	24683.01	20937.60	0.0014	3.4%	0.6907
1B2	1B2 Natural Gas Transmission	CH_4	10600.72	3337.33	0.0012	2.9%	0.7199
1A3b	1A3b DERV	CO_2	33008.88	61012.20	0.0012	2.9%	0.7488
3D	3D Agricultural Soils	N_2O	14552.30	11648.42	0.0011	2.7%	0.7761
1A	1A Other (waste)	CO_2	245.26	6706.96	0.0011	2.7%	0.8030
2B	2B Chemical industry	HFCs	17670.77	0.00	0.0011	2.6%	0.8288
1A3b	1A3b DERV	N_2O	316.64	819.98	0.0010	2.5%	0.8538
5B	5B Biological treatment of solid waste	N_2O	12.97	715.01	0.0008	2.0%	0.8734
2G	2G Other Product Manufacture and Use	N_2O	595.92	752.65	0.0008	1.9%	0.8920
1A	1A (Stationary) Oil	CO_2	94431.33	39351.88	0.0006	1.5%	0.9066
1A3b	1A3b Gasoline/ LPG	CH_4	1166.71	60.90	0.0005	1.1%	0.9181
1A3b	1A3b Gasoline/ LPG	N_2O	996.92	71.98	0.0004	0.9%	0.9274
5D	5D Wastewater Handling	CH_4	2284.15	1711.17	0.0003	0.8%	0.9355
1A3b	1A3b Gasoline/ LPG	CO_2	75562.66	27660.36	0.0003	0.7%	0.9422
3B	3B Manure Management	N_2O	3433.79	2813.54	0.0002	0.5%	0.9477
1A3	1A3 Other diesel	CO_2	1696.57	2174.19	0.0002	0.5%	0.9529
3B	3B Manure Management	CH_4	4158.78	3812.01	0.0002	0.5%	0.9582
2B	2B Chemical industries	CO_2	6975.59	4513.43	0.0002	0.5%	0.9632
1A3d	1A3d Marine fuel	CO_2	7611.13	4777.23	0.0002	0.5%	0.9682
2C	2C Metal Industries	CO_2	25429.25	10672.94	0.0002	0.4%	0.9725
1A4	1A4 Petroleum Coke	CO_2	114.30	639.08	0.0002	0.4%	0.9767
3G	3G Liming	CO_2	1016.78	950.29	0.0001	0.3%	0.9794
1A4	1A4 Peat	CO_2	372.48	4.83	0.0001	0.2%	0.9810
2D	2D Non Energy Products from Fuels and Solvent Use	CO_2	552.81	379.49	0.0001	0.2%	0.9827
1A3a	1A3a Aviation Fuel	CO_2	1869.71	687.75	0.0001	0.1%	0.9842

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	LY emissions (Gg CO_2e)	Trend Assessment with Uncertainty	% Contribution to Trend Uncertainty	Cumulative Total
1A3b	1A3b DERV	CH_4	87.05	6.29	0.0001	0.1%	0.9856
1B1	1B1 Solid Fuel Transformation	CO_2	1698.56	197.11	0.0001	0.1%	0.9869
1A1 & 1A2 & 1A4 & 1A5	1A1 & 1A2 & 1A4 & 1A5 Other Combustion	CH_4	1968.95	1128.74	0.0001	0.1%	0.9882
1B2	1B2 Oil & Natural Gas	CO_2	5088.52	3221.84	0.0000	0.1%	0.9894
3J	3J OT & CD Agriculture	CH_4	270.85	193.22	0.0000	0.1%	0.9906
3H	3H Urea application to agriculture	CO_2	327.68	234.27	0.0000	0.1%	0.9916
2C	2C Metal Industries	PFCs	333.43	4.28	0.0000	0.1%	0.9925
5C	5C Waste Incineration	CH_4	136.32	7.39	0.0000	0.1%	0.9934
1A1 & 1A2 & 1A4 & 1A5	1A1 & 1A2 & 1A4 & 1A5 Other Combustion	N_2O	2208.02	1151.56	0.0000	0.1%	0.9942
3F	3F Field Burning	CH_4	187.03	0.00	0.0000	0.1%	0.9949
1B2	1B2 Other Energy Industries	CO_2	0.00	23.65	0.0000	0.0%	0.9954
3J	3J OT & CD Agriculture	N_2O	178.70	113.40	0.0000	0.0%	0.9959
2A	2A Mineral Industries	CO_2	10133.32	5659.21	0.0000	0.0%	0.9963
2A	2A Mineral Industries	CH_4	31.11	2.62	0.0000	0.0%	0.9966
2C	2C Metal Industries	SF_6	387.17	27.44	0.0000	0.0%	0.9970
1A3d	1A3d Marine fuel	N_2O	105.00	62.81	0.0000	0.0%	0.9973
1A3	1A3 Other diesel	N_2O	6.09	10.07	0.0000	0.0%	0.9976
2B	2B Chemical Industry	CH_4	221.63	67.21	0.0000	0.0%	0.9979
2E	2E Electronics Industry	HFCs	12.94	24.42	0.0000	0.0%	0.9981
1B2	1B2 Oil & Natural Gas	N_2O	44.69	30.89	0.0000	0.0%	0.9983
1A3c	1A3c Coal	CO_2	0.00	36.22	0.0000	0.0%	0.9986
3F	3F Field Burning	N_2O	57.80	0.00	0.0000	0.0%	0.9988
1A3d	1A3d Marine fuel	CH_4	3.66	6.26	0.0000	0.0%	0.9989
1B2	1B2 Upstream Oil & Gas	CH_4	1741.39	871.43	0.0000	0.0%	0.9991
2C	2C Iron & Steel	N_2O	20.73	7.12	0.0000	0.0%	0.9992
2C	2C Iron & Steel Production	CH_4	39.22	10.93	0.0000	0.0%	0.9993
2G	2G Other Product Manufacture and Use	PFCs	141.67	79.38	0.0000	0.0%	0.9994
1A3	1A3 Natural Gas	CO_2	0.00	56.98	0.0000	0.0%	0.9995
2G	2G Other Product Manufacture and Use	SF_6	858.16	379.50	0.0000	0.0%	0.9996

IPCC Code	IPCC Category	Gas	Base year emissions (Gg CO_2e)	LY emissions (Gg CO_2e)	Trend Assessment with Uncertainty	% Contribution to Trend Uncertainty	Cumulative Total
1A3a	1A3a Aviation Fuel	N_2O	17.70	6.51	0.0000	0.0%	0.9997
1A3a	1A3a Aviation Fuel	CH_4	6.87	0.42	0.0000	0.0%	0.9997
2B	2B Chemical industry	PFCs	113.90	76.13	0.0000	0.0%	0.9998
1B1	1B1 Solid Fuel Transformation	CH_4	0.18	3.80	0.0000	0.0%	0.9998
1A3	1A3 Natural Gas	CH_4	0.00	1.35	0.0000	0.0%	0.9999
5C	5C Waste Incineration	N_2O	50.93	26.37	0.0000	0.0%	0.9999
1A3	1A3 Other diesel	CH_4	2.75	0.66	0.0000	0.0%	1.0000
1A3c	1A3c Coal	CH_4	0.00	0.83	0.0000	0.0%	1.0000
2C	2C Metal Industries	HFCs	0.00	1.48	0.0000	0.0%	1.0000
2E	2E Electronics Industry	NF_3	0.27	0.36	0.0000	0.0%	1.0000
1A3c	1A3c Coal	N_2O	0.00	0.08	0.0000	0.0%	1.0000
2F	2F Product Uses as Substitutes for ODS	PFCs	0.44	0.00	0.0000	0.0%	1.0000
1A3	1A3 Natural Gas	N_2O	0.00	0.03	0.0000	0.0%	1.0000
1B1	1B1 Fugitive Emissions from Solid Fuels	N_2O	0.09	0.02	0.0000	0.0%	1.0000
4F	4F Other Land	CO_2	0.00	0.00	0.0000	0.0%	1.0000
2D	2D Non-energy Products from Fuels and Solvent Use	CH_4	0.00	0.00	0.0000	0.0%	1.0000
2D	2D Non-energy Products from Fuels and Solvent Use	N_2O	0.00	0.00	0.0000	0.0%	1.0000
Total			**813,352.09**	**409,523.61**		**1**	

A 1.5 KEY CATEGORY ANALYSIS (KCA) RANKING SYSTEM

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 it's score would be 4+3+5=12. The categories are then ranked from lowest score to highest, with scores that are equal resolved by the most recent year level assessment.

The assessments used in this ranking exercise are only those *including* LULUCF, because if the additional *excluding* LULUCF assessments were also used, the LULUCF sectors would only be included in half of the assessments and would therefore give an unrepresentative weighting.

The results of this ranking are presented in **Table A 1.5.1.**

Table A 1.5.1 KCA 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	4	1A1	Energy industries: solid fuels	CO_2
4	3	5A	Solid waste disposal	CH_4
5	5	1A2	Manufacturing industries and construction: gaseous fuels	CO_2
6	6	1A1	Energy industries: gaseous fuels	CO_2
7	7	1A1	Energy industries: liquid fuels	CO_2
8	8	3A1	Enteric fermentation from Cattle	CH_4
9	9	4B	Cropland	CO_2
10	10	1A2	Manufacturing industries and construction: liquid fuels	CO_2
11	11	1A4	Other sectors: liquid fuels	CO_2
12	12	4A	Forest land	CO_2
13	13	3D	Agricultural soils	N_2O
14	14	1A2	Manufacturing industries and construction: solid fuels	CO_2
15	15	2C1	Iron and steel production	CO_2
16	16	1A4	Other sectors: solid fuels	CO_2
17	17	1B2	Oil and gas extraction	CH_4
18	18	1B1	Coal mining and handling	CH_4
19	19	3A2	Enteric fermentation from Sheep	CH_4
20	20	4E	Settlements	CO_2
21	21	1A3d	Domestic Navigation: liquid fuels	CO_2
22	22	3B1	Manure management from Cattle	CH_4
23	23	3B2	Manure management from Sheep	N_2O
24	24	1A5	Other: liquid fuels	CO_2
25	25	4C	Grassland	CH_4
26	26	1B2	Oil and gas extraction	CO_2
27	27	2F1	Refrigeration and air conditioning	HFCs, PFCs, SF_6 and NF_3
28	28	4G	Harvested wood products	CO_2
29	29	4D	Wetlands	CH_4
30	30	1A1	Energy industries: other fuels	CO_2
31	31	2A1	Cement production	CO_2
32	32	2B1	Ammonia production	CO_2
33	33	5D	Wastewater treatment and discharge	CH_4
34	35	2B9	Fluorochemical production	HFCs, PFCs, SF_6 and NF_3

KCA rank (KCs only) - UNFCCC	KCA rank (KCs only) – KP	IPCC Code	IPCC Category	Greenhouse Gas
35	34	2B8	Petrochemical and carbon black production	CO_2
36	36	4C	Grassland	CO_2
37	37	2B2	Nitric acid production	N_2O
38	38	2B3	Adipic acid production	N_2O
39	39	5B	Biological treatment of solid waste	CH_4

A 1.6 APPROACH USED TO IDENTIFY KP-LULUCF KEY CATEGORIES

The NIR contains a list of the Key Categories for Land Use, Land-Use Change and Forestry Activities under the Kyoto Protocol. The description below explains the Key Category analysis for Article 3.3 activities and any elected activities under Article 3.4.

Seven 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), Article 3.4 Grazing Land Management (CO_2), Article 3.4 Grazing Land Management (CH_4) and Article 3.4 Wetland Drainage and Rewetting (CH_4). 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 Approach 1 for the latest reported year based on level of emissions (including LULUCF). The key category analysis for the latest reported year based on level of emissions (including LULUCF) is given in **Section 11.6.1** of the main NIR.

A 1.7 USING THE UNCERTAINTY ANALYSIS TO PLAN IMPROVEMENTS IN THE PREPARATION OF THE INVENTORY

The key category analysis is used to prioritise and plan improvements. The approach the UK takes to achieve this is described in **Section 1.2.2.5**. **Table 1.7** to **Table 1.11** in **Chapter 1** show the key category summary tables.

A 1.8 TABLE NIR 3, AS CONTAINED IN THE ANNEX TO DECISION 6/CMP.3

Table A 1.8.1 below is Table NIR 3, containing a summary overview for Key Categories for Land Use, Land-Use Change and Forestry Activities under the Kyoto Protocol[3].

Table A 1.8.1 Table NIR 3. Summary overview for Key Categories for Land Use, Land-Use Change and Forestry Activities under the Kyoto Protocol

KEY CATEGORIES OF EMISSIONS AND REMOVALS	GAS	Associated category in UNFCCC inventory (1) is key (indicate which category)	Category contribution is greater than the smallest category considered key in the UNFCCC inventory (1), (4) (including LULUCF)	Other Key Category Identification (2)	COMMENTS (3)
Specify key categories according to the national level of disaggregation used (1)					
Afforestation and Reforestation	CO_2	Land converted to forest land	Yes	Associated UNFCCC category (4A) is key	The associated UNFCCC inventory category is a key category for level and trend. The AR component is larger than the smallest UNFCCC key category in the latest inventory year.
Deforestation	CO_2	Land converted to cropland, Land converted to grassland, Land converted to wetland, Land converted to settlements	Yes	Associated UNFCCC categories (4B, 4C and 4E) are key.	The associated UNFCCC inventory categories are key categories for level and trend. The Deforestation category contribution is larger than the smallest UNFCCC key category in the latest inventory year.

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[3] Table NIR 3 can be found in FCCC/KP/CMP/2007/9/Add.2.

KEY CATEGORIES OF EMISSIONS AND REMOVALS	GAS	Associated category in UNFCCC inventory (1) is key (indicate which category)	Category contribution is greater than the smallest category considered key in the UNFCCC inventory (1), (4) (including LULUCF)	Other Key Category Identification (2)	COMMENTS (3)
Forest Management	CO_2	Forest land remaining forest land, Land converted to forest land	Yes	Associated UNFCCC category (4A) is key	The associated UNFCCC inventory category is a key category for level and trend and the Forest Management category contribution is greater than the smallest UNFCCC key category.
Cropland Management	CO_2	Cropland remaining Cropland, Land converted to Cropland	Yes	Associated UNFCCC category (4B) is key.	The associated UNFCCC inventory category is a key category for level and trend and the Cropland Management category contribution is greater than the smallest UNFCCC key category.
Grazing Land Management	CO_2	Grassland remaining Grassland, Land converted to Grassland	No	Associated UNFCCC category (4C) is key.	The associated UNFCCC inventory category is a key category for level and trend in the latest inventory year.
Grazing Land Management	CH_4	Grassland remaining Grassland, Land converted to Grassland	Yes	Associated UNFCCC category (4C) is key.	The associated UNFCCC inventory category is a key category for level and trend and the Grazing Land Management category contribution is greater than the smallest UNFCCC key category.
Wetland Drainage and Rewetting	CH_4	Wetland remaining Wetland	No	Associated UNFCCC category (4D) is key	The associated UNFCCC inventory category is a key category for level and trend.

(1) See section 5.4 of the IPCC good practice guidance for LULUCF

(2) This should include qualitative consideration as per Section 5.4.3 of the IPCC Good Practice Guidance for LULUCF or any other criteria

(3) Describe the criteria identifying the category as key

(4) If the emissions or removals of the category exceed the emissions of the smallest category identified as key in the UNFCCC inventory (including LULUCF), Parties should indicate YES. If not, Parties should indicate NO

ANNEX 2: Assessment of Uncertainty

Uncertainty estimates are calculated using two methods: Approach 1 (error propagation) and Approach 2 (Monte Carlo simulation). These are not to be confused with Approaches 1 and 2 for Key Category Analysis, of which Approach 2 KCA uses Approach 1 uncertainties to account for uncertainty in determining Key Categories. The uncertainty assessment estimates uncertainties according to IPCC sector in addition to presenting estimates by direct greenhouse gas. Estimated uncertainty presented for the sector breakdown used in UK Official Statistics are not reported here, since the categories are not consistent with the requirements of the UK's commitments under the UNFCCC and Kyoto Protocol.

Uncertainty parameters for new sources and sources which have been significantly revised are reviewed each year, particularly for sources which have a significant impact on overall uncertainties. The overall method used to estimate uncertainties is described below, and the work to improve the accuracy of the uncertainty analysis continues. The key category analysis used data from the uncertainty analysis, and the results of the key category analysis are given in **ANNEX 1:**.

A 2.1 ESTIMATION OF UNCERTAINTIES USING AN ERROR PROPAGATION APPROACH (APPROACH 1)

The IPCC 2006 Guidelines defines error propagation and Monte Carlo modelling approaches to estimating uncertainties in national greenhouse gas inventories. The results of the error propagation approach are shown in **Table A 2.1.1**. The uncertainties used in the error propagation approach are not exactly the same as those used in the Monte Carlo Simulation since the error propagation source categorisation is less detailed and has a more simplistic approach to uncertainties. The Approach 1 uncertainties assumes all parameters are normally distributed (which means it doesn't account for the skew, kurtosis or any other non-normal features of the expected distributions), and does not account for variations in uncertainty in the time series unlike the Monte Carlo approach which takes into account these factors. The parameters used for the Approach 1 uncertainties for both the base year and the most recent year are the values given for the most recent year in **Table A 2.3.1** to **Table A 2.3.4.**

In the 2021 submission there was an error in the model used to transpose agriculture sector uncertainties into the UK GHGI Approach 1 uncertainty analysis. The model has been improved, within-model documentation added to minimise the risk of such errors recurring, and Approach 1 uncertainty parameters in **Table A 2.1.1** have been updated for 3B1 (CH_4, N_2O) and 3D (N_2O).

A 2.1.1 Key Categories

Certain source categories are particularly significant in terms of their contribution to the overall uncertainty of the inventory. Key source categories in this respect are identified using Approach 1 uncertainties in the Approach 2 KCA. These have been identified so that the resources available for inventory preparation may be prioritised, and the best possible estimates prepared for the most significant source categories. We have used the method described in Section 4.3.2 of the 2006 IPCC Guidelines Volume 1 General Guidance and Reporting (Approach 2 to identify key categories). The results of this key category analysis can be found in **ANNEX 1:.**

A 2.1.2 Tables of uncertainty estimates from the error propagation approach

Table A 2.1.1 Summary of error propagation uncertainty estimates including LULUCF, base year to the latest reported year[4]

IPCC Category	Gas	Base year emissions (Gg CO_2e)	2020 emissions (Gg CO_2e)	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined uncertainty (%)	Contribution to variance by Category in 2020	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
1A (Stationary) Oil	CO_2	94,431.33	39,351.88	5.76%	2.17%	6.1%	0.0000	1.006%	4.838%	0.0218%	0.3938%	0.0016%
1A Coal	CO_2	225,554.66	11,183.18	1.75%	3.22%	3.7%	0.0000	12.553%	1.375%	0.4043%	0.0341%	0.0016%
1A Natural Gas	CO_2	109,602.22	146,528.67	1.06%	1.71%	2.0%	0.0001	11.215%	18.015%	0.1915%	0.2711%	0.0011%
1A Other (waste)	CO_2	245.26	6,706.96	1.02%	14.01%	14.0%	0.0000	0.809%	0.825%	0.1134%	0.0119%	0.0001%
1A3 Other diesel	CO_2	1,696.57	2,174.19	13.53%	1.87%	13.7%	0.0000	0.162%	0.267%	0.0030%	0.0511%	0.0000%
1A3 Natural Gas	CO_2	-	56.98	5.00%	2.00%	5.4%	0.0000	0.007%	0.007%	0.0001%	0.0005%	0.0000%
1A3a Aviation Fuel	CO_2	1,869.71	687.75	19.83%	3.27%	20.1%	0.0000	0.031%	0.085%	0.0010%	0.0237%	0.0000%
1A3b DERV	CO_2	33,008.88	61,012.20	1.00%	2.00%	2.2%	0.0000	5.456%	7.501%	0.1091%	0.1061%	0.0002%
1A3b Gasoline/ LPG	CO_2	75,562.66	27,660.36	0.99%	1.99%	2.2%	0.0000	1.276%	3.401%	0.0254%	0.0478%	0.0000%

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[4] Data by source presented are for UNFCCC geographical coverage unless stated otherwise. Values for EU and KP geographical coverages are similar

IPCC Category	Gas	Base year emissions (Gg CO_2e)	2020 emissions (Gg CO_2e)	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined uncertainty (%)	Contribution to variance by Category in 2020	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
1A3c Coal	CO_2	-	36.22	20.00%	6.00%	20.9%	0.0000	0.004%	0.004%	0.0003%	0.0013%	0.0000%
1A3d Marine fuel	CO_2	7,611.13	4,777.23	18.01%	1.80%	18.1%	0.0000	0.116%	0.587%	0.0021%	0.1496%	0.0002%
1A4 Peat	CO_2	372.48	4.83	30.00%	10.00%	31.6%	0.0000	0.022%	0.001%	0.0022%	0.0003%	0.0000%
1A4 Petroleum Coke	CO_2	114.30	639.08	20.00%	15.00%	25.0%	0.0000	0.071%	0.079%	0.0107%	0.0222%	0.0000%
1B1 Solid Fuel Transformation	CO_2	1,698.56	197.11	5.01%	4.69%	6.9%	0.0000	0.081%	0.024%	0.0038%	0.0017%	0.0000%
1B2 Oil & Natural Gas	CO_2	5,088.52	3,221.84	4.35%	4.53%	6.3%	0.0000	0.081%	0.396%	0.0037%	0.0244%	0.0000%
1B2 Other Energy Industries	CO_2	-	23.65	50.00%	50.00%	70.7%	0.0000	0.003%	0.003%	0.0015%	0.0021%	0.0000%
2A Mineral Industries	CO_2	10,133.32	5,659.21	0.71%	2.28%	2.4%	0.0000	0.068%	0.696%	0.0016%	0.0069%	0.0000%
2B Chemical industries	CO_2	6,975.59	4,513.43	17.20%	2.92%	17.5%	0.0000	0.123%	0.555%	0.0036%	0.1350%	0.0002%
2C Metal Industries	CO_2	25,429.25	10,672.94	1.35%	6.72%	6.9%	0.0000	0.262%	1.312%	0.0176%	0.0251%	0.0000%

IPCC Category	Gas	Base year emissions (Gg CO_2e)	2020 emissions (Gg CO_2e)	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined uncertainty (%)	Contribution to variance by Category in 2020	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
2D Non Energy Products from Fuels and Solvent Use	CO_2	552.81	379.49	40.05%	39.72%	56.4%	0.0000	0.012%	0.047%	0.0049%	0.0264%	0.0000%
3G Liming	CO_2	1,016.78	950.29	0.00%	20.90%	20.9%	0.0000	0.054%	0.117%	0.0113%	0.0000%	0.0000%
3H Urea application to agriculture	CO_2	327.68	234.27	0.00%	50.00%	50.0%	0.0000	0.009%	0.029%	0.0043%	0.0000%	0.0000%
4A Forest Land	CO_2	-13,992.50	-17,933.72	1.00%	15.00%	15.0%	0.0000	1.339%	2.205%	0.2008%	0.0312%	0.0004%
4B Cropland	CO_2	15,947.46	14,403.93	1.00%	20.00%	20.0%	0.0000	0.784%	1.771%	0.1567%	0.0250%	0.0003%
4C Grassland	CO_2	114.65	-1,873.95	1.00%	20.00%	20.0%	0.0000	0.237%	0.230%	0.0475%	0.0033%	0.0000%
4D Wetland	CO_2	571.12	605.99	1.00%	20.00%	20.0%	0.0000	0.039%	0.075%	0.0078%	0.0011%	0.0000%
4E Settlements	CO_2	5,427.63	4,032.04	1.00%	45.00%	45.0%	0.0000	0.160%	0.496%	0.0719%	0.0070%	0.0001%
4F Other Land	CO_2	-	-	0.00%	0.00%	0.0%	-	0.000%	0.000%	0.0000%	0.0000%	0.0000%
4G Other Activities	CO_2	-2,087.72	-2,128.72	1.00%	15.00%	15.0%	0.0000	0.132%	0.262%	0.0199%	0.0037%	0.0000%
5C Waste Incineration	CO_2	1,360.37	248.95	300.00%	40.00%	302.7%	0.0000	0.054%	0.031%	0.0214%	0.1299%	0.0002%

IPCC Category	Gas	Base year emissions (Gg CO2e)	2020 emissions (Gg CO2e)	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined uncertainty (%)	Contribution to variance by Category in 2020	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
1A1 & 1A2 & 1A4 & 1A5 Other Combustion	CH_4	1,968.95	1,128.74	0.65%	32.49%	32.5%	0.0000	0.017%	0.139%	0.0055%	0.0013%	0.0000%
1A3 Other diesel	CH_4	2.75	0.66	15.00%	130.00%	130.9%	0.0000	0.000%	0.000%	0.0001%	0.0000%	0.0000%
1A3 Natural Gas	CH_4	-	1.35	5.00%	130.00%	130.1%	0.0000	0.000%	0.000%	0.0002%	0.0000%	0.0000%
1A3a Aviation Fuel	CH_4	6.87	0.42	15.50%	60.85%	62.8%	0.0000	0.000%	0.000%	0.0002%	0.0000%	0.0000%
1A3b DERV	CH_4	87.05	6.29	1.00%	130.00%	130.0%	0.0000	0.005%	0.001%	0.0060%	0.0000%	0.0000%
1A3b Gasoline/ LPG	CH_4	1,166.71	60.90	1.00%	74.93%	74.9%	0.0000	0.065%	0.007%	0.0485%	0.0001%	0.0000%
1A3c Coal	CH_4	-	0.83	20.00%	110.00%	111.8%	0.0000	0.000%	0.000%	0.0001%	0.0000%	0.0000%
1A3d Marine fuel	CH_4	3.66	6.26	19.36%	125.81%	127.3%	0.0000	0.001%	0.001%	0.0007%	0.0002%	0.0000%
1B1 Coal Mining	CH_4	21,826.68	470.90	2.00%	20.00%	20.1%	0.0000	1.293%	0.058%	0.2586%	0.0016%	0.0007%
1B1 Solid Fuel Transformation	CH_4	0.18	3.80	0.00%	49.82%	49.8%	0.0000	0.000%	0.000%	0.0002%	0.0000%	0.0000%
1B2 Natural Gas Transmission	CH_4	10,600.72	3,337.33	5.00%	50.00%	50.2%	0.0000	0.246%	0.410%	0.1229%	0.0290%	0.0002%

IPCC Category	Gas	Base year emissions (Gg CO$_2$e)	2020 emissions (Gg CO$_2$e)	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined uncertainty (%)	Contribution to variance by Category in 2020	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
1B2 Upstream Oil & Gas	CH$_4$	1,741.39	871.43	4.42%	87.65%	87.8%	0.0000	0.001%	0.107%	0.0006%	0.0067%	0.0000%
2A Mineral Industries	CH$_4$	31.11	2.62	0.00%	100.00%	100.0%	0.0000	0.002%	0.000%	0.0016%	0.0000%	0.0000%
2B Chemical Industry	CH$_4$	221.63	67.21	0.00%	20.00%	20.0%	0.0000	0.005%	0.008%	0.0011%	0.0000%	0.0000%
2C Iron & Steel Production	CH$_4$	39.22	10.93	1.76%	44.09%	44.1%	0.0000	0.001%	0.001%	0.0005%	0.0000%	0.0000%
2D Non-energy Products from Fuels and Solvent Use	CH$_4$	-	-	0.00%	0.00%	0.0%	-	0.000%	0.000%	0.0000%	0.0000%	0.0000%
3A Enteric Fermentation	CH$_4$	24,683.01	20,937.60	13.73%	0.00%	13.7%	0.0000	1.046%	2.574%	0.0000%	0.5000%	0.0025%
3B Manure Management	CH$_4$	4,158.78	3,812.01	0.00%	10.47% corr	10.5% corr	0.0000	0.211%	0.469%	0.0221%	0.0000%	0.0000%
3F Field Burning	CH$_4$	187.03	-	25.61%	0.00%	25.6%	-	0.012%	0.000%	0.0000%	0.0000%	0.0000%
3J OT & CD Agriculture	CH$_4$	270.85	193.22	50.00%	50.00%	70.7%	0.0000	0.007%	0.024%	0.0035%	0.0168%	0.0000%
4A Forest Land	CH$_4$	87.54	103.13	1.00%	85.00%	85.0%	0.0000	0.007%	0.013%	0.0062%	0.0002%	0.0000%
4B Cropland	CH$_4$	291.94	279.33	1.00%	90.00%	90.0%	0.0000	0.016%	0.034%	0.0146%	0.0005%	0.0000%

IPCC Category	Gas	Base year emissions (Gg CO_2e)	2020 emissions (Gg CO_2e)	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined uncertainty (%)	Contribution to variance by Category in 2020	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
4C Grassland	CH_4	2,385.87	2,420.90	1.00%	40.00%	40.0%	0.0000	0.150%	0.298%	0.0600%	0.0042%	0.0000%
4D Wetland	CH_4	1,961.70	2,043.62	1.00%	35.00%	35.0%	0.0000	0.130%	0.251%	0.0454%	0.0036%	0.0000%
4E Settlements	CH_4	16.31	30.19	1.00%	40.00%	40.0%	0.0000	0.003%	0.004%	0.0011%	0.0001%	0.0000%
5A Solid Waste Disposal	CH_4	60,389.54	12,912.14	15.00%	46.00%	48.4%	0.0002	2.149%	1.588%	0.9887%	0.3368%	0.0109%
5B Biological treatment of solid waste	CH_4	18.13	1,216.79	30.00%	99.50%	103.9%	0.0000	0.148%	0.150%	0.1477%	0.0635%	0.0003%
5C Waste Incineration	CH_4	136.32	7.39	5.00%	50.00%	50.2%	0.0000	0.008%	0.001%	0.0038%	0.0001%	0.0000%
5D Wastewater Handling	CH_4	2,284.15	1,711.17	14.63%	47.34%	49.5%	0.0000	0.069%	0.210%	0.0327%	0.0435%	0.0000%
1A1 & 1A2 & 1A4 & 1A5 Other Combustion	N_2O	2,208.02	1,151.56	0.67%	66.63%	66.6%	0.0000	0.005%	0.142%	0.0033%	0.0013%	0.0000%
1A3 Other diesel	N_2O	6.09	10.07	15.00%	130.00%	130.9%	0.0000	0.001%	0.001%	0.0011%	0.0003%	0.0000%
1A3 Natural Gas	N_2O	-	0.03	5.00%	130.00%	130.1%	0.0000	0.000%	0.000%	0.0000%	0.0000%	0.0000%
1A3a Aviation Fuel	N_2O	17.70	6.51	19.83%	109.07%	110.9%	0.0000	0.000%	0.001%	0.0003%	0.0002%	0.0000%

IPCC Category	Gas	Base year emissions (Gg CO_2e)	2020 emissions (Gg CO_2e)	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined uncertainty (%)	Contribution to variance by Category in 2020	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
1A3b DERV	N_2O	316.64	819.98	1.00%	130.00%	130.0%	0.0000	0.081%	0.101%	0.1056%	0.0014%	0.0001%
1A3b Gasoline/ LPG	N_2O	996.92	71.98	0.99%	74.53%	74.5%	0.0000	0.053%	0.009%	0.0394%	0.0001%	0.0000%
1A3c Coal	N_2O	-	0.08	20.00%	110.00%	111.8%	0.0000	0.000%	0.000%	0.0000%	0.0000%	0.0000%
1A3d Marine fuel	N_2O	105.00	62.81	17.86%	116.11%	117.5%	0.0000	0.001%	0.008%	0.0014%	0.0020%	0.0000%
1B1 Fugitive Emissions from Solid Fuels	N_2O	0.09	0.02	1.00%	118.00%	118.0%	0.0000	0.000%	0.000%	0.0000%	0.0000%	0.0000%
1B2 Oil & Natural Gas	N_2O	44.69	30.89	4.98%	99.52%	99.6%	0.0000	0.001%	0.004%	0.0010%	0.0003%	0.0000%
2B Chemical industries	N_2O	23,797.38	51.08	0.28%	10.05%	10.1%	0.0000	1.466%	0.006%	0.1474%	0.0000%	0.0002%
2C Iron & Steel	N_2O	20.73	7.12	1.00%	118.00%	118.0%	0.0000	0.000%	0.001%	0.0005%	0.0000%	0.0000%
2D Non-energy Products from Fuels and Solvent Use	N_2O	-	-	0.00%	0.00%	0.0%	-	0.000%	0.000%	0.0000%	0.0000%	0.0000%
2G Other Product Manufacture and Use	N_2O	595.92	752.65	100.00%	100.00%	141.4%	0.0000	0.056%	0.093%	0.0556%	0.1309%	0.0002%

IPCC Category	Gas	Base year emissions (Gg CO_2e)	2020 emissions (Gg CO_2e)	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined uncertainty (%)	Contribution to variance by Category in 2020	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
3B Manure Management	N_2O	3,433.79	2,813.54	0.00%	17.30% corr	17.3% corr	0.0000	0.133%	0.346%	0.0231%	0.0000%	0.0000%
3D Agricultural Soils	N_2O	14,552.30	11,648.42	0.00%	21.71% corr	21.7% corr	0.0000	0.531%	1.432%	0.1153%	0.0000%	0.0001%
3F Field Burning	N_2O	57.80	-	25.62%	0.00%	25.6%	-	0.004%	0.000%	0.0000%	0.0000%	0.0000%
3J OT & CD Agriculture	N_2O	178.70	113.40	50.00%	50.00%	70.7%	0.0000	0.003%	0.014%	0.0014%	0.0099%	0.0000%
4 Indirect LULUCF Emissions	N_2O	305.49	171.77	1.00%	165.00%	165.0%	0.0000	0.002%	0.021%	0.0036%	0.0003%	0.0000%
4A Forest land	N_2O	752.90	712.25	1.00%	85.00%	85.0%	0.0000	0.041%	0.088%	0.0348%	0.0012%	0.0000%
4B Cropland	N_2O	734.60	398.47	1.00%	35.00%	35.0%	0.0000	0.004%	0.049%	0.0012%	0.0007%	0.0000%
4C Grassland	N_2O	202.42	184.75	1.00%	45.00%	45.0%	0.0000	0.010%	0.023%	0.0046%	0.0003%	0.0000%
4D Wetland	N_2O	21.29	24.81	1.00%	90.00%	90.0%	0.0000	0.002%	0.003%	0.0016%	0.0000%	0.0000%
4E Settlements	N_2O	441.11	293.94	1.00%	130.00%	130.0%	0.0000	0.009%	0.036%	0.0115%	0.0005%	0.0000%
5B Biological treatment of solid waste	N_2O	12.97	715.01	30.00%	90.00%	94.9%	0.0000	0.087%	0.088%	0.0784%	0.0373%	0.0001%
5C Waste Incineration	N_2O	50.93	26.37	7.00%	230.00%	230.1%	0.0000	0.000%	0.003%	0.0002%	0.0003%	0.0000%

IPCC Category	Gas	Base year emissions (Gg CO_2e)	2020 emissions (Gg CO_2e)	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined uncertainty (%)	Contribution to variance by Category in 2020	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
5D Wastewater Handling	N_2O	893.23	1,016.77	9.29%	217.21%	217.4%	0.0000	0.070%	0.125%	0.1514%	0.0164%	0.0002%
2C Metal Industries	SF_6	387.17	27.44	5.00%	5.00%	7.1%	0.0000	0.021%	0.003%	0.0010%	0.0002%	0.0000%
2G Other Product Manufacture and Use	SF_6	858.16	379.50	0.00%	5.60%	5.6%	0.0000	0.006%	0.047%	0.0004%	0.0000%	0.0000%
2B Chemical industry	HFCs	17,670.77	-	0.00%	10.00%	10.0%	-	1.094%	0.000%	0.1094%	0.0000%	0.0001%
2C Metal Industries	HFCs	-	1.48	5.00%	10.00%	11.2%	0.0000	0.000%	0.000%	0.0000%	0.0000%	0.0000%
2E Electronics Industry	HFCs	12.94	24.42	0.00%	47.15%	47.1%	0.0000	0.002%	0.003%	0.0010%	0.0000%	0.0000%
2F Product Uses as Substitutes for ODS	HFCs	885.83	12,182.92	8.40%	8.47%	11.9%	0.0000	1.443%	1.498%	0.1222%	0.1779%	0.0005%
2E Electronics Industry	NF_3	0.27	0.36	0.00%	47.15%	47.1%	0.0000	0.000%	0.000%	0.0000%	0.0000%	0.0000%
2B Chemical industry	PFCs	113.90	76.13	0.00%	10.00%	10.0%	0.0000	0.002%	0.009%	0.0002%	0.0000%	0.0000%
2C Metal Industries	PFCs	333.43	4.28	0.00%	20.00%	20.0%	0.0000	0.020%	0.001%	0.0040%	0.0000%	0.0000%

IPCC Category	Gas	Base year emissions (Gg CO_2e)	2020 emissions (Gg CO_2e)	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined uncertainty (%)	Contribution to variance by Category in 2020	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
2F Product Uses as Substitutes for ODS	PFCs	0.44	-	0.00%	25.00%	25.0%	-	0.000%	0.000%	0.0000%	0.0000%	0.0000%
2G Other Product Manufacture and Use	PFCs	141.67	79.38	0.00%	47.15%	47.1%	0.0000	0.0010%	0.0098%	0.0005%	0.0000%	0.0000%

Percentage uncertainty in UNFCCC inventory:	**2.6%**
Percentage uncertainty in KP inventory:	**2.6%**

UNFCCC trend uncertainty	**1.5%**
KP trend uncertainty	**1.5%**

A 2.2 ESTIMATION OF UNCERTAINTY BY SIMULATION (APPROACH 2)

A 2.2.1 Overview of the Method

Quantitative estimates of the uncertainties in the emissions were calculated using a Monte Carlo simulation. This corresponds to the IPCC Approach 2 method, discussed in the 2006 Guidelines (IPCC, 2006). The background to the implementation of the Monte Carlo simulation is described in detail by Eggleston *et al* (1998), with the estimates reported here revised to reflect changes in the latest inventory and improvements made in the model. This section gives a brief summary of the methodology, assumptions and results of the simulation.

The computational procedure is detailed below.

- A probability distribution function (PDF) was allocated to each unique emission factor and piece of activity data. The PDFs were mostly normal or log-normal, with more specific distributions given to a handful of sources. The parameters of the PDFs were set by analysing the available data on emission factors and activity data, and by expert judgement;
- A calculation was set up to estimate the total emissions of each gas for the years 1990 and the latest reported year;
- Each PDF was sampled at least 20,000 times, such that the emission calculations performed produced a converged output distribution;
- The distribution of errors in the parameter values was calculated from the difference between 2.5 and 97.5 percentile values in the distribution, as a percentage of the distribution mean; and,
- The uncertainty in the trend between 1990 and the latest reported year, according to gas, was also estimated. This was calulcated as the latest year sample minus the 1990 sample, divided by the 1990 mean.

A 2.2.2 Methodological details of the Monte Carlo model

A 2.2.2.1 Uncertainty Distributions

Nearly all of the distributions of emissions from sources in the inventory are modelled used normal or log normal distributions, with more specific distributions given to a handful of sources. The specific distributions include log-logistic and Gamma distributions. The primary use of custom distributions is for agriculture; these are fitted distributions that reflect the results of an agriculture-specific Monte Carlo analysis done by Rothamsted Research which accounts for the various factors that influence the modelled agriculture emissions.

Emissions from landfill have been modelled using a custom distribution. Aitchison *et al*. (cited in Eggleston *et al*., 1998) estimated the uncertainty for landfill emissions using Monte Carlo analysis and found it to be skewed. The distribution histogram was used to generate an empirical distribution of emissions. We examined the distribution and fitted a log normal distribution to Aitchison’s data. The emissions are scaled according to the mean estimate of landfill emissions for each year.

There are a couple of other specific distributions for F-gases and wastewater which reflect specific distributions we expect for those sources.

A 2.2.2.2 Correlations

The Monte Carlo model contains a number of correlations. If A and B are correlated, then if emissions are under or overestimated from A it would be expected to be over or underestimated by a similar amount from B.

The type and implementation of the correlations has been examined as part of a review (Abbott *et al.*, 2007). The sensitivity analysis that we have completed on the Monte Carlo model suggest that the uncertainties are not sensitive to the correlations between emission factors for fuel used, and for LULUCF sources.

A 2.2.2.2.1 Across years

In running this simulation, it was necessary to make assumptions about the degree of correlation between sources in 1990 and the latest reported year. If source emission factors are correlated this will have the effect of reducing the trend uncertainty but will not affect uncertainties on emission totals in 1990 or the latest inventory year. The trend estimated by the Monte Carlo model is particularly sensitive to N_2O emissions from agricultural soils.

A 2.2.2.2.2 Between Sources in the same year

In many cases the same factors, or factors derived on the same basis are used for multiple sources. In these cases, we’d say that the emission factors are correlated. For example, the coal emissions factors for N_2O used for cement industry use may be the same as coal use in other industrial combustion due to lack of a more specific factor, in this case we may say the two factors are correlated. Omitting these correlations leads to an underestimate of uncertainty in any given year.

A 2.2.2.3 Simulation Method

Following recommendations in the 2006 IPCC Guidelines, the model uses a true Monte Carlo sampling method.

A 2.2.3 Quality Control Checks on the Monte Carlo Model Output

A number of quality control checks are completed as part of the uncertainty analysis.

A 2.2.3.1 Checks against totals of the national emissions

To ensure the emissions in the Monte Carlo model closely agree with the reported totals in the NIR, the emissions in the model were checked against the national totals both before and after the simulation was run. The central estimates from the model are expected to be similar to the reported emissions totals but are not expected to match exactly.

A 2.2.3.2 Inter-comparison between the output of the error propagation and Monte Carlo models

A formal check to compare the output of the error propagation and Monte Carlo model is completed. The results of this comparison are discussed in **Section A 2.6.**

A 2.2.3.3 Calculation of uncertainty on the total

The uncertainty on the 1990 and the most recent year emissions was calculated using two different methods;

i) Using $\frac{1.96 s.d}{\mu}$

ii) Using $\frac{(97.5 percentile - 2.5 percentile)}{2 \times \mu}$

The first method uses the standard deviation calculated by the simulation and the mean to give a percentage uncertainty, while the second method uses the 95% confidence interval given by the percentiles quoted. When a distribution is completely normally distributed, the two methods should give the same results. However, when a distribution is skewed the two methods diverge, since the variance is dominated by outliers which aren't necessarily accounted for in the 95% confidence interval.

Calculating the uncertainty using both of these methods allows us to check that the Monte Carlo analysis is behaving in the way we would expect, and that convergence of the distributions is being achieved. Comparing the results using both calculations showed that the uncertainties were almost the same for gases where the distributions used were predominantly normal, but higher for N_2O and the GWP weighted total, as expected.

A 2.3 UNCERTAINTY PARAMETERS

The following sections present the uncertainties in emissions, and the trend in emissions according to gas.

A 2.3.1 Uncertainty Parameters used

Table A 2.3.1 to **Table A 2.3.4** summarise the uncertainty parameters used for both Approach 1 and 2 uncertainties. For all of these tables the following apply:

- Uncertainties expressed as 0.5*R/E where R is the difference between 2.5 and 97.5 percentiles and E is the mean;
- Where custom distributions are used for the Approach 2 uncertainties the parameters are not used directly, but the below parameters should still be a reasonable indicator of the uncertainty in the distribution used for Approach 2;
- (r) means revised in comparison to previous NIR;
- (n) represents a new uncertainty parameter, either because sources are considered at a more granular level, or because a new source is included in the inventory; and
- (a) means uncertainty for emission factors and activity cannot be separated, so one uncertainty that represents both is displayed.

Table A 2.3.1 Uncertainties in the activity data and emission factors for fuels used in the carbon dioxide (CO_2) inventory

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1A	Lubricants	50.00%	5.00%	50.00%	5.00%	It's challenging to determine the proportion of lubricant used as a fuel, hence a high activity uncertainty.
1A1	Blast Furnace Gas	1.50%	10.00%	1.00%	10.00%	Overall uncertainty for all coke & steelmaking emissions is quite low but allocation to individual sources is definitely higher - we've assumed 10%
1A1	Coke Oven Coke	1.00%	10.00%	1.00%	10.00%	Overall uncertainty for all coke & steelmaking emissions is quite low but allocation to individual sources is definitely higher - we've assumed 10%
1A1	Coke Oven Gas	1.50%	10.00%	1.00%	10.00%	Overall uncertainty for all coke & steelmaking emissions is quite low but allocation to individual sources is definitely higher - we've assumed 10%
1A1	Colliery Methane	5.00%	5.00%	5.00%	5.00%	(Minor fuel in sector context)
1A1	Gas/Diesel Oil	20.00% (r)	2.00% (r)	5.00% (r)	2.00% (r)	Dominated by activity in 1A1cii. There may be limited gas oil use unreported by e.g. MODUs in latest year; base year notably higher as the inventory AD are derived from sector-wide reported data, to address known under-reports in DUKES. Typically, gas oil CEFs reported are within 1% of each other but occasional deviations further.
1A1	Liquefied Petroleum Gas	25.70%	2.10%	2.50%	2.10%	The DUKES data from 2009 onwards were revised considerably in the energy / NEU split for LPG, and we have created a new split for earlier years. Chosen 2.1% Emission Factor (EF) uncertainty to be consistent with gas oil - the makeup of LPG is well understood and documented

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1A1	Motor Gasoline	2.50%	2.10%	2.50%	2.10%	Outside of 1A3, the motor gasoline allocations are probably much more uncertain as they are reliant on the off-road model etc., so chosen 2.5%.
1A1	Municipal Solid Waste	1.00%	15.00%	1.00%	15.00%	MSW quantity is known accurately. Uncertainty is in mass of fossil carbon per tonne of residual MSW. This is based on reasonable waste composition data from peer reviewed sources, adapted from landfill data.
1A1	Naphtha	50.00%	5.00%	50.00%	5.00%	DUKES are uncertain about where naphtha is used (or not), so a high activity uncertainty has been chosen. EF uncertainty chosen as 5%. The content of naphtha is quite variable - it contains a huge range of hydrocarbons from C5 up to C70+, so the exact carbon content is variable and there are about 5 different grades of naphtha according to UKPIA.
1A1	Natural Gas	20.00% (r)	2.00%	1.00%	2.00%	ETS-based data, so low uncertainties. Base year activity is dominated by 1A1cii, where uncertainty is notably higher as the inventory AD are derived from sector-wide reported data, to address known under-reports in DUKES.
1A1	Orimulsion	5.00%	5.00%	5.00%	5.00%	(Minor fuel in sector context)
1A1	Other Bituminous Coal	2.00%	2.00%	2.00%	2.00%	ETS-based data, so low uncertainties.
1A1	Other Kerosene	1.25%	5.00%	1.25%	5.00%	ETS-based data, so low uncertainties.
1A1	Other Oil: Other	11.90%	5.00%	10.00%	5.00%	(Minor fuel in sector context)

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1A1	Petroleum Coke	7.80%	10.00%	5.00%	10.00%	ETS-based data, so low uncertainties. 10% chosen for EF uncertainty as there is only a small dataset for the quality of petcoke used in the sector and the CEF could be quite variable depending on the source of the petcoke.
1A1	Refinery Gas	50.00%	20.00%	25.00%	15.00%	Comparisons between EU ETS and DUKES are variable over time. Risk that in earlier years the “own use” may have been mis-reported to energy stats. High uncertainty on AD. Also, a variable quality fuel, so the EF is also uncertain.
1A1	Residual Fuel Oil	5.50%	2.55%	1.25%	2.55%	ETS-based data, so low uncertainties.
1A1	Scrap Tyres	15.00%	10.00%	15.00%	10.00%	Limited reported use of this fuel; only a small amount of reporting (typically cement kilns) within EU ETS and a modest number of fuel quality analyses either through the BCA/MPA (trade body) or the EU ETS. Also, some variability in the fossil C versus bio-C content of the tyres adds to EF uncertainty.
1A2	Blast Furnace Gas	1.50%	10.00%	1.00%	10.00%	Overall uncertainty for all coke & steelmaking emissions is quite low but allocation to individual sources is definitely higher - we've assumed 10%
1A2	Coke Oven Coke	3.00%	10.00%	1.00%	10.00%	Overall uncertainty for all coke & steelmaking emissions is quite low but allocation to individual sources is definitely higher - we've assumed 10%
1A2	Coke Oven Gas	3.00%	10.00%	1.00%	10.00%	Overall uncertainty for all coke & steelmaking emissions is quite low but allocation to individual sources is definitely higher - we've assumed 10%
1A2	Colliery Methane	5.00%	5.00%	5.00%	5.00%	(Minor fuel in sector context)

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1A2	Gas/Diesel Oil	20.00%	2.00%	20.00%	2.00%	Low EF uncertainty as the composition of gas oil is well understood across the time series. The AD for stationary combustion in industrial sectors is quite uncertain, however. DUKES does not distinguish between mobile and stationary sources, and other AD data sources (e.g. EU ETS) have limited coverage of gas oil use across all of 1A2.
1A2	Liquefied Petroleum Gas	25.70%	2.10%	2.50%	2.10%	The DUKES data from 2009 onwards were revised considerably in the energy / NEU split for LPG, and we have created a new split for earlier years. Chosen 2.1% EF uncertainty to be consistent with gas oil - the makeup of LPG is well understood and documented
1A2	Motor Gasoline	20.00%	2.10%	20.00%	2.10%	Outside of 1A3, the motor gasoline allocations are probably much more uncertain. Chosen 2.1% EF uncertainty to be consistent with gas oil - the makeup of motor gasoline is well understood and documented
1A2	Municipal Solid Waste	5.00%	15.00%	5.00%	15.00%	MSW quantity is known accurately. Uncertainty is in mass of fossil carbon per tonne of residual MSW. This is based on reasonable waste composition data from peer reviewed sources, adapted from landfill data.
1A2	Natural Gas	2.80%	3.00%	1.00%	3.00%	Low EF uncertainty as gas composition is monitored and reported across much of the time series, and the fuel has narrow compositional range. AD are also well understood and low uncertainty. Gas supplier data to DUKES can be checked against periodic data matching (meter point data against industry sector information).
1A2	non-fuel combustion	50.00%	100.00%	50.00%	100.00%	(Minor emission source in sector context)

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1A2	Other Bituminous Coal	5.00%	10.00%	5.00%	10.00%	Limited compositional data over time (e.g. EU ETS data for coal is incomplete), so EF uncertainty reflects the range of composition of coal types in 1A2. AD uncertainty is moderate for 1A2, reflecting energy supplier reporting to BEIS.
1A2	Other Kerosene	6.00%	2.00%	6.00%	2.00%	(Minor fuel in sector context)
1A2	Other Oil: Other	5.00%	50.00%	5.00%	3.00%	(Minor fuel in sector context)
1A2	Patent Fuel	10.00%	3.00%	10.00%	3.00%	(Minor fuel in sector context)
1A2	Petroleum Coke	25.00%	15.00%	20.00%	15.00%	EF uncertainty reflects range of petcock composition that may be used for fuel in 1A2. AD uncertainty is quite high as we have limited data from DUKES and not much AD from EU ETS on petcoke use.
1A2	Refinery Gas	50.00%	15.00%	50.00%	15.00%	(Minor fuel in sector context)
1A2	Residual Fuel Oil	5.50%	2.10%	1.50%	2.10%	Low EF uncertainty as the composition of fuel oil is well understood across the time series. The AD uncertainty is low in recent years as the fuel is not widely used other than by larger operators that report under EU ETS. Moderate uncertainty in earlier years when fewer routine annual AD sources.
1A2	Scrap Tyres	15.00%	10.00%	15.00%	10.00%	(See 1A1 comment – same applies here.)
1A3	Aviation Gasoline	20.00%	3.30%	20.00%	3.30%	Activity uncertainty is higher than many other similar fuels because of the uncertainty in the international-domestic split
1A3	Jet Gasoline	20.00%	3.30%	20.00%	3.30%	Activity uncertainty is higher than many other similar fuels because of the uncertainty in the international-domestic split

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1A3	liquid biofuels	5.00%	5.00%	5.00%	5.00%	Activity data are not very uncertain, as it's taken from RTFO data. There is a total potential range of 10% variability in the fossil fuel carbon content of FAME (i.e. judging from the contents of the different fatty acid types used to synthesize the FAME, the highest content is around 44.8g/kg, whilst the lowest is 40.2g/kg). In reality, these are the extremes, so a lower overall uncertainty is expected. the other liquid biofuels are consumed in much smaller quantities than FAME.
1A3	Other Bituminous Coal	20.00%	6.00%	20.00%	6.00%	(Minor fuel in sector context)
1A3	Other Gas/Diesel Oil	15.00%	2.00%	15.00%	2.00%	(Minor fuel in sector context)
1A3	Natural Gas	5.00% (n)	2.00% (n)	5.00% (n)	2.00% (n)	Using parameters for road transport LPG; note that source is very small.
1A3b	Gas/Diesel Oil	1.80%	2.00%	1.00%	2.00%	Low EF uncertainty as the composition of gas oil is well understood across the time series. Low AD uncertainty as good corroboration between fuel sales data and estimates based on vehicle movement data.
1A3b	Liquefied Petroleum Gas	5.00%	2.00%	5.00%	2.00%	EF uncertainty is consistent with gas oil - the makeup of LPG is well understood and documented. Not a major fuel in the sector but AD are considered moderately uncertain.
1A3b	Motor Gasoline	1.00%	2.00%	1.00%	2.00%	Low EF uncertainty as the composition of petrol is well understood across the time series. Low AD uncertainty as good corroboration between fuel sales data and estimates based on vehicle movement data.
1A3d	Gas/Diesel Oil	20.00%	2.00%	20.00%	2.00%	Activity uncertainty is higher than many other similar fuels because of the uncertainty in the international-domestic split

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1A3d	Residual Fuel Oil	20.00%	2.00%	20.00%	2.00%	Activity uncertainty is higher than many other similar fuels because of the uncertainty in the international-domestic split
1A4	Anthracite	1.50%	6.00%	1.00%	6.00%	Low AD uncertainty as tax data helps establish residential use. EF uncertainty reflects variability in anthracite composition.
1A4	Coke Oven Coke	3.00%	10.00%	1.00%	10.00%	(Minor fuel in sector context)
1A4	Gas/Diesel Oil	30.00%	2.00%	30.00%	2.00%	Low EF uncertainty as the composition of gas oil is well understood across the time series. High AD uncertainty as scarce data on use of this fuel, e.g. in mobile machinery, in 1A4.
1A4	Gas Works Gas	5.00%	5.00%	5.00%	5.00%	(Minor fuel in sector context)
1A4	Liquefied Petroleum Gas	25.70%	2.10%	2.50%	2.10%	The DUKES data from 2009 onwards were revised considerably in the energy / NEU split for LPG, and we have created a new split for earlier years. Chosen 2.1% EF uncertainty to be consistent with gas oil - the makeup of LPG is well understood and documented
1A4	Motor Gasoline	50.00%	2.00%	50.00%	2.00%	Low EF uncertainty as the composition of petrol is well understood across the time series. High AD uncertainty as scarce data on use of this fuel in mobile machinery in 1A4.
1A4	Natural Gas	2.80%	3.00%	2.00%	3.00%	(As for 1A2)
1A4	Other Bituminous Coal	3.00%	10.00%	3.00%	10.00%	Chosen 3% activity uncertainty as we know that there are some limitations on the coal allocation to small-scale users.
1A4	Other Kerosene	3.00%	2.00%	3.00%	2.00%	Low AD uncertainty as tax data helps establish residential use. EF uncertainty reflects narrow range of fuel composition.

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1A4	Patent Fuel	3.30%	3.00%	2.00%	3.00%	(Minor fuel in sector context)
1A4	Peat	30.00%	10.00%	30.00%	10.00%	(Minor fuel in sector context)
1A4	Petroleum Coke	20.00%	15.00%	20.00%	15.00%	Limited information on the AD of use in domestic fuels which increases uncertainty. Moderate emission factor uncertainty as there is only a small dataset for the quality of petcoke used in the sector and the CEF could be quite variable depending on the source of the petcoke.
1A4	Residual Fuel Oil	5.50%	2.10%	3.00%	2.10%	(Minor fuel in sector context)
1A5	Gas/Diesel Oil	6.25%	2.05%	6.25%	2.05%	Moderate AD uncertainty as data from very few data suppliers. EF uncertainty reflects narrow range of fuel composition.
1A5	Jet Gasoline	10.00%	3.00%	10.00%	3.00%	Activity Data comes directly from fuel users so should have high confidence.
1B1	Coke Oven Gas	1.50%	10.00%	1.00%	10.00%	(Minor fuel in sector context)
1B1	Other Bituminous Coal	1.50%	6.00%	1.50%	6.00%	EF uncertainty reflects the range of composition of coal types in SSF manufacture. AD uncertainty is quite low, reflecting the small number of operators and high level of AD reporting.
1B1	petroleum coke	20.00%	10.00%	20.00%	10.00%	(Minor fuel in sector context)

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1B2a	non-fuel combustion	15.00% (r)	20.00% (r)	10.00% (r)	30.00% (r)	The dominant sources are onshore oil production (latest year) and offshore oil well testing (base year). The PPRS data underpin the oil production data and whilst they are very consistent across years, it is plausible that up to 10% error may occur if one of the larger site's mis-reports as these dominate. For the base year, the AD for well testing is extrapolated to 1990 using well drilling statistics so introduces some additional uncertainty. The dominant source in recent years is onshore oil production which applies an IPCC 2019 Refinement Tier 1 EF which cites a 30% uncertainty margin. In the base year due to the (large) dominance of oil well testing, a lower overall EF uncertainty is applied.
1B2b	non-fuel combustion	15.00% (r)	20.00% (r)	2.00% (r)	10.00% (r)	The dominant sources are direct process releases from both offshore gas rigs and terminals (latest year) and gas well testing (base year). The installation-level reporting underpins latest year estimates, and hence low AD estimates and the EF reflects that there is a good dataset with known sites contributing fairly consistently but there may be a reasonably high measurement uncertainty at source. For the base year, the AD for well testing is well documented back to 1995, and then extrapolated to 1990 introducing some additional uncertainty. For the base year, the CEF is only based on operator guidance rather than any monitoring, making it more uncertain.

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1B2c	non-fuel combustion	20.00% (r)	5.00% (r)	5.00%	5.00% (r)	Flaring emissions dominate this sector in all years. There is a lot of high quality reporting of flaring since around 1995, but the monitoring of gas to flare and need for assumptions to estimate the mass will undermine that somewhat. For the Base Year we have extrapolated back from 1995 so the uncertainty in AD is higher. There is a large dataset on gas to flare composition, but then an assumption of 98% combustion, whereas if a few sites have notably lower oxidation this would impact the CEF.
2A1	non-fuel combustion	1.00%	3.00%	1.00%	3.00%	EU ETS-type data collected from BCA for all sites so assume very good quality and complete.
2A2	non-fuel combustion	10.00%	5.00%	(a)	5.00%	High level of reporting in EU ETS for recent years and EF reflects small range of data for carbonates used in lime production. AD uncertainty higher in earlier years.
2A3	non-fuel combustion	(a)	5.00%	(a)	5.00%	Mostly based on ETS data. Very small sites outside EU ETS; it's not certain how well EU ETS factor will apply to these non-EU ETS sites.
2A4	non-fuel combustion	2.00%	3.00%	2.00%	3.00%	(Minor source in UK context)
2B	Coke	1.00%	20.00%	1.00%	10.00%	(Minor source in UK context)
2B	coke oven coke	(a)	20.00%	(a)	20.00%	(Minor source in UK context)
2B	Natural Gas	2.80%	1.25%	1.75%	1.25%	Covers both feedstock and fuel (i.e. total fuel used at the sites), so AD should be very good.
2B	non-fuel combustion	2.00%	5.00%	2.00%	5.00%	(Minor source in UK context)

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
2B	OPG	(a)	5.00%	(a)	5.00%	Moderate uncertainty in EF reflecting good level of reporting of fuel quality in EU ETS but range of variability of process off-gases that are generated and used in the chemical sector.
2B	petroleum coke	1.00%	10.00%	1.00%	10.00%	(Minor source in UK context)
2B	refinery gas	30.00%	5.00%	30.00%	5.00%	High uncertainty, as we deviate from DUKES. Low emission factor uncertainty, but not a well-characterised fuel.
2C	Blast Furnace Gas	2.00%	10.00%	2.00%	10.00%	Overall uncertainty in 2C is quite low and uncertainty is more about where the carbon input (from the coking coal) ends up being emitted, and less about the overall amount of carbon emitted.
2C	Coke	2.00%	10.00%	2.00%	10.00%	Good level of reporting from I&S operators across the time series.
2C	coke oven coke	2.00%	5.00%	2.00%	5.00%	Activity data has low uncertainty since it's based on ETS/ISSB/DUKES. Emissions are based on regulator data, so low uncertainty.
2C	non-fuel combustion	2.00%	10.00%	2.00%	10.00%	Overall uncertainty in 2C is quite low and uncertainty is more about where the carbon input (from the coking coal) ends up being emitted, and less about the overall amount of carbon emitted.
2C	Petroleum Coke	10.00%	7.50%	10.00%	7.50%	(Minor source in UK context)

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
2D	Lubricants	50.00%	50.00%	50.00%	50.00%	It's challenging to determine the size of the recovered lubricant market, as this is outside the scope of energy statistics, hence a high activity uncertainty. The fraction of lubricant incidentally oxidised is also highly uncertain, so should be reflected in a high EF uncertainty.
2D	non-fuel combustion	25.00%	2.00%	25.00%	2.00%	Some uncertainty as to the proportion of HDVs requiring urea and how much is needed per vehicle. Very low EF uncertainty because carbon content of urea solution known accurately.
2D	Petroleum Coke	20.00%	30.00%	20.00%	30.00%	(Minor source in UK context)
2D	Petroleum Waxes	10.00%	50.00%	10.00%	50.00%	(Minor source in UK context)
2G		25.00%	2.00%	25.00%	2.00%	High activity uncertainty due to it being unclear if bicarbonate of soda is used for emissive or non-emissive applications. Low uncertainty in emission factors as it's determined from stoichiometry.
3G	non-fuel combustion	(a)	20.90%	(a)	20.90%	Reflects overall uncertainty of AD and EF for carbonate application to soils.
3H	non-fuel combustion	(a)	50.00%	(a)	50.00%	(Minor source in UK context)
4A	non-fuel combustion	5.00%	20.00%	5.00%	20.00%	In order to assess the uncertainties for Forest Land a Monte Carlo analysis was performed using the CARBINE model. The probability density functions (PDFs) assigned to the various CARBINE input parameters were based on information from the literature and expert judgement. A selection of 100 sets of input parameters were generated using a Latin hypercube, as this was considered to be the minimum number of model runs to get a reasonable estimate of the uncertainty.

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
4B	non-fuel combustion	1.00%	25.00%	1.00%	25.00%	High uncertainty reflects modelled assumptions and limited AD and is focussed in the EF parameter.
4C	non-fuel combustion	1.00%	30.00%	1.00%	30.00%	High uncertainty reflects modelled assumptions and limited AD and is focussed in the EF parameter.
4D	non-fuel combustion	1.00%	25.00%	1.00%	25.00%	High uncertainty reflects modelled assumptions and limited AD and is focussed in the EF parameter.
4E	non-fuel combustion	1.00%	25.00%	1.00%	25.00%	High uncertainty reflects modelled assumptions and limited AD and is focussed in the EF parameter.
4F	non-fuel combustion	(a)	50.00%	(a)	50.00%	High uncertainty reflects modelled assumptions and limited AD and is focussed in the EF parameter.
4G	non-fuel combustion	1.00%	20.00%	1.00%	15.00%	In order to assess the uncertainties for Forest Land a Monte Carlo analysis was performed using the CARBINE model. The probability density functions (PDFs) assigned to the various CARBINE input parameters were based on information from the literature and expert judgement. A selection of 100 sets of input parameters were generated using a Latin hypercube, as this was considered to be the minimum number of model runs to get a reasonable estimate of the uncertainty.
5C	Chemical waste	300.00%	40.00%	10.00%	30.00%	(Minor source in UK context)
5C	Clinical waste	300.00%	40.00%	5.00%	20.00%	(Minor source in UK context)
5C	Municipal Solid Waste	300.00%	40.00%	1.00%	15.00%	(Minor source in UK context)
5C	non-fuel combustion	300.00%	40.00%	300.00%	40.00%	Unauthorised and widely dispersed activity estimated from indirect data sources so high uncertainty. Significant uncertainty in the composition of material burnt.

Table A 2.3.2 Estimated uncertainties in the activity data and emission factors used in the methane (CH_4) inventory

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1A1		10.00% (r)	50.00%	1.00%	50.00%	Minor source but uncertainty mainly reflects uncertainty in the EF from combustion of biomass. A large proportion of base year emissions are associated with 1A1ciii data which are extrapolated based on production trends, therefore has a higher uncertainty than the 1A1a-dominated emissions in later years.
1A2		1.50%	50.00%	1.00%	50.00%	As above.
1A3	Aviation Gasoline	20.00%	78.50%	20.00%	78.50%	(Minor source in UK context)
1A3	Jet Gasoline	20.00%	78.50%	20.00%	78.50%	(Minor source in UK context)
1A3	Other Bituminous Coal	20.00%	110.00%	20.00%	110.00%	(Minor source in UK context)
1A3	Other Gas/Diesel Oil	15.00%	130.00%	15.00%	130.00%	(Minor source in UK context)
1A3	Natural Gas	5.00% (n)	130.00% (n)	5.00% (n)	130.00% (n)	Using parameters for road transport LPG; note that source is very small.
1A3b	Gas/Diesel Oil	1.80%	130.00%	1.00%	130.00%	Road transport fuel sales well documented, so uncertainty in AD should be low. Uncertainty in EF reflects the variability in EFs for the range of vehicle (car, van, HGV) and road types.
1A3b	Liquefied Petroleum Gas	5.00%	130.00%	5.00%	130.00%	(Minor source in UK context)

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1A3b	Motor Gasoline	1.00%	75.00%	1.00%	75.00%	Road transport dominates consumption of these fuels, so uncertainty in AD should be low. Uncertainty in EF reflects the variability in EFs for petrol cars and road types. Lower uncertainty than diesel vehicles because consumption dominated by only one vehicle type.
1A3d	Gas/Diesel Oil	20.00%	130.00%	20.00%	130.00%	Uncertainty in AD due to uncertainty in getting domestic/international split from bottom-up method. Uncertainty in EF should be consistent with other 1A3 gas oil
1A3d	Residual Fuel Oil	20.00%	130.00%	20.00%	130.00%	Uncertainty in AD due to uncertainty in getting domestic/international split from bottom-up method.
1A4		1.50%	50.00%	1.00%	50.00%	Minor source but uncertainty mainly reflects uncertainty in the EF from combustion of biomass.
1A5		7.07%	65.55%	7.07%	65.55%	(Minor source in UK context)
1B1	Coke Oven Gas	1.50%	50.00%	1.00%	50.00%	(Minor source in UK context)
1B1	non-fuel combustion	2.00%	20.00%	2.00%	20.00%	High EF uncertainty reflects the modelled estimates of emissions from coal mines.
1B1	wood	(a)	50.00%	(a)	50.00%	(Minor source in UK context)

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1B2a	non-fuel combustion	20.00% (r)	50.00% (r)	5.00%	50.00% (r)	Latest year methane 1B2a is dominated by direct process fugitives from offshore oil rigs and oil terminals and oil loading. In all cases the AD are of reasonable quality from installation-level reporting (the oil loading AD are from production stats, of good quality). Base year AD are more uncertain; industry reporting is not source-specific and IPCC good practice gap-filling methods are used to derive 1990-1994 estimates. The 2019 Refinement cites 50% uncertainty for direct process / fugitive EFs.
1B2b	non-fuel combustion	20.00% (r)	50.00% (r)	5.00% (r)	50.00% (r)	Latest year methane 1B2b is dominated by direct process fugitives from offshore gas rigs gas oil terminals and from onshore gas production and gathering. In all cases the AD are of reasonable quality from installation-level reporting. Base year AD are more uncertain; industry reporting is not source-specific and IPCC good practice gap-filling methods are used to derive 1990-1994 estimates. The 2019 Refinement cites 10-20% uncertainty for direct process / fugitives EFs whilst the IPCC default uncertainty for process fugitives is 100%. The UK applies 50% as a compromise between these values.
1B2c	non-fuel combustion	20.00% (r)	100.00% (r)	5.00%	100.00% (r)	Flaring and venting both contribute a high share of total sector emissions in all years. Operator reporting informs flaring and venting emissions since 1995; accuracy will be limited by measurement uncertainty on gas to flare/vent and assumptions applied. Base year AD are more uncertain; industry reporting is not source-specific and IPCC good practice gap-filling methods are used to derive 1990-1994 estimates. Flaring uncertainty dominates as operators assume that flare gas is 98% oxidised; this assumption is very sensitive to a few sites if they have notably lower oxidation.

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
2A4		(a)	100.00%	(a)	100.00%	(Minor source in UK context)
2B		(a)	20.00%	(a)	20.00%	(Minor source in UK context)
2C	Blast Furnace Gas	2.00%	50.00%	2.00%	50.00%	(Minor source in UK context)
2C	coke oven coke	2.00%	50.00%	2.00%	50.00%	Activity data has low uncertainty since it's based on ETS/ISSB/DUKES. Emissions are based on literature factors, so a high EF uncertainty.
2C	non-fuel combustion	1.00%	50.00%	1.00%	50.00%	(Minor source in UK context)
2D		50.00%	50.00%	50.00%	50.00%	(Minor source in UK context)
3A	non-fuel combustion	13.73%	(a)	13.73%	(a)	Based on monte Carlo analysis for the agriculture model
3B	non-fuel combustion	(a)	8.37%	(a)	8.37%	Based on monte Carlo analysis for the agriculture model
3F	non-fuel combustion	25.61%	(a)	25.61%	(a)	Based on monte Carlo analysis for the agriculture model
3J		50.00%	50.00%	50.00%	50.00%	
4A	non-fuel combustion	5.00%	90.00%	5.00%	70.00%	(Minor source in UK context)
4B	non-fuel combustion	1.00%	90.00%	1.00%	90.00%	(Minor source in UK context)
4C	non-fuel combustion	1.00%	40.00%	1.00%	40.00%	(Minor source in UK context)
4D	non-fuel combustion	1.00%	40.00%	1.00%	35.00%	(Minor source in UK context)
4E	non-fuel combustion	1.00%	50.00%	1.00%	40.00%	(Minor source in UK context)

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
5A	non-fuel combustion	15.00%	46.00%	15.00%	46.00%	Moderate/high uncertainty in historical waste data, rates of decomposition and generation of methane in the modelled approach. Some extrapolation of data needed for methane utilisation, hence high uncertainty overall, across AD and EF.
5B		30.00%	99.50%	30.00%	99.50%	Scarce data for UK biological treatments. High uncertainty.
5C	Municipal Solid Waste	5.00%	75.00%	1.00%	75.00%	(Minor source in UK context)
5C	non-fuel combustion	5.00%	50.00%	5.00%	50.00%	(Minor source in UK context)
5C	wood	50.00%	50.00%	50.00%	50.00%	(Minor source in UK context)
5D1	non-fuel combustion	10.00%	25.00%	10.00%	25.00%	UK industry research and model. Moderate-high uncertainty.
5D2		25.00%	82.54%	25.00%	82.54%	Calculated based on 2006 IPCC guidelines ranges for model parameters and weighted depending on their contribution to the final emissions estimate.

Table A 2.3.3 Estimated uncertainties in the activity data and emission factors used in the nitrous oxide (N_2O) inventory

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1A1		1.50%	100.00%	1.00%	100.00%	
1A2		1.50%	100.00%	1.00%	100.00%	
1A3	Aviation Gasoline	20.00%	110.00%	20.00%	110.00%	

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1A3	Jet Gasoline	20.00%	110.00%	20.00%	110.00%	
1A3	Other Bituminous Coal	20.00%	110.00%	20.00%	110.00%	
1A3	Other Gas/Diesel Oil	15.00%	130.00%	15.00%	130.00%	
1A3	Natural Gas	5.00% (n)	130.00% (n)	5.00% (n)	130.00% (n)	Using parameters for road transport LPG; note that source is very small.
1A3b	Gas/Diesel Oil	1.80%	130.00%	1.00%	130.00%	Road transport dominates consumption of these fuels, so uncertainty in AD should be low. Uncertainty in EF reflects the variability in EFs for different diesel vehicle types and road types.
1A3b	Liquefied Petroleum Gas	5.00%	130.00%	5.00%	130.00%	
1A3b	Motor Gasoline	1.00%	75.00%	1.00%	75.00%	Road transport dominates consumption of these fuels, so uncertainty in AD should be low. Uncertainty in EF reflects the variability in EFs for petrol cars and road types. Lower uncertainty than diesel vehicles because consumption dominated by only one vehicle type.
1A3d	Gas/Diesel Oil	20.00%	130.00%	20.00%	130.00%	Uncertainty in AD due to uncertainty in getting domestic/international split from bottom-up method. Uncertainty in EF should be consistent with other 1A3 gas oil
1A3d	Residual Fuel Oil	20.00%	130.00%	20.00%	130.00%	Uncertainty in AD due to uncertainty in getting domestic/international split from bottom-up method.
1A4		1.50%	100.00%	1.00%	100.00%	
1A5		7.07%	85.15%	7.07%	85.15%	

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
1B1		1.50%	118.00%	1.00%	118.00%	
1B2a	non-fuel combustion	15.00% (r)	100.00% (r)	10.00% (r)	200.00% (r)	Assume same AD uncertainty as carbon. Most UK reporting is based on operator guidance EFs with very little or no monitoring, so it is only marginally better than using IPCC defaults. The IPCC default uncertainty for nitrous oxide from such process sources is typically 100% or higher. Also note that for onshore oil production (~half of more recent emissions) we use the IPCC default which is -10 to +1000% uncertainty range, so the latest year is more uncertain.
1B2b	non-fuel combustion	15.00% (r)	100.00% (r)	2.00% (r)	100.00% (r)	Assume same AD uncertainty as carbon. Most UK reporting is based on operator guidance EFs with very little or no monitoring, so it is only marginally better than using IPCC defaults. The IPCC default uncertainty for nitrous oxide from such process sources is typically 100% or higher.
1B2c	non-fuel combustion	20.00% (r)	100.00% (r)	5.00%	100.00% (r)	Assume same AD uncertainty as carbon. Most UK reporting is based on operator guidance EFs with very little or no monitoring, so it is only marginally better than using IPCC defaults. The IPCC default uncertainty for nitrous oxide from such process sources is typically 100% or higher.
2B1		2.00%	50.00%	2.00%	50.00%	Strong activity data, so low activity uncertainty. Assume a high uncertainty for the literature factor.
2B2		10.00%	100.00%	(a)	10.00%	Emission estimates for recent years have been based partially (1998-2008) or wholly (2009-2017) on continuous monitoring, and therefore will be subject to low uncertainty. The monitoring systems used at the 2 sites currently in operation are subject to an uncertainty of 5-10%. Uncertainty in earlier years is much higher due to more limited information

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
2B3		2.00%	100.00%	2.00%	100.00%	
2B8		10.00%	100.00%	10.00%	100.00%	
2C		1.50%	118.00%	1.00%	118.00%	
2D		50.00%	100.00%	50.00%	100.00%	
2G		100.00%	100.00%	100.00%	100.00%	
3B		(a)	68.07%	(a)	9.53%	Based on separate monte Carlo analysis for the agriculture model
3D		(a)	53.28%	(a)	11.16%	Based on separate monte Carlo analysis for the agriculture model
3F		25.63%	(a)	25.62%	(a)	
3J		50.00%	50.00%	50.00%	50.00%	
4A	non-fuel combustion	1.00%	80.00%	1.00%	80.00%	
4B	non-fuel combustion	1.00%	40.00%	1.00%	40.00%	
4C	non-fuel combustion	1.00%	50.00%	1.00%	45.00%	
4D	non-fuel combustion	1.00%	120.00%	1.00%	65.00%	
4E	non-fuel combustion	1.00%	135.00%	1.00%	130.00%%	
4only	non-fuel combustion	1.00%	165.00%	1.00%	165.00%	
5B		30.00%	90.00%	30.00%	90.00%	

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
5C		7.00%	230.00%	7.00%	230.00%	
5D1		10.00%	248.00%	10.00%	248.00%	
5D2		25.00%	129.37%	25.00%	129.37%	Calculated based on 2006 IPCC guidelines ranges for model parameters and weighted depending on their contribution to the final emissions estimate.

Table A 2.3.4 Estimated uncertainties in the activity data and emission factors used in the F-gas inventory

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
HFCs	2B9	(a)	15.00%	(a)	10.00%	
HFCs	2C4	5.00%	10.00% (r)	5.00%	10.00%	
HFCs	2E1	(a)	44. 50%	(a)	47.15%	
HFCs	2F1	10.00%	10.00%	10.00%	10.00%	Good UK data on refrigerant supply is used to tune the model of emissions for this sector, which means that there is a high confidence in the overall estimates of an activity for this sector. Good activity data helps mitigate the uncertainty in emissions, as leakage and disposal is directly linked to refrigerant demand.
HFCs	2F2	(a)	15.00% (r)	(a)	15.00%	
HFCs	2F3	(a)	25.00% (r)	(a)	25.00%	
HFCs	2F4a	5.00% (r)	10.00%	5.00%	10.00%	

Category	Fuel	1990 Activity uncertainty (%)	1990 Emission factor uncertainty (%)	2020 Activity uncertainty (%)	2020 Emission factor uncertainty (%)	Justification for key sources
HFCs	2F4b	(a)	10.00% (r)	(a)	10.00%	
HFCs	2F5	(a)	25.50%	(a)	25.50%	
HFCs	2F6	(a)	51.00%	(a)	42.00%	
NF_3	2E1	(a)	44.50%	(a)	47.15%	
PFCs	2B9	(a)	15.00%	(a)	10.00%	
PFCs	2C3	(a)	20.00% (r)	(a)	20.00%	
PFCs	2F3	(a)	25.00% (r)	(a)	25.00%	
PFCs	2G2e	(a)	44.50%	(a)	47.15%	
SF_6	2C4	5.00%	5.00%	5.00%	5.00%	
SF_6	2G1	(a)	20.00%	(a)	5.00%	
SF_6	2G2a	(a)	50.00%	(a)	50.00%	
SF_6	2G2b	(a)	17.50%	(a)	15.50%	
SF_6	2G2e	(a)	40.00%	(a)	10.00%	

A 2.3.2 General Considerations

The uncertainty parameters presented above are based primarily on expert judgment, but where applicable will account for:

- The uncertainty range presented for data (for example the confidence interval in the 2006 IPCC guidelines for default factors)
- Monte Carlo Analysis of some of the more sophisticated models, most notably for agriculture, LULUCF and F-gases

In some cases, the individual uncertainties for the activity data and the emission factor are difficult to separate, but the uncertainty on the total emission can more easily be estimated. In these cases, the uncertainties are listed in the columns for emission factor uncertainties.

The analysis of the uncertainties in the nitrous oxide emissions is particularly difficult because emissions sources are diverse, and few data are available to form an assessment of the uncertainties in each source. Emission factor data for the combustion sources are scarce and for some fuels are not available. The uncertainty assumed for agricultural soils (IPCC category 3D) uses a custom distribution. These parameterised functions have been defined and provided by Rothamsted Research as the best possible fit to the expected distribution of uncertainties in 1990 and the most recent year's emissions, and are normalised in the Approach 2 methodology such that the resultant mean is consistent with the current inventory emissions in 1990 and the most recent year.

Many of the uncertainties in the emissions of HFCs, PFCs, NF_3 and SF_6 (collectively known as F-gases) are based on the study to update emissions and projections of F-gases (ICF, 2014) in line with the 2006 IPCC guidelines. Some sources have been updated since then and the uncertainties for those sources have been revisited accordingly.

We assume that all F-gas emissions are independent between years as the technologies, gases (which have a very wide range of GWPs) used and regulations have changed drastically between the base year and the most recent year. Many HFCs in particular were not in use until the early 90s.

A 2.3.3 Uncertainty in the Trend

In simulating trend uncertainty, it was necessary to make assumptions about the degree of correlation between sources and between 1990 and the most recent year. The assumptions were as follows:

- Activity data are uncorrelated;
- Emission factors of some similar fuels are correlated;
- Land Use Change and forestry emission factors are correlated (e.g. 1990 4A CO_2 with 4A CO_2 for the most recent year);
- Emission factors covered by the Carbon Factors Review (Baggott et al, 2004) are not correlated;
- Process emissions from blast furnaces, coke ovens and ammonia plants are not correlated;
- Landfill emissions were partly correlated across years in the simulation. It is likely that the emission factors used in the model will be correlated, and also the historical estimates of waste arisings will be correlated since they are estimated by extrapolation from the year

of the study. However, the reduction in emissions is due to flaring and utilisation systems installed since 1990 and this is unlikely to be correlated. As a simple estimate it was assumed that the degree of correlation should reflect the reduction in emissions since 1990;

- Emissions from agricultural soils and manure management are correlated in the base and inventory year;
- The emission factor used for sewage treatment was assumed to be correlated between years, though the protein consumption data used as activity data were assumed not to be correlated between years; and,
- Nitric acid production emission factors were assumed not to be correlated, since the mix of operating plants is very different in the most recent year compared with 1990 – only two of the original eight units are still operating in the latest inventory year, all of which now have differing levels of abatement fitted.

A 2.4 UNCERTAINTIES IN GWP WEIGHTED EMISSIONS

A 2.4.1 Uncertainty in the emissions

The uncertainty in the combined GWP weighted emission is given in **Table A 2.4.1**, along with uncertainties for each of the seven categorised GHGs. This is calculated as half of the 95% confidence range, i.e. the limits between which there is a 95% probability that the actual value of emissions falls. Note that the uncertainty in the GWP is not accounted for.

A 2.4.2 Uncertainty in the Trend

The uncertainty estimates for all gases are summarised in **Table A 2.4.1**. The trend is calculated for each simulation as $\frac{latest\ year\ sample - 1990\ sample}{1990\ mean}$ and the 2.5 and 97.5 percentiles are shown to indicate a 95% confidence range. This can produce different results from a trend calculated as $\frac{latest\ year\ sample - 1990\ sample}{1990\ sample}$, particularly where simulations of 1990 emissions are near or can go below zero.

Note that the uncertainty in the GWP is not accounted for.

Table A 2.4.1 Summary of Monte Carlo Uncertainty Estimates

IPCC Source Category	Gas	1990 Emissions	2020 Emissions	95% confidence interval for 1990 emissions 2.5 percentile	95% confidence interval for 1990 emissions 97.5 percentile	Uncertainty in 1990 emissions as % of emissions in category	95% confidence interval for 2020 emissions 2.5 percentile	95% confidence interval for 2020 emissions 97.5 percentile	Uncertainty in 2020 emissions as % of emissions in category	Trend in emissions between 1990 and 2020	Uncertainty in the trend in emissions between 1990 and 2020 as % of 1990 emissions[a] 2.5 percentile	Uncertainty in the trend in emissions between 1990 and 2020 as % of 1990 emissions[a] 97.5 percentile
		Gg CO$_2$e	Gg CO$_2$e	Gg CO$_2$e	Gg CO$_2$e	%	Gg CO$_2$e	Gg CO$_2$e	%	%	%	%
TOTAL	CO$_2$ (net)	608,643	324,010	597,828	619,483	1.8%	317,742	330,347	1.9%	-47%	-49%	-45%
	CH$_4$	134,785	51,619	107,876	173,081	24.2%	45,125	60,221	14.6%	-62%	-90%	-41%
	N$_2$O	49,820	21,170	38,114	68,011	30.0%	18,257	25,566	17.3%	-58%	-94%	-34%
	HFC	14,403	12,215	12,239	16,576	15.1%	11,031	13,388	9.6%	-15%	-32%	2%
	PFC	1,649	160	1,338	1,962	18.9%	125	200	23.5%	-90%	-109%[a]	-71%
	SF$_6$	1,201	407	1,074	1,327	10.5%	386	428	5.1%	-66%	-77%	-55%
	NF$_3$	0.1	0.4	0.1	0.2	44.1%	0.2	0.5	46.5%	208%	71%	369%
	All	**810,501**	**409,581**	**777,283**	**853,272**	**4.7%**	**399,617**	**420,845**	**2.6%**	**-49%**	**-55%**	**-45%**

Uncertainty calculated as 0.5*R/E where R is the difference between 2.5 and 97.5 percentiles and E is the mean calculated in the simulation.

Emissions of CO$_2$ are net emissions (i.e. sum of emissions and removals).

Emissions in this table are taken from the Monte Carlo model output. The central estimates, according to gas, for 1990 and the latest inventory year are very similar but not identical to the emission estimates in the inventory. The Executive Summary of this NIR and the accompanying CRF tables present the agreed national GHG emissions and removals reported to the UNFCCC.

[a] What is specifically presented here is the 95% confidence interval for the change in emissions as a percentage of 1990 emissions; this is different to the 95% confidence interval of the percentage changes since 1990.

[b] Note that for categories where emissions have completely, or almost completely stopped generating emissions in the latest year (i.e. has a trend of near -100%), the 2.5th percentile for the trend might be presented as a decline of over 100%. This should not be interpreted to mean that emissions might now be negative, instead this reflects that if we were underestimating base-year emissions, then the decline in emissions in CO_2e from this source might be greater that the current total emissions estimated for the base year. The below simplified example illustrates how this might occur.

If:

- Base year emissions for a category is estimated to be 1 Mt CO_2e
- Latest year emissions for a category is estimated to be 0 Mt CO_2e
- Uncertainty in the base year and latest year emissions estimate is 10%

Then:

- The central estimate for the trend is -100%
- The lower limit for the trend (in Mt CO_2e) would be

  lower bound for latest year emissions estimated [i.e. 0 Mt CO_2e * (100% - 10%)]] minus the upper bound for base year estimated emissions [i.e. 1 Mt CO_2e * (100% + 10%)]

  which equates to -1.1 Mt CO_2e

- -1.1 Mt CO_2e is -110% of the best estimate of base year emissions

A 2.5 SECTORAL UNCERTAINTIES

A 2.5.1 Overview of the Method

Sectoral uncertainties were calculated from the same base data used for the “by gas” analysis. The emissions and uncertainties per sector are presented in **Table A 2.5.1**. The estimates are presented in IPCC categories, which is consistent with the reporting format used within this submission to the UNFCCC, but we recommend that these estimates should only be considered as indicative.

Table A 2.5.1 Sectoral Uncertainty Estimates

IPCC Source Category	1990 Emissions (kt CO_2e)	2020 Emissions (kt CO_2e)	95% confidence interval for 2020 emissions 2.5 percentile	95% confidence interval for 2020 emissions 97.5 percentile	Uncertainty in 2020 emissions as % of emissions in category	% Trend in emissions between 1990 and 2020	Uncertainty in the trend in emissions between 1990 and 2020 as % of 1990 emissions[a] 2.5 percentile[a]	Uncertainty in the trend in emissions between 1990 and 2020 as % of 1990 emissions[a] 97.5 percentile
1A1a	205,405	51,571	49,962	53,201	3.1%	-75%	-78%	-72%
1A1b	17,864	11,122	9,668	12,698	13.6%	-38%	-62%	-15%
1A1c	16,448	14,479	14,167	14,859	2.4%	-12%	-27%	3%
1A2a	3,594	935	888	981	5.0%	-74%	-80%	-68%
1A2b	4,338	639	605	672	5.2%	-85%	-105%	-67%
1A2c	12,081	4,961	4,689	5,236	5.5%	-59%	-67%	-51%
1A2d	4,637	1,321	1,244	1,398	5.8%	-72%	-82%	-61%
1A2e	7,636	3,986	3,768	4,205	5.5%	-48%	-55%	-41%
1A2f	6,695	2,314	2,056	2,582	11.4%	-65%	-89%	-43%
1A2g	38,495	25,178	23,980	26,369	4.7%	-35%	-42%	-27%
1A3a	1,892	695	556	835	20.1%	-63%	-84%	-43%
1A3b	111,151	89,901	88,341	91,488	1.8%	-19%	-21%	-17%
1A3c	1,478	1,440	1,163	1,718	19.3%	-3%	-28%	23%
1A3d	7,721	4,843	3,965	5,719	18.1%	-37%	-56%	-18%
1A3e	228	567	457	678	19.5%	149%	97%	201%

IPCC Source Category	1990 Emissions (kt CO_2e)	2020 Emissions (kt CO_2e)	95% confidence interval for 2020 emissions 2.5 percentile	95% confidence interval for 2020 emissions 97.5 percentile	Uncertainty in 2020 emissions as % of emissions in category	% Trend in emissions between 1990 and 2020	Uncertainty in the trend in emissions between 1990 and 2020 as % of 1990 emissions[a] 2.5 percentile[a]	Uncertainty in the trend in emissions between 1990 and 2020 as % of 1990 emissions[a] 97.5 percentile
1A4a	25,377	18,383	17,781	18,989	3.3%	-28%	-33%	-23%
1A4b	80,313	65,332	62,753	67,909	3.9%	-19%	-24%	-14%
1A4c	6,258	5,052	3,487	6,625	31.1%	-19%	-63%	19%
1A5b	5,351	1,420	1,309	1,530	7.8%	-73%	-81%	-66%
1B1	23,516	672	586	756	12.6%	-97%	-115%	-80%
1B2	17,489	7,489	6,303	9,068	18.5%	-57%	-88%	-34%
2A1	7,295	3,900	3,775	4,025	3.2%	-47%	-48%	-45%
2A2	1,329	1,000	950	1,050	5.0%	-25%	-35%	-15%
2A3	412	323	307	340	5.0%	-22%	-23%	-20%
2A4	1,128	438	423	454	3.6%	-61%	-65%	-57%
2B1	1,896	1,645	1,610	1,681	2.1%	-13%	-17%	-9%
2B2	3,855	49	44	54	10.0%	-99%	-187%	-45%
2B3	19,946	-	-	-	n/a	-100%	-100%	-100%
2B6	105	135	121	148	10.0%	29%	5%	53%
2B7	224	142	134	150	5.6%	-37%	-46%	-28%
2B8	4,789	2,607	1,830	3,402	30.1%	-46%	-74%	-17%
2B9	14,406	76	69	84	10.0%	-99%	-115%	-84%

IPCC Source Category	1990 Emissions (kt CO_2e)	2020 Emissions (kt CO_2e)	95% confidence interval for 2020 emissions 2.5 percentile	95% confidence interval for 2020 emissions 97.5 percentile	Uncertainty in 2020 emissions as % of emissions in category	% Trend in emissions between 1990 and 2020	Uncertainty in the trend in emissions between 1990 and 2020 as % of 1990 emissions[a] 2.5 percentile[a]	Uncertainty in the trend in emissions between 1990 and 2020 as % of 1990 emissions[a] 97.5 percentile
2B10	191	56	43	69	23.6%	-71%	-95%	-47%
2C	27,420	10,722	9,810	11,636	8.5%	-61%	-69%	-53%
2D	553	379	227	618	51.7%	-32%	-100%	26%
2E	6	25	14	38	46.5%	339%	149%	568%
2F	8	12,189	11,006	13,365	9.7%	144186%	130178%	158101%
2G	1,484	1,216	750	2,187	59.1%	-18%	-82%	54%
3A	24,688	20,937	18,778	23,330	10.9%	-15%	-30%	0%
3B	7,594	6,629	5,817	7,521	12.9%	-13%	-30%	4%
3D	14,634	11,726	9,702	14,532	20.6%	-20%	-44%	4%
3F	245	-	-	-	n/a	-100%	-100%	-100%
3G	1,016	950	752	1,147	20.8%	-7%	-35%	22%
3H	329	235	153	345	40.8%	-29%	-83%	21%
3J	449	307	180	449	43.8%	-32%	-83%	19%
4	305	171	57	398	99.3%	-44%	-182%	57%
4A	-13,151	-17,126	-19,806	-14,396	15.8%	30%	25%	36%
4B	16,962	15,092	12,220	17,977	19.1%	-11%	-18%	-4%
4C	2,704	730	-297	1,764	141.1%	-73%	-87%	-59%

IPCC Source Category	1990 Emissions (kt CO_2e)	2020 Emissions (kt CO_2e)	95% confidence interval for 2020 emissions 2.5 percentile	95% confidence interval for 2020 emissions 97.5 percentile	Uncertainty in 2020 emissions as % of emissions in category	% Trend in emissions between 1990 and 2020	Uncertainty in the trend in emissions between 1990 and 2020 as % of 1990 emissions[a] 2.5 percentile[a]	Uncertainty in the trend in emissions between 1990 and 2020 as % of 1990 emissions[a] 97.5 percentile
4D	2,553	2,679	1,945	3,418	27.5%	5%	-36%	47%
4E	5,891	4,349	2,399	6,299	44.8%	-26%	-36%	-16%
4F	-	-	-	-	n/a	n/a	n/a	n/a
4G	-2,089	-2,128	-2,445	-1,813	14.9%	2%	-3%	7%
5A	60,604	12,889	7,398	20,862	52.2%	-79%	-142%	-34%
5B	31	1,933	1,200	2,993	46.4%	6106%	3754%	9503%
5C	1,552	281	106	665	99.3%	-82%	-192%	-22%
5D	3,168	2,726	1,545	6,165	84.7%	-14%	-45%	19%
Grand Total	**810,501**	**409,581**	**399,617**	**420,845**	**2.6%**	**-49%**	**-55%**	**-45%**

Note: Emissions in this table are taken from the Monte Carlo model output. The central estimates, according to gas, for 1990 and the latest inventory year are very similar but not identical to the emission estimates in the inventory. The Executive Summary of this NIR and the accompanying CRF tables present the agreed national GHG emissions and removals reported to the UNFCCC.

[a] What is specifically presented here is the 95% confidence interval for the change in emissions as a percentage of 1990 emissions; this is different to the 95% confidence interval of the percentage changes since 1990. Further detail can be found in section **A 2.4.2**.

[b] Note that for categories where emissions have completely, or almost completely stopped generating emissions in the latest year (i.e. has a trend of near -100%), the 2.5th percentile for the trend might be presented as a decline of over 100%. This should not be interpreted to mean that emissions might now be negative, instead this reflects that if we were underestimating base-year emissions, then the decline in emissions in CO_2e from this source might be greater that the current total emissions estimated for the base year. The below simplified example illustrates how this might occur.

If:

- Base year emissions for a category is estimated to be 1 Mt CO_2e
- Latest year emissions for a category is estimated to be 0 Mt CO_2e
- Uncertainty in the base year and latest year emissions estimate is 10%

Then:

- The central estimate for the trend is -100%
- The lower limit for the trend (in Mt CO_2e) would be

  lower bound for latest year emissions estimated [i.e. 0 Mt CO_2e * (100% - 10%)]] minus the upper bound for base year estimated emissions [i.e. 1 Mt CO_2e * (100% + 10%)]

  which equates to -1.1 Mt CO_2e

- -1.1 Mt CO_2e is -110% of the best estimate of base year emissions

A 2.6 COMPARISON OF UNCERTAINTIES FROM THE ERROR PROPAGATION AND MONTE CARLO ANALYSES

Comparing the results of the error propagation approach, and the Monte Carlo estimation of uncertainty by simulation, is a useful quality control check on the behaviour of the Monte Carlo model.

The reason that the error propagation approach is used as a reference is because the approach to the error propagation approach has been defined and checked by the IPCC, and is clearly set out in the IPCC 2000 Good Practice Guidance and the 2006 Guidelines. The UK has implemented the IPCC error propagation approach as set out in this guidance. The implementation of an uncertainty estimation by simulation cannot be prescriptive, and will depend on how the country constructs its model, and the correlations included within that model. Therefore, there is a greater likelihood of errors being introduced in the model used to estimate uncertainty by Monte Carlo simulation.

If all the distributions in the Monte Carlo model were normal, and the assumed correlations were identical, the estimated errors on the trend from the Monte Carlo model should approach those estimated by the error propagation approach if enough iterations are done. The error propagation approach assumes 100% correlation between EFs in the base and inventory year, and no correlation between sources, however in reality the nature and degree of correlation varies by source, and many distributions are not normal but heavily skewed, particularly those with very high uncertainty. These differences interact in various ways, but would be expected broadly to result in higher trend uncertainty, and lower uncertainty on the most recent year’s total in the Monte Carlo uncertainty estimates compared to the error propagation approach. This can be seen in **Table A 2.6.1** which shows differences in the trend uncertainty between the error propagation and Monte Carlo approaches. These differences mostly arise from the fact that the error propagation approach only uses normal distributions, cannot account for different uncertainty parameters between the 1990 and the latest inventory year, cannot account for correlations between sources, and automatically assumes a correlation between the emission factor uncertainty in 1990 and the most recent year.

The central estimates of emissions generated by the Monte Carlo model in 1990, and those in the latest inventory year, are very close. We would not expect the central estimates from the two methods to be identical, but with a very large number of iterations we would expect the difference to tend to zero. It should be noted that the Approach 1 uncertainties base year is 1990 for N_2O, CH_4 and CO_2, but is 1995 for the F-gases; this differs from the Approach 2 uncertainties which uses 1990 emission for all gases for the starting year.

Table A 2.6.1 Comparison of the error propagation (Approach 1) and Monte Carlo (Approach 2) uncertainty analyses

Method of uncertainty estimation	Central estimate (Gg CO_2 equivalent) [b] Base year	Central estimate (Gg CO_2 equivalent) [b] 2020	Uncertainty on level in 2020, 95% CI	Uncertainty on trend, 95% CI (1990 / base year to 2020)[a]
Error propagation	813,352	409,524	2.6%	1.5%
Monte Carlo	813,659	409,581	2.6%	2.7%

Notes:

CI Confidence Interval

[a] Calculated as half the difference between 2.5 and 97.5 percentiles, assuming a normal distribution is equal to ±1.96 standard deviations on the central estimate.

[b] Net emissions, including emissions and removals from LULUCF

ANNEX 3: Other Detailed Methodological Descriptions for Individual Source or Sink Categories, Including for KP-LULUCF Activities.

This Annex contains background information about methods used to estimate emissions in the UK GHG inventory. This information has not been incorporated in the main body of the report because of the level of detail, and because the methods used to estimate emissions cut across sectors.

This Annex provides background information on the fuels used in the UK GHG inventory, mapping between IPCC and NAEI source categories and detailed description of methods used to estimate GHG emissions, and emission factors used in those methods.

A 3.1 ENERGY

Methods for calculating emissions within the energy sector are detailed in the method statements set out in **Chapter 3**. This Annex details the emission factors used and their source, and elaborates on references commonly used within the Energy sector. The national energy balance (and how it is used) is described in **ANNEX 4:**.

A 3.1.1 Emission factors

Emission factors used for the 2021 submission for sectors 1A and 1B can be found in the accompanying excel file: 'Energy_background_data_uk_2022.xlsx'. This can be found as one of the additional documents here: https://naei.beis.gov.uk/reports/reports?report_id=1072. Note that there can be a delay between the NIR being published on the NAEI website after official submission.

A 3.1.2 Commonly used references

This section describes data sources that are used across multiple emission sources within the energy sector, and how they are used.

Baggott et al., 2004 ‑ Carbon factors review

A review of the carbon factors used in the UK GHG inventory was carried out in 2004. The report detailing this study is available from:

http://naei.beis.gov.uk/reports/reports?report_id=417

This aimed to validate existing emission factors and seek new data for country specific emission factors for the UK. At the time of publication this reference provided new emission factors for:

- coal from power stations;
- fuels used in the cement industry;
- a number of petroleum based fuels;
- natural gas; and
- coke oven and blast furnace gas.

Since then following updates are made to the following emission factors based on new information:

1. Coal emission factors are adjusted based on the annual variations in the GCV of the fuels using methods developed as part of the 2004 analysis (Baggott et al., 2004).

   $EF_y = EF_{ref} / GCV_{ref} * GCV_y$

   Where

   EF_y is the emission factor (EF) in year y

   EF_{ref} is the EF in the reference year (the year for which data are available)

   GCV_{ref} is the GCV in the reference year

   GCV_y is the GCV in year y

2. Since the advent of EU ETS in 2005, a number of sources of emissions from coal which had previously been reliant on Baggott et al., 2004 have now been replaced with data from the ETS, where the data set was considered suitable (high proportion of source included, and high proportion of T3 plant specific data). In addition, in 2014 the use of oxidation factors from this report was reviewed, and where suitable background evidence to support the factors used were not available, the IPCC default (of 1, IPCC 2006) has been used.
3. Emission factors for petroleum based fuels (where ETS data are not available) are still largely based on Baggott et al., 2004. These were reviewed in 2014 and compared with the defaults in the 2006 IPCC Guidelines and found to be largely within the range of the 2006 Guidelines. No new data for the UK has been identified and the emission factors from Baggott et al., 2004 are still considered to be relevant country specific emission factors.
4. During 2017-18, a review of the UK's shipping inventory was conducted (Scarborough et al., 2018). This identified new carbon emission factors for marine fuels, which replace the factors identified as part of Baggot et al., 2004.
5. Emission factors for natural gas are updated annually based on analyses from the gas network operators (Personal Communications from network operators, 2019). As part of the systems improvements made to the inventory database in 2020 (moving from mass to energy units, and from gross to net), data from the gas operators has been further analysed and a revised gross to net conversion has been derived. This has

been applied to the data from the early part of the time series, which came from Baggott et al., 2004.

6. Emission factors for coke oven gas and blast furnace gas are estimated based on a carbon balance approach (as described in Chapter 3, **MS 4**).
7. The Mineral Products Association provide data for fuels used in the cement industry annually on a confidential basis, and these are validated with EU ETS data (Personal Communication, MPA, 2021). For the 2020 submission, data received for the 2004 review was reconsidered for cement, and revised coal factors for the early part of the time series (that were not received in time for inclusion in the final review report) have now been incorporated into the inventory.

A new review of carbon emission factors was conducted during 2017, focusing on those factors retained from the 2004 review (Brown et al., 2017). This concluded that the factors that are currently in use are slightly more conservative than more recent values identified, and that there was no new robust evidence upon which we could justify changing the current factors. This report is available here: http://naei.beis.gov.uk/reports/reports?report_id=947

A 3.1.2.1 The Pollution Inventory and other regulators' inventories

The Pollution Inventory (PI) has, since 1998, provided emission data for the six Kyoto gases (NF_3 is not included) and other air pollutant for installations regulated by the Environment Agency (EA) in England and Natural Resources Wales (NRW) in Wales. This is part of the UK’s process for managing regulated emissions from industry processes under the IPCC permitting system. The PI does contain earlier data of carbon dioxide emissions at some sites reported from 1994 onwards. The Scottish Pollutant Release Inventory (SPRI) covers processes regulated by the Scottish Environment Protection Agency (SEPA), and contains data from 2002 and 2004 onwards. The Northern Ireland Pollution Inventory (NIPI) covers processes regulated by the Northern Ireland Environment Agency and includes data for 1999 onwards.

These data are subject to some very significant limitations:

- Emissions of each pollutant are reported for each permitted installation as a whole, so emissions data for carbon dioxide, for example, can cover emissions from fuel use as well as from an industrial process. No information is given on what the source of emissions is, so a judgement has to be made about the scope of reporting;
- Permitting arrangements have changed over time, so the reporting of data is not on a consistent basis across the time-series. In general, the tendency has been to reduce the number of permits, so that whereas in the early 1990s there might have been separate permits at an industrial installation covering the boiler plant and the chemical processes, from the late 1990s onwards the tendency would be to issue a single permit to cover both. Therefore, the problems with the scope of emissions data mentioned in the first bullet point are most severe for the second half of the GHGI time series; and,
- Since 1998, process operators need only report emissions of each pollutant if those emissions exceed a reporting threshold. For example, where emissions from an installation are less than 10,000 tonnes of CO_2, or 10 tonnes of methane, the operator does not need to report any emissions data for that substance in that year. Reporting thresholds are irrelevant for many of the sectors of interest to this study, since emissions would be many times higher than the thresholds, but the reporting

thresholds do mean that it is necessary to consider whether the data available in the PI (and in the SPRI & NIPI for later years) will be complete.

Despite these limitations, these data are still a useful source of information for the UK GHG inventory. A considerable amount of effort is put into manually interpreting the individual returns and allocating these to appropriate categories for use in the inventory estimates by the Inventory Agency.

A 3.1.2.2 The Environmental and Emissions Monitoring System (EEMS) Reporting System

Emissions from upstream oil and gas production facilities, including onshore terminals, are estimated based on operator reporting via EEMS, managed by the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED) and developed in conjunction with the trade association Oil & Gas UK (formerly the UK Offshore Operators' Association, UKOOA). The EEMS data provides a detailed inventory of point source emissions estimates, based on operator returns for the years 1995-2020. However, the EEMS data for 1995 to 1997 are not complete, frequently exhibiting duplicate entries with identical submissions by operators across years. Since the 1995 – 1997 data are not considered reliable, the EEMS dataset is only used directly to inform national inventory estimates from 1998 onwards for the following sources:

- gas flaring;
- own gas combustion;
- well testing; and
- oil loading (onshore and offshore).

[Activity data are not routinely collected via EEMS for sources including: fugitive releases, direct process activities, oil storage or gas venting. The emissions from these sources are reported as annual estimates by operators and used directly within the inventory.]

These EEMS-derived activity data enable detailed analysis of the oil & gas emissions and related emission factors at the installation level, providing a high degree of data transparency and enabling the Inventory Agency to perform quality checks by source, by site, by year to identify and check/resolve any potential data gaps or outliers. The EEMS data per installation are only available back to 1998. The UK inventory estimates for the 1990-1997 period are based on industry surveys and analysis that were submitted to UK Government by the trade association, UKOOA; these data are more aggregated, per source but aggregated across all installations during 1995 to 1997, and aggregated across sources for 1990-1994. The EEMS data from 1998 onwards help to inform the EFs that are combined with oil and gas sector-wide activity statistics back to 1990 in order to derive time series consistent estimates.

A 3.1.2.3 Fynes & Sage (1994)

Fynes and Sage is a country-specific reference from the mid-1990s, and it includes analysis of solid fuels typically used in the UK economy in that period, deriving mass-based emission factors that are used within the UK GHGI. In the 1990s, coal used in the UK economy was predominantly mined in the UK, whereas over the time series of the inventory there has been a decline in the share of coal from UK sources and an increase in coal imports from around the world.

For recent years, for the more significant emission sources, e.g. energy industries and manufacturing industries, the Inventory Agency uses EFs that are derived from EU ETS data, but for smaller emission sources in the UK that still use solid fuels (such as residential, collieries) the Fynes and Sage data are retained, as there are no EU ETS data for fuels used in these sectors. There is some uncertainty regarding how representative the EFs from Fynes and Sage may be for these smaller combustion sources, but we note that the use of coal-fired technology in sectors such as collieries and residential is predominantly in the UK coal production areas, where local supplies are still available.

A 3.1.3 Feedstocks and Non-Energy Use (NEU) of fuels

The estimation methods are described within individual sections of the NIR, but are summarised here. The general approach adopted in the UK GHG inventory is to assume that emissions from all non-energy uses of fuels are zero (i.e. the carbon is assumed to be sequestered in products such as plastics and other chemicals), except for cases where emission sources can be identified and emission estimates included in the inventory. There is one exception to this, for petroleum coke where we have no information on any non-emissive uses at all, and so we adopt the conservative approach of assuming that all petroleum coke use is emissive.

The UK Inventory Agency conducts periodic studies into the fate of fuels reported as non-energy use, in order to assess the levels of stored carbon and carbon emitted for different fuels over the time series. These detailed studies are supplemented through annual data gathering and consultation with stakeholders to maintain an accurate representation of the emitted and stored carbon in the inventory.

The assumptions and estimates for individual sources are based on a review conducted in 2013-14 (Ricardo-AEA, 2014b) which included research into UK-specific activities and data sources as well as a review of the National Inventory Reports (NIRs) of other countries.

The sections below outline the emission sources from feedstock and NEU of fuels that are included in the UK GHGI, the source data and estimation methods and a summary of the time series for each of the fuel types where there is a stored carbon component in the UK energy balance. The estimates are all presented in CRF Tables 1.Ab and 1.Ad.

Table A 3.1.1 Summary of Emission Sources for UK Fuels Allocated as Non Energy Use in UK Energy Statistics

Fuel	IPCC	Source Category
Light petroleum distillates and natural gas liquids[5]	1A1a	Scrap tyre combustion in power stations (1994 to 2000 only). Fossil carbon in MSW combustion in energy from waste plant.
	1A1b	Other petroleum gas use in refineries (2004, 2006 to 2011, 2013 to 2020 only). *Re-allocated from non-energy use as EU ETS and trade association data indicates that DUKES data on OPG combustion are an under-report.*
	1A2f	Waste solvents, waste-derived fuels containing fossil carbon, in cement kilns. Scrap tyres and waste plastics etc. combusted in cement kilns.
	1A2g	Industrial combustion of waste solvents. *Emissions of carbon from chemical feedstock via combustion of products such as synthetic rubbers and solvents.*
	2B8	Energy recovery from process off-gases in the chemical industry. *Large quantities of naphtha, butane, propane, ethane, and other petroleum gases are listed in DUKES as used for non-energy applications and these fuels are known to be used extensively as chemical feedstocks. However, EU ETS and operator data indicate that process off-gases, derived from the chemical feedstocks, are a major fuel for ethylene production processes and other petrochemical sites. Emissions of CO_2 are reported in 2B8.*
	5C	Fossil carbon in chemical waste incineration. Fossil carbon in MSW incineration. Fossil carbon in clinical waste incineration.
Lubricants	1A1a	Waste oil combustion in power stations.
	1A2f	Waste oil combustion in cement kilns.
	1A2g	Waste oil combustion in unclassified industry (including road-stone coating plant)
	1A3biv	Lubricant combustion in moped engines
	2D1	Lubricant oxidation in aircraft, industrial, road vehicle (except moped), marine shipping and agricultural engines.
	5C	Incineration of waste oil.
Bitumen	n/a	*No known UK applications that lead to GHG emissions.*

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[5] I.e. naphtha, Liquid Petroleum Gases (LPG), Refinery Fuel Gas (RFG) / Other Petroleum Gases (OPG), gas oil and Ethane. Including emissions of carbon from chemical feedstock via combustion of products such as synthetic rubbers and plastics.

Fuel	IPCC	Source Category
Petroleum coke	1A2f, 1A2g, 1A4b	Based on reported energy use data by specific industries within datasets such as EU ETS and also from direct dialogue with industry representatives, the Inventory Agency re-allocates a small proportion of the reported “NEU” allocation from DUKES, and reports emissions within the UK GHG inventory. This re-allocation generates emissions for the mineral processing sector (1A2f) and other industry (1A2g) and for petcoke use in the domestic sector (1A4b).
	2A4, 2B6, 2C1, 2C3, 2D4	There are non-combustion, emissive uses of petcoke in the UK through the use of petcoke-derived anodes in the metal processing industries. Emissions from these uses of petcoke are reported in 2C1 (electrode use in electric arc furnaces) and 2C3 (anode use in aluminium manufacture). Petroleum coke is also used in the minerals (2A4) and chemicals industries (2B6) leading to further emissions. The remaining consumption of petroleum coke is also assumed to be emissive, with emissions reported under 2D4.
Other Oil	2D2	Carbon released from use of petroleum waxes. Uses of petroleum waxes includes candles, with carbon emitted during use.
Coking coal (coal oils and tars)	n/a	*Unknown quantities of coal tar pitch are used in the manufacture of anodes for industrial processes. In the UK inventory the emissions from the use of these anodes are allocated only against petroleum coke (also used in anode production). This is a small mis-allocation of emissions between the two fuels since the carbon emitted is likely to arise from both petroleum coke and the coal tar pitch, but it is due to lack of detailed data, and does not affect the accuracy of UK inventory emissions.*
Natural Gas	2B1 2B8	Ammonia and methanol production leading to direct release of CO_2 from natural gas used to provide the energy for steam reforming and from natural gas feedstock to the reformer. Carbon originating in the natural gas feedstock which is converted into methanol is assumed to be stored.

A 3.1.3.1 Naphtha, Ethane, Gas Oil, Refinery/Other Fuel Gas (RFG/OPG) Propane and Butane (LPG)

Ethane, LPG (given separately as propane & butane in the energy statistics), gas oil, refinery / other fuel gas (RFG/OPG) and naphtha are all consumed in very significant quantities for non-energy uses, primarily as feedstock in chemical manufacturing. In the UK, several major petrochemical production facilities are supplied with Natural Gas Liquid (NGL) feedstock directly from upstream production pipelines, and then utilise NGL fractions such as ethane, propane and butane in their manufacturing processes. In addition, several integrated refinery / petrochemical complexes in the UK use a proportion of the refinery fuel gas as a feedstock in petrochemical production.

The NEU allocations presented in DUKES reflect the reported disposals of these commodities as feedstocks to chemical and petrochemical companies. There are several sources of GHG emissions from this stock of “NEU” feedstock carbon, although a high proportion of carbon is stored into products and not emitted.

One large emission source known to occur in the UK is the use of carbon-containing process off-gases as a fuel within the chemical facilities. Whilst the exact source of the carbon cannot be traced directly to a specific feedstock commodity within the UK sectoral approach, the available information from EU ETS and from consultation with operators enables the Inventory

Agency to derive estimates of the GHG emissions across the time series from this emission source.

The majority of emissions are from installations manufacturing ethylene, but a number of other chemical sites report additional emissions in the EU ETS that can be attributed to the combustion of process off-gases and residues derived from the chemical feedstock. As a result, the UK inventory emissions in 2B8 now include estimates of emissions from use of process off-gases and residues at 5 ethylene manufacturing installations and 17 other chemical manufacturing installations in the UK. The derivation of a time series of emission estimates from these sources is based as far as possible on reported data by plant operators within trading scheme data and other regulatory reporting mechanisms. For the early part of the time series, data on changes in plant capacity over time is used to derive the best estimates of activity and emissions by extrapolation back from later emission estimates, whilst for later years the completeness and transparency of operator reporting is greater. Therefore, whilst the uncertainty for the emission estimates in the early part of the time series is significantly greater than for those in recent years, the Inventory Agency has made best use of the available data to derive the time series estimates of emissions from “NEU” activity. Consultation with a sector trade association has also confirmed that there are no other sector estimates of this activity, or of production data across the time series, that could be used to further improve the time series (Personal communication: Chemical Industries Association, 2014).

Other emissions included within the UK GHG inventory include emissions from the destruction of chemical products, e.g. when wastes are incinerated or used as fuels. Although emissions from incineration and combustion of wastes are estimated, we cannot relate the carbon in these wastes back to individual feedstock, so it is not possible to generate reliable UK estimates of the proportion of carbon that is ultimately emitted from each individual fuel. Incineration of wastes derived from chemical feedstocks will be reported in 1A1a (in the case of plastics etc. in municipal waste incinerated with energy recovery) and in 5C (in the case of chemical, clinical and municipal wastes incinerated without energy recovery). Waste-derived fuels, including waste solvents, waste plastics and scrap tyres are used as fuels in cement kilns and other industrial plants, and emissions reported in 1A2. Tyres contain a mixture of natural and synthetic rubbers, and so where waste tyres are used as a fuel, the emission estimates take into account that only some of the carbon emitted is derived from fossil fuels.

Some propane / butane mixtures are used as a propellant in aerosols and are emitted as VOC. The UK inventory contains estimates of these VOC emissions, combined with emissions of solvents used in aerosols.

It is assumed that all gas oil used for non-energy purposes is used as a feedstock material, and consultation with DECC (now BEIS) energy statisticians supports this (Personal communication: Will Spry, DECC Energy Statistics team, 2014). A possible alternative use would be in explosives, but consultation with the Health and Safety Executive, who regulate the UK explosives industry, has confirmed that no UK installations manufacture explosives using gas oil or fuel oil as a feedstock (HSE, 2013).

A 3.1.3.2 Lubricants

Lubricants are listed separately in the UK energy statistics and are used in vehicles and in machinery. The inventory includes estimates of emissions of carbon due to oxidation of lubricants during use, and also includes estimates of emissions from the combustion of waste lubricants and other oils used as fuel.

UK GHG inventory estimates of the quantities of lubricants burnt as fuels are based on data from Recycling Advisory Unit, 1999; BLF/UKPIA/CORA, 1994; Oakdene Hollins Ltd, 2001 & ERM, 2008, as well as recent research to access information regarding the UK market for waste oils and the impact of European Directives to consolidate industrial emission regulations such as the Waste Incineration Directive (Oil Recycling Association, 2010). Estimates of waste oil combustion are derived for the following source categories:

- 1A1a Power stations;
- 1A2f Cement kilns; and
- 1A2f Other (unclassified) industry.

The estimated emissions for other industry assume that waste oils are used by two sectors: road-stone coating plant and garages. Other sectors may use waste oils as a fuel or as a reductant, but research to date provides no compelling evidence that there is a significant gap in the UK inventory for waste oil use by industrial operators.

The emission trends from power station use of waste lubricants reflect the fact that the Waste Incineration Directive (WID) had a profound impact on the market for waste oil, used as a fuel. It is assumed that no waste oil was burnt in power stations for the years 2006-2008, on the basis that the classification of waste oil as a fuel would have led to users being subject to the requirements of WID. In 2009 a Quality Protocol[6] was introduced that allowed compliant fuel produced from waste oils to be burned as non-waste and this has encouraged a resumption in the consumption of waste oil-derived fuels from 2009 onwards.

Carbon dioxide emission estimates for the oxidation of lubricants within vehicle engines and machinery, and the use of waste oils for energy are all based on a single carbon emission factor derived from analysis of the elemental composition of a series of UK-sourced samples of waste oil (Passant, 2004). The UK inventory adopts the IPCC Tier 1 methodology for lubricant use i.e. assuming that 20% of all lubricants are oxidized during use. This assumption is used for the various sub-categories of lubricant use (including road, rail, marine, off-road and air transport) given in DUKES.

A 3.1.3.3 Bitumen

In the UK, bitumen is used only for applications where the carbon is stored. By far the most important of these is the use of bitumen in road dressings. The inventory does assume that a very small proportion of the carbon in the bitumen itself is emitted as VOC during road-stone coating but does not include any estimates of direct carbon emissions from uses of bitumen. Industry consultation in 2013 (UK Petroleum Industries Association, 2013; Refined Bitumen

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[6] http://www.environment-agency.gov.uk/business/topics/waste/116133.aspx

http://webarchive.nationalarchives.gov.uk/20140328084622/

Association, 2013) has confirmed that there are no emissive applications of bitumen in the UK. Around 85% of bitumen is used in road paving, with the remaining proportion used almost entirely in the manufacture of weather-proofing materials.

A 3.1.3.4 Coal Oils and Tars

Coal-tars and benzole are by-products of coke ovens. Consultation with the operators of coal ovens (Tata, 2013) and also the UK company that refines and processes coal tars and benzole (Koppers UK, 2013) has confirmed that all of these materials are collected, refined and processed into a range of products that are not used as fuels. The carbon within coal tars and oils are entirely used within chemical processes. In some cases, the carbon is processed into anodes used in the ferrous and non-ferrous metals industries and then used (in the UK and overseas) within emissive applications. The UK inventory already includes estimates of emissions from UK consumption of carbon anodes within these industries, using methods based on UK metal production statistics.

Based on the evidence from process operators, the Inventory Agency allocates all of the reported coal tars and oils to Non Energy Use, i.e. assuming that all carbon is stored and there are no GHG emissions from this source-activity. The Digest of UK Energy Statistics (BEIS, 2021) also report the use of tars and benzole entirely to Non Energy Use.

Coal-tar pitch is used in the manufacture of electrodes, together with petroleum coke and a proportion of the carbon ultimately emitted, but details of input materials are scarce; emissions of carbon from these sources are included in the inventory attributed to petroleum coke. This may introduce a small mis-allocation of emissions between petroleum coke and coal oils and tars, but does not affect the UK inventory emissions total.

A 3.1.3.5 Natural Gas

Natural gas is used as a chemical feedstock for the manufacture of ammonia and formerly for methanol as well, though production of the latter ceased in 2001. Emissions occur directly as a result of a) combustion of natural gas used to power the steam reforming process that is required for manufacture of both ammonia and methanol; b) oxidation of gas in the steam reforming, producing CO_2 which in the case of ammonia production is not needed and is instead emitted. The emissions are reported under 2B1 for ammonia and 2B8 for methanol.

Most of the emissions from feedstock use of natural gas in ammonia production are at source, i.e. waste gases containing carbon are emitted directly from the ammonia plant. Up until 2001, some was exported to a neighbouring methanol plant and here converted into methanol, and this CO_2 is treated as stored. Further CO_2 is captured and sold for use elsewhere, for example, in carbonated drinks and this CO_2 is assumed all to be emitted in the UK.

A 3.1.3.6 Other Oil (industrial spirit, white spirit, petroleum wax, miscellaneous products)

White Spirit and Special Boiling Point (SBP) spirits are used exclusively for non-energy applications, and are listed in CRF Table 1.A(d) within the category ‘other oil’. They are used as solvents; SBP spirits are used for industrial applications where quick drying times are needed (e.g. adhesives and other coatings) while white spirit is used as a solvent for decorative paint, as a cleaning solvent and for other applications. Estimates of VOC emissions are included in the UK inventory, but no estimates are made of direct emissions of carbon from these products, as they are regarded as “not occurring”.

The only emissions from this group of petroleum feedstock that are included in the UK GHG inventory are the releases of carbon from petroleum waxes which are reported under 2D2. These are accounted for in the UK inventory under the fuel category “Other Oils” in CRF Table 1Ad.

A 3.1.3.7 Petroleum Coke

The evidence from industrial reporting of fuel use and from periodic surveys of fuel producers that use petroleum coke to produce domestic fuels (including smokeless fuels) indicates that the allocation of petroleum coke to combustion activities in the UK energy balance is an under-estimate across all years. Therefore, the Inventory Agency generates revised estimates for all combustion activities and effectively re-allocates some of the petroleum coke reported in DUKES as non-energy use to energy-related emission sources in the UK inventory.

Within the UK inventory, petroleum coke is included for the following energy and non-energy source categories:

- 1A1a: Power station use of petroleum coke, primarily within blends with coal at a small number of UK facilities; in some years only,
- 1A1b: Refinery emissions from regeneration of catalysts;
- 1A2f: Cement industry use of petroleum coke as a fuel;
- 1A2g: Other industry use of petroleum coke as a fuel;
- 1A4b: Petroleum coke use within domestic fuels;
- 2A4: Use in brick manufacture (reported combined with other emissions e.g. from use of carbonate minerals in brickmaking;
- 2B6: Use in chemicals manufacturing;
- 2C1: Carbon emissions from electrodes used in electric arc furnaces and ladle arc furnaces and petroleum coke added to furnaces as a carbon source;
- 2C3: Carbon emissions from anode use in primary aluminium production; and
- 2D4: Petroleum coke used for non-energy applications not included elsewhere.

The UK energy balance tables in DUKES contain data on the energy use in power stations (1A1a) and refineries (1A1b), although the former are only available for 2007 onwards, and both sets of data do not always agree with the available activity data from EU ETS. The remaining energy uses in industrial combustion (1A2f, 1A2g) and the domestic sector (1A4b) are not included in DUKES. The UK Inventory Agency therefore makes independent estimates of the consumption of petroleum coke in all of these sectors.

Petroleum coke is burnt in **cement kilns** (1A2f) and has been burnt in some years at a handful of **power stations** (1A1a). A few other **large industrial sites** (1A2g) have also used the fuel. Good estimates of the consumption of petroleum coke by these large sites are available from the operators themselves, from trade associations and from EU ETS data (from 2005 onwards).

Fuel grade petroleum coke is also used as a **domestic fuel** (both smokeless and non-smokeless types, reported in 1A4b). The Inventory Agency uses data supplied by the UK fuel supply industry to estimate petroleum coke consumption for domestic fuels across the time series, from 1990 to the latest year; these estimates are broadly consistent with fuel use data published in earlier editions of DUKES for a few years in the late 1990s.

Carbon deposits build up with time on catalysts used in **refinery** processes such as catalytic cracking. These deposits need to be burnt off to regenerate the surface area of the catalyst and ensure continued effectiveness of the catalyst; emissions from this process are reported within EU ETS since 2005, with the time series estimates provided by the trade association (UKPIA, 2020a) and the catalyst regeneration is treated in the inventory as use of a fuel (since heat from the process is used) and are reported under 1A1b.

Estimates of carbon released from electrodes and anodes during **metal processes** are estimated based on operator data and reported in 2C1 and 2C3. Petroleum coke content of these electrodes and anodes is estimated based on operator data and literature sources such as Best available techniques REFerence documents (BREF notes). EU ETS data also show that some petroleum coke is added to electric arc furnaces as a carbon source, and the emissions from this use are also reported in 2C1. EU ETS data are also used for emission estimates for brickmaking, which include a component from petroleum coke. Finally, petroleum coke is used in the manufacture of titanium dioxide, with emission estimates generated from EU ETS and other operator data.

Based on data from DUKES we believe that there is some additional non-energy use of petroleum coke for most years; we assigned this residue to 2D4 and assume that it is all eventually emitted. The total fuel assigned to sector 2 is what we report as ‘excluded carbon’ in the CRF, table 1A(d). The consumption estimates for industrial users of petcoke as a fuel or in industrial processes are associated with low uncertainty as they are primarily based on operator reported data within the EU ETS or other regulatory reporting mechanisms. Whilst it is conceivable that other sectors may also use petroleum coke as a fuel, there is no evidence from resources such as EU ETS and Climate Change Agreement reporting that this is the case in the UK. The remaining petroleum coke consumption given in DUKES is therefore assumed to be used in various unidentified non-energy uses, all of which are assumed to be emissive. The estimates of petroleum coke used to generate fuels for the domestic sector are associated with higher uncertainty as they are based on periodic consultation with fuel suppliers to that market, and expert judgement of stakeholders.

As well as the total UK supply figure from UK energy statistics, DUKES has data on UK production, imports and exports of petroleum coke, which together provide more information on the nature of the UK consumption of petroleum coke. These data cover three distinct types of petroleum coke – catalyst coke, produced and consumed at refineries only (so no import/export or supply of fuel to other UK sectors), and then two products made in a refinery process known as coking: fuel grade (green) coke and anode-grade coke, with the former being used as a fuel, and the latter being a calcined[7] version of the former, used in various non-energy processes. Consultation with the DECC (now BEIS) energy statistics team and the only UK refinery with a coking process (DECC, 2013) has confirmed that the UK produces only anode-grade coke, and exports will also be anode-grade coke, whilst imports will be fuel

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[7] Calcined petroleum coke is a processed petroleum coke that has a very high carbon content; the resulting fuel is somewhat similar to coke oven coke

grade coke for use as a cost-effective fuel source or raw material for production processes under NEU.

Carbon factors for petroleum coke use are derived from industry-specific data (including EU ETS fuel analysis) in the case of cement kilns (MPA, 2021), power stations and other industrial sites (EA, 2021; SEPA, 2021). The petroleum coke factor for refinery consumption is based on trade association analysis conducted as part of the 2004 Carbon Factors Review (UKPIA, 2004) while the factor for domestic consumption is based on compositional analysis of samples of petroleum coke sold as domestic fuels (Loader et al, 2008).

These factors do show quite a large variation from sector to sector: this is probably primarily a reflection of the different requirements of fuels for different sectors (higher quality, higher carbon for some, less so for others). The highest carbon factor is for ‘petroleum coke’ burnt in sector 1A1b, but this fuel is actually of a different nature from the fuel burnt as petroleum coke in sectors 1A1a, 1A2f and 1A4b. In the case of 1A1b, the fuel is a build-up of carbon on catalysts used in various refinery process units, while in the other three cases, the petroleum coke is a solid by-product of a totally different refinery process (coking) which has different characteristics.

A 3.1.3.8 Carbon Storage Fractions: Import-Export balance for Carbon-containing Materials

The analysis within the UK energy statistics or GHG inventory compilation system cannot accurately account for the variable (over time) import-export balance of carbon-containing materials in the UK economy. For example, where the Inventory Agency accounts for the carbon emissions from scrap tyres burned in cement kilns, power stations, incinerators and so on within the inventory estimates or from the incineration of plastics or synthetic fibres, there is no way of tracing the quantity that is derived from imported tyres/plastics/fibres.

The reported estimate of the fate of the reported NEU of fuels from the UK energy balance is based on an assumed “closed system”, whereby we account for all emissions from carbon-containing products and fuel types that are allocated as NEU as if they are derived from the fuel statistics in the UK energy balance. In reality, the source of the carbon emitted from feedstock and NEU of fuels will partly be carbon from imported materials, with UK feedstock carbon also exported and emitted elsewhere.

A 3.1.4 Aviation (MS 7)

Table A 3.1.2 CAA aircraft types assigned to EMEP-EEA Emissions Inventory Guidebook aircraft types

EMEP/EEA Aircraft Type	CAA Aircraft Types
A306	AIRBUS A300 600/600F/600ST/B4/F4
A30B	AIRBUS A300 B1/B2
A310	AIRBUS A310
A318	AIRBUS A318
A319	AIRBUS A319

EMEP/EEA Aircraft Type	CAA Aircraft Types
A320	AIRBUS A320-100/200
A321	AIRBUS A321
A332	AIRBUS A330 200
A333	AIRBUS A330 300
A342	AIRBUS A340 200
A343	AIRBUS A340 300
A345	AIRBUS A340 500
A346	AIRBUS A340 600
AN12	ANTONOV AN-12
AN24	ANTONOV AN-24
AN26	ANTONOV AN-26B/32
AN72	ANTONOV AN-72/74
ATP	BAE ATP
B721	BOEING 727-100/100C
B722	BOEING 727-200/200 ADVANCED
B732	BOEING 737 200
B733	BOEING 737 300
B734	BOEING 737 400
B735	BOEING 737 500
B736	BOEING 737 600
B737	BOEING 737 700
B737	BOEING BBJ
B738	BOEING 737 800
B739	BOEING 737 900/900 ER
B742	BOEING 747 200B/200C/200F
B743	BOEING 747 300/300M
B744	BOEING 747 400/400F/400M
B748	BOEING 747 8/8F/8I
B74S	BOEING 747 SP
B752	BOEING 757 200
B753	BOEING 757 300

EMEP/EEA Aircraft Type	CAA Aircraft Types
B762	BOEING 767 200/200ER
B763	BOEING 767 300/300ER/300F
B764	BOEING 767 400ER
B772	BOEING 777 200/200ER
B773	BOEING 777 300
B77W	BOEING 777 300ER
B788	BOEING 787 8
B789	BOEING 787 9
BE18	BEECHCRAFT 18/SUPER H18
BE50	BEECHCRAFT 50 TWIN BONANZA
BE55	BEECHCRAFT BARON MOD 55/58/58P
BE60	BEECHCRAFT DUKE
BE99	BEECHCRAFT 99/99A
C208	CESSNA 208 CARAVAN I
C303	CESSNA T303 CRUSADER
C340	CESSNA 340
C401	CESSNA 401/402/411/421
C404	CESSNA 404 TITAN
C414	CESSNA 414A CHANCELLOR
C425	CESSNA 425 CONQUEST I
C441	CESSNA 441 CONQUEST II
C500	CESSNA 500 CITATION I
C510	CESSNA 510 CITATION MUSTANG
C525	CESSNA 525 / 525 A CITATIONJET
C550	CESSNA 550 CITATION II
C560	CESSNA 560 CITATION V
C650	CESSNA 650 CITATION III/VI/VII
C680	CESSNA 680 CITATION SOVEREIGN
C750	CESSNA 750 CITATION X
DC10	MCDONNELL-DOUGLAS DC10-10/30/40
DC3	DOUGLAS DC3 C47 DAKOTA

EMEP/EEA Aircraft Type	CAA Aircraft Types
DC6	DOUGLAS DC6/6A/6B/6C
DHC2	DHC2 BEAVER
DHC6	DE HAVILLAND DH6 TWIN OTTER
E110	EMBRAER EMB110 BANDEIRANTE
E120	EMBRAER EMB120 BRASILIA
E121	EMBRAER EMB121 XINGU
E135	EMBRAER EMB135
E145	EMBRAER EMB145
E170	EMBRAER ERJ170 100
E190	EMBRAER ERJ190 100
E195	EMBRAER ERJ190 200
F100	FOKKER 100
F27	FOKKER F27
F28	FOKKER F28-1000/2000/30004000/6000

A 3.1.5 Gas leakage

An overview of the time series of estimates of gas leakage at the point of use, together with overall gas use by economic sector and appliance type is presented in **Table A 3.1.3** below.

Table A 3.1.3 Activity data and methane leakage estimates for Gas leakage at Point of Use, including cooking appliances, gas fires and boilers

Source / Appliance type	Units	1990	1995	2000	2005	2010	2015	2018	2019	2020
Annual Gas Use										
Domestic gas fires	ktoe (net)	417	470	561	587	608	429	445	430	437
Domestic manual ignition hobs / cookers	ktoe (net)	532	479	462	448	401	414	416	401	407
Domestic auto-ignition hobs / cookers	ktoe (net)	191	171	165	160	144	148	149	144	146

Source / Appliance type	Units	1990	1995	2000	2005	2010	2015	2018	2019	2020
Domestic auto-ignition space and water heating	ktoe (net)	22,182	24,190	27,525	28,447	29,089	22,104	22,679	21,906	22,235
Service sector catering (ovens and hobs)	ktoe (net)	538	688	697	699	636	515	686	671	593
Other service sector appliances (boilers)	ktoe (net)	5999	7680	8863	8386	7802	7316	7168	7242	7043
Methane Leakage										
Domestic cooking and gas fires	ktCH$_4$	1.02	0.94	0.86	0.85	0.8	0.78	0.8	0.77	0.79
Domestic boilers and water heating	ktCH$_4$	0.76	0.83	0.94	0.98	1	0.76	0.78	0.75	0.76
Service sector (all sources)	ktCH$_4$	0.83	1.06	1.09	1.05	1	0.91	0.98	0.98	0.93
Total	**ktCH$_4$**	2.61	2.83	2.9	2.88	2.8	2.46	2.56	2.5	2.49

A 3.1.6 Upstream oil and gas production (1A1cii, 1B2)

A 3.1.6.1 Introduction

The UK has recently completed an oil and gas sector improvement project (Thistlethwaite et al, 2022) which has led to method improvements and recalculations affecting the fuel combustion emissions, reported under 1A1cii, and the fugitive emission estimates, reported under 1B2.

The research was commissioned to improve the accuracy and completeness of the UK inventory and to make use of improved oil and gas sector data availability in recent years, such as the Oil and Gas Authority's new national online data repository 'Open Data', which includes field-level oil and gas production data. In addition, the 2019 Refinement to the 2006 IPCC Guidelines for National GHG Inventories ('the 2019 Refinement') includes several new or updated inventory methods for the estimation of fugitives from oil and gas production; several of these new methods have been applied in the UK GHGI as they provide the best available basis for accurate and complete UK GHGI estimates, reflecting UK circumstances.

The research comprised: (i) a review of the new and emerging datasets, (ii) a critical review of pre-existing reports and data used to inform estimates across the inventory time series, and

(iii) consideration of the 2019 Refinement suite of inventory methods for fugitive emissions, including to address any reporting gaps by applying the new methods.

This NIR annex text provides an insight into the key data sources used to derive inventory estimates, a summary of the inventory methods that have been developed for use in the 2022 UK GHGI submission and a summary of the recalculations arising from the project.

For more information, please refer to the Thistlethwaite et al (2022) project report.

A 3.1.6.2 Scope of Upstream Oil and Gas Source Categories in the UK Inventory

The scope of emissions from the upstream oil and gas sector in the UK comprise a wide range of emission sources that are reported within the Common Reporting Format (CRF) tables under:

- 1A1cii (fuel combustion emissions); and
- 1B2 (fugitive emissions, including from flaring and venting).

For the early part of the inventory time series (i.e.1990 to 1997) the emissions data available to inform UK inventory estimates is limited in detail due to the limited source resolution in early industry-wide reporting. Since the inception of EEMS reporting in 1998, there are annual operator emission reports per source per facility.

As a result, the ability to generate a consistent time series of emissions per source from 1990 onwards is compromised. Source-specific estimates have been derived by the Inventory Agency through the use of IPCC good practice gap-filling techniques to provide estimates back to 1990; through access to and use of new data to estimate the emission trends across 1990-1997 the oil and gas improvement project has led to improved time series consistency for many sources. However, the assurance of time series consistency for the sector as a whole may only properly be assessed at an aggregate level (i.e. across 1A1cii and 1B2 combined).

The precise source allocation of emission estimates in the 1990-1994 period is subject to higher uncertainty than in the rest of the time series, but at an aggregate level the sector-wide estimates are based on the best available data from Government and industry and analysis indicates them to be time series consistent with data post-1997 at that aggregate level.

In developing methods for all sources in the upstream sector, there are several changes over time in data availability to address, most notably for UK energy statistics (due to changes in reporting requirements and data gathering systems managed by the UK Government over the period since 1990) and for atmospheric emissions data reporting.

A 3.1.6.3 UK Regulatory Landscape and Key Data Sources

(Also see Thistlethwaite et al (2022) project report section 2.2.)

The UK regulatory landscape for the oil and gas exploration and production sector is complex, with financial, energy and environmental reporting obligations across a range of onshore and offshore regulators. There are separate regulations (and regulatory agencies) governing the requirements for permits to operate or perform certain activities (e.g. well drilling, production activities, flaring, venting) and company reporting of activity data (e.g. production data) and environmental emissions data. As a result, there are numerous permitting and data reporting systems in place across the sector that may provide useful data to inform inventory estimates; systems for onshore installations (well sites, terminals) often differ from those for offshore installations. Furthermore, some data reporting mechanisms provide a high degree of source resolution in annual (or more frequent) operator reporting, whilst others provide no source resolution but rather present activity and/or emissions totals per year per field or per installation.

The scope and detail of data available varies considerably across the time series, which reflects the evolution of regulations in the UK and consequent changing reporting requirements on plant operators. There are long-standing data collection and reporting systems evident for activity data, such as from UK energy statistics and from the regulations governing oil exploration and production; even these however exhibit changes in scope, completeness and resolution through time.

For example, at the end of the 1990s there was an overhaul to the reporting to oil and gas regulators regarding oil and gas production, venting and flaring, as a new system, the *Petroleum Producers Reporting System* (PPRS) was implemented from 2000 onwards, to replace systems that had previously informed the UK Government statistical annual called "*Development of the Oil and Gas Resources of the UK*", known universally as the *DTI Brown Book*, production of which ceased from 2004. Much more granular data are now available from the PPRS system than were published in the Brown Book, although analysis of aggregate data across the overlap years (2000 to 2003) between the PPRS and the Brown Book indicates a highly consistent overall scope of reporting.

Therefore, a key challenge to compile accurate and complete inventory activity and emissions estimates is to assess the scope and quality of data reported across these mechanisms and determine how best to integrate them. The UK inventory improvement project has enabled the Inventory Agency to review the data in detail, consult with key stakeholders and to identify where there are high quality data that should be prioritised for use for specific emission sources, and where there are opportunities to use inter-comparisons (between reporting mechanisms) to validate or improve (e.g. gap-fill) inventory data.

Key regulatory and data reporting mechanisms that help to inform UK inventory estimates include:

- **EU Emissions Trading Scheme (EU ETS):** Operators of upstream installations submit annual estimates of CO_2 emissions from combustion of fuels (i.e. fuel gas and diesel) since 2005, and from flaring since 2008. The scope of reporting includes all high emitting offshore and onshore fixed installations, and reporting is per installation (i.e. per platform, FPSO or terminal); the EU ETS scope does not include smaller sites (e.g. onshore well sites and smaller offshore platforms) where the annual combustion and flaring emissions fall below the EU ETS threshold, and it also excludes mobile installations such as drilling units. Data are subject to Third Party verification checks and the system is managed via UK regulatory agencies for onshore (i.e. EA, SEPA, NRW) and offshore (BEIS OPRED). The EU ETS provides a large, detailed dataset that includes the mass or volume of fuel burned or flared, the NCV, carbon emission factors, oxidation factors. The monitoring and reporting methods agreed across the sector include assumptions such as that flaring efficiency is 98%; sampling and compositional analysis of fuel gas samples is required for high emitting source streams.

- **EU ETS National Allocation Plans (NAPs) for Phase I and Phase II:** The NAPs for EU ETS Phase I (combustion sources only) and Phase II (combustion and flaring) were prepared in the early 2000s in order to enable trading scheme allocations to reflect the recent historical emissions per installation. The NAPs data present installation totals of CO_2 emissions for 1998 to 2003, with no breakdown by source or by fuel; however, due to the different scope of the NAP I and NAP II, an assessment of the emissions from *all combustion* and from *all flaring* per installation can be calculated (i.e. flaring by difference between NAP I and NAP II). NAPs data were based on operator activity data and installation-level fuel gas sampling and analysis, to improve the accuracy compared to previous estimates where default carbon emission factors had been applied (e.g. within EEMS reporting) by some operators. Where oil or gas fields were scheduled to cease production pe-EU ETS (which began in 2005), the NAPs excluded the emission estimates from installations for those production streams, to ensure that the NAPs did not over-estimate site allocations.
- **Environmental and Emissions Monitoring System (EEMS)[8]:** EEMS is an emissions reporting system managed by BEIS OPRED to accommodate statutory reporting obligations such as those under PPC/IED for reporting of GHG and air quality pollutants from combustion installations above 50MWth. Scope of reporting is from offshore fixed and mobile installations (i.e. it encompasses platforms, FPSOs, mobile drilling units), and includes reporting from the smaller platforms that may fall below the EU ETS reporting threshold. Operators submit annual returns of emissions of CO_2, CH_4, N_2O, NMVOCs, NO_X, CO and SO_2 as well as activity data (where appropriate) in tonnes per year. Activity and emissions are reported per source, per installation, i.e. with separate estimates provided for emission sources that may occur on the installation, including: fuel combustion (fuel gas, diesel consumption), gas flaring, gas venting, well testing, fugitives, direct process sources (e.g. acid gas treatment) and from oil loading. Operators of *onshore* oil and gas facilities and terminals are not mandated to use the EEMS system but report their total emissions to the Regulator Inventories (RIs) of the onshore regulatory agencies in England, Scotland and Wales. The data in the RIs is less granular than EEMS as it is not broken down by source (see below). Up to 2010, however, the onshore terminals did voluntarily report emission estimates per source to EEMS.
- **Pollution Prevention and Control Regulations / Industrial Emissions Directive (PPC/IED):** All onshore terminals and most other onshore facilities (e.g. Natural Gas Liquid processing plant, onshore well sites, transit terminals where crude oil and oil products are stored and transferred between vessels, terminals, refineries, other sites) report to the relevant Regulator Inventory (RI) according to their location. The onshore installations are regulated by the EA (in England), SEPA (in Scotland) and NRW (in Wales). Under the terms of PPC permits, operators submit annual emission estimates per pollutant for all emissions sources (combined) within the boundary of the permitted installation. These annual emission submissions are verified by the regulatory agencies onshore and are then published on public registers. However, for onshore facilities the resolution of emissions data *per source* is not available, with a single value for each pollutant *per facility*. The scope of pollutant reporting is as per EEMS (above), but there are pollutant reporting thresholds which limit the completeness of operator reporting, i.e. annual returns to the RIs may not provide any estimate of pollutant

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[8] https://www.gov.uk/guidance/oil-and-gas-eems-database

emissions if the operator determines that the sum of emission across all sources falls below the reporting threshold. In addition, reporting of activity data (e.g. fuel use data, production or throughout data, flaring or venting data) is not required under PPC/IED;

- **Petroleum Production Reporting System (PPRS):** The OGA's Petroleum Production Reporting System (PPRS) collects monthly data from operators of onshore and offshore hydrocarbon production in the UK Continental Shelf (UKCS), per oil or gas field and per terminal. The PPRS data provides useful activity data for inventory purposes, such as crude oil and/or gas production per month, own gas use, venting and flaring volumes, and in some cases there are other useful parameters reported such as gas density, gas NCV. The PPRS data are not collected with environmental reporting in mind; they are the basis for BEIS energy statistics reporting for e.g. crude oil production, dry gas and associated gas production, Natural Gas Liquid (NGL) production, as well as statistics on gas flaring and gas venting volumes. The high level of resolution of data (to field level) and the reporting of similar units (fields or terminals) enables ready analysis of key data that can support inventory estimates; for example, the sum of production at all Offshore Tanker Loader oil fields (i.e. oil fields not connected to pipelines, and hence reliant of crude oil export via shuttle tankers) directly provides an activity dataset for the annual transfers of crude oil to shuttle tankers, and onwards to refineries and terminals. The data are available since the inception of the PPRS in 2000. Whilst the production data are aggregated and published, most of the data in the PPRS reports are not public domain and were provided to the Inventory Agency solely for the purposes of the inventory improvement research project.
- **DTI annual statistical publication "Development of Oil and Gas Resources of the United Kingdom", known historically as the DTI Brown Book:** Until 2004 the UK Department of Trade and Industry (now part of BEIS) published annual statistics for the upstream oil and gas sector, which brought together statistics from upstream operators that were then rolled into the PPRS reporting system (above) from 2000 onwards. The scope of data reported in those annual publications is similar to the data that can now be derived from the PPRS system, and similarly it underpins the long-term oil and gas production time series that are included in the Digest of UK Energy Statistics (DUKES). Whilst the PPRS data are more granular (e.g. monthly data), for the overlapping years (2000-2003) there is close consistency, even at the field-level aggregate annual production data. The Inventory Agency has reviewed the DTI Brown Book information across 1990-2003, which includes more detail and qualitative information used to establish material flow mapping from oil/gas fields to platforms/FPSOs and then onto specific oil and/or gas terminals. This is critical information to enable the development of the field to installation to terminal mapping that is needed to aggregate and compare field-level Brown Book/PPRS data against reported activity and emissions data. As a result, the inventory has been able to perform cross-comparisons to help identify where there may be data gaps or double-counts, and to build a more detailed understanding of production and emissions sources across the UKCS. For example, the Brown Book notes where an installation offshore is not connected to a gas export line, which we then expect to see in the emissions datasets as a high flaring site.
- **Digest of UK Energy Statistics (DUKES):** DUKES is one of the primary input datasets to the UK GHGI, and the Inventory Agency has worked with the DUKES datasets for many years, and has consulted extensively during the oil and gas improvement project with BEIS energy statistics leads for the upstream oil and gas sector, in order to understand the relationship between the "clean, final" data that are presented in

DUKES, and the upstream data inputs from systems such as the PPRS. DUKES includes numerous data time series that are ultimately derived from the upstream datasets outlined above, including data on UK crude oil production, gas production, and on the energy consumption across the sector, which is (in most years) limited to data entries for “oil and gas extraction” for two fuels: natural gas and gas oil. In addition, DUKES presents data such as GCVs and NCVs for “natural gas produced” as well as for “natural gas consumed” (i.e. in downstream sectors). There are some data gaps evident within DUKES for some of the historic data, which all previous UK GHGI submissions have also sought to address, the most significant being an under-report in fuel gas activity data presented in DUKES up to the inception of PPRS in 2000. The oil and gas improvement project has provided an opportunity to revisit the estimates for actual fuel gas use, based on analysis of other datasets and testing of the trends reported in different reporting mechanisms.

- **UKOOA 2005 oil and gas sector data submission:** The EEMS reporting system (see above) was developed from an emissions reporting system developed during the 1990s by the UK Offshore Operators Association (UKOOA) in conjunction with the offshore regulator (now OPRED) and managed by a team of consultants that conducted company surveys, data gathering and generated a database of emission estimates. This dataset from 1995 onwards was able to generate source-specific estimates for the sector, in a format closely comparable to the subsequent format of EEMS. Data for 1990-1994 were estimated and reported to UK Government based on industry surveys in 1990 and 1991, together with an analysis of the production trends across all years. Subsequently the industry conducted further analysis of key emission sources, such as to derive more accurate carbon emission factors per installation, through the process to develop the National Allocation Plans (see above) to underpin allocations per installation for the EU ETS. The 1990-2003 dataset (originally based on the early industry surveys, 1990-1994, the 1995-1997 data, and then the first few years of EEMS reporting, 1998-2003) were re-analysed to reflect the improvements in industry knowledge, and reported to UK Government in 2005. The UKOOA 2005 data submission has been used in part to inform previous UK GHG inventory estimates, primarily to inform some of the fugitive source estimates. The oil and gas improvement project has enabled a re-analysis of the data alongside the other datasets that are now available for the early part of the time series. Together with the time series (sector wide and per installation) of oil and/or gas production, and well drilling activity data, the Inventory Agency has used the UKOOA 2005 dataset and IPCC good practice methods to derive estimates per source for the sector back to 1990.
- **OGA Well Data records, Well Operations Notification System (WONS):** The Oil and Gas Authority (OGA), established in 2016, is the regulator responsible for managing the UK’s well consent system for the oil and gas exploration sector. The OGA manages the data records[9] from well drilling activity (from well spudding, to testing, completions) and well status (e.g. when wells are suspended or abandoned by operators). The Inventory Agency consulted with the OGA throughout the improvement project in order to access data held in the transactional databases used to manage the consent process, but it was not possible to develop suitable queries to extract useful annual data from these resources. This may become possible in future, however the existing online data resources for well drilling activity provides a good indication of the

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[9] https://www.ogauthority.co.uk/data-centre/data-downloads-and-publications/well-data/

level of exploration activity on the UKCS across the time series, with data on numbers of wells drilled per year.

A 3.1.6.4 Oil and Gas sector data pre-processing

(Also see Thistlethwaite et al (2022) project report section 3.1.)

The raw data from the reporting systems outlined above requires pre-processing in order to derive a dataset in a suitable format and with data labels added to enable (i) data from parallel reporting mechanisms to be compared per installation, and (ii) the inventory calculations to be performed. The pre-processing of the raw data includes:

- Aggregation and labelling of data from multiple years of reporting to develop a dataset in a consistent format, with data labels added to facilitate subsequent data processing within inventory models (e.g. spreadsheets, databases, coded models). Data labels include: year of activity / emission, unit of activity / emission, and numeric identifiers to represent the installation or emission source / activity / pollutant.
- Initial data consistency checking and ‘cleansing’ to identify and correct data gaps and/or outliers that may affect the accuracy of subsequent calculations, e.g. to apply range checks on input data to identify where a parameter (e.g. fuel gas density, NCV) has been reported at the wrong order of magnitude.
- Initial data validation checks and enhancements, for example to conduct time series consistency checks through cross-comparison with other datasets, and to derive other useful parameters for use in inventory methods, e.g. unit conversions / other data transformations to derive weighted-average parameters across a source/sector to apply in inventory methods.

The sections below describe the key raw data pre-processing steps and checks that the Inventory Agency has conducted to generate data for input into the source-specific inventory methods.

Field to Installation Mapping

OGA data (on oil and gas production, own gas use, flaring and venting) is gathered in the monthly operator returns within the PPRS; these data are gathered *per individual oil or gas field*, i.e. at the level of each individual geological formation that has been developed for production.

All of the environmental data reporting, through EEMS or EU ETS, is at the level of the top-side installation, i.e. *per oil or gas platform, mobile drilling unit or FPSO.*

Both types of dataset exhibit data quality problems (or potential problems) such as data reporting gaps and outliers, and both the *production / activity* and *emissions* datasets have notable step-changes in data availability across the time series. Inter-comparison of the OGA/PPRS and EEMS or EU ETS datasets enables gaps and outliers to be checked, corrected where necessary, and uncertainties minimised. To do this, the Inventory Agency researched documentation (e.g. DTI Brown Book section “*Review of Fields in Production and Under Development*”) and online information to develop a mapping to link each geological oil or gas field to the platform or FPSO that receives and processes the oil and gas. In many cases the mapping is a 1-1 relationship with low uncertainty. In cases where there was some uncertainty in the mapping, e.g. fields that may export to several installations, the Inventory Agency shared the mapping table with the OGA to seek clarifications and corrections.

This pre-processing step enables text (such as names of fields and installations) to be linked to numeric values for simpler data processing in databases and other models. The process of developing this mapping has also significantly enhanced the information resources available to the UK GHG inventory team, as the research has led to development of a resource of information to aid the understanding of the pipeline networks, outlier oil platforms/FPSOs that are not linked to gas export pipelines (and hence are likely to conduct more gas flaring), and those OTLs where oil loading emissions are expected to be reported within EEMS.

Installation-level Data Labelling

Similar to the item above, the management of data from numerous reporting systems for a given installation requires the development of a series of translation tables that enable links to be made and calculations performed to compare and/or integrate data from those multiple data sources, to derive “the best” emission estimates per installation per source to minimise inventory uncertainty.

Over time, the upstream installations may be opened / closed / mothballed, they may be sold to a new operator, have a change of name, a change of permit reference, they may re-locate (e.g. FPSOs may service one area of production and then be re-deployed to a new area), or they may be divested (one site sold and split into several smaller parts, with different operators and permits) or merged. Furthermore, underpinning regulations and guidance to operators evolves over time and hence the consistency of data reported year to year may change.

All of these potential changes to raw data provision may lead to difficulties for inventory compilers in accurately tracking emissions from a consistent scope of emission sources per installation over time. Hence for each installation, clear labelling of input data sources is needed, to provide the requisite references and audit trail for the input data, and to allow querying of the data to check for potential changes in scope.

To enable the data tracking, comparisons and (ultimately) the appropriate use of the data in inventory calculations, the Inventory Agency has developed a series of data translation tables to document the data sources and enable the linkages and comparisons to be performed within inventory calculations.

The development of these data translation tables and detailed enquiry of reported data from across the time series has helped to identify numerous errors and inconsistencies in the data used in previous inventory submissions. For example, it has led to revisions in some site allocations between reporting under “oil production” or “gas production” IPCC source categories, leading to (in general) equal and opposite recalculations between the oil and gas sectors.

Through the research and consultation with industry, the Inventory Agency has also reviewed and updated the scope of installations that are “upstream” oil and gas sites, including the identification and removal of some double counts with downstream or other industrial sites. For example, one LNG terminal and one power plant (previously considered part of an adjacent terminal) were included within the scope of upstream estimates in previous submissions, and also the associated fuel use and emissions were included in other inventory sectors (i.e. 1A1ci and 1A2gviii in those two examples).

Activity and Emissions Data Pre-Processing

EU ETS: The reported CO_2 emissions (and underlying AD and EFs) from the EU ETS are from a very limited sub-set of inventory (mostly *key*) source categories, comprising:

- Upstream oil production; Upstream gas production

  - Fuel combustion: Fuel gas or Diesel
  - Gas flaring

The allocation of the EU ETS data to flaring, fuel gas combustion or diesel combustion is then conducted manually by the Inventory Agency, through review of the reported parameters (activity data, emission factors, oxidation factors, NCVs) and the accompanying text descriptions provided by operators:

- An oxidation factor (OF) of 98% is used for flaring; an OF of 100% is used for combustion;
- Diesel use is identified through returns indicating *source type* “combustion: commercial standard fuels”, *source stream description* “Gas/diesel oil” or “Diesel”, and a CO_2 EF for diesel;
- Fuel gas is identified through returns indicating *source type* “combustion: other gaseous and liquid fuels”, *source stream description* may be wide range of names but typically includes “fuel gas” or “export gas”. The activity data, emission factors and NCVs show a wider range of variability, with typically EFs in the range ~2.5 to 2.8 tCO_2 per tonne

The Inventory Agency has access to detailed EU ETS data available from 2013 onwards (i.e. Phase III of EU ETS) and for some earlier years back to 2005, and hence there is a relatively large, detailed dataset and the emission sources and fuel types / qualities per installation show good time series consistency. For some earlier EU ETS years the Inventory Agency does not have access to fully detailed data (i.e. information per source, per fuel, including EFs, NCVs) but does have the (public domain) EU Transaction Log emission totals per installation, and EEMS reporting for offshore installations which does present data split between combustion and flaring sources also.

EEMS: A similar, but simpler, data allocation process as applied for the EU ETS data is conducted for the EEMS data reporting, in order to align the reported data to installation codes and to UK inventory source categories and fuels / activities. The EEMS data reporting documentation assigns each line of data to one emission source from a defined list of sources, together with the operator name, facility name and type (fixed or mobile). The annual emissions data and activity data (“Total use”) are all presented in mass units (tonnes). The EEMS emission sources are used in the inventory for both upstream *oil* or *gas* installations, and include:

- **Gas consumption**: in either turbines, engines or heaters, each with different default EFs per pollutant. Scope of pollutants: CO_2, NO_X, N_2O, SO_2, CO, CH_4, NMVOC.
- **Diesel consumption**: Scope and resolution of data reported is the same as for gas consumption. Notably a high proportion of the diesel use is reported as used in engines within mobile drilling units.
- **Fuel Oil consumption**: Scope and resolution of data reported is the same as for gas consumption. Reporting of fuel oil use is limited to a small number of sites and years.
- **Gas flaring**: Scope of pollutants: CO_2, NO_X, N_2O, SO_2, CO, CH_4, NMVOC. Sub-categorisations of flaring (e.g. *gross, routine operations, maintenance, upsets/other*) are used by some operators but does not appear to be reported consistently.
- **Gas venting**: Scope of pollutants is typically: CO_2, CH_4, NMVOC. As with flaring, sub-categorisations of venting (e.g. gross, maintenance, operational, emergency) are used by some operators but does not appear to be reported consistently.

- **Well testing**: Reported under either *Emission Category* Oil or Gas, defining whether the well being drilled was for oil or gas exploration. Scope of pollutants: CO_2, NO_X, N_2O, SO_2, CO, CH_4, NMVOC. The EEMS operator guidance indicates that the emissions are primarily due to the flaring of gases as the liquid and gaseous materials eluted from a well test are separated, with the liquids collected for disposal.
- **Fugitive emissions**: Scope of pollutants: CO_2, CH_4, NMVOC. The vast majority of reported fugitives are described (sub-source) as gross, but in some cases more details are provided of the precise source (e.g. valves, connectors, open-ended pipes).
- **Direct process**: Scope of pollutants: CO_2, NO_X, N_2O, SO_2, CO, CH_4, NMVOC. Many of the direct process entries have further information provided to clarify the source, which are typically: sour gas vent, thermal oxidiser, acid gas treatment, amine regeneration, incinerator.
- **Oil loading**: Scope of pollutants: CH_4, NMVOC. Analysis of the time series of EEMS data shows that the reporting of this source is inconsistent with many sites only reporting the source intermittently. This source is only reported by OTLs, and not by upstream gas producers nor oil sites connected to pipelines.
- **Storage tanks:** Scope of pollutants: CH_4, NMVOC. This source was used in the earlier years of EEMS reporting by the terminal operators. Since 2010 when reporting to EEMS was deemed not to be a mandatory requirement for terminal operators (as they also report to the RIs), this source is not reported consistently in EEMS.

The EEMS data as received from the BEIS OPRED team are compiled into a multi-year table holding all historic EEMS data, i.e. from 1998 onwards. These data are then quality checked, e.g. time series checks to identify gaps and outliers in AD and EFs, compared against the EU ETS data (for flaring and combustion sources) and applied within the inventory source category calculations.

National Allocation Plans: Prior to commencement of the EU ETS, upstream operators reviewed the available data from combustion and flaring emissions at offshore facilities and onshore terminals. Updated installation-level CO_2 emission estimates over the years prior to 2005 for the source-activities per installation consistent with the EU ETS scope were agreed with the UK Government and incorporated into the UK's National Allocation Plan for Phase I of the EU ETS (Phase I NAP, Defra 2005)[10], the scope for which was fuel combustion only, and the National Allocation Plan for Phase II of the EU ETS (Phase II NAP, Defra 2007)[11], the scope for which comprised combustion and flaring.

In compiling the NAPs, the sector generated a dataset of installation level total CO_2 emissions using the latest site-specific data on activity and emissions across the period 1998 to 2003 (Phase I NAP) and 2000 to 2004 (Phase II NAP). These data reflected the improvement in

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

[11] EU Emissions Trading Scheme, Approved Phase II National Allocation Plan 2008-2012, Defra (2007) https://webarchive.nationalarchives.gov.uk/ukgwa/20121024154051/https://www.decc.gov.uk/en/content/cms/emissions/eu_ets/EU ETS_phase_ii/phaseii_nap/phaseii_nap.aspx

understanding of installation-level emission factors and activity data, after several years of running the EEMS data reporting system from 1998 onwards, and its predecessor datasets of similar structure and detail since 1995. The data held in the NAPs was therefore an updated estimate of combustion and flaring emissions compared to the original EEMS data.

Furthermore, in the development and agreement of the NAPs installation allocations with UK Government, the NAPs data were subjected to additional data checks to ensure the veracity of the emission estimates as they were to be used to establish allocations per installation in the financial trading mechanism; all sector and site allocations were subject to scrutiny to ensure the consistency and fungibility of the allocations across all participants. The NAPs data are therefore considered the better-quality dataset and where the NAPs data differ from EEMS, the NAPs estimates have been used to inform UK inventory estimates, for the first time in the 1990-2020 inventory dataset.

The Inventory Agency analysed the NAP I and NAP II datasets and compared them, per installation, against the original EEMS data submissions, to assure and/or improve the accuracy of the data for the upstream sector in the 1998-2003 period. By subtracting the NAP I data from the NAP II data for the overlap years (2000 to 2003 inclusive), the NAPs together can be used to derive best estimates for:

1. Total combustion emissions per installation, 1998 to 2003 inclusive; and
2. Total flaring emissions per installation, 2000 to 2003 inclusive.

For a large number of installations, the EEMS and NAPs data are consistent, and this comparison has afforded a further quality check to assure that the EEMS data for those installations in the early years of EEMS were of sufficient quality to inform inventory estimates. However, in several cases the NAPs data indicated different combustion and/or flaring emission compared to the original EEMS data submissions; a small number of reporting gaps in the EEMS data were also identified and addressed.

This analysis and data comparison has led to a number of recalculations over the 1998 to 2003 period and in general has increased the sector estimates of total CO_2 emissions from combustion and flaring in this period; whilst this is mid-time-series from an inventory reporting perspective, the emission estimates in these years have wider significance as they represent the first years of reporting for the EEMS system. Further, they cover the period that coincides with the step-change in UK energy statistics to use PPRS to inform the sector fuel gas consumption data. In the previous UK inventory submissions, the 1998 to 2000 combustion emission estimates from EEMS were used to assess the level of under-reporting of fuel gas use within UK energy statistics, prior to the inception of PPRS, i.e. for all years up to 2000; the analysis of the gap in data between the sum of operator-reported fuel gas estimates and those reported in DUKES for the upstream oil and gas sector was then used to inform the uplift of DUKES fuel gas data back through the 1990s.

The updates (increases) to sector estimates of fuel use and emissions as a consequence of use of NAPs data undermines the methodology used previously to estimate the level of fuel gas use and hence combustion GHG emissions across the sector in the 1990s, leading the Inventory Agency to seek a better method to estimate emissions from fuel combustion during the 1990s.

PPRS: Since 2000, operators have submitted monthly data returns from individual oil and gas fields, and from oil, dry gas and associated gas terminals; these data are useful to inform or quality check inventory estimates. The PPRS data are confidential and have not been made available previously for use in the UK inventory development. The Inventory Agency was granted access to the data via BEIS (BEIS, 2021e) and has reviewed the data in detail to identify opportunities to use the data to improve inventory estimates.

The monthly reports are available for defined unit types (*terminals*: oil, dry gas, associated gas; *fields*: oil, gas, offshore loaders, onshore loaders), with a consistent scope of data fields reported by each operator per unit type. The Inventory Agency has critically reviewed the data across the time series, to check for time series consistency, look at data reporting gaps per terminal or oil or gas fields, and assess how best to use PPRS data to improve the accuracy and completeness of the UK inventory.

We note that these PPRS data underpin the UK energy statistics for the sector, with quality checks and data gap-filling conducted by the BEIS energy statistics team. The oil and gas improvement project has afforded a useful parallel analysis of the data; in many cases the Inventory Agency has been able to reproduce the data that is published in DUKES and hence understand more completely the processing that is conducted and the scope of data that is used to inform energy statistics, including not only the annual fuel use totals but also useful other parameters such as fuel calorific values and densities.

Deviations from UK energy statistics based on the analysis from PPRS are detailed in the inventory methodology sections, including for: (i) total upstream oil and gas fuel gas use, (ii) fuel gas NCVs, and (iii) oil loading activity data from Offshore Tanker Loaders (OTLs).

The analysis of the PPRS datasets per unit type implemented numerous data checks (e.g. time series consistency, outlier identification, internal consistency checks such as mass balance on material flows though the terminals), gap-filling and aggregation of data to compare against other datasets, such as the industry summary data presented in DUKES or other BEIS statistical outputs. This detailed “deep dive” analysis enabled the Inventory Agency to assess the overall data quality per PPRS report, and to better understand the scope and potential usefulness of the different monthly returns, the parameters reported and the expected internal consistencies for each PPRS report. Once lessons had been learned and (for example) acceptable ranges of parameters identified, more automated approaches were developed to conduct data cleansing of the raw data, identifying data gaps or outliers, and applying assumptions to derive a revised, more complete and internally consistent dataset for subsequent use in inventory methods.

The PPRS data provide a detailed insight into the variable quality of the products and the eluted gases at each site, which in turn reflect the variability of the geological formations across the different areas in the UKCS and the changes over time as production trends have shifted across the many individual oil and gas fields. The PPRS data that have been used in the inventory methods are:

- Time series of field, installation and sector-wide crude oil and natural gas production data, used primarily as a proxy dataset to address reporting gaps, i.e. to help identify where emissions data may be missing from EEMS, and in some cases estimating emissions in a missing year using production trends as the proxy to indicate activity and emission trends;
- Time series of fuel gas density and calorific values, derived for the different types of installation and fuel gas, to reflect whether the origin of the fuel gas was a dry gas field / installation / terminal, or associated gas from an oil field / installation / terminal.
- Time series of production from Offshore Tanker Loaders (OTLs) to underpin the oil loading fugitive emissions from transfers of crude oil to shuttle tankers, for transport to shore.

The tables below present the fuel quality data that have been derived from PPRS, EU ETS and EEMS data across the time series, including the CO_2 EF per TJ (net), NCV and density of fuel gas in four sub-sectors: offshore oil installations, offshore gas installations, oil terminals and gas terminals. The variable fuel gas composition across the different sub-sectors of the industry is based on the annual weighted averages of operator-reported data from each UK installation and reflects the different composition of the untreated fuel gases that are encountered at the different stages of upstream oil and gas production.

Table A 3.1.4 UK Upstream Fuel Gas Carbon Dioxide EF per Source, 1990-2020

Installation	Units	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Oil field	tCO$_2$/Tjnet	64.5	64.5	64.5	64.5	64.5	65.1	64.8	66.4	65.3	64.1
Gas field	tCO$_2$/Tjnet	59.0	59.0	59.0	59.0	59.0	59.5	59.3	60.7	60.0	58.2
Oil terminal	tCO$_2$/Tjnet	65.7	65.7	65.7	65.7	65.7	63.4	64.1	67.3	67.6	66.7
Gas terminal	tCO$_2$/Tjnet	58.6	58.6	58.6	58.6	58.6	56.5	57.1	60.0	59.7	58.5

Installation	Units	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Oil field	tCO$_2$/Tjnet	64.2	63.4	63.8	64.4	64.1	63.1	62.9	63.6	63.4	64.0
Gas field	tCO$_2$/Tjnet	58.6	58.3	57.4	58.1	58.1	59.0	58.1	58.1	58.0	57.2
Oil terminal	tCO$_2$/Tjnet	66.6	68.8	67.5	67.8	67.4	67.4	67.3	67.2	64.5	65.2
Gas terminal	tCO$_2$/Tjnet	57.6	57.4	57.3	57.6	56.8	57.0	56.5	58.8	57.6	57.5

Installation	Units	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Oil field	tCO$_2$/Tjnet	63.2	65.4	64.0	62.9	65.3	64.5	63.9	63.7	64.1	63.0	63.2
Gas field	tCO$_2$/Tjnet	57.5	58.2	60.4	62.0	58.3	59.1	59.3	57.4	58.3	58.5	59.6
Oil terminal	tCO$_2$/Tjnet	67.2	70.2	68.7	66.5	68.3	67.9	66.9	67.3	67.3	66.6	66.3
Gas terminal	tCO$_2$/Tjnet	57.2	57.9	59.5	57.6	57.1	57.2	57.5	57.9	58.1	57.3	56.2

Table A 3.1.5 UK Upstream Fuel Gas Net Calorific Value per Source, 1990-2020

Installation	Units	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Oil field	GJ/tonne	41.7	41.7	41.7	41.7	41.7	41.7	41.7	41.7	41.7	41.7
Gas field	GJ/tonne	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7
Oil terminal	GJ/tonne	41.7	41.7	41.7	41.7	41.7	41.7	41.7	41.7	41.7	41.7
Gas terminal	GJ/tonne	46.1	46.1	46.1	46.1	46.1	46.1	46.1	46.1	46.1	46.1

Installation	Units	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Oil field	GJ/tonne	41.7	42.1	41.5	41.3	41.5	41.7	41.7	41.5	41.7	41.5
Gas field	GJ/tonne	45.7	46.1	45.8	45.8	46.0	45.1	45.6	45.4	45.2	46.0
Oil terminal	GJ/tonne	41.7	42.1	41.5	41.3	41.5	41.7	41.7	41.5	41.7	41.5
Gas terminal	GJ/tonne	46.1	46.8	46.2	45.9	46.1	45.5	46.1	46.3	45.9	46.2

Installation	Units	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Oil field	GJ/tonne	41.9	40.6	41.2	41.8	40.8	41.0	41.7	41.6	41.4	41.9	42.1
Gas field	GJ/tonne	46.2	45.6	44.2	45.6	45.8	45.3	45.2	46.4	45.8	45.5	45.2
Oil terminal	GJ/tonne	41.9	40.6	41.2	41.8	40.8	41.0	41.7	41.6	41.4	41.9	42.1
Gas terminal	GJ/tonne	46.4	45.9	44.7	46.0	46.2	46.3	46.5	46.4	45.7	46.0	46.2

Table A 3.1.6 UK Upstream Fuel Gas Density per Source, 1990-2020

Installation	Units	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Oil field	kg/sm^3	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Gas field	kg/sm^3	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
Oil terminal	kg/sm^3	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Gas terminal	kg/sm^3	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76

Installation	Units	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Oil field	kg/sm^3	0.86	0.86	0.86	0.86	0.85	0.86	0.85	0.86	0.85	0.85
Gas field	kg/sm^3	0.76	0.75	0.76	0.76	0.75	0.77	0.76	0.75	0.76	0.75
Oil terminal	kg/sm^3	0.86	0.86	0.86	0.86	0.85	0.86	0.85	0.86	0.85	0.85
Gas terminal	kg/sm^3	0.76	0.75	0.76	0.76	0.75	0.77	0.76	0.75	0.76	0.75

Installation	Units	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Oil field	kg/sm^3	0.84	0.86	0.85	0.85	0.86	0.85	0.85	0.84	0.85	0.85	0.85
Gas field	kg/sm^3	0.75	0.76	0.78	0.76	0.75	0.76	0.75	0.75	0.75	0.76	0.76
Oil terminal	kg/sm^3	0.84	0.86	0.85	0.85	0.86	0.85	0.85	0.84	0.85	0.85	0.85
Gas terminal	kg/sm^3	0.75	0.76	0.78	0.76	0.75	0.76	0.75	0.75	0.75	0.76	0.76

PPRS vs DTI Brown Book Data: Once the PPRS data quality checking and cleansing was completed, the Inventory Agency conducted further data quality checks focusing on the time series consistency of field-level oil and (dry or associated) gas production data between the 1990-2003 datasets from the DTI Brown Book compared against the 2000 onwards PPRS data. This comparison indicted that the overlap years of 2000-2003 show very close consistency for all crude oil production data, not only at the overall level (as summarised below), but also for each individual field. The close comparability of the overlapping years in the two datasets gives a high level of confidence that the data reported across the time series from the two data sources are on a consistent basis and scope. There are larger differences evident of around 1-2% for the gas production data, but no systematic difference and an average difference of only 0.8% across the four years, again indicating that there are no step-changes in the scope of gas production data from the two sources.

UKOOA 2005 submission to UK Government: In February 2005 the UK Offshore Operators' Association (UKOOA) submitted an updated dataset of upstream oil and gas facility emission estimates for each year from 1990 to 2003 to UK Government. The data were prepared by the same team of experts that had developed the EEMS dataset over the preceding decade, and the update was based on the latest data from the industry, following work to develop the EU ETS NAPs; the estimates were updated to use detailed analysis of AD and EFs from 1998 to 2003 per installation to derive the best estimates for each site for the NAPs. The UKOOA 2005 data are tabulated below.

There were two datasets: 1995 to 1997 data follow a very similar structure to the EEMS 1998 onwards dataset, but rather than data per installation, each source-activity data point is aggregated, either to "onshore" or "offshore" totals per year. The 1990 to 1994 dataset is much more highly aggregated; this reflects the level of data resolution from the industry emission returns from operator surveys in the early 1990s. The 1990 to 1994 data are based on the first UKOOA emissions inventory study, using:

- **1990:** CO_2 and CH_4 data calculated from company reported data; VOC data estimated using export data; CO, NO_X and SO_2 estimated based on the reported CO_2 data and EFs.
- **1991:** Company reported data
- **1992 to 1994:** Calculated, scaled on production data.

The oil and gas improvement project afforded the Inventory Agency the time and resources to evaluate the UKOOA 2005 dataset, compare it to other data from the period and seek to maximise its usefulness to inform UK GHG inventory estimates. There are no other, better industry data from this period from which to derive emission estimates although the lack of data resolution impairs the transparency of these data; it is impossible to fully understand/confirm whether these data are complete and correct, but they are the best data available for that period.

Table A 3.1.7 UKOOA 2005 Submission to Defra: 1990 to 1994 Emissions Data

(All emissions data are in tonnes.)

Year	Activity	CO	NOx	SO2	CH4	VOC	CO2
1990	Drilling	5,140	10,113	7,310	7,201	3,098	1,352,461
1990	Production	31,152	46,855	2,023	67,372	47,029	14,263,066
1990	Loading	0	0	0	781	39,671	0
1990	Offshore total	36,293	56,969	9,333	75,354	89,798	15,615,527
1990	Onshore total	2,529	11,328	202	36,440	68,609	2,098,340
1990	Upsteam total	38,821	68,297	9,535	111,794	158,407	17,713,867

Year	Activity	CO	NOx	SO2	CH4	VOC	CO2
1991	Drilling	5,082	9,999	7,227	6,798	3,201	1,337,160
1991	Production	30,800	46,325	2,000	63,600	48,600	14,101,700
1991	Loading	0	0	0	737	40,996	0
1991	Offshore total	35,882	56,324	9,227	71,135	92,797	15,438,860
1991	Onshore total	2,500	11,200	200	34,400	70,900	2,074,600
1991	Upsteam total	38,382	67,524	9,427	105,535	163,697	17,513,460

Year	Activity	CO	NOx	SO2	CH4	VOC	CO2
1992	Drilling	5,302	9,975	7,434	6,813	3,259	1,434,645
1992	Production	32,131	46,214	2,057	63,739	49,484	15,129,775
1992	Loading	0	0	0	739	41,742	0
1992	Offshore total	37,433	56,189	9,491	71,290	94,485	16,564,419
1992	Onshore total	2,608	11,173	206	34,475	72,190	2,225,847
1992	Upsteam total	40,041	67,362	9,697	116,089	166,675	18,790,267

Year	Activity	CO	NOx	SO2	CH4	VOC	CO2
1993	Drilling	5,521	9,951	7,641	6,221	3,317	1,532,129
1993	Production	33,463	46,103	2,114	58,197	50,368	16,157,849
1993	Loading	0	0	0	674	42,488	0
1993	Offshore total	38,984	56,054	9,755	65,092	96,174	17,689,979
1993	Onshore total	2,716	11,146	211	31,478	73,480	2,377,095
1993	Upsteam total	41,700	67,201	9,967	105,996	169,654	20,067,074

Year	Activity	CO	NOx	SO2	CH4	VOC	CO2
1994	Drilling	5,741	9,927	7,847	6,234	3,376	1,629,614
1994	Production	34,794	45,992	2,172	58,324	51,253	17,185,924
1994	Loading	0	0	0	676	43,234	0
1994	Offshore total	40,535	55,919	10,019	65,233	97,862	18,815,538
1994	Onshore total	2,824	11,120	217	31,546	74,770	2,528,342
1994	Upsteam total	43,359	67,039	10,236	106,226	172,632	21,343,880

Note that the methane totals for 1992, 1993 and 1994 are not internally consistent. The "Upstream total" line is less than the sum of the "Offshore total" and "Onshore total". In the UK GHGI, we have applied the individual data for offshore and onshore totals and disregarded the "Upstream total" line. We note that these are not critical years in the UK GHGI anyway, as they are not a base year for any pollutant.

For each emission source, the Inventory Agency has (i) assessed the data quality in the UKOOA 2005 dataset against the EEMS and NAPs data for the "overlap" years of 1998 to 2003, to identify any key outliers or step changes in the data, and (ii) developed a time series per inventory emission source back to 1990 using the best available data and applying IPCC good practice gap-filling methods.

Table A 3.1.8 UKOOA 2005 Submission to Defra: 1995 to 2000 Emissions Data

Year	Area	Source	Activity (t)	t CO_2	t NO_X	t N_2O	t CO	t SO_2	t CH_4	t VOC
1995	Offshore	Drilling Diesel Consumption	246,951	790,243	9,804	55	2,593	1,482	27	321
1995	Offshore	Drilling Well Testing	200,000	591,369	520	16	2,670	6,001	7,000	3,000
1995	Offshore	Flaring	2,020,782	5,354,615	3,031	162	17,581	173	20,400	20,016
1995	Offshore	Fuel <20MW facilities	139,467	407,540	1,684	31	508	319	39	57
1995	Offshore	Fuel >20MW facilities	4,038,195	10,926,151	33,293	864	12,289	1,934	1,613	485
1995	Offshore	Fugitive Emissions	8,254	0	0	0	0	0	5,942	3,727
1995	Offshore	Gas Venting	38,134	2,741	0	0	0	0	23,438	14,696
1995	Offshore	Oil Loading	20,554,999	0	0	0	0	0	740	41,110
1995	Offshore	Other Gases	1,122,135	1,095,864	6,849	0	2,854	244	9,817	6,507
1995	Offshore	Total	28,368,918	19,168,523	55,181	1,129	38,495	10,154	69,016	89,918

Year	Area	Source	Activity (t)	t CO_2	t NO_X	t N_2O	t CO	t SO_2	t CH_4	t VOC
1995	Onshore	Flaring	250,728	618,990	854	55	2,209	26	2,787	2,228
1995	Onshore	Fuel <20MW facilities	26,615	70,961	83	6	21	15	2	17
1995	Onshore	Fuel >20MW facilities	677,204	1,775,221	7,532	149	2,702	305	494	150
1995	Onshore	Fugitive Emissions	2,912	0	0	0	0	0	2,740	411
1995	Onshore	Gas Venting	13,032	997	0	3	0	0	9,592	3,440
1995	Onshore	Oil Loading	89,065,629	0	0	0	0	0	1,608	75,493
1995	Onshore	Other Gases	1,084,142	1,056,636	3,302	0	1,609	21	20,249	2,325
1995	Onshore	Storage Tanks	12,514,460	0	0	0	0	0	2	21
1995	Onshore	Total	103,634,722	3,522,806	11,771	213	6,542	367	37,473	84,084

Year	Area	Source	Activity (t)	t CO_2	t NO_X	t N_2O	t CO	t SO_2	t CH_4	t VOC
1996	Offshore	Drilling Diesel Consumption	268,560	859,392	11,936	60	3,177	1,611	31	374
1996	Offshore	Drilling Well Testing	221,562	618,299	576	18	2,958	6,648	7,755	3,323
1996	Offshore	Flaring	2,054,542	5,395,941	3,082	165	17,875	34	21,298	19,793
1996	Offshore	Fuel <20MW facilities	119,903	346,809	976	26	311	236	36	38
1996	Offshore	Fuel >20MW facilities	4,186,471	11,291,744	34,605	896	12,758	1,667	1,671	506
1996	Offshore	Fugitive Emissions	10,990	0	0	0	0	0	7,455	3,534
1996	Offshore	Gas Venting	46,697	3,046	0	0	0	0	29,340	17,279
1996	Offshore	Oil Loading	24,054,521	0	0	0	0	0	847	47,043
1996	Offshore	Other Gases	761,896	746,732	4,061	0	1,686	133	5,642	3,642
1996	Offshore	Total	31,725,141	19,261,963	55,236	1,165	38,764	10,329	74,075	95,533

Year	Area	Source	Activity (t)	t CO_2	t NO_X	t N_2O	t CO	t SO_2	t CH_4	t VOC
1996	Onshore	Flaring	253,686	626,232	381	56	2,207	5	2,682	2,392
1996	Onshore	Fuel <20MW facilities	26,615	70,961	83	6	21	15	2	17
1996	Onshore	Fuel >20MW facilities	667,348	1,767,780	4,680	147	1,565	201	448	174
1996	Onshore	Fugitive Emissions	6,852	0	0	0	0	0	5,049	1,803
1996	Onshore	Gas Venting	4,364	298	0	1	0	0	3,198	1,166
1996	Onshore	Oil Loading	85,748,128	0	0	0	0	0	208	73,002
1996	Onshore	Other Gases	1,898,831	1,880,837	3,138	0	1,232	30	12,384	1,211
1996	Onshore	Storage Tanks	11,372,438	0	0	0	0	0	2	16
1996	Onshore	Total	99,978,262	4,346,109	8,282	209	5,025	251	23,971	79,781

Year	Area	Source	Activity (t)	t CO_2	t NO_X	t N_2O	t CO	t SO_2	t CH_4	t VOC
1997	Offshore	Drilling Diesel Consumption	257,592	824,294	10,796	57	2,865	1,546	29	346
1997	Offshore	Drilling Well Testing	209,682	619,713	545	17	2,799	6,292	7,339	3,145
1997	Offshore	Flaring	1,859,027	5,015,393	2,778	149	16,073	822	19,234	18,053
1997	Offshore	Fuel <20MW facilities	140,240	405,116	1,643	31	510	229	56	50
1997	Offshore	Fuel >20MW facilities	4,486,736	12,396,246	42,113	960	14,668	4,257	2,662	697
1997	Offshore	Fugitive Emissions	9,600	0	0	0	0	0	6,164	3,436
1997	Offshore	Gas Venting	46,392	2,817	0	0	0	0	31,226	14,908
1997	Offshore	Oil Loading	29,072,962	0	0	0	0	0	1,035	57,511
1997	Offshore	Other Gases	257,179	254,462	620	0	249	757	772	319
1997	Offshore	Total	36,339,410	19,518,040	58,496	1,215	37,164	13,902	68,519	98,465

Year	Area	Source	Activity (t)	t CO_2	t NO_X	t N_2O	t CO	t SO_2	t CH_4	t VOC
1997	Onshore	Flaring	182,586	504,605	598	40	1,608	4	2,529	1,731
1997	Onshore	Fuel <20MW facilities	20,882	50,578	65	5	17	10	1	13
1997	Onshore	Fuel >20MW facilities	916,131	2,556,287	5,925	202	2,579	211	613	210
1997	Onshore	Fugitive Emissions	7,122	0	0	0	0	0	5,299	1,823
1997	Onshore	Gas Venting	6,073	255	0	1	0	0	4,859	1,119
1997	Onshore	Oil Loading	79,612,227	0	0	0	0	0	304	71,548
1997	Onshore	Other Gases	491,535	489,433	143	0	118	63	1,777	0
1997	Onshore	Storage Tanks	45,516,421	0	0	0	0	0	58	1,893
1997	Onshore	Total	126,752,976	3,601,158	6,732	247	4,322	287	15,440	78,337

Year	Area	Source	Activity (t)	t CO_2	t NO_X	t N_2O	t CO	t SO_2	t CH_4	t VOC
1998	Offshore	Drilling Diesel Consumption	259,920	831,743	18,018	58	4,889	1,514	36	490
1998	Offshore	Drilling Well Testing	214,434	631,097	558	17	2,863	6,061	7,344	3,046
1998	Offshore	Flaring	1,886,572	5,077,343	2,758	152	15,708	666	19,699	16,978
1998	Offshore	Fuel <20MW facilities	140,117	392,506	1,675	31	547	87	72	37
1998	Offshore	Fuel >20MW facilities	5,050,946	13,028,492	43,714	1,081	15,290	2,376	2,204	654
1998	Offshore	Fugitive Emissions	9,716	0	0	0	0	0	6,222	3,494
1998	Offshore	Gas Venting	47,437	2,794	0	0	0	0	34,062	10,835
1998	Offshore	Oil Loading	30,638,811	0	0	0	0	0	1,321	44,126
1998	Offshore	Other Gases	38,061	36,410	10	0	55	846	382	358
1998	Offshore	Total	38,286,014	20,000,385	66,731	1,339	39,353	11,550	71,342	80,019

Year	Area	Source	Activity (t)	t CO_2	t NO_X	t N_2O	t CO	t SO_2	t CH_4	t VOC
1998	Onshore	Flaring	169,177	463,001	469	37	1,487	4	2,240	1,546
1998	Onshore	Fuel <20MW facilities	13,705	33,361	43	3	11	6	1	9
1998	Onshore	Fuel >20MW facilities	991,391	2,866,817	6,369	218	2,486	309	579	219
1998	Onshore	Fugitive Emissions	7,567	0	0	0	0	0	5,699	1,868
1998	Onshore	Gas Venting	5,059	49	0	1	0	0	4,058	932
1998	Onshore	Oil Loading	105,203,268	0	0	0	0	0	1,336	98,133
1998	Onshore	Other Gases	586,861	584,757	321	0	0	236	1,547	0
1998	Onshore	Storage Tanks	72,034,691	0	0	0	0	0	176	1,710
1998	Onshore	Total	179,011,720	3,947,985	7,202	259	3,984	555	15,637	104,416

Year	Area	Source	Activity (t)	t CO_2	t NO_X	t N_2O	t CO	t SO_2	t CH_4	t VOC
1999	Offshore	Drilling Diesel Consumption	121,127	387,608	7,256	27	1,931	343	20	231
1999	Offshore	Drilling Well Testing	70,361	211,907	178	6	892	1	2,421	1,097
1999	Offshore	Flaring	1,934,442	5,140,414	2,324	155	12,973	3,300	20,223	15,378
1999	Offshore	Fuel <20MW facilities	129,660	360,036	1,897	29	557	417	213	54
1999	Offshore	Fuel >20MW facilities	5,224,232	13,251,233	43,534	1,118	16,278	4,842	6,413	767
1999	Offshore	Fugitive Emissions	3,399	0	0	0	0	0	3,361	1,495
1999	Offshore	Gas Venting	52,150	11,300	0	0	0	0	30,012	9,720
1999	Offshore	Oil Loading	37,646,811	0	0	0	0	0	2,686	52,042
1999	Offshore	Other Gases	124,068	121,615	229	0	135	786	1,124	180
1999	Offshore	Total	45,306,248	19,484,113	55,418	1,335	32,766	9,689	66,474	80,965

Year	Area	Source	Activity (t)	t CO_2	t NO_X	t N_2O	t CO	t SO_2	t CH_4	t VOC
1999	Onshore	Flaring	178,246	480,739	354	9	1,539	247	1,498	1,919
1999	Onshore	Fuel <20MW facilities	12,542	29,952	21	3	8	8	1	0
1999	Onshore	Fuel >20MW facilities	1,114,515	2,854,980	7,804	211	2,855	427	1,045	193
1999	Onshore	Fugitive Emissions	1,026	0	0	0	0	0	1,199	4,840
1999	Onshore	Gas Venting	2,869	56	0	0	0	0	2,079	654
1999	Onshore	Oil Loading	102,395,302	0	0	0	0	0	658	85,179
1999	Onshore	Other Gases	549,165	539,121	823	0	22	409	990	7,800
1999	Onshore	Storage Tanks	103,985,206	0	0	0	0	0	64	1,399
1999	Onshore	Total	208,238,871	3,904,848	9,003	223	4,424	1,091	7,534	101,985

Year	Area	Source	Activity (t)	t CO_2	t NO_X	t N_2O	t CO	t SO_2	t CH_4	t VOC
2000	Offshore	Drilling Diesel Consumption	109,560	350,594	6,508	24	1,720	349	20	331
2000	Offshore	Drilling Well Testing	44,659	138,010	135	4	666	1	1,361	872
2000	Offshore	Flaring	1,711,814	4,363,285	2,057	137	11,484	1,775	19,260	11,071
2000	Offshore	Fuel <20MW facilities	126,749	361,776	1,874	28	524	59	322	60
2000	Offshore	Fuel >20MW facilities	5,113,427	13,855,459	41,053	1,093	16,066	3,868	6,561	806
2000	Offshore	Fugitive Emissions	3,752	2	0	0	0	0	3,600	1,530
2000	Offshore	Gas Venting	37,389	3,613	0	0	0	0	23,768	8,436
2000	Offshore	Oil Loading	33,610,348	0	0	0	0	0	3,713	56,968
2000	Offshore	Other Gases	0	0	0	0	0	0	0	0
2000	Offshore	Total	40,757,699	19,072,740	51,627	1,285	30,461	6,052	58,604	80,076

Year	Area	Source	Activity (t)	t CO_2	t NO_X	t N_2O	t CO	t SO_2	t CH_4	t VOC
2000	Onshore	Flaring	274,719	698,684	270	17	1,368	107	2,354	1,679
2000	Onshore	Fuel <20MW facilities	6,806	16,278	17	1	4	4	1	0
2000	Onshore	Fuel >20MW facilities	1,290,767	3,476,874	7,459	273	2,839	319	959	116
2000	Onshore	Fugitive Emissions	949	1	0	0	0	0	2,622	13,313
2000	Onshore	Gas Venting	4,620	104	0	0	0	0	2,803	1,621
2000	Onshore	Oil Loading	93,321,395	0	0	0	0	0	1,103	81,467
2000	Onshore	Other Gases	536,576	535,357	523	0	0	471	0	225
2000	Onshore	Storage Tanks	134,908,528	10,429	0	0	0	0	110	10,996
2000	Onshore	Total	230,344,359	4,737,727	8,269	291	4,211	900	9,952	109,416

UKOOA 2005 vs EEMS/NAPs time series consistency: In order to assess the consistency between the data reported within the UKOOA 2005 dataset (1990-2003) and the EEMS dataset (1998 onwards), the Inventory Agency compared the reported data at the source-specific level. Findings are noted below per source.

- **Drilling diesel consumption:** UKOOA 2005 data presents data specifically for "drilling diesel use". This can be compared against the diesel consumption reported in EEMS for the installations that are identified as Mobile Drilling Units (MODUs).
    - ✓ The result is that the activity data are identical between UKOOA and EEMS datasets for 1998-2002, with a small % difference in 2003.
- **Drilling well testing:** The UKOOA 2005 dataset presented total well testing AD and emissions; EEMS data presented data separately for well testing at oil wells and gas wells.
    - ✓ Comparing the total AD, the data are identical for 1999-2003, with a low % difference evident in 1998. Therefore, the data are regarded as closely consistent.
- **Gas flaring:** EEMS data holds data specific to flaring at oil sites and gas sites, UKOOA data is aggregated.
    - o There is slightly more variable comparison between UKOOA and EEMS across the time series. E.g. in 1999 the UKOOA 2005 estimate for gas flaring offshore is notably higher than that in EEMS.
    - ✓ However, there is very close comparability in both 1998 (identical) and 2000 (within 1%). Therefore, the overall assessment is that there is no clear systematic difference between the two datasets for flaring. The two datasets are reasonably consistent.
    - o There is a clear difference in reporting of N_2O across the UKOOA data time series. The use of N_2O default EFs is noted as sporadic across several sources within EEMS also.
    - o Therefore, to be time series consistent, the estimates for N_2O in the earlier part of the time series were revised to apply the EFs used in EEMS from 1998 onwards.
- **Gas Venting:** Estimates for venting are presented by gas, for onshore and offshore separately in UKOOA 2005.
    - o The CO_2 data are identical for both onshore and offshore in 1998. The onshore venting data are within 1% in all years.
    - o The offshore venting data are identical in 1998, 2001 and 2003; in the other years (1999, 2000, 2002) the EEMS data are all lower than the reported UKOOA 2005 data.
    - ✓ Therefore, the overall assessment is that the venting data are closely consistent between UKOOA and EEMS; they demonstrate good time series consistency.
- **Fugitive emissions:** The analysis focused on NMVOC as this is the key pollutant from this emission source.
    - o The 1998 datasets are closely consistent once a "known error" was corrected, to add in data for Theddlethorpe - *a new site in 1998* - noted as missing from EEMS data;
    - o In other years the estimates of NMVOC are all identical or within a very few % for both onshore and offshore estimates of fugitives, with one exception: in 1999 there is a ~400t difference between the two datasets.
    - ✓ Therefore, the overall assessment is that the fugitives data are closely consistent between UKOOA and EEMS; they demonstrate good time series consistency.
    - o The 1999 outlier could be due to a single site reporting new data; our approach is to use the higher emission estimate, i.e. to take a conservative approach.

- **Fuel gas combustion:** In the UKOOA 2005 dataset, these emissions are presented split by >20MW and <20MW combustion units. There is also an assumption in the approach in UKOOA 2005 for 1998 onwards that the total NAPs emission is the best estimate for the sum of all >20MW installations. The comparison for these estimates is the most significant component of overall GHG emissions, as fuel gas combustion is by far the single most significant GHG emission source for the sector. The updated EEMS dataset, to align at installation level with NAPs data, is considered to be of good quality.
    - Across 1998 to 2001 in total the estimates are closely consistent, with 1% over those years, although the detail within those years is somewhat variable; 1998 data are very closely consistent (within 0.1%), within 1% in both 1999 and 2001, but with a 3% difference between the data in 2000.
    - ✓ Therefore, the overall assessment is that the fuel gas combustion data are closely consistent between UKOOA and EEMS; they exhibit good time series consistency.

Method development per source, to use the UKOOA 2005 dataset: To develop time series consistent estimates, the Inventory Agency has applied a range of proxy data to estimate the 1990 onwards emission totals per emission source per pollutant. The general overall approach is that the sum of the estimates will align with the UKOOA 2005 totals per pollutant, except where data outliers or gaps have been identified, such as the inconsistent use of N_2O EFs and the incomplete reporting of oil loading emissions evident in EEMS.

The parameters used to inform trends are the DTI Brown Book data on UK oil production and gas production, as well as the OGA Well Operations Notification System records of wells drilled per year:

Table A 3.1.9 Parameters used to inform the 1990-1998 time series per source

Parameter	Units	1990	1991	1992	1993	1994	1995	1996	1997	1998
Crude oil	kt/yr	86,234	83,129	85,222	90,213	114,383	116,743	116,679	115,340	118,919
Natural Gas	Mm^3/yr	49,506	55,051	55,738	65,109	69,343	75,158	89,514	91,170	95,171
∑ wells drilled	#wells	348	331	302	280	308	360	396	350	367

Gas oil consumption

Gas oil consumption at stationary installations producing crude oil is estimated using the time series of crude oil production, assuming the same IEF of CO_2 emissions per unit production from EEMS data (1998-). Gas oil consumption at stationary installations producing natural gas is estimated using the time series of natural gas production, assuming the same IEF of CO_2 emissions per unit production from EEMS data (1998-). Gas oil consumption in Mobile Drilling Units is derived by difference:

UKOOA Total drilling emissions = Well Testing emissions + Gas oil use by MODUs

Well Testing

Well testing (oil) and well testing (gas) emissions are estimated using the OGA data on total wells drilled, assuming the same level of well testing activity and emissions per number of wells tested from EEMS data (1998-). The total emissions from 1995 onwards are aligned to the UKOOA 2005 estimates for well drilling emissions, which leads to a slightly low outlier in 1996. Note that the OGA data (1990-1998) does not distinguish between wells drilled for oil or gas exploration; the overall trend from all wells drilled is applied to both.

Fugitives, Venting and Flaring

For each source, the total emissions from 1995 to 1997 across the oil and gas sector are aligned to the UKOOA 2005 dataset. The split of those total source emissions across “oil” and “gas” in 1995-1997 assume the same split between oil and gas as in the EEMS dataset (1998-) per source. Then the estimates for 1990-1994 are back-cast from 1995 using the oil production and natural gas production trends.

Direct Processes

The estimates of emissions from direct processes are based on a series of assumptions and are in part a "residual" category for GHG emissions, to align the sum of source estimates across 1A1cii and 1B2 with the UKOOA 2005 dataset.

The installation-level reporting of direct process CO_2 emissions within the EEMS data from 1998 are dominated by a small number of installations: Tartan Alpha, SAGE-St Fergus terminal and Kinneil terminal. For each installation, an estimate of emissions is back-cast from the EEMS data (1998-) using the installation-specific crude oil production (Tartan), crude oil throughput (Kinneil) or gas throughput (SAGE St-Fergus). One-off direct process estimates are made to reflect emissions from process upsets and commissioning of the SAGE (in 1992) and CATS (in 1993) terminals and the upstream oil and gas fields that came on-stream in those years.

Finally, across the time series, the direct process source is used as a residual to align to the UKOOA 2005 data totals, calculated by difference from the sum of other sources. NMVOC and methane residual emissions are calculated for the offshore and onshore components:

Direct process = UKOOA (excl. loading) - ∑ (gas oil, fuel gas, flaring, fugitives, venting, well testing)

The allocation to "oil" and "gas" from these derived residuals is based on an assumption derived from historic reporting of methane and NMVOC from all sources aggregated, which indicates that methane emissions are around ~63% gas sector and ~37% oil sector, whilst NMVOC emissions are around ~21% gas sector, ~79% oil sector. The direct process estimates per source are thus derived by applying these %s and are subject to high uncertainty, but overall, the totals align to the UKOOA industry totals.

Fuel Gas Combustion

The CO_2 emission estimates from fuel gas use are reported within the UKOOA 2005 dataset for 1995 to 1997, aggregated across oil and gas. For 1990-1994 the fuel gas estimates are derived by difference from the UKOOA 2005 emission totals from production sources, for both offshore and onshore sites:

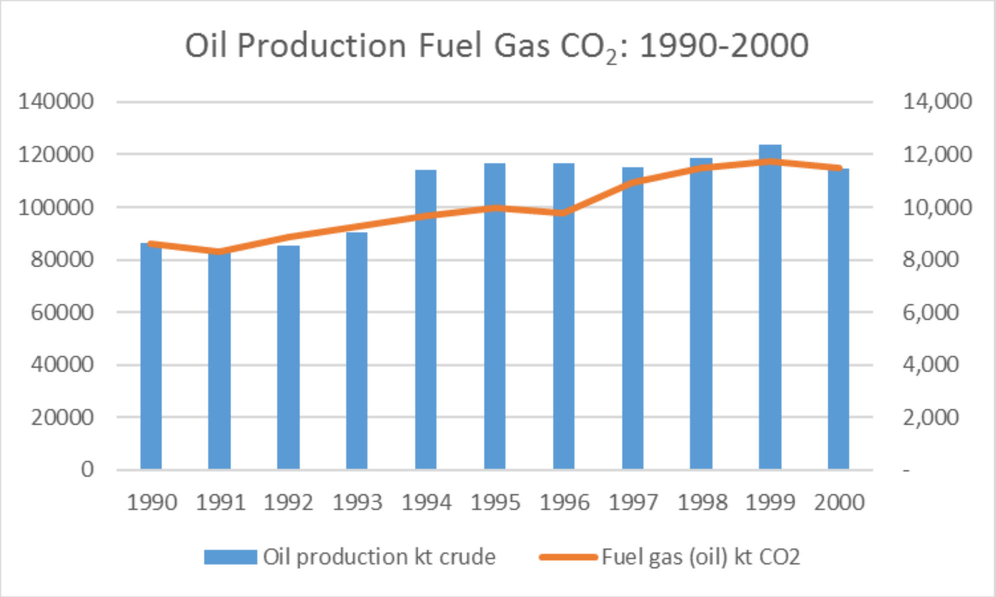
Fuel gas use = UKOOA (production) - ∑ (gas oil not drilling*, gas flaring, venting, direct processes)*

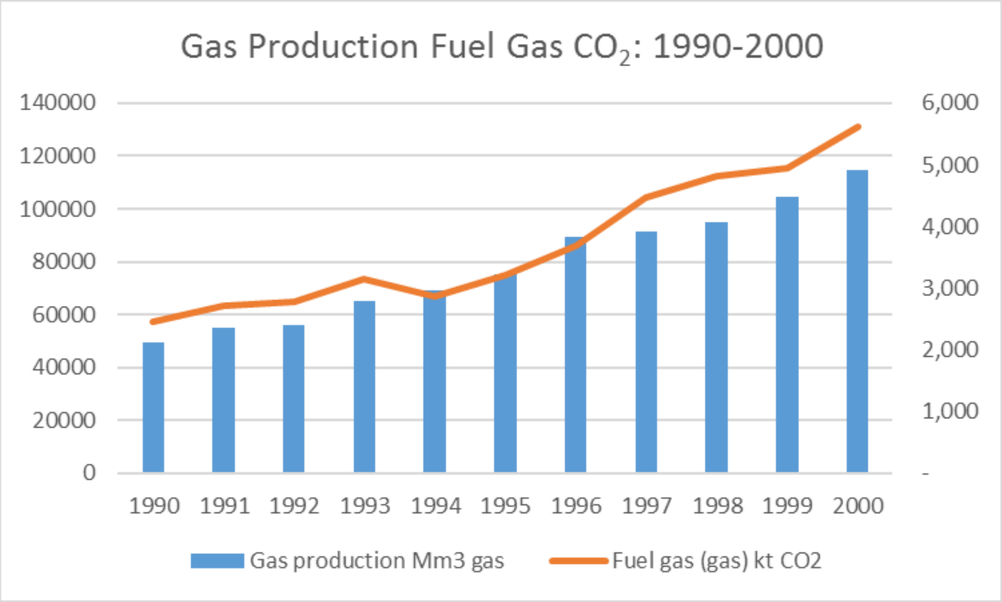
The total fuel gas emissions of CO_2 across oil and gas installations are then divided between "oil" and "gas" sectors by extrapolating back an estimate from the EEMS data (1998-) and using the production trends for crude oil and natural gas, and then aligning the derived interim estimates to the calculated "oil and gas" fuel gas total. This approach therefore seeks to reflect both the UKOOA 2005 CO_2 emissions total and the trends in oil and gas production.

The outputs from these calculations are illustrated in the graphs below. Analysis of the IEF of CO_2 per unit production gives an *indication* of the likely representativeness of these estimates. The 1990-1991 oil production IEF of ~100 tCO_2 per kt crude oil is comparable to the IEF towards the end of the 1990s, after which the IEF increases to a range 107-115 from 2001 onwards. During the 1990s, there is a short-term increase in IEF around 1992-1993 (IEF of ~103) which coincides with the period that many new platforms and a number of terminals were being brought into production, and then a few years where the IEF is lower (IEF of ~85 during 1994-1996), before reverting to ~95-100 during 1997-2000 and then rising to >107 from 2001 onwards.

Similarly, for natural gas production, the IEF of ~49 tCO_2 per Mm^3 natural gas produced is comparable to the IEFs in the late 1990s before the emissions intensity increases from 2001 onwards to a range of 56-58. Similar trends are evident across the 1990s, with an IEF of ~49 across 1990-1993, a period of lower IEFs (IEFs ~41,42 in 1994-1996), then back to an IEF ~47-51 across 1997-2000, before increasing from 2001 onwards to >56.

The limited data resolution for 1990-1994 in particular leads to uncertainty over the allocation of emissions across 1A1cii and 1B2 sources, but these trends in IEF per unit production do indicate that the 1990 estimates for fuel gas combustion emissions are within the range of typical UKCS production efficiency.





More detailed information on UK GHGI methods per source category under 1B2

Method statement 18 presents an overview of the data sources and methods developed and applied in the UK GHGI for upstream oil and gas sector fugitive source categories that are reported in 1B2. This annex presents additional details per source category. For all sources, the individual assessment of uncertainties (as presented in Thistlethwaite et al, 2022) have been used to inform the uncertainty parameters per category, per gas, as presented in Annex A2.3.

1B2a1: Oil Exploration; 1B2b1: Gas Exploration

Emission Sources

- Offshore oil well testing
- Onshore conventional oil well exploration
- Offshore gas well testing
- Onshore unconventional gas well exploration

The initial phases of exploration for oil and gas resources lead to fugitive emissions of GHGs; these sources occur prior to production, including prospecting, exploratory well drilling, well testing, completion, field and well development.

In the UK the main emission source is in the well testing phase offshore, where wells are drilled and tested to assess the available resources, the field depth, pressure and so on to assess the feasibility of extracting the oil or gas. During the well tests, the produced fluids are separated, water and oil collected, and the gases are flared. These activities may be conducted directly from existing platforms, or from Mobile Drilling Units (MODUs), and all UK operators report their well testing emission estimates to EEMS. The 2019 Refinement (Energy Volume, Fugitives Chapter page 4.48) notes that there are no EFs for offshore well drilling / exploration activities and that these emissions "*are thought to be negligible*"; we interpret this to mean that the fugitive leaks from the initial phases of well drilling may be assumed to be negligible and/or dissolve in the water column.

There are a small number of onshore oil wells in the UK; there are limited emissions data reported by operators within the IED/PPC regulatory inventories as often the level of annual emissions of GHGs from these well sites fall below the reporting threshold. The OGA Well Operations Notification System (WONS) includes reports on annual well drilling activity, and these data can be used to derive GHG emission estimates from the exploration phase, using the method set out in the 2019 Refinement.

BEIS commissioned a separate study to estimate GHG emissions from unconventional gas well drilling; there has been no subsequent gas production, but very minor emissions of methane are reported in 1B2b1 from the exploratory drilling conducted in the UK during 2010 to 2019.

Pollutants Reported

- Carbon dioxide, methane, nitrous oxide, oxides of nitrogen, carbon monoxide, sulphur dioxide, NMVOCs, particulate matter

Method Summary

Onshore oil well exploration

- IPCC 2019 Refinement Tier 1 method: *Emission = AD x Default EF*
- Activity data: Number of conventional oil wells drilled per year. These data on wells drilled onshore area available across the time series:
  - 1990 to 1993: DTI Brown Book 2001, Appendix 4;
  - 1994 to 1999 data from DTI Brown Book 2004; and
  - 2000 onwards from the OGA Well Operations Notification System (WONS)[12] annual reports on drilling activity
- Emission Factor(s): Default (D) EFs from IPCC, mass of pollutant emitted per conventional oil well drilled: *IPCC Refinement 2019 Table 4.2.4: Tier 1 EFs for Oil Exploration*.

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[12] https://www.ogauthority.co.uk/data-centre/data-downloads-and-publications/well-data/

Offshore Oil Well Testing and Offshore Gas Well testing

- UK industry Tier 2/3 method, utilising the facility-level EEMS data for 1998 onwards, the industry-wide sector estimates for 1995 to 1997 (UKOOA 2005) and an estimate of well testing activity for 1990-1994 through extrapolation back from 1995 using well drilling statistics. The EEMS dataset specifies if the well test was for oil or gas.
- The EEMS data (BEIS, 2021a) present the AD in tonnes (of gases flared) and the emissions of individual gases including: CO_2, CH_4, N_2O, NO_X, NMVOC, CO, SO_2.
- UK GHGI emissions = ∑ operator emissions data per pollutant
- EFs for each pollutant are derived: EF = ∑ operator emissions / ∑ activity data

Onshore Unconventional Gas Well Exploration

- UK GHGI emissions = ∑ operator emissions data per pollutant
- Information obtained direct from the regulatory agency, the EA, for each of the 12 well sites spudded during 2011-2019; none of these wells have gone into production.

Method Assumptions and Observations

- There is no unconventional oil exploration and production in the UK. The method applied to the onshore conventional oil sector is taken from the 2019 Refinement and addresses a minor gap in UK regulatory reporting, as the well operators onshore seldom exceed the reporting threshold for IED/PPC reporting during the exploration phase. There is a small risk of a minor double-count if for some of the larger well sites the operators have included some well drilling/exploration emission estimates in their annual submissions to regulators (which are used in the method outlined below for onshore oil production emissions).
- Well testing emission estimates on an installation-specific basis are included within the EEMS datasets from 1998 onwards at all sites of offshore exploration activities within UK's territorial waters, including data on both activity and emission factors of excess gas that is flared or released to the atmosphere. Emissions released at the seabed are not included in estimates; it is assumed that any such releases will dissolve in the water column without subsequent release to the atmosphere. Following a change of reporting systems used by the regulators in 2017, the inventory team noted a step-change (down) in reported oil and gas well testing emissions; it was assumed that the change in reporting system had led to the step-change and hence higher well testing estimates were reported within the 2021 submission. This research project has enabled further consultation with the BEIS OPRED team; it has been confirmed that the EEMS data are complete and hence in the 2022 submission we have corrected the previous over-report for estimates from 2017 onwards.
- 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 seabed 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.
- **Completeness**: In the UK there are no known omissions. The addition of estimates for onshore oil well exploration address a minor gap in previous UK submissions. There is a risk that operators offshore may not report their oil or gas well testing activity to EEMS; mobile drilling units by their nature are deployed across different production regions of the world and hence they may appear and disappear from the EEMS reporting year to year, which makes it difficult to evaluate the completeness of EEMS over the time series.

However, we have no evidence that under-reporting occurs. The UK inventory for the first time includes estimates from drilling activities at unconventional gas sites during 2010-2019, which total <60 tCH_4 in any one year; see Method Statement 18 for details.

- **Accuracy**: The onshore oil production method is Tier 1, applying default EFs from the 2019 IPCC Refinement which are associated with high uncertainty (cited as -12.5% to +800%). It is a minor source in the UK context and hence does not impact significantly on overall inventory uncertainty. The oil and gas well testing EFs that operators typically apply in their EEMS returns are taken from operator guidance that was last updated for this source in 2008, based on UK industry research. There is some uncertainty that the carbon emission factors from that research are representative of the carbon content of the eluted gases from all oil and gas wells across the UKCS, given the range in crude oil, associated gas and dry gas compositional analysis that is noted from different installations reporting from different production areas on the UKCS. However, the data are UK-specific EFs, derived from analysis of fluids from UKCS production historically.
- **Time Series Consistency:** The underlying data (well drilling numbers) for the onshore oil exploration source is time series consistent. The offshore oil and gas well testing reporting by operators has been to a consistent reporting mechanism since ~1995. The 1990-1994 data are extrapolated using IPCC good practice methods, i.e. proxy data on well drilling to deliver a time series consistent dataset as far as is practicable. This research has significantly improved this time series, noting that in the 2021 submission there was a large step-down in well testing emissions between 1994 and 1995 that is not consistent with the trend in well drilling statistics.

Scope for future research and improvement

- To conduct drilling activities, offshore operators are required to report to OGA under the Energy Act / Petroleum Act, request drilling consents, submit data to the OGA WONS portal and also apply for Consent to Locate to a given oil or gas field. Through analysis of information on Consent to Locate and PETS EIA directions, it may be feasible to check on the completeness of reporting to EEMS by MODUs, i.e. to ensure that all operating MODUs have reported to EEMS, and to gap-fill where needed. However, operators are only required to obtain an OGA flaring consent and an EIA Direction for *extended* well tests (i.e. well tests scheduled to run for longer than 96 hours) and not for standard well tests and hence there may not be a complete list from OGA to use to validate the completeness of EEMS.
- The EFs applied in the EEMS system for oil and gas well testing have not been reviewed by the industry for >10 years; they may or may not be accurate and representative for the well testing practices and drilling activities in new production areas of the UKCS in recent years. To improve accuracy and ensure that the UK estimates are based on current EFs, new research and/or monitoring would need to be conducted.

Uncertainties

- The uncertainty parameters applied at category-gas level are presented in Annex 2.3.
- As noted above, the EFs applied for onshore oil exploration are associated with high uncertainty; the 2019 Refinement cites a range of -12.5% to +800% of the stated EF.
- The oil and gas well testing EFs are based on UK industry research from ~15 years ago. The GHG emissions are dominated by CO_2, which is closely linked to the carbon content of the flared gases. Based on many years of EEMS and EU ETS reporting of combustion of gas from the UKCS, the gas content can vary considerably, but the overall average CEF does not. The well testing EFs uncertainty is therefore estimated to be quite low, at ±10%.

1B2a2: Oil Production & Upgrading

Emission Sources

- Offshore oil production: Direct Processes
- Offshore oil production: Other fugitives
- Oil terminals: Direct processes
- Oil terminals: Other fugitives
- Onshore conventional oil production

These emission sources cover the release of fugitive gases from the processing units on upstream facilities, where the produced fluids are extracted, treated (e.g. to remove acid gases), separated to allow the onwards delivery or use of liquids (crude oil, condensate) and gases. The emissions arise from leaks on the platform / FPSO / terminal infrastructure, from pipes, flanges, connectors, compressors, dehydrators, separators and other units. In the UK the reporting of fugitive releases by operators tends to fall into two categories: (i) several installations report "direct process" emissions that are usually due to the treatment of acid gases which are processed or flared / incinerated leading (usually) to additional releases of CO_2 and other gases such as SO_2 (e.g. Tartan Alpha, Piper Bravo, Kinneil Terminal); and (ii) all offshore facilities and oil terminals report operational fugitive releases from leaking infrastructure, which are usually estimated based on an inventory of all of the equipment on the facility (i.e. counts of flanges, pipelines, connectors, compressors and so on) and UK industry EFs (from EEMS) on leaks per year per piece of equipment.

Onshore oil production sites also exhibit similar fugitive releases but for most sites the level of annual emissions is below the reporting threshold for IED/PPD regulatory inventories, and hence an alternative method is needed to address that reporting gap.

Pollutants Reported

- Carbon dioxide, methane, nitrous oxide, oxides of nitrogen, carbon monoxide, sulphur dioxide, NMVOCs

Method Summary

Onshore oil production

- For CH_4 and NMVOC, a hybrid method that uses UK operator data where they are reported and gap-filling for sites that do not report. For CO_2 and N_2O there is no operator reporting of any emissions data and hence an IPCC Tier 1 method is applied: *Emission = AD x Default EF*
- Activity data: Over the time series there are 47 oil well sites active, and for each we have an annual volume of crude oil produced from industry reporting to OGA and its predecessors:
  - 1990 to 2003: DTI Brown Book 2004;
  - 2004 onwards from the PPRS system of monthly reporting.
- Emission Factor(s): For the larger sites, such as Wytch Farm, Scampton North, Singleton and Cold Hanworth, there are operator reported estimates of CH_4 and NMVOC available from the PI, and these are used directly. For the remaining sites, CH_4 and NMVOC estimates are gap-filled using their reported production data and the weighted-average EF from the reporting sites, i.e. derived by dividing the sum of reported emissions by the sum of production at sites that reported emissions. This is effectively a Tier 2 method, applying UK-specific EFs.

  For CO_2 and N_2O, for all sites the method uses the IPCC default EFs from the 2019 Refinement for sites with high emitting technologies and practices; this EF is selected on the basis that whilst there is a regulatory system in place in the UK, these are small producing sites where implementing mitigation techniques are unlikely to be economic to apply. We further note that these are very small producers and the impact on the UK GHGI totals of the choice of default EF is almost negligible; if they were significant emitters they would report to the PI/SPRI.

Offshore Oil Direct Processes and Fugitives

- UK industry Tier 2/3 method, utilising the facility-level EEMS data for 1998 onwards, the industry-wide sector estimates for 1995 to 1997 (UKOOA 2005) and an estimate of direct process and fugitive emissions for 1990-1994 through extrapolation back from 1995 using crude oil production statistics. A small number of installations account for the direct process sources and in those cases the time series of their estimated annual oil production or throughput was used to estimate the process emissions.
- The EEMS data (BEIS, 2021a) present the AD in tonnes (of all gases released) and the emissions of individual gases including: CO_2, CH_4, N_2O, NO_X, NMVOC, CO, SO_2. Emissions of fugitives (rather than direct process emissions) are dominated by CH_4 and NMVOC, with some reporting of CO_2 also evident.
- UK GHGI emissions = $\sum$ operator emissions data per pollutant

Oil Terminal Direct Processes and Fugitives

- The method is as described for offshore units above, i.e. a UK industry Tier 2/3 method, utilising the facility-level EEMS data for 1998 to 2010 (when most terminals ceased reporting to EEMS), the industry-wide sector estimates for 1995 to 1997 (UKOOA 2005) and an estimate of direct process and fugitive emissions for 1990-1994 through extrapolation back from 1995 using crude oil production statistics.
- For onshore terminals, the annual submissions to the PI/SPRI are verified by the regulatory agency, whereas EEMS data are not. Therefore, to align the inventory totals to these verified data, across all years where PI/SPRI > EEMS totals per pollutant, the inventory method allocates the residual emissions to this source category. Further, for 2011 onwards, where the *only* data reported are from the PI/SPRI, the inventory method across all sources aligns to the total reported to the PI/SPRI and estimates of direct process and fugitive emissions are modelled based on previously reported source estimates and the trend in annual emissions per pollutant, per installations.
- This source category is also used for residual emissions once all other source estimates have been made, for the 1990-1997 dataset. The UKOOA 2005 dataset provides source-specific estimates back to 1995, and the 1990-1994 estimates per source are modelled (see other method descriptions across 1A1cii and 1B2) using proxy data. CO_2 and N_2O arise primarily from fuel combustion and gas flaring. For methane and NMVOC, the allocation of emissions across a range of sources is especially uncertain for 1990-1994; it is unknown whether the reported emissions from industry were from process sources, fugitive leaks, material storage or from venting. Our approach is to estimate specific allocations of methane and NMVOC from direct processes, storage and venting, and allocate the rest to “other fugitives” and report them here.

Method Assumptions and Observations

- For process and fugitive sources where the EEMS emissions data are provided without any underlying AD and EF information, the UK inventory method is to aggregate those operator-reported data and conduct QC against other reported data (such as production data to identify when installations start and cease production) to ensure completeness.
- Fugitive emissions reported within EEMS are typically aggregated for each installation, without any further information on the specific source/unit. Similarly, emissions reported

under IED/PPC to the PI/SPRI by terminal operators are aggregated across all sources on the defined installation. These national circumstances of data availability mean that the UK inventory data cannot be disaggregated to separate fugitive emissions from oil and gas processing units, from other fugitives, such as acid gas removal units (except where these are specifically identified as “direct process” sources), other connectors, flanges and pipeline infrastructure. The transparency of the underlying operator calculations is limited, and QC of the data focuses on time series consistency per installation.

- The time series of estimates is heavily influenced by reported data from a relatively small number of installations. As noted in the method overview, a number of sites have additional processing requirements due to, for example, the incidence of acid gases from the upstream oil fields. The UK GHGI trend is therefore influenced significantly by the production trends at those installations. As with all sources, there is greater uncertainty regarding the estimates at the start of the time series due to the limited data resolution in the UKOOA 2005 dataset, but IPCC good practice gap-filling techniques have been used to deliver a plausible time series per source.
- The CH_4 and NMVOC method for onshore oil well sites uses operator reported emissions for larger sites and then applies an assumption that the smaller non-reporting sites operate at a similar EF of emissions per unit production.

Scope for future research and improvement

- The method is reliant on the operator reporting to EEMS; in order to test against an IPCC default or other methodology (such as the fugitives methodology developed through research in Norway in recent years) would require significant investment to gathering more detailed data about the infrastructure on UK platforms, FPSOs and terminals. To develop a more comprehensive Tier 2 method would require UK regulators and industry to generate more detailed activity and emissions data through either annual submissions or periodic research.
- For terminals there is an opportunity to update the requirements within IED/PPC permits (e.g. in response to the latest BREF notes) to include additional operator reporting (annual or periodic) of source-specific estimates, to supplement the installation-wide emission estimates that are currently reported to the PI/SPRI. Additional data (including AD or contextual info on e.g. production) would provide transparency of the source-specific emissions, and remove the need for assumptions to be applied to estimate the allocation of total emissions across fugitives, venting, storage, combustion etc, improving accuracy and opportunities to conduct QC.

Uncertainties

- The uncertainty parameters applied at category-gas level are presented in Annex 2.3.
- The EFs applied for onshore oil production are associated with high uncertainty; the 2019 Refinement indicates that CO_2 EF uncertainties are around ±30%, whilst the range for N_2O is -10% to +1000%.
- In the latest year and considering the relative contributions to emission estimates per pollutant and the underlying methods and EFs, our expert judgement is that the activity data uncertainty is around 5 to 10% and the EF uncertainties are around 30% for CO_2, 50% for CH_4 and 200% for N_2O. Some of the EF uncertainties are *higher* than previously considered in the 2021 submission; the research has not reduced the inventory uncertainty, although the data and method selection across the time series has minimised it, but we better *understand* the sources of uncertainty in the data and have revised the uncertainty parameters accordingly.

1B2a3: Oil Transport

Emission Sources

- Offshore oil loading
- Onshore oil loading
- Oil transport fugitives: pipeline (onshore)
- Oil transport fugitives: road and rail tankers

The transfer of oil from the upstream production installations to refineries and terminals leads to fugitive emissions of hydrocarbons due to venting and leakage from pipelines, marine tankers, rail and road tankers. In the UK, these emissions arise from:

(i) crude oil production and offshore loading from OTLs to shuttle tankers;
(ii) off-loading of crude oil from oil tankers to onshore terminals and refineries;
(iii) transfer of crude oil via pipelines from offshore platforms and FPSOs to onshore terminals;
(iv) onshore loading of crude oil to road or rail tankers at onshore well sites; and
(v) the subsequent oil unloading from road/rail tankers at onshore terminals.

Under the IED/PPC reporting scope for onshore terminals, the items (ii), (v) and the onshore pipeline component of (iii) are already accounted for, and further any fugitives from the offshore end of oil pipelines under (iii) are covered within the scope of operator reporting of fugitive releases to EEMS.

The 2019 Refinement presents new guidance and EFs (Table 4.2.4B) for pipeline transfers, and two sets of EFs for shuttle tanker ships to account for those operating abatement equipment (“VRU”) and those that do not. These EFs are based on Norwegian research; information from the industry indicates that North Sea shuttle tankers operate across the UK and Norwegian Continental Shelf production area, and hence the 2019 IPCC Refinement EFs are regarded as representative of UK circumstances.

Loading emissions are influenced by many contributing factors including: the composition and temperature of the crude oil; the design and operation of the loading system; whether the vessel cargo tanks contain HC gases, inert gases or a mixture of these when the loading operation starts; and (for offshore loading) the wave heights and weather conditions during loading.

Pollutants Reported

- Methane, NMVOC and carbon dioxide

Method Summary

Offshore Oil Loading

- IPCC 2019 Refinement Tier 1 method: *Emission = AD x Default EF*
- Activity data: Over the time series there are 33 offshore installations that service the crude oil from oil fields that are OTLs, and for each we can derive an annual volume of crude oil produced across the time series, from industry reports to OGA and DTI, and the field-installation mapping:
    - 1990 to 2003: DTI Brown Book. [1990-1994, BB 1995 Annex 6; 1995-1997, BB 2000 Appendix 9; 1998-2000, BB 2001 Appendix 9; 2001 to 2003, BB 2004 Appendix 9.]
    - 2004 onwards from the PPRS system of monthly reporting per field, aggregated across all fields and months per installation.

- Emission Factor(s): Default (D) EFs from IPCC. EF units are mass of pollutant emitted per 1000m^3 of oil produced: *IPCC Refinement 2019 Table 4.2.4B: Tier 1 EFs for Oil Transport*.
    - Shuttle tankers (no VRU): 0.065 t CH_4 /1000 m^3; 1.10 t NMVOC /1000 m^3

Onshore Oil Loading

- UK industry Tier 2/3 method, utilising the facility-level EEMS data for 1998 to 2010 (when most terminals ceased reporting to EEMS), the industry-wide sector estimates for 1995 to 1997 (UKOOA 2005) and an estimate of onshore oil loading emissions for 1990-1994 through extrapolation back from 1995 using crude oil production statistics.
- The EEMS data (BEIS, 2021a) present the AD in tonnes of crude oil received from shuttle tankers at the terminal and the emissions of individual gases in tonnes, including: CH_4 and NMVOC.
- UK GHGI emissions = ∑ operator emissions per pollutant
- For 2011 onwards, where installations continued to report to EEMS (e.g. Nigg, Flotta reported to 2014) then these data are used. For other sites where the only data reported are from the Pollution Inventory (PI) or the Scottish Pollutant Release Inventory (SPRI), there is no source resolution of reported emissions, only a total per pollutant per year per site is reported. The inventory method across all sources aligns to the total reported to the PI/SPRI and an estimate of oil loading emissions has been modelled based on previously reported source estimates and site total. These estimates have been augmented through operator consultation, for example with the ConocoPhillips Seal Sands oil terminal environmental manager (ConocoPhillips, 2019. Personal Communication) who provided a breakdown of total reported NMVOC emissions.

Oil transport fugitives: pipeline (onshore)

- IPCC 2019 Refinement Tier 1 method: *Emission = AD x Default EF*
- Activity data: There is only one onshore production site where the level of annual production warrants the investment in a pipeline to a nearby terminal, and that is the 91 km 16” diameter pipeline from Wytch Farm to Hamble terminal, via Fawley refinery. The annual production of crude oil at Wytch Farm is published via the historic DTI Brown Book, and now via the PPRS:
    - 1990 to 2003: DTI Brown Book. [1990-1992, BB 1995 Annex 6; 1993-1994, BB 2008 Annex 6; 1995-1997, BB 2000 Appendix 9; 1998-2000, BB 2001 Appendix 9; 2001 to 2003, BB 2004 Appendix 9.]
    - 2004 onwards from the PPRS, through annual aggregation of monthly reported data.
- Emission Factor(s): Default (D) EFs from IPCC. EF units are mass of pollutant emitted per 1000m^3 of oil transported by pipeline: *IPCC Refinement 2019 Table 4.2.4B: Tier 1 EFs for Oil Transport*.
    - 0.0054 t CH_4 /1000 m^3; 0.00049 t CO_2 /1000 m^3; 0.054 t NMVOC /1000 m^3

Oil transport fugitives: road and rail tankers (onshore)

- IPCC 2019 Refinement Tier 1 method: *Emission = AD x Default EF*
- Activity data: The annual production of crude oil at all onshore well-sites is published via the historic DTI Brown Book, and now via the PPRS. The AD here is the total for all onshore fields less that for Wytch Farm, where the product is transferred via pipeline (*see above*):
    - 1990 to 2003: DTI Brown Book. [1990-1992, BB 1995 Annex 6; 1993-1994, BB 2008 Annex 6; 1995-1997, BB 2000 Appendix 9; 1998-2000, BB 2001 Appendix 9; 2001 to 2003, BB 2004 Appendix 9.]

  - 2004 onwards from the PPRS, through annual aggregation of monthly reported data.
- Emission Factor(s): Default (D) EFs from IPCC. EF units are mass of pollutant emitted per 1000m^3 of oil transported by pipeline: *IPCC Refinement 2019 Table 4.2.4B: Tier 1 EFs for Oil Transport*.
  - 0.025 t CH_4 /1000 m^3; 0.0023 t CO_2 /1000 m^3; 0.25 t NMVOC /1000 m^3

Method Assumptions and Observations

- Offshore loading of crude oil is a key source category for NMVOCs in the UK inventory, and therefore a higher-Tier approach has been sought. We note that operators do report emission estimates from oil loading at offshore assets in EEMS, but that the data show significant inter-annual variability in scope with some installations only reporting periodically and other known OTLs not reporting at all, indicating that EEMS data for this source are not complete.
- The activity data required for estimates of emissions of hydrocarbons from oil loading offshore is the annual mass of crude oil production at UKCS platforms or FPSOs that are not connected to oil pipelines and hence the crude oil is transported to shore using shuttle tankers. The operator reporting in EEMS includes activity data for the mass of crude oil transferred per year. However, the OGA PPRS data for Offshore Tanker Loaders (OTLs) provides an alternative dataset via the monthly returns per OTL field on crude oil production which can be aggregated to the installation (i.e. platform or FPSO) level using the field to installation mapping. We note that the PPRS data are underpinned by statutory reporting obligations whilst EEMS is a voluntary reporting system for the oil loading source. As noted above, comparison of EEMS against PPRS and subsequent consultation with operators via the BEIS OPRED team confirmed that the EEMS-reported data by offshore operators are incomplete.
- Another alterative dataset is presented within DUKES Table F.1 *Crude Oil and Natural Gas Liquids production*, which reports an aggregated time series of mass (in kt) of crude oil production at OTLs per year. The DUKES data is derived from the OGA PPRS data and shows close consistency in most recent years. However, the DUKES data is derived based on a calculation method that considers disposals and stock changes month to month within the tankers; our analysis indicates that in most years this provides very similar estimates to a direct aggregation of the reported mass of production per month per OTL field in PPRS. For several years in the 2000s however, the DUKES Table F.1 indicates a much lower level of OTL production when compared against the aggregate of crude oil production data in the PPRS dataset; comparison of the PPRS vs. DUKES data at the field and installation level, shared with the BEIS energy statistics team, shows that production at three BP oil fields West of Shetland are significantly under-reported in the DUKES time series. Hence to deviate from the UK energy statistics in these mid-time-series years to use the higher PPRS data is justified and was agreed with BEIS; this is important to ensure that the 2005 Base Year for NMVOC reporting is accurate.
- The outcome of this analysis indicates that the **PPRS activity data are the most complete** and accurate dataset for the UK inventory method, rather than the EEMS or DUKES Table F.1 data. For the data back to 1990, we have the Brown Book production data per field, and we have identified which oil fields are OTLs and can hence derive an aggregate total; the overlap years (2000-2003) between the Brown Book and the PPRS show very close consistency and hence we are confident that the UK inventory method has a **time series consistent** activity data time series, using the Brown Book and PPRS data together from 1990 to latest year.
- The scope of reporting of fugitive emissions at offshore installations addresses any leaks at the offshore end of oil pipelines, whilst leaks under-sea we assume to be dissolved in

the water column and any leaks at the onshore terminal receiving end of the pipelines will be reported under the scope of PPC/IED annual returns. Hence, we do not consider that the 2019 Refinement method for fugitive emissions from oil transport via pipelines is appropriate for the UK GHGI as it would introduce a double-count. We note that there is a risk that applying the pipelines method to the onshore production at Wytch Farm may introduce a small double count where fugitive leaks occur at Wytch Farm or at Hamble terminal and are already included within their annual reported emissions to the PI; however, the pipeline is on land rather than under-sea and hence any leaks at connections, compressors on the route are otherwise a gap in the UK GHGI. Hence the estimates are likely conservative but address a minor completeness issue.

- Across all of these transport fugitive sources, there is scarce data from UK sources to inform a country-specific EF; further, the many parameters that influence actual emissions (e.g. sea and weather conditions) make the accurate characterisation of this emission source highly uncertain. For the offshore loading source, there is the EEMS 2008 operator guidance which presents EFs that are derived from research in the UK in the 1990s; however we note that the 2019 Refinement EFs are derived primarily from research in the North Sea production area by the Norwegian authorities. The fleet of shuttle tankers that service the Norwegian sector also service UK installations and hence we consider that the 2019 Refinement EFs are the more recent data, based on circumstances similar to the UK and hence are the best available option.
- In deriving the offshore loading OTL activity data, we note that the crude oil production in the UK share of the median-line oil field, Statfjord, is processed and exported from a platform in Norwegian waters, and hence we have omitted the Statfjord production data in the UK GHGI activity data across the time series, as the emissions arise in Norwegian waters.
- The method described above is the recommended approach to derive both CH_4 and NMVOC emissions from these emission sources, but we note that to apply the new methods for NMVOCs is a decision for Defra.
- The onshore loading emissions dataset from EEMS for the small number of UK oil terminals shows clear step-changes in the NMVOC EFs applied by individual operators, which reflect the deployment of mitigation at each site over the years. Step-changes down are notable for NMVOC from: Kinneil Terminal (2003-4); Sullom Voe (2008-9); Flotta (2010-11); Seal Sands (2009-10). The default EFs in EEMS are hence not representative for onshore loading at oil terminals, where more stringent controls are now in place, due to the risk to local receptors of high NMVOC emissions at terminal ports and oil storage tank farms.

Scope for future research and improvement

- There is scope for UK research into the EFs applied for all sources in this section of the industry. We note that, for example, in the update of onshore facility permits to operate under PPC/IED that the onshore regulators (EA and SEPA) have the opportunity to request that plant operators provide further insight into the source-specific estimates of pollutants within the boundary of the defined installation. This would be especially helpful to improve the evidence base for the origin of fugitive NMVOC and CH_4 emissions, not only for oil loading but across all sources. This type of data is likely to be gathered already by operators; however, we note that there are a range of measurement options available to operators to estimate fugitive hydrocarbons, and a standard method applied across all UK installations would be needed to generate a more accurate and comprehensive dataset.

Uncertainties

- The uncertainty parameters applied at category-gas level are presented in Annex 2.3.
- As noted above, the EFs are associated with high uncertainty; the 2019 Refinement cites a range of ±100% of the EFs for CH_4 and CO_2 from oil transport by pipelines, and -50% to +200% for NMVOC. The uncertainty range for oil transport by road and rail tankers is similar with a range of ±50% of the EFs for CH_4 and CO_2 and -50% to +200% for NMVOC. For offshore oil loading to shuttle tankers with or without VRUs the uncertainty range for CH_4 is cited as ±50%; no data are provided for NMVOC for that source.
- Noting the IPCC default uncertainty ranges above and the data limitations as regards no source-specific data reported by onshore terminal operators, our expert judgement is that overall the uncertainties for this group of sources is ±50% for methane, which is the only significant GHG emission, and similar for other gases.

1B2a4: Refining / Storage; 1B2b4: Natural Gas Transmission and Storage

Emission Sources

- Oil terminal storage
- Gas terminal storage

The storage of oil in onshore terminal tank farms leads to relatively low releases of hydrocarbons as the tanks breathe and minor fugitive releases occur. In the UK the regulation of NMVOC emissions in particular has led to mitigation of such sources through closed-loop tank filling and storage systems, floating roofs and so on. There are similar, even less significant, fugitive emission sources for hydrocarbons from storage of fluids at many UK gas terminals, which also lead to NMVOC emissions and very low releases of CH_4.

Emissions from oil and gas terminals are reported under the scope of IED/PPC annual returns to UK regulators (EA and SEPA), but as with other sources there are no source-specific estimates available.

[The methods for downstream sources such as fugitives from refining of mineral oil or from gas transmission networks are reported in the NIR Energy Chapter, Method Statement 19.]

Pollutants Reported

- Methane, NMVOC

Method Summary

<u>Oil Terminal Storage</u> and <u>Gas Terminal Storage</u>

- Tier 2/3 method, utilising the facility-level EEMS data for 1998 to 2010 (when most terminals ceased reporting to EEMS), the industry-wide sector estimates for 1995 to 1997 (UKOOA 2005). Estimates of oil terminal storage emissions for 1990-1994 are derived through extrapolation back from 1995 using crude oil production statistics; a similar method is used to estimate gas terminal storage using gas production statistics as a proxy.
- The EEMS data (BEIS, 2021a) present the AD in tonnes of fluids stored at the oil or gas terminal and the emissions of individual gases in tonnes, including: CH_4 and NMVOC.
- UK GHGI emissions = $\sum$ operator emissions per pollutant
- For 2011 onwards where the only data reported are to the PI/SPRI, there is no source resolution of reported emissions; only a total per pollutant per year per oil or gas terminal is reported. The inventory method across all sources aligns to the total reported to the PI/SPRI and an estimate of storage emissions has been modelled based on previously reported source estimates and the trend in annual site emission totals.
- Oil terminals that report storage emissions in EEMS include: Flotta, Sullom Voe, Nigg, Kinneil, Seal Sands.
- Gas terminals that report storage emissions in EEMS include: Barrow North, Theddlethorpe, Dimlington, Easington.

Method Assumptions and Observations

- There is a very limited dataset to inform estimates from these minor sources across both oil and gas terminals, but the historic EEMS data do consistently show that total emissions of CH_4 are almost negligible; NMVOC emissions are slightly more significant.

Scope for future research and improvement

- There is scope for UK research into the EFs applied for all sources in this section of the industry, but we note that given the relative insignificance of these sources that this is not a priority for improvement in future.

Uncertainties

- The uncertainty parameters applied at category-gas level are presented in Annex 2.3.
- Noting the data limitations as regards no source-specific data reported by onshore terminal operators, our expert judgement is that overall, the uncertainty for this source is ±50% for CH_4 and NMVOC. These sources are very low emitters; hence in the context of uncertainties across the upstream oil and gas sector they are immaterial.

1B2a6: Additional/Other Oil Fugitives

Emission Sources

- Abandoned Oil Wells (onshore)
- Abandoned Oil Wells (offshore)

Pollutants Reported

- Methane

Method Summary

- IPCC 2019 Refinement Tier 1 method: AD x Default EF = Emission
- Activity data: Number of wells abandoned per year (cumulative), derived from the OGA public wellbore search facility, at: https://itportal.ogauthority.co.uk/edufox5live/fox/edu/
- Emission Factor(s): Default (D) EFs from IPCC. EF units are mass of pollutant emitted per well abandoned per year. IPCC Refinement 2019 provides Tier 1 emissions factors for plugged, unplugged and both types for onshore and offshore oil wells.

Method Assumptions and Observations

- That each well, once abandoned, continues to emit low levels of hydrocarbons in each subsequent year, and that the IPCC default EFs are representative of UK circumstances.
- Over the history of onshore oil and gas production in the UK, there has been an evolution of post-operational practices as regulation has increased; older wells are unlikely to have been capped, whereas more recently all wells abandoned are required to be capped to minimise risk of hydrocarbon leakage.
- The OGA has not been able to provide analysis of the wells dataset to present the specific information on the year in which each well was abandoned. The OGA well status is listed according to when the well was drilled. Therefore, we have assumed, given the large number of wells drilled and abandoned over time, that the records of wells drilled that are subsequently abandoned (in any future year) is a good proxy for the actual number of wells abandoned in a given year.
- *(Inherent in the IPCC method)* The emissions of hydrocarbons for offshore wells that are abandoned is estimated to be only 2% that compared to onshore wells, as the IPCC Refinement Tier 1 method states that it is assumed that 98% of hydrocarbons released will dissolve in the water column and not be emitted to atmosphere.
- As the activity dataset is available only for all *oil and gas* wells aggregated, the method applies the same EFs to the full estimate of all abandoned *oil and gas* wells; hence emissions that ideally ought to be reported under 1B2b for leaks from abandoned *gas* wells are included here. The EF for oil wells is assumed to be applicable for gas wells also.
- This is a minor source and **not a key category** for methane emissions and hence a Tier 1 method is proportionate. The UK regulatory system for mining and oil production and after-care requirements for former production sites is such that only low levels of seepage of hydrocarbons is expected. We note that whilst there are academic studies in the UK to research the rate of leakage of methane from individual abandoned oil and gas well sites, there are no country specific EFs available and hence no Tier 2 method option. Therefore, to apply the IPCC 2019 Refinement default is the best available dataset to address what would otherwise be a minor completeness issue in the UK GHGI.
- **Completeness**: In the UK there are no known omissions, the scope of reporting is complete. We note that there are no EFs for NMVOC from UK research nor IPCC or EMEP/EEA inventory guidance; NMVOC emissions my occur from these sources, notably from abandoned onshore oil wells. There is no known activity as no previous history of oil

production in any OT or CD. There have been a small number of exploratory drilling campaigns offshore in the waters around the Falkland Islands, but no subsequent production and well abandonment.

- **Accuracy**: The method is Tier 1 using detailed AD for the UK and methods from the 2019 IPCC Refinement. The EFs are associated with high uncertainty (as high as -99 to 150% of the stated emission factor).
- **Time Series Consistency:** Annual OGA data on oil wells drilled and their current status is available across the time series, including whether wells are suspended or abandoned, via the public wellbore status search facility of the OGA. The method is therefore time series consistent.

Scope for future research and improvement

- The inventory agency will continue to engage with OGA to seek a solution that may enable us to derive a time series of wells abandoned in each year.
- Research to improve the understanding of when / how many wells abandoned have/have not been capped would enable an improvement to the method to apply the IPCC default EFs (or other EFs) that are specific to (i) capped wells and (ii) uncapped wells, rather than the (iii) “we don’t know if capped or uncapped” default EF that is currently applied to the full activity data.
- There are no default EFs for NMVOC or specific hydrocarbons (e.g. benzene) in either IPCC nor EMEP-EEA guidebooks; there may be suitable EFs in other literature sources.

Uncertainties

- The uncertainty parameters applied at category-gas level are presented in Annex 2.3.
- As noted above, the EFs are associated with high uncertainty; the 2019 Refinement cites a range of -99 to 150% of the stated EFs. The tier 1 method involves large uncertainties both in factor selection and also in determining whether an abandoned well has been plugged or not after decommissioning due to data limitations.
- The method complies with IPCC 2019 guideline for fugitive emissions from abandoned offshore and onshore oil wells. The Tier 1 approach has been applied as Tier 2 or 3 approaches are not available. We note that EFs for abandoned wells have high uncertainty. Activity data for this source are counts of total abandoned onshore and offshore wells in each year of the time series.
- Available information on abandoned wells do not indicate a clear distinction between abandoned oil and abandoned gas wells regarding practices or emission rates. Thus, all the EFs for 1.B.2.A/B.VII in IPCC 2019 are developed from data for both abandoned oil and gas wells. The EFs of abandoned wells are split into either “plugged” (or, properly decommissioned per regulations) and “unplugged” well sub-segments. If insufficient data on plugging practices is available to disaggregate activity data in such a way, the default EF for all type wells is to be used. More limited data are available on offshore wells and disaggregated (i.e. plugged versus unplugged) factors for offshore abandoned wells are developed in IPCC 2019 from onshore wells data considering that most methane (around 98 percent) from offshore abandoned wells is dissolved in marine water.

1B2b2: Natural Gas Production

Emission Sources

- Onshore natural gas production (conventional)
- Onshore natural gas gathering

These emission sources cover the release of fugitive gases from sources from the gas wellhead through to the delivery of gas to processing plants (where necessary), or to the connections to the National Transmission System. UK gas production onshore is limited to a small number of well sites, all conventional (i.e. no fracturing) and hence fugitives arise mainly from any leaks around the wellhead and through infrastructure (pipes, connectors, dehydrators, compressors).

Pollutants Reported

- Carbon dioxide, methane, nitrous oxide and NMVOC

Method Summary

Onshore natural gas production (conventional)

- IPCC Tier 1 method: *Emission = AD x Default EF*
- Activity data: Annual volume of natural gas (million m^3) produced, obtained from industry reporting to OGA, BEIS and their predecessors (DTI, DECC):
  - **1990 to 1998**: DTI Brown Book. [1990, BB 1995 Appendix 7; 1991-1992, BB 1996 Annex 7; 1993-1995 BB 1998 Appendix 7; 1996-1998 BB 2001 Appendix 10; 1999 onwards is from DUKES Annex F2
  - **1999 onwards** from DUKES Annex F.2.
- Emission Factor(s): Default (D) EFs from IPCC. EF units are mass of pollutant emitted per million m^3 of natural gas produced onshore: *IPCC Refinement 2019 Table 4.2.4G: Tier 1 EFs for Natural Gas Production Segment, 1B2b2*. Onshore activities occurring with higher-emitting technologies and practices.
  - 4.09 t CH_4 / Mm^3; 1.45 t CO_2 / Mm^3; 0.98 t NMVOC / Mm^3; 0.000025 t N_2O / Mm^3

Onshore natural gas gathering

- Method identical to the method presented above for onshore natural gas production (conventional), but applying the following EFs from IPCC *Refinement 2019 Table 4.2.4G: Tier 1 EFs for Natural Gas Production Segment, 1B2b2*. Onshore activities occurring with higher-emitting technologies and practices.
  - 3.20 t CH_4 / Mm^3; 0.35 t CO_2 / Mm^3; 0.77 t NMVOC / Mm^3; 0.000006 t N_2O / Mm^3

Method Assumptions and Observations

- There is a very limited dataset to inform estimates from these minor sources from the UK onshore gas production sector, as there are no reported data to the Pollution Inventory.
- The annual level of fugitive releases per well site is below the reporting threshold for IED/PPC regulatory inventories, and the UK industry does not produce any country specific EFs or estimates of fugitive leaks; hence to apply the IPCC 2019 Refinement Tier 1 default method is proportionate to address what would otherwise be a minor completeness issue in the UK GHGI.
- **Completeness**: In the UK there are no known omissions, the scope of reporting is complete. We note that there are no EFs for GHG nor NMVOC from UK research or the industry.
- **Accuracy**: The method is Tier 1 using detailed AD for the UK and methods from the 2019 IPCC Refinement; hence uncertainties are high %s of very small emission estimates.

- **Time Series Consistency:** Annual natural gas production onshore data is available across the time series, via the UK energy statistics and previous annual statistics publications (DTI Brown Book). The method is therefore time series consistent.

Scope for future research and improvement

- There is scope for UK research into the EFs applied for all sources in this section of the industry, but we note that given the relative insignificance of these sources that this is not a priority for improvement in future.

Uncertainties

- The uncertainty parameters applied at category-gas level are presented in Annex 2.3.
- The EFs applied for onshore natural gas production are associated with high uncertainty; the 2019 Refinement indicates that CH_4 and CO_2 EF uncertainties are around ±20%, whilst the range for N_2O is -10% to +1000% and for NMVOC is -75% to +250%.
- The EFs applied for onshore natural gas gathering are associated with high uncertainty; the 2019 Refinement indicates that CH_4 and CO_2 EF uncertainties are around ±10%, whilst the range for N_2O is -10% to +1000% and for NMVOC is -75% to +250%.

1B2b3: Natural Gas Processing

Emission Sources

- Offshore gas production: Direct Processes
- Offshore gas production: Other fugitives
- Gas terminals: Direct processes
- Gas terminals: Other fugitives

These emission sources cover the release of fugitive gases from the processing units on upstream facilities, where the produced fluids are extracted, treated (e.g. to remove acid gases), separated to allow the onwards delivery or use of gas and condensate. The emissions arise from leaks on the platform / FPSO / terminal infrastructure, from pipes, flanges, connectors, compressors, dehydrators, separators and other units. In the UK the reporting of fugitive releases by operators tends to fall into two categories: (i) several installations report “direct process” emissions that are usually due to the treatment of acid gases which are processed or flared / incinerated leading (usually) to additional releases of CO_2 and other gases such as SO_2 (e.g. platforms: Elgin, Rough BD, Markham, and gas terminals: SAGE-St Fergus, Barrow, CATS, Point of Ayr, Theddlethorpe); and (ii) all offshore facilities and gas terminals report operational fugitive releases from leaking infrastructure, which are usually estimated based on an inventory of all of the equipment on the facility (i.e. counts of flanges, pipelines, connectors, compressors and so on) and UK industry EFs (from EEMS) on leaks per year per piece of equipment.

Pollutants Reported

- Carbon dioxide, methane, nitrous oxide, oxides of nitrogen, sulphur dioxide, carbon monoxide and NMVOC

Method Summary

Offshore Gas Direct Processes and Fugitives[13]

- Tier 2/3 method, utilising the facility-level EEMS data for 1998 onwards, the industry-wide sector estimates for 1995 to 1997 (UKOOA 2005) and an estimate of direct process and fugitive emissions for 1990-1994 through extrapolation back from 1995 using natural gas production statistics. A small number of installations account for the direct process sources; emissions are dominated by CO_2 arising from sour gas treatment/venting and amine regeneration at the Elgin platform and from Rough BD platform. The time series of the annual gas production at each installation was used to estimate process emissions in pre-EEMS years.
- The EEMS data (BEIS, 2021a) present the AD in tonnes (of all gases released) and the emissions of individual gases including: CO_2, CH_4, N_2O, NO_X, NMVOC, CO, SO_2. Emissions of fugitives (rather than direct process emissions) are dominated by CH_4 and NMVOC, with some reporting of CO_2 also evident.
- UK GHGI emissions = ∑ operator emissions data per pollutant

Gas Terminal Direct Processes and Fugitives

- The method is as described for offshore units above, i.e. a UK industry Tier 2/3 method, utilising the facility-level EEMS data for 1998 to 2010 (when most terminals ceased reporting to EEMS), the industry-wide sector estimates for 1995 to 1997 (UKOOA 2005) and an estimate of direct process and fugitive emissions for 1990-1994 through

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[13] An additional source reported in the UK GHGI as a fugitive emission is the emissions from the 2012 Elgin blow-out. A country-specific method was applied here, based on reported daily methane flow-rate observations taken on 5 days over the blow-out period. [This method was developed in previous research and is noted here for completeness.]

extrapolation back from 1995 using natural gas production statistics. The installations at SAGE-St Fergus and CATS terminals opened in 1992 and 1993 respectively; the Inventory Agency has estimated process releases back to those years (and zero emissions in 1990).

- For onshore terminals, the annual submissions to the PI/SPRI are verified by the regulatory agency, whereas EEMS data are not. Therefore, to align the inventory totals to these verified data, across all years where PI/SPRI > EEMS totals per pollutant, the inventory method allocates the residual emissions to this source category. Further, for 2011 onwards, where the *only* data reported are from the PI/SPRI, the inventory method across all sources aligns to the total reported to the PI/SPRI and estimates of direct process and fugitive emissions are modelled based on previously reported source estimates and the trend in annual emissions per pollutant, per installations.
- This source category is also used for residual emissions once all other source estimates have been made, for the 1990-1997 dataset. The UKOOA 2005 dataset provides source-specific estimates back to 1995, and the 1990-1994 estimates per source are modelled (see other method descriptions across 1A1cii and 1B2) using proxy data. CO_2 and N_2O arise primarily from fuel combustion and gas flaring. For methane and NMVOC, the allocation of emissions across a range of sources is especially uncertain for 1990-1994; it is unknown whether the reported emissions from industry were from process sources, fugitive leaks, material storage or from venting. Our approach is to estimate specific allocations of methane and NMVOC from direct processes, storage and venting, and allocate the rest to "other fugitives" and report them here.

Method Assumptions and Observations

- For process and fugitive sources where the EEMS emissions data are provided without any underlying AD and EF information, the UK inventory method is to aggregate those operator-reported data and conduct QC against other reported data (such as production data to identify when installations start and cease production) to ensure completeness.
- Fugitive emissions reported within EEMS are typically aggregated for each installation, without any further information on the specific source/unit. Similarly, emissions reported under IED/PPC to the PI/SPRI by terminal operators are aggregated across all sources on the defined installation. These national circumstances of data availability mean that the UK inventory data cannot be disaggregated to separate fugitive emissions from oil and gas processing units, from other fugitives, such as acid gas removal units (except where these are specifically identified as "direct process" sources), other connectors, flanges and pipeline infrastructure. The transparency of the underlying operator calculations is limited, and QC of the data focuses on time series consistency per installation.
- The time series of estimates is heavily influenced by reported data from a relatively small number of installations. As noted in the method overview, a number of sites have additional processing requirements due to, for example, the incidence of acid gases from the upstream gas / condensate fields. The UK GHGI trend is therefore influenced significantly by the production trends at those installations. As with all sources, there is greater uncertainty regarding the estimates at the start of the time series due to the limited data resolution in the UKOOA 2005 dataset, but IPCC good practice gap-filling techniques have been used to deliver a plausible time series per source.

Scope for future research and improvement

- The method is reliant on the operator reporting to EEMS; in order to test against an IPCC default or other methodology (such as the fugitives methodology developed through research in Norway in recent years) would require significant investment to gathering more detailed data about the infrastructure on UK platforms, FPSOs and terminals. To develop a more comprehensive Tier 2 method would require UK regulators and industry to generate more detailed activity and emissions data through either annual submissions or periodic research.

- For terminals there is an opportunity to update the requirements within IED/PPC permits (e.g. in response to the latest BREF notes) to include additional operator reporting (annual or periodic) of source-specific estimates, to supplement the installation-wide emission estimates that are currently reported to the PI/SPRI. Additional data (including AD or contextual info on e.g. production) would provide transparency of the source-specific emissions, and remove the need for assumptions to be applied to estimate the allocation of total emissions across fugitives, venting, storage, combustion etc, improving accuracy and opportunities to conduct QC.

Uncertainties

- The uncertainty parameters applied at category-gas level are presented in Annex 2.3.
- In the latest year and considering the relative contributions to emission estimates per pollutant and the underlying methods and EFs, our expert judgement is that the activity data uncertainty is ~2-5% and the EF uncertainties are ~10% for CO_2, 50% for CH_4 and 100% for N_2O. Some of the EF uncertainties are *higher* than previously considered in the 2021 submission; the research has not reduced the inventory uncertainty, although the data and method selection across the time series has minimised it, but we better *understand* the sources of uncertainty in the data and have revised the uncertainty parameters accordingly.

1B2c1i: Upstream Oil Production, Venting; 1B2c1ii Upstream Gas Production, Venting

Emission Sources

- Upstream oil production: venting
- Oil terminal: venting
- Upstream gas production: venting
- Gas terminal: venting

This source category comprises emissions from the venting of waste gases that arise through production activities for all upstream oil and gas installations on the UK Continental Shelf (UKCS) and onshore, i.e. including at offshore assets (platforms and FPSOs) and at onshore terminals. Venting releases comprise discharges of waste gas streams and process by-products, either through intentional releases or in emergencies; operators report a wide range of emissions as venting such as solution gas emissions from storage tanks, purging and blowdowns, pressure relief releases and disposal of waste gases or off-specification products where there is no option to flare. In operator reporting via EEMS, venting sub-sources include: emergency, maintenance and operational.

Pollutants Reported

- Carbon dioxide, methane, NMVOC and (rarely) nitrous oxide

Method Summary

Offshore oil production: Venting and Offshore gas production: Venting

- UK industry Tier 2/3 method, utilising the facility-level EEMS data for 1998 onwards, the industry-wide sector estimates for 1995 to 1997 (UKOOA 2005) and an estimate of gas venting emissions for 1990-1994 through extrapolation back from 1995 using crude oil (for oil sites) or natural gas (for gas sites) production statistics.
- The EEMS data (BEIS, 2021a) present the emissions of individual gases including: CO_2, CH_4, and NMVOC with occasional reporting of other gases such as N_2O, NO_X and CO. The EEMS reporting of activity data is inconsistent; in most cases the EEMS AD are the sum of the mass of the individual gases, but in others no AD are reported. In the UK GHG inventory model and reporting outputs, we simply aggregate the emissions data per pollutant across all sites and report that as the emission and the EF, with AD = 1.
- UK GHGI emissions = $\sum$ operator emissions per pollutant = EF ; AD = 1

Oil Terminals: Venting and Gas Terminals: Venting

- The method is as above, except that most terminals ceased to report emissions to EEMS beyond 2010 and hence for 2011 onwards, where the only data reported are from the PI or SPRI, there is no source resolution of reported emissions, only a total per pollutant per year per site. The inventory method for 2011 onwards therefore aligns to the total reported to the PI/SPRI across all sources, and an estimate of venting emissions has been modelled based on previously reported source estimates and the trend in annual site emission totals.

Method Assumptions and Observations

- EEMS data for venting are provided as emissions data without any underlying activity and emission factor information. The UK inventory method is to aggregate those operator-reported data and conduct QC against other reported data (such as production data to identify when installations start and cease production) to ensure completeness of reporting. In a small number of cases, operators may report gases other than CO_2, CH_4

and NMVOC under venting in EEMS; where there are reports of small amounts of N_2O, NO_X and CO reported as venting in EEMS, these data are included in the inventory, assuming that there are some waste combustion gases recorded as vented, e.g. from maintenance activities. This happens rarely and the mass of these gases is always very low; they may be misallocated, but it is a minor issue.

- **Completeness**: In the UK there are no known omissions, the scope of reporting is complete. Time-series checks by the Inventory Agency are used to assess the completeness of reporting each year; there are a small number of terminals that regularly report notable venting emissions, whilst offshore there are tens of installations that report notable venting of hydrocarbons (methane and NMVOC), and a small number (Elgin, Shearwater, Brae only in recent years) that report venting of CO_2. Onshore terminals that routinely report notable venting emissions include: Flotta, Theddlethorpe, SAGE-St. Fergus, Shell-St Fergus, Barrow and Bacton.
- **Accuracy**: The method is Tier 2/3 across the time series, using the best available data from operator reporting throughout. Noting that in many cases the operator estimates are not presented via an “activity” and “emission factor” but rather are direct estimates of the gases vented from monitoring of the gas throughput and an assumed gas composition, the accuracy is hard to evaluate. Where there are installation-specific processes (e.g. acid gas stripping) that lead to high emissions of vented gases (e.g. Shearwater and Elgin often encounter high-CO_2 produced gases that cannot be flared; several terminals vent the process gases from fuel gas treatment facilities) the composition of the gases is monitored by operators. Smaller-scale vented emissions may be estimated through engineering calculations and default data on gas composition.
- **Time Series Consistency:** The method is compromised by the lack of fully detailed data for the 1990-1997 period, where only aggregate emissions data across all sources in 1A1cii and 1B2 are available from the industry submissions to UK Government. However, the inventory agency has conducted validation checks across the UKOOA dataset versus EEMS data in overlap years, which indicates good time series consistency, and the inventory agency has deployed gap-filling methods consistent with the 2006 IPCC Guidelines to develop time series consistent reporting per source category back to the early 1990s. Therefore, the time series consistency is as good as practicable, given the limited resolution of the available industry emissions and activity data.

Scope for future research and improvement

- The method is reliant on the operator reporting to EEMS. The PPRS monthly reports also include data on venting. Comparisons of PPRS and EEMS data during this project have indicated that for many sites there is good correlation between EEMS and PPRS, whilst for other sites there are gaps in the PPRS data where EEMS includes venting estimates. This indicates that PPRS is not always reliable for QC of EEMS and/or to inform better estimates. The OGA has recently begun to consider revisions to the system of flare and vent consents, and there may be scope to establish better quality routine reporting of gas venting through the PPRS system, which could then provide an additional data source or QC step for the inventory.

Uncertainties

- The uncertainty parameters applied at category-gas level are presented in Annex 2.3.
- Uncertainties of emissions reported are based on expert judgement, informed by the understanding of the available data and the likelihood of error compensation across all UK installations.
- In the latest year of the time series, the uncertainty for venting is estimated to be ±5% for CO_2, 100% for CH_4, whilst in the Base Year (1990) the uncertainty is assumed to be ±20%

for CO_2 and 100% for CH_4 due to the more limited information available from industry and assumptions applied to estimate venting emissions.

- The limited alternative data against which the EEMS data can be validated undermines confidence in the accuracy and completeness of the venting estimates.

1B2c2i: Upstream Oil Production, Gas Flaring; 1B2c2ii Upstream Gas Production, Gas Flaring

Emission Sources

- Upstream oil production: gas flaring
- Oil terminal: gas flaring
- Onshore oil production: gas flaring
- Upstream gas production: gas flaring
- Gas terminal: gas flaring

This source category comprises emissions from the flaring of waste gases that arise through production activities for all upstream oil and gas installations on the UK Continental Shelf (UKCS) and onshore, i.e. including at offshore assets (platforms, FPSOs, MODUs), at onshore terminals and at onshore production sites. The gases may need to be flared to address operational issues (e.g. excess gas supply), structural issues (e.g. some platforms/FPSOs that produce crude oil and associated gas do not have any gas export line), safety issues. In operator reporting by offshore operators to BEIS OPRED, via EEMS, flaring sub-sources include: routine operations, gross, maintenance, upsets / other. Flaring of gases is also conducted at oil and gas terminals, again to manage waste gas and maintain operational and safety standards across the sites. For all offshore production sites and terminals, gas flaring emissions are reported by operators under EU ETS since 2008 (i.e. from EU ETS Phase 2 onwards), and within EEMS from 1998 onwards.

Onshore oil well sites are smaller production sites in the UK context but do still conduct a small amount of gas flaring during production; separate flaring estimates are made for these sites, for completeness.

The flaring of waste gases during well exploration and testing is reported separately under the 1B2a1 and 1B2b1 IPCC source categories for oil and gas well testing respectively. This enables a distinction to be made between emissions from exploration activities, and emissions from production activities.

Pollutants Reported

- Carbon dioxide, methane, nitrous oxide, oxides of nitrogen, carbon monoxide, sulphur dioxide, non-methane volatile organic compounds (NMVOCs)

Method Summary

The emission estimates across the time series are based on the sum of the best available data from upstream oil and gas operators, onshore and offshore. The method since 1998 is essentially a Tier 3 method, aggregating installation-level activity and emission estimates; estimates for 1990-1997 are based on lower resolution source data but are still a Tier 2 method, using industry-wide estimates from the trade association (UKOOA 2005) which are derived from operator surveys through the 1990s and assuming that carbon emission factors from gas flaring from 1998 are representative for earlier years.

Offshore oil production: Gas Flaring and Offshore gas production: Gas Flaring and

Oil Terminals: Gas Flaring and Gas Terminals: Gas Flaring

- UK industry Tier 2/3 method, utilising the facility-level EU ETS data for 2008 onwards and EEMS data for 1998-2007, the industry-wide sector estimates for 1995 to 1997 (UKOOA 2005) and an estimate of gas flaring emissions for 1990-1994 through extrapolation back from 1995 using crude oil (for oil sites) or natural gas (for gas sites) production statistics.
- The EEMS data (BEIS, 2021a) present the AD of gas flaring in tonnes and the emissions of individual gases including: CO_2, CH_4, N_2O, NO_X, NMVOC, CO, SO_2. The EU ETS data

(BEIS, 2021c) provide the AD of gas flared in tonnes together with the carbon emission factor and verified CO_2 emissions total per flaring source per installation. As such the EU ETS data are considered highly accurate; they provide a rich and detailed dataset that exhibits a range of variability in the flared gas composition across installations. Reporting to both EEMS and EU ETS is underpinned by the sector-wide assumption of 98% oxidation of flared gas.

- UK GHGI emissions = ∑ operator emissions data per pollutant
- Activity data = ∑ operator activity data (tonnes): IEF = Emissions / AD

<u>Onshore oil production: Gas Flaring</u>

- IPCC Tier 2 method: *Emission = AD x Country Specific EF*
- <u>Activity data</u>: Annual mass of gas flared at onshore oil production facilities, obtained from industry reporting to OGA, BEIS and their predecessors (DTI, DECC):
  - **1990 to 1999**: Estimates of mass flared derived from the reported volumes of gas flared by DTI at onshore fields, scaled according to the mass and volume data for flaring at offshore fields, i.e. assuming similar gas density;
  - **2000 onwards** from monthly returns under PPRS for onshore loader fields.
- <u>Emission Factor(s)</u>: The EF derived for offshore oil production per year is applied to the onshore flaring AD, as the best estimate of emissions per unit mass gas flared, as there are no operator-reported emissions data nor EFs from these smaller onshore well sites.

Method Assumptions and Observations

- Note that where the gas flaring emissions are reported for an installation via both EEMS and EU ETS, the EU ETS data are regarded as better quality as they are subject to Third Party verification, as part of the requirements of the trading scheme.
- The estimates of methane emissions from gas flaring are amongst the most uncertain of all estimates of GHGs from the upstream oil and gas sector. The EEMS operator guidance methane EF and the accepted EU ETS sector-wide methodology (to estimate CO_2 emissions under EU ETS) are based on a sector-wide assumption that the oxidation of flared gases is 98%. There is no routine monitoring and reporting of the performance of flares to industry regulators. Consultation with operators and regulators indicates that there is a variable approach by operators to track, monitor and resolve issues such as unlit flares, which will instead be cold venting flare gases. During such events, methane emissions will be much higher and carbon dioxide emissions much lower than the estimates reported based on the measurement of the amount of gas to flare and applying the 98% oxidation factor assumption. Aside from the issue of unlit flares, there is no routine industry monitoring of flare oxidation efficiency, and we note that just a small under-performance in flare efficiency, below the 98% industry assumption, will lead to a significant under-report in the methane estimates (e.g. a 96% flare efficiency equates to double the reported methane emissions).
- Gas flaring a minor source of emissions of nitrous oxide. Operators report estimates to EEMS, predominantly applying defaults from operator guidance, and hence this is essentially a Tier 2 approach; the Inventory Agency gap-fills reported data where necessary, using the default EF.
- The gas flaring an onshore well sites is a small component of total flaring emissions, e.g. in 2020 it is estimated to account for 0.6% of total flaring GHG emissions. The available data for this source is limited to activity data across the time series, with assumptions applied to use the EF from offshore oil production facilities and to derive the AD in the early part of the time series. This component of the gas flaring estimates is therefore

subject to greater uncertainty than the well-documented other sources (offshore and at terminals).

- **Completeness**: In the UK there are no known omissions, the scope of reporting is complete. The Inventory Agency draws upon a range of data sources to ensure completeness (and accuracy), using EU ETS supplemented by EEMS data for smaller installations that fall below the EU ETS reporting threshold.
- **Accuracy**: The method is Tier 2/3 across the time series, using the best available data from operator reporting throughout. In the UK there has been a high level of flare gas compositional analysis to inform EU ETS allocations (from the National Allocation Plans from 1998 onwards) and subsequently in all operator submissions to EU ETS. Further, the stringent monitoring and reporting and other QAQC requirements of the EU ETS system gives confidence that the reported mass of flare gas sent to flare per installation per year is highly accurate. As noted above, the biggest source of potential inaccuracy in GHG estimates is the assumption across all operator reporting that flare oxidation efficiency is 98%; deviation from that assumed level of oxidation will impact both the methane and carbon dioxide estimates.
- The 1990-1997 data are based on the UKOOA 2005 report to UK Government, which took account of the work in the National Allocation Plans to derive better installation-level carbon emission factors but are based on more limited industry surveys from the early 1990s and hence are associated with higher uncertainty than the later data.
- **Time Series Consistency:** The method is compromised by the lack of fully detailed data for the 1990-1997 period, where only aggregate emissions data across all sources in 1A1cii and 1B2 are available from the industry submissions to UK Government. Therefore, the time series consistency is “as good as possible” given the limitations of the available data.

QA/QC

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

- Comparisons between EEMS and EU ETS, to review installation-specific activity data and CO_2 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 quality (AD, EFs) are third-party verified and hence regarded as the more accurate dataset;

- Comparisons of 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 (and EEMS if the terminal reports to EEMS also).

Scope for future research and improvement

- A high priority for further research is to develop a more rigorous and comprehensive evidence base for flare performance at all upstream installations, especially for those that operate offshore in potentially harsh conditions and with more limited opportunities for flare stack maintenance. Priorities are to seek more measurement data on the performance of different flare stack types (enclosed or open flare designs etc.) and to develop more rigorous and consistent operator monitoring and reporting systems to track when flares are operational, when they are unlit, and the volume/mass of flare gas passed to the flare stack during these different periods of operation.

Uncertainties

- The uncertainty parameters applied at category-gas level are presented in Annex 2.3.

- Uncertainties for both AD and EFs are based on expert judgement, informed by the understanding of the available data, the level of uncertainty that is accepted within the reporting systems (e.g. EU ETS) and the likelihood of error compensation across all UK installations.
- In the latest year of the time series, the AD uncertainty for gas flaring is estimated to be ±5%, whilst in the Base Year (1990) the AD uncertainty is assumed to be ±20% due to the more limited information available from industry and assumptions applied to estimate flaring activity.
- Across the time series, the CO_2 EF uncertainty is estimated to be ±5% whilst the uncertainty in the EFs for both methane and nitrous oxide are estimated to be ±100% across all installations, reflecting the uncertainty in oxidation factor assumption (for methane) and the widespread use of a default EF (for nitrous oxide).
- Uncertainties in flaring AD are typically low. However, we note (as outlined above) that there are different operator flare stack monitoring (lit/unlit) practices evident (across the time series) and also that there are less detailed activity and emissions data available for the 1990-1997 period. Hence uncertainties for the estimates in 1990 are higher than for recent years where much more detailed and complete operator-reporting of activity and emissions are evident.
- The CO_2 EFs are based on UK-specific data, from sampling and compositional analysis of gas sent to flare. Despite the uncertainty regarding the assumed gas flaring oxidation factor, across the sector the uncertainty of the CO_2 EF is still expected to be low, however the uncertainty of the CH_4 EF is considered to be high.

A 3.2 INDUSTRIAL PROCESSES (CRF SECTOR 2)

There is currently no additional information for this sector in this Annex.

A 3.3 AGRICULTURE (CRF SECTOR 3)

Note that the references for this section are included in **Section 17.4.**

Table A 3.3.1 Livestock Population Data by Animal Type (‘000 animal places)

Livestock Category	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Total cattle	12,125	11,760	11,048	10,698	10,014	9,785	9,886	9,838	9,735	9,574	9,429
- dairy cows	2,848	2,603	2,336	2,003	1,839	1,906	1,910	1,901	1,888	1,875	1,853
- all other cattle	9,277	9,157	8,713	8,695	8,175	7,879	7,977	7,937	7,848	7,699	7,577
Sheep	45,475	44,233	43,154	36,140	31,724	34,032	34,649	35,557	34,490	34,289	33,427
Pigs	7,548	7,627	6,482	4,862	4,468	4,739	4,866	4,969	5,012	5,078	5,069
Total poultry	138,381	142,267	169,773	173,909	163,842	167,579	172,607	181,811	188,442	186,982	182,882
- laying hens	33,624	31,837	28,687	29,544	28,751	28,311	29,184	30,193	31,098	31,820	31,067
- broilers	73,944	77,177	105,689	111,475	105,309	107,056	110,639	117,612	123,946	121,500	120,047
Total horses	570	684	1,006	1,036	1,024	978	963	954	945	947	932
- horses kept on agricultural holdings	202	273	287	346	312	283	268	258	250	251	236
- professional horses	62	62	70	91	91	87	87	87	87	87	87
- domestic horses	305	348	649	599	621	608	608	608	608	608	608
Goat	98	75	74	95	93	101	104	105	108	111	112
Deer	47	37	36	33	31	31	31	31	34	38	38

A 3.3.1 Enteric Fermentation (3A)

Table A 3.3.2 Methane Emission Factors for Livestock Emissions for 2020

Animal type		Enteric methane kg CH_4/head/year	Methane from manures kg CH_4/head/year
Cattle	Dairy cows	123.81	38.43
	Dairy heifers	54.90	6.19
	Dairy replacements >1 year	51.32	5.91
	Dairy calves <1 year	43.50	3.89
	Beef cows	76.23	10.64
	Beef females for slaughter	49.18	5.92
	Bulls for breeding	57.39	7.96
	Cereal fed bull	49.88	9.20
	Heifers for breeding	48.67	6.37
	Steers	50.04	5.98
Pigs		1.50	4.06
Sheep	Ewes	7.11	0.19
	Rams	8.31	0.23
	Lambs	3.03	0.07
Other livestock	Goats	9.0	0.39
	Horses	18.0	0.41
	Deer	20.0	0.22
Poultry	Laying hens	NA	0.016
	Growing pullets	NA	0.007
	Broilers	NA	0.017
	Turkeys	NA	0.061
	Breeding flock	NA	0.007
	Ducks	NA	0.121
	Geese	NA	0.122
	All other poultry	NA	0.007

A 3.3.2 Manure Management (3B)

A 3.3.2.1 Methane emissions from animal manures

Table A 3.3.3 Methane conversion factors for Manure Management Systems in the UK

Manure Handling System	Methane Conversion Factor %
Liquid[a]	17
Daily spread	0.1
Deep bedding/farmyard manure – cattle, pigs	17
Deep bedding/farmyard manure – sheep	2.0
Pasture range and paddock	1.0
Poultry manure	1.5
Anaerobic digestion - cattle[b]	3
Anaerobic digestion - pigs[b]	4
Anaerobic digestion - poultry[b]	1.5

[a] No differentiation is made between crusted and non-crusted slurry storage

[b] Values used for the anaerobic digestion of livestock manures are based on the values used in the German inventory

A 3.3.2.2 Nitrous Oxide emissions from Animal Waste Management Systems

Table A 3.3.4 Nitrogen Excretion Factors, kg N animal place^{-1} year^{-1} for livestock in the UK (1990-2020)

Livestock Category	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Dairy cows	85.0	86.9	92.9	101.8	103.8	108.0	105.6	108.8	109.6	112.5	114.3
Other cattle[a]	39.7	41.2	43.2	44.7	45.7	45.7	45.2	44.7	43.9	44.4	44.5
Sows	23.6	22.5	21.4	20.6	20.8	21.1	21.1	21.1	21.1	21.1	21.1
Gilts	15.5	15.5	15.5	15.2	13.6	12.0	11.7	11.7	11.7	11.7	11.7
Boars	28.8	27.4	26.1	24.5	21.9	19.4	18.9	18.9	18.9	18.9	18.9
Fatteners > 80 kg	20.2	19.3	18.4	17.2	15.4	13.5	13.2	13.2	13.2	13.2	13.2
Fatteners 20-80 kg	14.6	13.9	13.2	12.4	11.1	9.9	9.6	9.6	9.6	9.6	9.6
Weaners (<20 kg)	4.6	4.4	4.2	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Ewes	8.3	8.5	8.6	8.6	8.3	8.6	8.3	8.5	8.3	8.7	8.8
Rams	11.3	11.4	11.4	11.3	11.1	11.2	11.1	11.2	11.1	11.4	11.4
Lambs	3.7	3.8	3.9	4.1	4.0	4.2	4.0	4.1	4.0	4.3	4.2
Goats	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Horses											
– horses kept on agricultural holdings	50	50	50	50	50	50	50	50	50	50	50
– professional horses	129	129	129	129	129	129	129	129	129	129	129
– domestic horses	50	50	50	50	50	50	50	50	50	50	50
Deer	29.3	29.3	29.3	29.3	29.3	29.3	29.3	29.3	29.3	29.3	29.3

Livestock Category	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Laying hens	0.87	0.84	0.80	0.78	0.80	0.81	0.81	0.81	0.81	0.81	0.82
Broilers	0.64	0.59	0.55	0.49	0.38	0.27	0.25	0.25	0.25	0.25	0.25
Turkeys	1.50	1.59	1.68	1.75	1.76	1.78	1.78	1.78	1.78	1.78	1.78
Pullets	0.42	0.39	0.36	0.34	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Breeding flock	1.16	1.13	1.10	1.09	1.11	1.14	1.14	1.14	1.14	1.14	1.14
Ducks	1.30	1.41	1.52	1.57	1.41	1.25	1.22	1.22	1.22	1.22	1.22
Geese	1.30	1.41	1.52	1.57	1.41	1.25	1.22	1.22	1.22	1.22	1.22
Other poultry	1.30	1.41	1.52	1.57	1.41	1.25	1.22	1.22	1.22	1.22	1.22

[a] Weighted average for all other cattle categories

Table A 3.3.5 Distribution of Animal Waste Management Systems (%) used for Different Animal types, 2020

Animal Type		Liquid System	Daily Spread	Solid storage/Deep litter/Poultry litter[b]	Pasture Range and Paddock	Anaerobic digestion
Cattle	Dairy cows	61	8	9	20	2
	All other cattle	18	12	21	49	1
Pigs	All pigs	36	14	34	11	4
Sheep	Ewes	0	0	8	92	0
	Rams	0	0	1	99	0
	Lambs	0	0	1	99	0
Other livestock	Goats	0	0	8	92	0
	Deer	0	0	25	75	0
	Horses	0	0	30	70	0
Poultry	All poultry	0	32	58	3	7

Table A 3.3.6 Other agricultural waste management data and parameters

a) Quantities of poultry manure incinerated as kt and expressed as % of broiler and turkey manure for each Devolved Administration

	1990	2000	2005	2010	2015	2020
Litter incinerated, UK (kt)	0	464.55	659.63	648.32	676.47	605.38
% of broiler and turkey litter:						
England	0	19	29	32	35	29
Wales	0	0	0	0	0	0
Scotland	0	61	64	58	77	61
Northern Ireland	0	0	0	0	3	3

b) Amounts of poultry litter exported from Northern Ireland to be incinerated in England and Scotland

	2015	2016	2017	2018	2019	2020
Amount of poultry litter sent from Northern Ireland for incineration in England and Scotland, tonnes	1,160	4,650	2,026	0	0	3,163

c) Direct N_2O Emission Factors for Animal Waste Management Systems

Emission source	EF (% of total N)	Uncertainty limits (95% CI)	Data source
Cattle manure management			
Slurry – solid floor	0	N/A	IPCC 2006
Slurry – slatted floor	0.2	Factor of 2	IPCC 2006
FYM systems	2.0	Factor of 2	UK measurement (at storage)
Outdoor yards	0	N/A	IPCC 2006
Pig manure management			
Slurry – slatted floor	0.2	Factor of 2	IPCC 2006
FYM systems	2.0	Factor of 2	UK measurement (at storage)
Sheep manure management (FYM)	0.5	Factor of 2	IPCC 2006
Layer manure management	0.5	Factor of 2	UK measurement (at storage)
Broiler manure management	0.5	Factor of 2	UK measurement (at storage)

Emission source	EF (% of total N)	Uncertainty limits (95% CI)	Data source
Ducks and geese manure management	2.0	Factor of 2	Based on cattle/pig
Turkeys manure management	0.5	Factor of 2	UK measurement (at storage)
Other poultry manure management	0.5	Factor of 2	UK measurement (at storage)
Goats, deer and horses manure management	2	Factor of 2	UK measurement (at storage)
Anaerobic digestion	0	N/A	IPCC 2006

CS EFs presented in this table are derived from UK measurements as described in documents available on request, as summarised within “N_2O Emission Factors for Manure Management in UK Agriculture”, Misselbrook (2017).

d) UK measurement data on mean N_2O emission factors for manure management systems compared against the IPCC 2006 GL default EFs

This table summarises the results from UK measurement tests, which are used to underpin the UK CS EFs for N_2O from AWMS, as presented in the table above and summarised in Misselbrook (2017).

Manure management system	Number of UK tests	Mean EF	Standard error	IPCC 2006GL default value
		kg N_2O-N per kg N in manure		
Cattle FYM storage	6	0.022	0.0073	0.005
Pig FYM storage	4	0.018	0.0050	0.005
Broiler litter	3	0.005	0.0019	0.001

A 3.3.3 Agricultural Soils (3D)

Table A 3.3.7 Percentage of layer manure and all other poultry manure applied to cropland

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
% of layer manure spread to cropland	53	53	67	70	70	70	70	70	70	70	70
% of all other poultry manure spread to cropland	53	53	67	82	82	82	82	82	82	82	82

Table A 3.3.8 Other Organic N Fertilisers applied to soils – manure and non-manure based digestates

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
N input from manure based digestate applied to soils (kt N/y)	0	63,238	64,293	150,859	758,589	9,959,470	13,837,093	15,358,916	15,646,055	15,842,529	15,886,381
Direct N_2O emissions from manure based digestate applied to	0	0.00074	0.00076	0.00177	0.00891	0.11699	0.16254	0.18041	0.18379	0.18609	0.18661

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
soils (kt N_2O/y)											
N input from crop based digestate applied to soils (kt/y)	0	1,112	1,112	1,707	838,782	12,450,031	16,257,349	18,278,793	18,411,034	18,411,010	18,698,859
Direct N_2O emissions from crop based digestate applied to soils (kt N_2O/y)	0	0.00002	0.00002	0.00003	0.01318	0.19564	0.25547	0.28724	0.28932	0.28932	0.29384
N input from food based digestate applied to soils (kt/y)	0	0	0	894,125	3,690,375	18,676,865	23,406,615	27,962,865	29,087,865	29,330,324	30,001,895
Direct N_2O emissions from food based digestate	0	0	0	0.01405	0.05799	0.29349	0.36782	0.43942	0.45710	0.46091	0.47146

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
applied to soils (kt N_2O/y)											
N input from other organic residue digestate applied to soils (kt N/y)	0	0	670	345,720	359,120	2,165,641	2,564,006	2,899,006	3,228,144	3,228,140	3,228,144
Direct N_2O emissions from other organic residue digestate applied to soils (kt N_2O/y)	0	0	0.00001	0.00543	0.00564	0.03403	0.04029	0.04556	0.05073	0.05073	0.05073

Table A 3.3.9 EF for direct N_2O emissions from managed soils in the UK inventory

Emission source	EF (% of total N)	Uncertainty	Data source
Urea fertiliser	Non-linear function of application rate (see Section 5.5.2.1)		Topp et al., in prep
Other mineral fertilisers	Non-linear function of application rate and annual rainfall (see Section 5.5.2.1)		Topp et al., in prep
Livestock slurry	0.7475	SE 0.17328	Topp et al., in prep
Livestock solid manure (FYM)	0.33	SE 0.07	Topp et al., in prep
Poultry manure	1.01	SE 0.15	Topp et al., in prep
Sewage sludge	1.0	0.3 – 3.0	IPCC 2006
Manure-based digestate	0.7475	SE 0.17328	Topp et al., in prep
Non-manure based digestate	1.0	0.3 – 3.0	IPCC 2006
Crop residues	1.0	0.3 – 3.0	IPCC 2006
N mineralisation	1.0	0.3 – 3.0	IPCC 2006
Histosols - cropland	13 kg N_2O-N/ha	SE 2.5	2013 Supplement to IPCC 2006
Histosols – intensive grassland	5.69 kg N_2O-N/ha	SE 2.110	Artz, R., 2019
Cattle urine	0.629	SE 0.0930	Topp et al., in prep
Cattle dung	0.193	SE 0.0212	Topp et al., in prep
Sheep urine	0.315	SE 0.0658	Topp et al., in prep, IPCC 2019
Sheep dung	0.097	SE 0.0150	Topp et al., in prep, IPCC 2019
Outdoor goats, horses and deer	0.3	0.0 – 1.0	IPCC 2019
Outdoor pigs and poultry	0.4	0.0 – 1.4	IPCC 2019

Table A 3.3.10 Areas of UK Crops and quantities of fertiliser applied for 2020

Crop Type	Crop area, ha	Fertiliser, ktN	Crop Type	Crop area, ha	Fertiliser, ktN
Oats	176,025	20.5	Potatoes (maincrop)	119,113	14.1
Spring oats	26,000	2.2	Potatoes (seed or earlies)	23,430	2.8
Winter oats	7,984	0.9	Sugar beet	111,149	8.3
Spring barley	12,564	1.1	Maize	87,787	6.6
Spring barley (malting)	611,093	53.8	Grain maize	11,605	0.9

Crop Type	Crop area, ha	Fertiliser, ktN	Crop Type	Crop area, ha	Fertiliser, ktN
Spring barley (non-malting)	450,634	47.2	Forage maize	138,156	10.3
Winter barley	7,772	1.0	Rootcrops for stockfeed	45,254	4.2
Winter barley (malting)	55,479	6.8	Leafy forage crops	4,993	0.5
Winter barley (non-malting)	248,982	30.6	Other fodder crops	52,695	4.9
Wheat	7,132	1.1	Vegetables (not-differentiated)	1,507	0.1
Wheat (milling)	494,369	88.0	Vegetables (brassicas)	5,135	0.4
Wheat (non-milling)	887,173	154.5	Vegetables (legumes)	40,905	0.1
Minor cereals	53,119	4.6	Vegetables (other non-legumes)	74,010	5.2
Oilseed rape	4,935	0.8	Other horticultural crops	11,461	0.8
Spring oilseed rape	14,307	2.3	Soft Fruit	7,861	0.6
Winter oilseed rape	361,399	59.1	Top Fruit	23,284	1.6
Linseed	32,902	2.9	Miscanthus	8,286	0.0
Field beans (harvested dry)	180,946	0.3	Willow (short rotation coppice)	2,565	0.0
Field peas (harvested dry)	51,443	0.1	Other field crops	23,506	2.0
Fruit (mixed top & soft fruit)	8	0.0	Wine grapes	2,503	0.0
Permanent grass	6,121,864	297.6	Temporary grass	1,181,430	112.7

Table A 3.3.11 Trends in area grown (‘000 ha) and N fertiliser applied (kg/ha) for the major UK crops, 1990-2020

Year	Wheat		Spring barley		Winter barley		Main crop potatoes		Oilseed rape		Grass leys (<5yrs)		Permanent grassland	
	‘000 ha	kg/ha N	‘000 ha	kg/ha N	‘000 ha	kg/ha N	‘000 ha	kg/ha N	‘000 ha	kg/ha N	‘000 ha	kg/ha N	‘000 ha	kg/ha N
1990	2,014	183	635	90	882	140	148	184	390	226	1,606	166	5,316	108
1991	1,981	189	553	90	841	142	148	188	440	225	1,607	168	5,314	107
1992	2,067	185	515	89	784	141	151	175	421	197	1,582	157	5,266	95
1993	1,759	182	518	90	649	134	143	187	377	177	1,581	146	5,261	100
1994	1,811	189	481	95	627	145	138	194	404	182	1,455	170	5,375	110
1995	1,859	193	504	97	689	144	144	176	354	187	1,407	170	5,375	108
1996	1,977	185	519	93	749	140	149	171	356	190	1,393	166	5,338	105
1997	2,036	191	519	93	840	143	133	165	445	199	1,403	147	5,266	103
1998	2,045	182	484	91	769	136	131	187	506	193	1,302	156	5,365	99
1999	1,847	186	631	99	548	143	148	154	493	197	1,226	180	5,449	101
2000	2,086	191	539	107	589	148	138	159	393	192	1,226	142	5,363	90
2001	1,635	193	783	114	462	150	137	160	444	205	1,205	130	5,584	84
2002	1,996	193	555	112	546	153	129	154	436	198	1,243	135	5,519	77
2003	1,836	197	621	107	455	148	118	149	549	194	1,200	129	5,683	75
2004	1,990	190	587	101	420	137	121	156	498	202	1,246	116	5,620	71
2005	1,870	188	553	98	384	133	113	168	588	201	1,193	109	5,711	66
2006	1,836	181	494	100	388	131	117	145	568	191	1,137	106	5,967	59

Year	Wheat		Spring barley		Winter barley		Main crop potatoes		Oilseed rape		Grass leys (<5yrs)		Permanent grassland	
	‘000 ha	**kg/ha N**	**‘000 ha**	**kg/ha N**	**‘000 ha**	**kg/ha N**	**‘000 ha**	**kg/ha N**	**‘000 ha**	**kg/ha N**	**‘000 ha**	**kg/ha N**	**‘000 ha**	**kg/ha N**
2007	1,830	180	515	95	383	130	112	139	674	187	1,176	98	5,965	55
2008	2,080	177	616	84	416	112	114	147	598	182	1,141	91	6,036	44
2009	1,814	186	749	95	411	128	118	162	581	174	1,262	87	6,081	47
2010	1,939	195	539	88	382	126	114	131	642	189	1,231	99	5,925	52
2011	1,969	191	611	90	359	124	120	156	705	184	1,278	92	5,877	50
2012	1,992	190	618	87	385	120	123	131	756	174	1,357	91	5,799	49
2013	1,615	185	903	97	310	122	114	166	715	167	1,390	96	5,802	54
2014	1,936	184	651	104	429	135	115	144	675	187	1,396	101	5,824	50
2015	1,832	194	659	98	442	133	105	161	652	187	1,167	96	6,078	48
2016	1,823	191	690	96	439	125	115	137	579	179	1,144	92	6,118	49
2017	1,792	189	754	90	423	131	121	132	562	178	1,144	98	6,135	49
2018	1,748	193	751	94	387	126	117	142	583	189	1,152	94	6,178	51
2019	1,816	186	703	93	453	127	119	149	530	176	1,193	96	6,207	48
2020	1,389	175	1,074	95	312	123	119	119	381	163	1,181	95	6,122	49

A 3.3.3.1 Crop Residues

Table A 3.3.12 Parameter values for crop residue management

Crop	Crop Harvest Index[a]	Above Ground Residue Retained after harvest	IPCC Crop Yield To Above Ground Residue Slope[b]	IPCC Crop Yield To Above Ground Residue Intercept[b]	IPCC Above To Below Ground Residue ratio
Oats	0.46	0.5	NA	NA	0.25
Spring oats	0.46	0.5	NA	NA	0.25
Winter oats	0.46	0.5	NA	NA	0.25
Spring barley	0.52	0.5	NA	NA	0.22
Spring barley (malting)	0.52	0.5	NA	NA	0.22
Spring barley (non-malting)	0.52	0.5	NA	NA	0.22
Winter barley	0.52	0.5	NA	NA	0.22
Winter barley (malting)	0.52	0.5	NA	NA	0.22
Winter barley (non-malting)	0.52	0.5	NA	NA	0.22
Wheat	0.50	0.5	NA	NA	0.23
Wheat (milling)	0.50	0.5	NA	NA	0.23
Wheat (non-milling)	0.50	0.5	NA	NA	0.23
Minor cereals	0.49	0.5	NA	NA	0.23
Oilseed rape	0.30	1	NA	NA	0.35
Spring oilseed rape	0.30	1	NA	NA	0.35
Winter oilseed rape	0.30	1	NA	NA	0.35
Linseed and Flax	0.38	0.5	NA	NA	0.35
Linseed	0.38	1	NA	NA	0.35
Flax	0.38	0.2	NA	NA	0.35
Field beans and peas combined	NA	1	1.13	0.85	0.19
Potatoes	NA	1	0.10	1.06	0.20
Potatoes (maincrop)	NA	1	0.10	1.06	0.20

Crop	**Crop Harvest Index**[a]	**Above Ground Residue Retained after harvest**	**IPCC Crop Yield To Above Ground Residue Slope**[b]	**IPCC Crop Yield To Above Ground Residue Intercept**[b]	**IPCC Above To Below Ground Residue ratio**
Potatoes (seed or earlies)	NA	1	0.10	1.06	0.20
Sugar beet	NA	1	1.07	1.54	0.20
Maize	NA	1	1.03	0.61	0.22
Grain maize	NA	1	1.03	0.61	0.22
Forage maize	NA	0.15	1.03	0.61	0.22
Rootcrops for stockfeed	NA	0.15	1.07	1.06	0.20
Leafy forage crops	NA	0.15	0.30	0.00	0.35
Other fodder crops	NA	0.1	NA	NA	0.35
Vegetables (not-differentiated)	NA	1	0.30	0.00	0.35
Vegetables (brassicas)	NA	1	0.30	0.00	0.35
Vegetables (legumes)	NA	1	0.30	0.00	0.35
Vegetables (other non-legumes)	NA	1	0.30	0.00	0.35
Other horticultural crops	NA	1	0.30	0.00	0.35
Soft Fruit	NA	1	0.20	0.00	0.35
Top Fruit	NA	1	0.20	0.00	0.35
Miscanthus	NA	1	1.00	0.00	0.35
Willow (short rotation coppice)	NA	1	1.00	0.00	0.35
Other field crops	0.52	0.5	NA	NA	0.22
Wine grapes	NA	1	0.20	0.00	0.35
Fruit (mixed top & soft fruit)	NA	1	0.20	0.00	0.35

[a] Where ‘NA’ appears in the Harvest Index column, it indicates that the IPCC 2006 method was used; [b] where ‘NA’ appears in the IPCC slope or intercept column, it means that the Harvest Index approach was used

Table A 3.3.13 N concentrations in above and below ground biomass

Crop	Below Ground N, kg N/[t DM]	Crop Residue Above Ground N, kg N/[t DM]
Oats	8.0	5.4
Spring oats	8.0	5.4
Winter oats	8.0	5.4
Spring barley	14.0	6.7
Spring barley (malting)	14.0	6.7
Spring barley (non-malting)	14.0	6.7
Winter barley	14.0	6.7
Winter barley (malting)	14.0	6.7
Winter barley (non-malting)	14.0	6.7
Wheat	9.0	6.2
Wheat (milling)	9.0	6.2
Wheat (non-milling)	9.0	6.2
Minor cereals	9.0	6.6
Oilseed rape	11.0	9.9
Spring oilseed rape	11.0	9.9
Winter oilseed rape	11.0	9.9
Linseed and Flax	11.0	9.9
Linseed	11.0	9.9
Flax	11.0	9.9
Field beans and peas combined	8.0	8.0
Potatoes	14.0	17.3
Potatoes (maincrop)	14.0	17.3
Potatoes (seed or earlies)	14.0	17.3
Sugar beet	14.0	24.6
Maize	7.0	6.0

Crop	**Below Ground N, kg N/[t DM]**	**Crop Residue Above Ground N, kg N/[t DM]**
Grain maize	7.0	6.0
Forage maize	7.0	6.0
Rootcrops for stockfeed	14.0	12.6
Leafy forage crops	12.0	26.3
Other fodder crops	14.0	6.7
Vegetables (not-differentiated)	12.0	26.1
Vegetables (brassicas)	12.0	38.4
Vegetables (legumes)	22.0	23.2
Vegetables (other non-legumes)	22.0	16.7
Other horticultural crops	22.0	26.1
Soft Fruit	11.0	17.7
Top Fruit	11.0	3.9
Miscanthus	11.0	0.3
Willow (short rotation coppice)	11.0	0.3
Other field crops	11.0	6.7
Wine grapes	11.0	3.3
Fruit (mixed top & soft fruit)	11.0	8.1

A 3.3.3.2 Mineralisation

Table A 3.3.14 Mineralised N from soils

	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
N in mineral soils that is mineralised as a result of historical land use change to Cropland (kt N/y)	38.84	49.62	63.99	75.58	81.87	83.99	84.00	83.91	83.45	83.00	82.07

	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
N in mineral soils that is mineralised as a result of Cropland Management (kt N/y)	0.05	0.07	0.06	0.06	0.06	0.06	0.05	0.06	0.07	0.08	0.88
Direct N_2O emissions from mineralised N as a result of historical land use change to Cropland, kt N_2O/y	0.61	0.78	1.01	1.19	1.29	1.32	1.32	1.32	1.31	1.30	1.29
Direct N_2O emissions from mineralised N as a result of Cropland Management, kt N_2O/y	0.00074	0.00115	0.00097	0.00098	0.00092	0.00096	0.00081	0.00095	0.00103	0.00120	0.01386
Indirect N_2O emissions from mineralised N as a result of historical land use change to Cropland and Cropland management (kt N_2O/y)	0.14	0.18	0.23	0.27	0.29	0.30	0.30	0.30	0.30	0.29	0.29
Total N_2O emissions from Mineralisation (kt N_2O/y)	0.75	0.96	1.23	1.46	1.58	1.62	1.62	1.62	1.61	1.60	1.60

A 3.3.3.3 Histosols

Table A 3.3.15 N_2O emissions from drained organic soils

	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Area of histosols – Cropland, ha	197,092	195,954	194,592	192,809	191,282	189,929	189,669	189,409	189,149	188,889	188,630

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Area of histosols - Intensive grassland, ha	184,787	180,898	177,017	174,095	172,275	170,978	170,743	170,508	170,273	170,004	169,769
Direct N_2O emissions from histosols - Cropland, kt N_2O/y	4.03	4.00	3.98	3.94	3.91	3.88	3.87	3.87	3.86	3.86	3.85
Direct N_2O emissions from histosols – Intensive grassland, kt N_2O/y	1.65	1.62	1.58	1.56	1.54	1.53	1.53	1.53	1.52	1.52	1.52
Total N_2O emissions from histosols, kt N/y	5.68	5.62	5.56	5.50	5.45	5.41	5.40	5.39	5.39	5.38	5.37

A 3.3.3.4 Atmospheric deposition of NO_x and NH_3

Table A 3.3.16 Amount of N that is volatilized from agricultural inputs and associated N_2O emissions

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Amount of volatilized N, kg/yr	142,661,901	127,457,053	122,872,251	115,451,274	110,867,121	119,358,826	123,368,497	125,554,931	126,209,317	122,900,151	116,365,328
Total N_2O emissions from volatilized N (kt N_2O/y)	3.14	2.80	2.70	2.54	2.44	2.63	2.71	2.76	2.78	2.70	2.56

A 3.3.3.5 Leaching and runoff

Table A 3.3.17 Amount of N fertilizers and other agricultural inputs that is lost through leaching and run-off and associated N_2O emissions

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Amount of N lost through leaching and runoff, kg/yr	538,001,796	515,495,512	524,299,909	498,640,253	483,034,087	499,234,798	486,349,741	503,498,169	497,477,996	498,981,378	451,498,951
Total N_2O emissions from N lost through leaching and runoff, kt N_2O/y	6.34	6.08	6.18	5.88	5.69	5.88	5.73	5.93	5.86	5.88	5.32

A 3.3.4 Liming

Table A 3.3.18 Amount of limestone and dolomite applied to soils and associated CO_2 emissions

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Amount of limestone applied to soils, t/yr	1,648,058	1,614,700	983,011	2,704,048	2,204,135	1,739,419	1,751,404	1,819,945	1,986,226	2,596,942	1,978,026
Amount of dolomite applied to soils, t/yr	606,060	760,435	417,588	450,782	438,307	342,579	331,672	285,101	381,792	346,997	162,585

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Total CO_2 emissions from application of limestone (kt CO_2/y)	725	710	433	1190	970	765	771	801	874	1143	870
Total CO_2 emissions from application of dolomite (kt CO_2/y)	289	362	199	215	209	163	158	136	182	165	77

A 3.3.5 Urea application

Table A 3.3.19 Amount of urea applied to soils and associated CO_2 emissions

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Amount of urea applied to soils, t/yr	445,743	202,972	182,777	266,172	336,801	433,485	478,069	461,802	441,295	435,816	318,536
Total CO_2 emissions from application of urea (kt CO_2/y)	327	149	134	195	247	318	351	339	324	320	234

A 3.3.6 Recalculations – Additional Information

This section provides some additional details to explain some of the recalculations, where the detailed re-analysis of underlying statistical data has led to changes in the EFs applied.

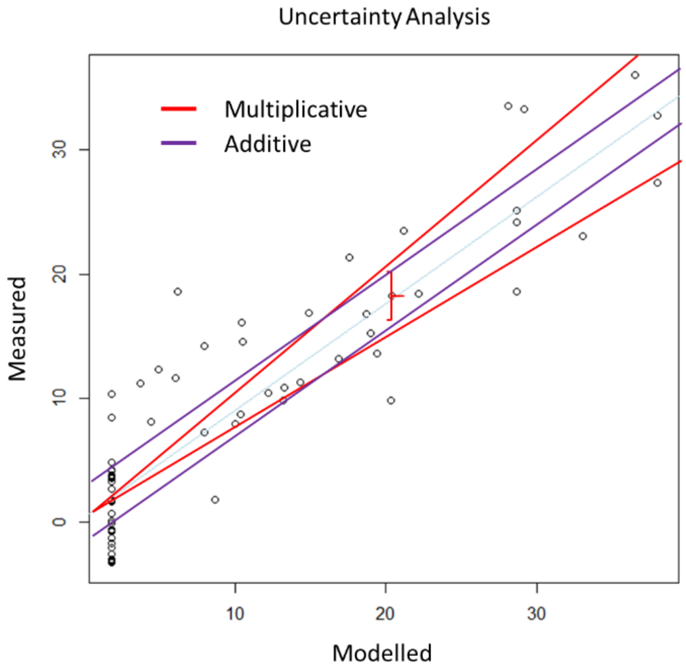
Revision to Grass and Sheep sector EFs

An empirical model is used in the Grass sector to estimate the ammonia emission factor (EF) from manufactured fertiliser, which is the fraction of applied fertiliser nitrogen that is emitted as ammonia, as measured in field experimentation. The model is sensitive to fertiliser type, soil pH, rainfall and ambient temperature.

The residual error or uncertainty in the model prediction was previously assumed to be a constant proportion of the expected value, centred on the expected value. This had the consequence that the confidence interval scaled proportionally with the expected value. This is referred to as the ‘multiplicative’ error model, as illustrated by the diverging lines in the figure below.

This model provided a good description of the uncertainty interval for emissions from the urea fertiliser type, which tend to be high – *around 20% on the modelled x-axis of the figure below* – but under-estimated the uncertainty for emissions from the ammonium nitrate fertiliser type, which tend to be low – *around 2% on the modelled x-axis*. Ammonium nitrate is the most common fertiliser type used in the Grass sector. The uncertainty model was therefore replaced with an ‘additive’ approach, wherein the residual error or uncertainty is a constant size for all expected values, as shown by the parallel lines in the figure below. This improved the representation of uncertainty associated with all fertiliser types in use in the Grass sector, at both high and low emission factors.

Figure A 3.1 **Schematic of ‘multiplicative’ and ‘additive’ uncertainty model structures describing the residual error in model predictions of the ammonia emission factor for manufactured fertiliser, based on field experimentation.**



The same change was made to the empirical model describing the rate of enteric methane emission in proportion to dry matter intake in the sheep sector, with an improved representation of the uncertainty interval at low (lamb) and high (adult sheep) dry matter intakes. In this case, the previous ‘multiplicative’ 95th-percentile uncertainty interval was defined as between 95.2 and 98.8% of the expected value, *i.e.* it was centred on a value of 97.1% of the expected value. This represented an apparent tendency for the empirical model to over-estimate the measured methane emission by around 3%. However, this over-estimate was not statistically significant ($p > 0.05$).

Therefore, the replacement ‘additive’ uncertainty was re-centred on the expected value as predicted by the model, with the effect that inventory calculations of enteric methane from sheep **were increased by 3%** in comparison to the previous submission.

A 3.3.7 Distribution of manure in different management systems

A review of the literature on livestock housing and manure management practices conducted by Ken Smith (ADAS) as part of Defra project AC0114 (Smith, 2012), updated with survey data on manure spreading practices from the British Survey of Fertiliser Practice[14], and data provided directly by DAERA statistics for Northern Ireland (Peter Cottney, pers. comm.) was used as the basis for developing the 1990 to 2020 timeseries of livestock housing and manure management practices for each country (England, Wales, Scotland and Northern Ireland) from which a weighted average was derived for the UK.

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[14] Most recent BSFP: https://www.gov.uk/government/statistics/british-survey-of-fertiliser-practice-2019

Detailed practice-specific data are applied at a country scale for each livestock category for the livestock housing, manure storage and manure application phases of the manure management continuum. Estimates for these activity data across the timeseries are derived from a number of routine and ad-hoc surveys including the Defra Farm Practices Surveys[15] and published manure management surveys (Smith et al., 2000, 2001a, 2001b). Tonnages of poultry litter incinerated in each year were obtained directly from MREL[16], with tonnage exported from Northern Ireland to be incinerated in Scotland and England provided by DAERA.

Quantities of livestock manure being used in anaerobic digestion (Table 5-7) are estimated from data provided by the National Non-Food Crops Centre[17] annual deployment report, a database listing operational, under-construction and proposed anaerobic digestion plants in the UK. Information in the database includes location, capacity, feedstock (inputs) types and feedstock quantities in five categories: manure, crops, crop wastes, food and other. Although co-digestion of two or more feedstocks is commonly practiced, for the purpose of the emission calculations each is treated individually. Manure as a feedstock is further categorised as cattle, pig, poultry, equine and miscellaneous animal.

For inventory calculations, the categories of equine and miscellaneous animal (i.e. not specifically identified) are summed and reallocated to cattle, pig and poultry based on the relative proportions of total manure (leaving housing) for those livestock types. Similarly, as cattle is not further defined, the relative proportions from the dairy and beef sectors are assumed to be in proportion to the total quantity of manure managed for those sectors. Within each livestock sector, for each livestock subcategory, the same proportions are applied to manure quantity going to anaerobic digestion as are applied to that sector as a whole. For cattle and pigs, slurry and farmyard manure are assumed to be equally applicable for anaerobic digestion, so have the same proportional implementation.

Within the sheep sector, all (100%) manure from the ewe housing period is managed as solid farmyard manure with additions of straw bedding. All (100%) manure from the housing period is stored for a period of several months as a field heap on grass before spreading to land. Therefore, there is a nitrate leaching loss from all stored sheep manure (estimated according to the measurements of Nicholson et al., 2011) and there is no need to assume that leachate from manure heaps stored on concrete pads is collected and managed differently. Based on Roderick (2001) survey of 2,649 flocks managed by members of the National Sheep Association from across the United Kingdom, the inventory calculations assume that 75% of ewes associated with lowland systems, 60% with upland systems, and 40% with hill systems are housed in the last weeks of pregnancy. From the same survey, we assumed that housed breeding ewes are housed for 42 days prior to lambing, and that neither the ewe nor new-born lamb are housed post lambing. Further detail on management housing for other activities (e.g. shearing) were obtained from a postal survey of 697 farms in England and Wales (Defra, 2004; Dauven and Crabb, 1998; Webb et al., 2001).

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[15] Defra Farm Practices Surveys: https://www.gov.uk/government/collections/farm-practices-survey

[16] Melton Renewable Energy Ltd., formerly EPRL: https://www.mreuk.com/

[17] National Non-Food Crops Centre: https://www.nnfcc.co.uk/

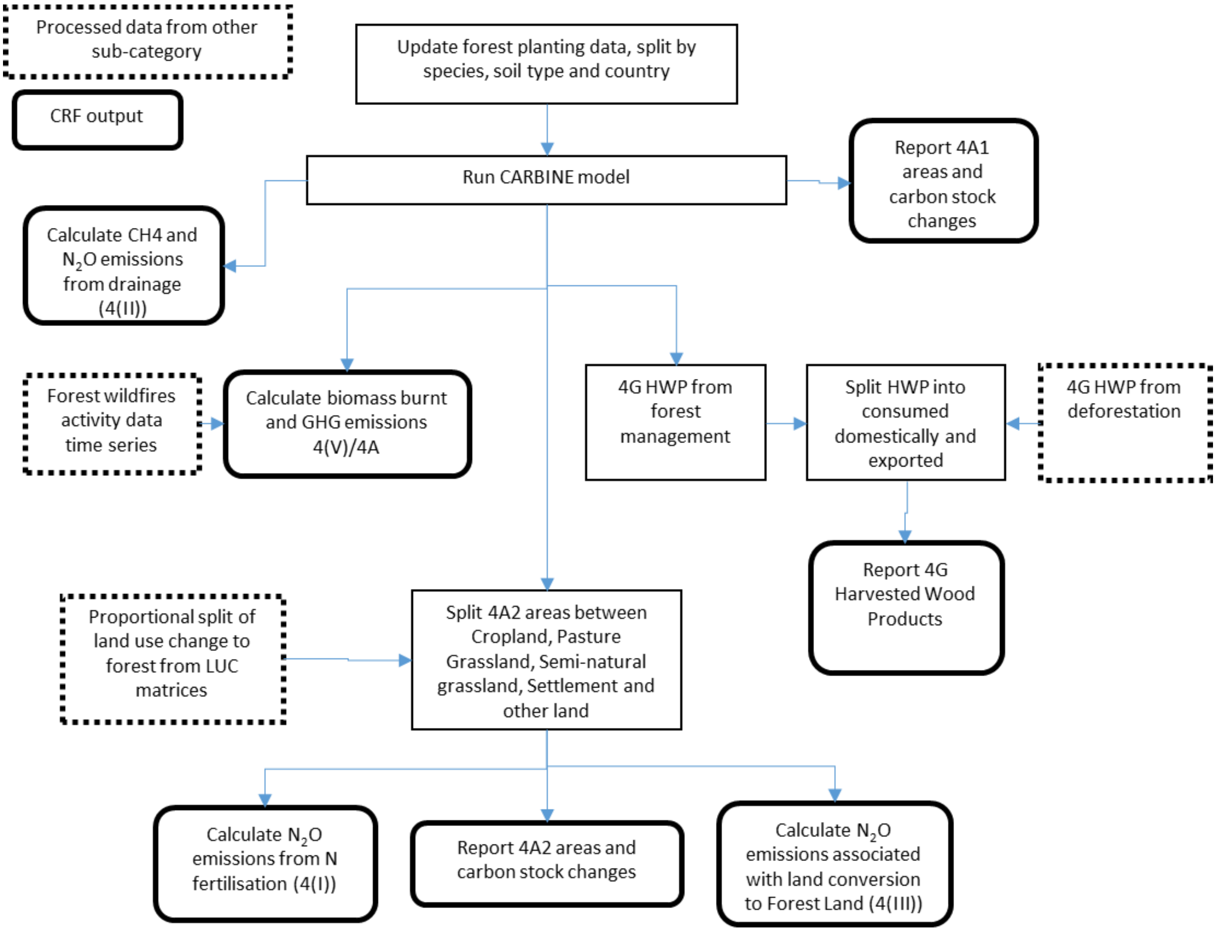
A 3.4 LAND USE, LAND USE CHANGE AND FORESTRY (CRF SECTOR 4)

The following section describes in detail the methodology used in the LULUCF sector described in **Chapter 6**.

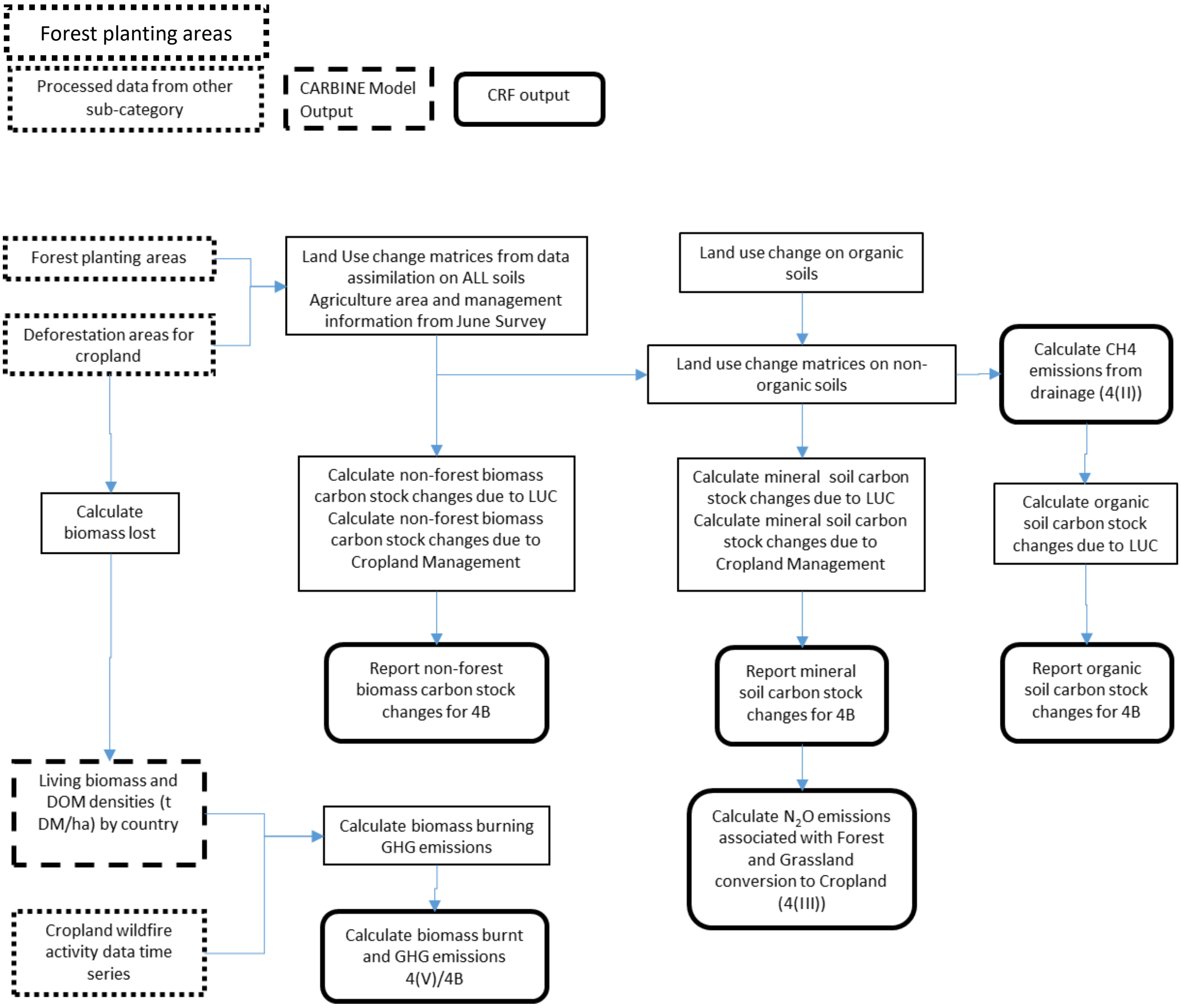
The flow chart below shows the interrelationships between different data sources and the main calculation steps.

Figure A 3.2 Data flow diagrams for each land use sub-category, showing cross-linkages between sectors: (i) 4A and 4G, (ii) 4B, (iii) 4C, (iv) 4D, (v) 4E

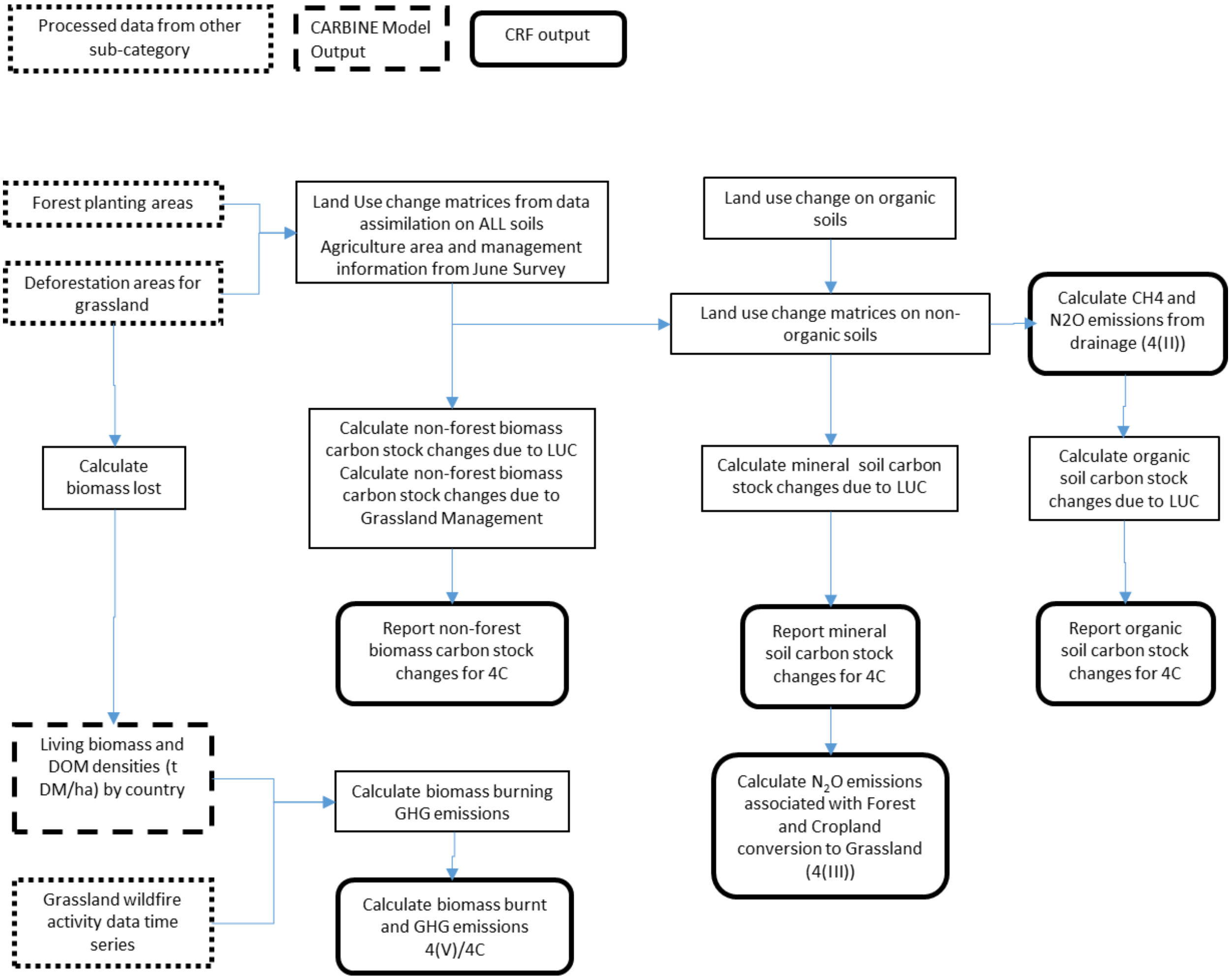
(i) 4A Forest Land and 4G Harvested Wood product data flows



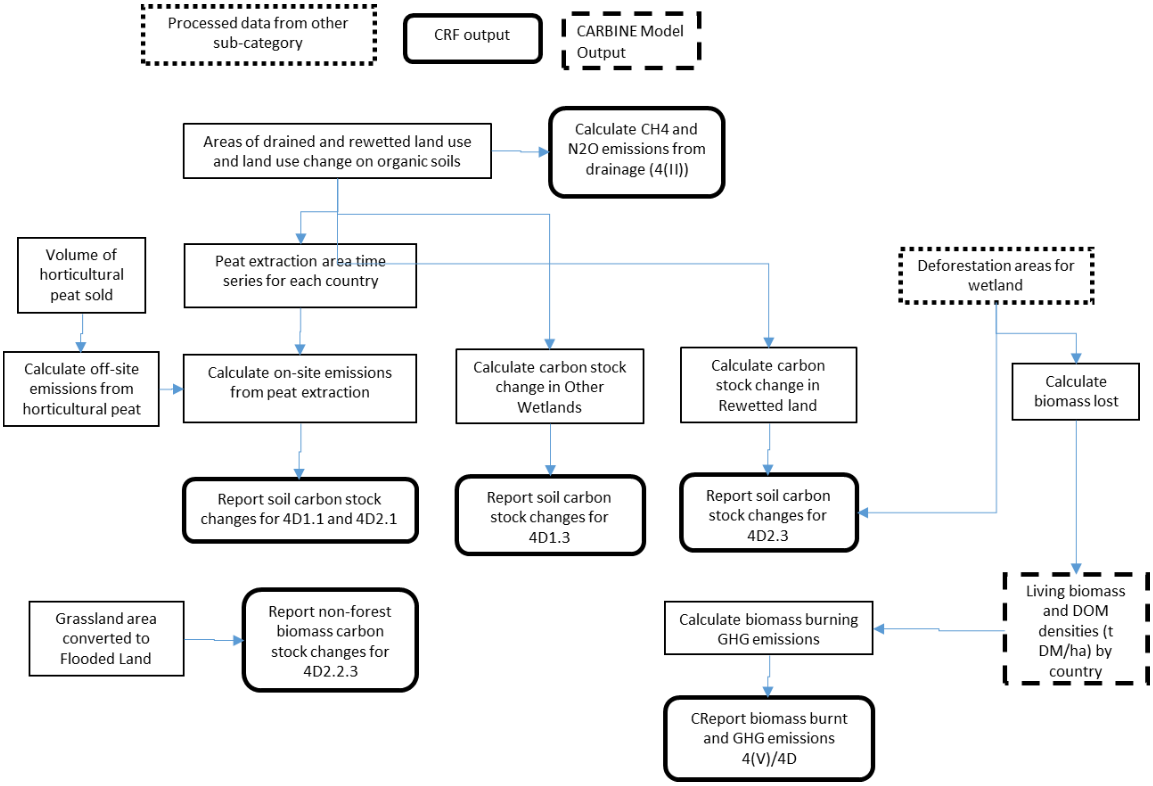
(ii) 4B Cropland data flows



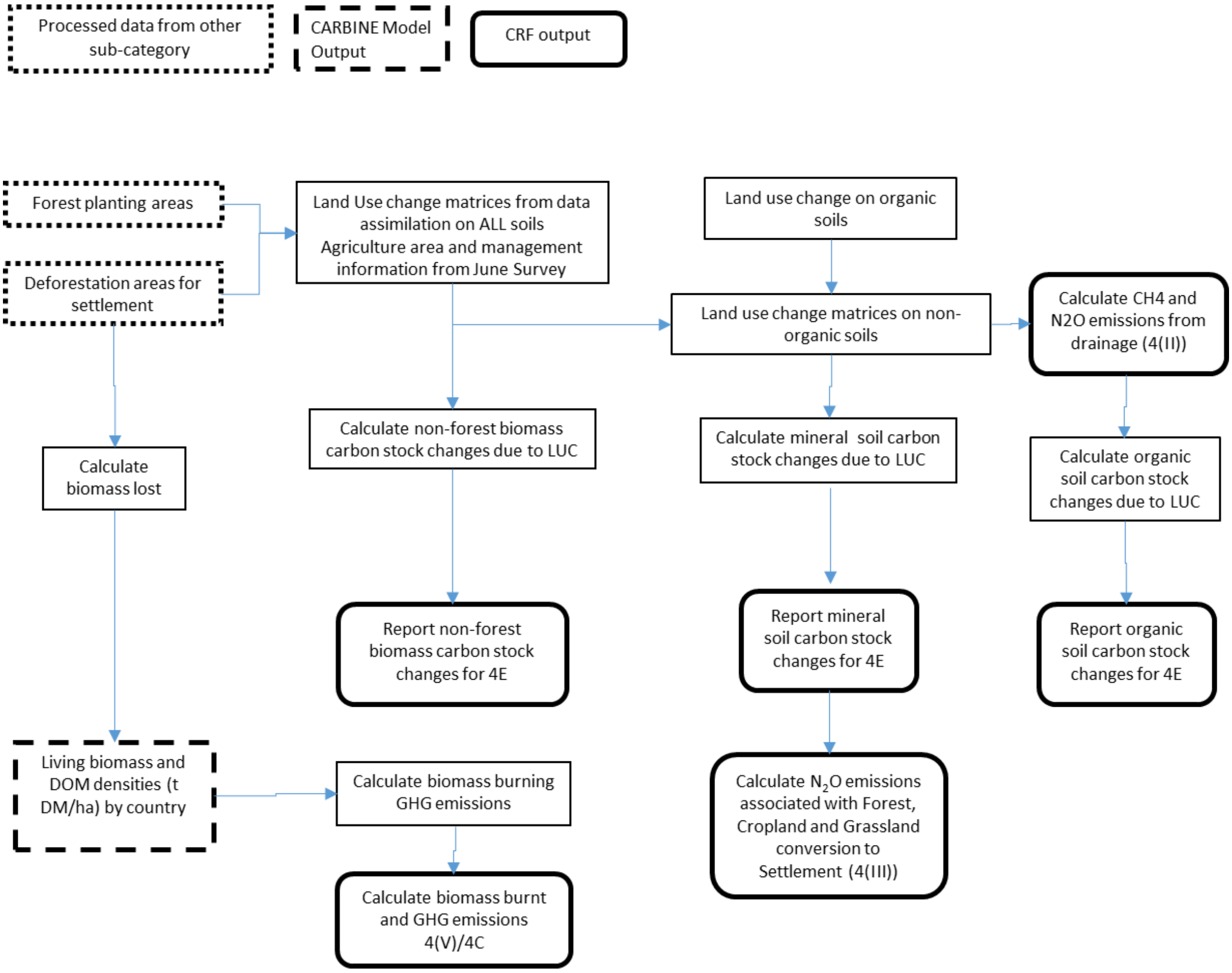
(iii) 4C Grassland data flows



(iv) 4D Wetlands data flows



(v) 4E Settlements data flows



A 3.4.1 Carbon stock changes due to afforestation and forest management (4A)

A 3.4.1.1 The Forest carbon accounting model CARBINE

Carbon uptake by the forests planted in the UK is calculated by a carbon accounting model, CARBINE, as gains and losses in pools of carbon in standing trees, litter and soil in conifer and broadleaf forests and in harvested wood products. Restocking is assumed in all forests. The method is Tier 3, as defined by IPCC (2006). **Section A 3.4.1.2** demonstrates how the use of this model complies with IPCC good practice criteria for the use tier 3 models.

CARBINE simulates forest C stock changes represented by tree biomass growth, mortality and subsequent loss. The CARBINE model is primarily dedicated to reproducing the UK forest conditions.

The model as used for this inventory consists of three sub-models or ‘compartments’ which estimate carbon stocks in the forest biomass, soil, and harvested wood products. The forest biomass carbon sub-model is further compartmentalised to represent fractions due to tree stems, branches, foliage, and roots.

A 3.4.1.1.1 Carbon in forest biomass

The main driving module of CARBINE consists of a set of computerised mathematical functions and algorithms describing the accumulation (and loss) of carbon in tree biomass of different forestry systems at the per-hectare scale. Different functions and algorithms are used to represent distinct forestry systems, defined in terms of:

- Tree species composition
- Tree growth rate (yield class)
- Management regime applied.

The tree species and growth rates represented are based on yield models originally produced by the British Forestry Commission (Matthews et al., 2016a, 2016b). The tree species covered include examples for coniferous species of spruces, pines, firs, larches, cedars, cypresses and all the major temperate and boreal broadleaf tree species. Growth rates in terms of mean annual increment (MAI) of stem volume can be represented in the range from 2 m^3 ha^{-1} yr^{-1} up to 30 m^3 ha^{-1} yr^{-1}.

The CARBINE model uses standard estimates for wood density wood carbon content to derive stem biomass from the stem volume predictions simulated by the M1 model (Lavers and Moore, 1983; Jenkins et al., 2011; Matthews, 1993). Wood and bark density along with the carbon content differences are not taken into account. The density of bark is lower than that of wood (Aaron, 1970), but the carbon content is usually higher (Matthews, 1993), hence it is assumed that the two effects cancel out. The biomass and carbon in tree foliage, branches, and coarse and fine roots are derived from the results for the stem by applying expansion factors. Species-specific biomass expansion factors are applied for these calculations.

The biomass of a component of interest is calculated by multiplying stem biomass by a corresponding expansion factor. The UK species-specific crown and root biomass expansion factors were derived from the report of Jenkins *et al*., (2011) report. Branch biomass is calculated by subtracting foliage biomass from crown biomass. The coarse root biomass expansion factor includes an allowance for stump material. Robust information on foliage expansion factors relevant to UK conditions were not available, hence these were obtained from scientific literature. The ratio of foliage to stem changes over time, but approaches an asymptote (Matthews et al., 1991; Matthews and Duckworth, 2005). However, the asymptote in general is more suited to older, larger trees and as such is considered not to be representative of typical forests under regular management. It was decided to use a biomass expansion relationship for trees of approximately 20 cm diameter in order to better represent managed forests. It is likely that this will ultimately underestimate foliage biomass in smaller trees, and conversely over-estimate in older, larger trees. Finally, fine root biomass is calculated with a uniform expansion factor β_r=0.02 from a Liski et al., (2002) study. The expansion factors are not sensitive to stand age, management regime or growth rate. This approach was adopted for the simplicity and ease of implementation on the large-scale simulations.

The mass of carbon in a forest was calculated from biomass by multiplying by the fraction of carbon in wood (0.5 assumed). As an example, the values used for these parameters for Sitka spruce (*P. Sitchensis*) are given in **Table A 3.4.1**. Sitka spruce is the most common species in UK forests (c. 30%); parameters for other tree species are given in Matthews *et al.* (2014).

Table A 3.4.1 Main parameters for forest carbon flow model used to estimate carbon uptake by planting of forests of Sitka spruce (*P. Sitchensis*), yield class 12.

Parameter	Value
Time of maximum mean annual increment (years)	60
Initial spacing (m)	2
First table age (years)	20
Age at first thinning (years)	25
Stemwood density (oven dried tonnes m^{-3})	0.33
% Stemwood conversion loss	10%
% Branchwood left in forest	100%
% Branchwood harvested for fuel	0%
% fuel from bark	30%
% non-fuel products from bark	70%
% small roundwood (underbark) used as fuel	20%
% Pallets and fencing from small roundwood (under bark)	20%
% Paper from small roundwood (under bark)	35%
% Particleboard etc. from small roundwood (under bark)	25%
% Fuel from sawlogs (under bark)	30%
% Pallets and fencing from sawlogs (under bark)	0%
% Particleboard from sawlogs (under bark)	40%
% Structural timber from sawlogs (under bark)	30%
Root:Stem ratio	0.49
Crown:Stem ratio	0.32
Foliage:stem ratio	0.13
Fine root:stem ratio	0.02
Foliage turnover rate (annual)	0.2
Branchwood turnover rate (annual)	0.04
Coarse Root Turnover rate (annual)	0.02
Fine Root turnover rate (annual)	0.8
Underbark/overbark ratio at 15cm DBH (varies with DBH)	0.9
Ratio of thinned stem volume that is sawlog at 15cm DBH (varies with DBH)	0.05

A 3.4.1.1.2 Dead wood and litter

CARBINE includes a sub-model for representing accumulation and loss of carbon in dead wood and litter. Inputs of litter are related to the standing biomass of trees and also to rates of tree mortality. Levels of tree mortality are represented implicitly in the standard Forestry Commission growth models, and explicit estimates are included in models for stands subject to no thinning, where mortality levels are high. Root and branch wood volume associated with dead trees is estimated in the same way as for living stemwood, by reference to allometric relationships. Deadwood and litter are assumed to decay according to a first order process, with rate constants that are normally set to be consistent with boreal and temperate conditions but can be adjusted for Mediterranean and tropical conditions. The other significant input of carbon to the dead wood and litter pool is due to harvesting operations (as part of either thinning or clearfelling). The carbon in roots of harvested trees is assumed to enter the litter pool. The harvesting of stem wood is assumed to involve a conversion loss equivalent to 10% of standing stem volume, which also enters the litter pool. It is difficult to make accurate assumptions about the fate of branch wood and foliage at time of harvesting. In many situations, this material will be left on-site to deteriorate and decay. Sometimes it is possible that branch wood remaining after clearfelling may be deliberately burned. There has also been an increasing interest in active harvesting of branch wood (or at least some proportion of it) to supply biomass to the Energy sector. However, currently, such practice remains very limited. For this inventory the assumption has been made that no branch wood is harvested but is left to degrade and decay on site as part of the litter pool.

The branch Annual Turnover Rate (ATR) was fixed at 4% in accordance to Canadian forest carbon accounting model CBM-CFS (Kurz et al., 2009). Deciduous species foliage turnover is assumed to be 100% (Kurz et al., 2009; Ťupek et al., 2015). Conifer species foliage ATRs were obtained by referring to relevant scientific literature. If insufficient empirical literature and data was available, the species were mapped to an allometrically similar species. Coarse root annual turnover was assumed to be 2% as in the CBM-CFS (Kurz et al., 2009; Kurz and Beukema, 1996; Li et al., 2003). Fine root ATRs were mapped from the available scientific literature and the UK specific datasets provided by Vanguelova (pers. com.). The UK ATRs for fine roots were derived from Kielder forest for Sitka spruce and Alice Holt forest for oak. Lastly, root exudate ATR was set to 160% of fine root dry biomass, the upper quartile of reported exudate mass from grassland was adopted (Jones et al., 2009), because of limited understanding about forest rhizodeposition. Aboveground shed litter, foliage and branches, are accumulated in a litter layer and after partial degradation passed to the Fermenting (F) layer. Residues that are left after thinning or felling can be set to enter a litter layer. If the crop is not a forest, it is assumed that the litter and F layers are zero. The litter layer decomposition is modelled using modified ForClim-D model version (Liski et al., 2002; Perruchoud et al., 1999). Below ground litter is not included in this simulation, while the annual transfer rates are applied to foliage (C_f) and branch (C_b) litter biomass. They are expressed as a proportion relocated annually.

Branch and foliage litter transfer are set according to the model proposed by Liski et al. (2002). The transferred biomass is pooled and degraded by a fixed constant of 0.5, which is the average of constants given in the Liski et al. (2002) study.

A 3.4.1.1.3 Soil carbon

The new CARBINE Soil Carbon Accounting model (SCOTIA, formerly referred to as CARBINE SCA; **Figure A 3.3**), is based on a simplified version of the ECOSSE model (Smith *et al*., 2011), coupled with a litter decomposition model derived from the ForClim-D model (Perruchoud *et al*., 1999; Liski *et al*., 2002). Above-ground turnover of material such as foliage, branches and dead stemwood enters the litter pool, which is then broken down to F-material (Fermenting) as a function of temperature and rainfall, releasing CO_2. Within the soil, a number of layers exist, each with its own set of texture (Sand, Silt, Clay) characteristics. Carbon from decayed litter, dead roots, and root exudates enters each layer and is assigned to four active pools; resistant plant material (RPM), readily decomposable plant material (DPM), biological material (BIO) and humic material (HUM). A proportion of organic carbon is also assumed to be inert, and unavailable for further activity. The active pools undergo decomposition and transference, releasing CO_2. Decomposition (aerobic and anaerobic) within each pool and layer is influenced by response functions to water saturation in the soil, temperature, pH, and the presence (or not) of plant cover on the soil surface. The availability of water within each layer, and the level of saturation are largely defined from soil texture following Saxton and Rawls (2006) coupled with inputs from rainfall, (or drainage) and removal of water through evapotranspiration. In any soil layer, water above field capacity can drain to lower soil layers, complete with any dissolved organic carbon (DOC). The rates of potential decomposition of each carbon pool and the response functions follow ECOSSE (Smith et al., 2011).

New carbon input to the soil arises from four sources:

- Recently dead root material (according to a rooting profile depth),
- Transfer from the F-material arising from the decomposition of above-ground litter,
- Secretions and exudates from the roots,
- DOC; this carbon can become available to the biological pool and enter the ‘reactive material cycle’.

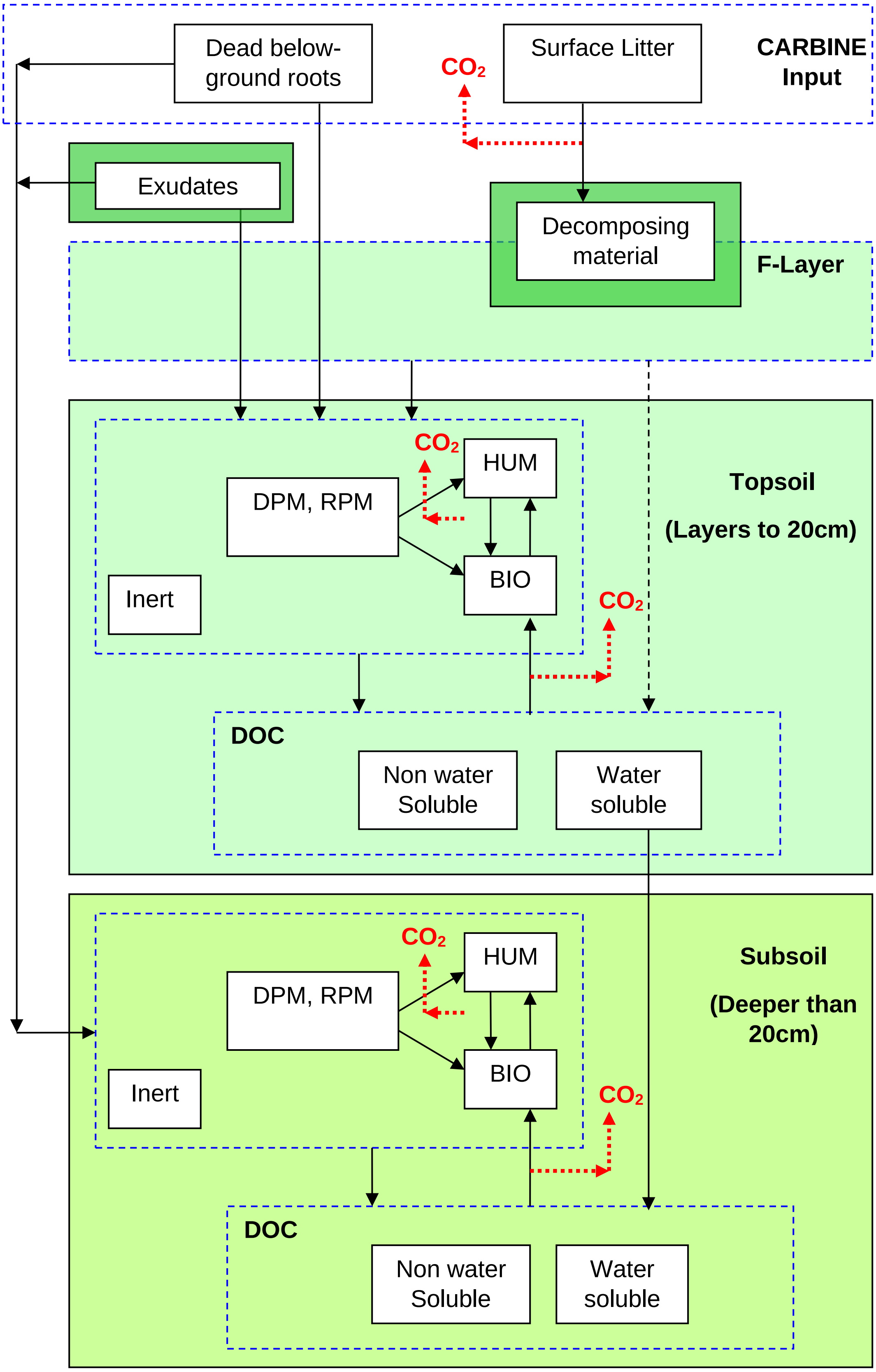
Turnover rates for mortality of tree components (roots, foliage etc.) are species dependent and obtained from scientific literature (see **Table A 3.4.1** for example).

An improved version of the soil sub-model was implemented for the 1990-2016 inventory. This included work on parameterisation of litter input from ground flora and other non-forest vegetation, assuming a decrease in the contribution of non-tree litter from that assumed in ECOSSE for pasture to zero contribution at canopy closure. after an initial year of clearance of vegetation on planting.

A more comprehensive description of the soil sub-model will be described in a technical report.

Additional pathways in which carbon is lost from organic soil include waterborne export of DOC and particulate organic carbon (POC) from drained organic soils, which is related to land use disturbances (erosion, burning), and drainage ditches. The off-site CO_2 emissions from the decomposition of POC and DOC exported from drained organic soils are calculated separately using Tier 1 and 2 approaches (see Evans et al 2017 and **Section A 3.4.6**).

Figure A 3.3 The CARBINE SCOTIA model



A 3.4.1.2 Alignment of CARBINE to the IPCC suggestions for “Use of Models in Good Practice National Greenhouse Gas Inventories”

The IPCC has published suggestions on the approach to implementing good practice in the use of models[18] in national GHG inventories. These suggestions are provided in “*Use of Models and Facility-Level Data in Greenhouse Gas Inventories. Report of the IPCC Expert Meeting on Use of Models and Measurements in GHG Inventories, 9-11 August 2010, Sydney, Australia*”. Chapter 3 provides a bullet point list of the key elements of a model that can be used to guide the description provided by inventory compilers of the modelling approach they use. Providing this detail increases the transparency of the methodological description.

Table A 3.4.2 is based on this bullet point list, and summarises the methodological approaches used in CARBINE for each of the elements, or criteria, and provides references to where further information can be found.

Table A 3.4.2 Compliance of the CARBINE model with the IPCC criteria on the use of models

Criteria (or element)	Reference to documentation
Basis and type of model	**Summary** Carbon change in the forests of the UK (meeting the UK definition of forest for inventory purposes) is calculated by a carbon accounting model, CARBINE, as the sum of gains and losses in pools of carbon in vegetation, litter and soil in conifer and broadleaf forests and in harvested wood products. Restocking is assumed in all forests. The method is Tier 3, as defined by IPCC (2006). **References** • UK NIR: Annex 3.4.1. Carbon stock changes due to afforestation and forest management (4A); Section 6.2. CATEGORY 4A – FOREST LAND; Section 6.8. CATEGORY 4G – HARVESTED WOOD PRODUCTS • Matthews et al. (in prep). The CARBINE model. A technical description Chapter 2. Modelling purpose and scope

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[18] In the application of models in National Greenhouse Gas Inventories, critical issues are suitability, parameterization, calibration, evaluation, and uncertainty.

Criteria (or element)	Reference to documentation
Application and adaptation of model (*description of why and how the model was adapted for conditions outside the originally intended domain of application*)	**Summary** The CARBINE model was first developed by the then Research Division of the Forestry Commission in 1988 (Thompson and Matthews, 1989), now Forest Research. It is built around the stand level M1 growth and yield model which is based on yield tables published in the early 80s (see Arcangeli and Matthews). The general purpose of the CARBINE model is to address questions about the carbon and GHG balances of forestry systems, and to inform the development of forest policy and practice, particularly regarding the goal of climate change mitigation. It was adapted for use specifically with the UK GHG inventory and first used in the GHG inventory submitted in 2014. The UK replaced the C-FLOW model with CARBINE because CARBINE has several advantages which allows it to more accurately estimate GHG emissions and removals. CARBINE can model a more diverse range of species and forest management practices, and model complex changes or trends in forest management over time. It also addresses a key limitation of C-FLOW, which assumed that forests planted prior to 1921 were at carbon equilibrium. Matthews et al. (2014) gives an overview of the CARBINE model and a comparison of its use in the 1990-2012 LULUCF inventory with the C-Flow model previously used model to forest carbon stock changes. The growth conditions of forests represented by CARBINE are principally of relevance to UK forest conditions. The CARBINE model is not operating outside its originally intended domain of application. **References** • UK NIR. Annex 3.4.1. Carbon stock changes due to afforestation and forest management (4A); Section 6.2. CATEGORY 4A – FOREST LAND; 6.8 CATEGORY 4G – HARVESTED WOOD PRODUCTS • Matthews et al. (in prep). The CARBINE model. A technical description. Chapter 2. Modelling purpose and scope • Thompson, D.A., Matthews, R.W., 1989. The storage of carbon in trees and timber. Forestry Commission Research Information Note 160. Forestry Commission: Edinburgh • 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)
Main equations / processes	**Summary** The CARBINE model is a complex model, with several sub models. These sub-models include: forest carbon sub-model, soil sub-model, SCOTIA, and wood products sub-model. The forest carbon and soil sub-models are used in the GHG inventory and the latest UK NIR provides a summary of CARBINE model. Forest Research are working on a report which documents the methods employed in the implementation of the CARBINE forest sector carbon accounting model. The report includes model equations, parameters, assumptions, verification and supporting scientific evidence, where available. Figure 2.2 in that report presents a schematic representation of the structure and components of CARBINE. **References** • Matthews et al. (in prep). The CARBINE model. A technical description. Chapter 3. Representation of forest stands; to; Chapter 4. Representation of harvested wood products; and; Annex 1. Detailed soil carbon model description • UK NIR: Annex 3.4.1. Carbon stock changes due to afforestation and forest management (4A)

Key assumptions (*important assumptions made in developing and applying the model*)	**Summary** The CARBINE model is a complex model, and only a summary of the key assumptions can be given here. A key concept of the methodology underlying the CARBINE model is that net exchanges of carbon between forest pools (trees, deadwood, litter and soil) and related pools (deforestation, HWP) can be inferred from the changes in the carbon stocks of these individual pools. The section numbers in the description below refer to the sections in Matthews et al. *The CARBINE model. A technical description*: **3.1. Stand volume growth.** The main assumption is that all types of forests and management in the UK can be represented by the FC yield models – including by assuming that species not covered by the UK yield tables can be mapped to a species for which a model is available. Immediate restocking is assumed in all forests. **3.2. Stand stem biomass and carbon.** The key assumption is that stem merchantable biomass can be calculated from stem volume from the yield tables using a species-specific stem density and a country-specific estimate of carbon content for all wood (50%) **3.3. Stand tree biomass and carbon.** The key assumption is that the stem biomass can be converted to whole tree biomass using biomass expansion factors for branches, leaves, coarse roots and fine roots. **3.4. Stand management.** Forest stand management is represented by four broad prescriptions: 1) No thinning and no felling (i.e. effectively no management for production); 2) Clear-felling on a specified rotation without thinning; 3) Thinning with clear-felling on a specified rotation; 4) ‘Continuous cover’ silviculture (i.e. woodland management with harvesting based on thinning only, that also aims to always maintain tree cover on the land). **3.5. Stand disturbance events.** The key assumption for the inventory is that there will be no mortality beyond the normal senescence of part of tree and within stand competition as predicted by the yield model as calibrated on the permanent sample plots. Supplementary calculations are carried out for the purposes of reporting relevant GHG emissions as part of GHG inventories for disturbances from fires on Forest Land. **3.6. Tree harvesting in stands.** The assumption is that the harvesting is as modelled in the yield tables and that only certain parts of the tree are removed – i.e. there is no whole-tree harvesting. **3.7. Losses of carbon from parts of living trees through senescence.** The key assumptions are that deadwood and litter inputs in the form of losses of branches and foliage from living trees can be modelled by annual turnover rates and that these losses will be replaced (i.e. that the relationships between the carbon in the different compartments implied by the biomass expansion factors still holds). **3.8. Stand deadwood and litter accumulation.** Carbon enters the deadwood and litter pools through several processes: • Losses of biomass from the senescence of parts of growing trees (Section 3.7) • Mortality of trees as a result of stand competition (Sections 3.2 and 3.3) • Mortality of trees as a result of stand natural disturbance (Section 3.5) • Tree biomass discarded in the forest during harvesting operations (Section 3.6). Carbon is lost from the deadwood and litter pools through decomposition. **3.10. Soil carbon (including fermenting material).** That the soil carbon and fermenting material can be represented using an “ECOSSE-style model”. This model, called SCOTIA, was developed to allow full representation of UK specific conditions, including both mineral and organic soils.

Criteria (or element)	Reference to documentation
	4.1. Representation of Harvest Wood Products. While a more disaggregated description of HWP is available in CARBINE, for the purpose of the Convention and Kyoto Protocol reporting, wood products are grouped in a more limited set of semi-finished product categories consistent with the IPCC guidelines and modelled using first order decay functions and product half-lives specified as part of Tier 1 methods in the IPCC good practice guidance. The summary above of the key assumptions increases the transparency of the of the CARBINE model. **References** • Matthews et al. (in prep). The CARBINE model. A technical description. Chapter 3. Representation of forest stands; to; Chapter 4. Representation of harvested wood products • UK NIR: Annex 3.4.1. Carbon stock changes due to afforestation and forest management (4A)
Domain of application (*description of the range of conditions for which the model has been developed to apply*)	**Summary** A version of CARBINE has been specifically developed for the UK GHG inventory. In principle, the M1 forest growth model that underlies CARBINE permits a very wide range of possible stand management regimes to be represented. However, when modelling UK forests at national scale, forest stand management are represented by four broad prescriptions types and a range of rotation length (see Annex 3 of the National Forestry Accounting Plan). **References** • Matthews et al. (in prep). The CARBINE model. A technical description. Chapter 2. Modelling purpose and scope • UK National Forestry Accounting Plan, 2021 to 2025 (2019) Annex 3. https://www.gov.uk/government/publications/uk-national-forestry-accounting-plan-2021-to-2025
How the model parameters were estimated	Many of the parameters in CARBINE are based on literature reviews and the key parameters are described in the report describing CARBINE. **References** • Matthews et al. (in prep). The CARBINE model. A technical description. Chapter 2. Modelling purpose and scope. • Lavers, G.M. and Moore, G.L. (1983) The strength properties of timber. Building Research Establishment Report CI/SFB I(J3). Building Research Establishment, Garston • Levy, P.E., Hale, S.E. and Nicoll, B.C. (2004) Biomass expansion factors and root:shoot ratios for coniferous tree species in Great Britain. Forestry, 77, 421-430.

Criteria (or element)	Reference to documentation
Description of key inputs and outputs	**Summary** Inputs: CARBINE uses a wide range of input data – see above for a description of these. The main input data are, inter alia, 1) information on the growth of stem wood volume in different stands of trees from the M1 growth model; 2) standard estimates for wood density (see Table 3.2 in Matthews et al.) and wood carbon content (0.5 t C odt^{-1}); 3) management practices; 4) soil turnover rates; 5) decomposition rates of active soil pools to DOC, 6) occurrence of land use changes over time. Outputs: All the data necessary for the reporting of forest land inventory: gains and losses in pools of carbon in standing trees, litter and soil in conifer and broadleaf forests and in harvested wood products and forest. Gains and losses in forest soils are also estimated. References • Matthews et al. (in prep). The CARBINE model. A technical description. Chapter 3. Representation of forest stands; to; Chapter 4. Representation of harvested wood products; and; Annex 1. Detailed soil carbon model description
Details of calibration and model evaluation	**Summary** **CARBINE (excluding soil carbon):** In 2003, Robertson *et al*. undertook a study to evaluate the completeness and suitability of the C-FLOW and CARBINE models for estimating carbon stocks and potential stock changes in the forestry sector at the stand and national levels, and the reliability of underpinning data and parameter estimates used by C-FLOW and CARBINE. Based on the results considered, Robertson et al. concluded that, while there may be some issues to address with regard to some inaccuracies in predictions of tree carbon stocks made by both CARBINE and C-FLOW, such model predictions are reasonably accurate. Although the analysis of Robertson et al. can only be regarded as an initial investigation, the results indicated that the accuracy of predictions made by both models is well within short-term fluctuations observed for individual stands (±10%). A more recent verification of the growth model M1 underpinning CARBINE started in 2017 has also confirmed that the growth model displayed good to reasonable consistency with growth trend data collected in sample plots. For some tree species, evidence of deviations in growth trends at older stand ages. This included Sitka spruce, but beyond the ages of conventional forest rotations. A programme to refine existing growth models is in progress. Significant work already done (new growth curves calibrated). The aspiration is to integrate the new growth models into CARBINE once fully tested. This is discussed in the report describing CARBINE. **SCOTIA (soil sub-model in CARBINE):** The work done to confirm the suitability of the soil carbon sub-model, SCOTIA, for use in the UK GHG inventory is explained in detail in a report in preparation. The work presents the evidence that the estimates of soil carbon stocks and stock changes produced by the SCOTIA model are consistent with available field observations. **References** • Matthews et al. (in prep). The CARBINE model. A technical description. Section 8.2.5. Long-term trajectories • Matthews et al. (in prep). SCOTIA forest soil carbon model: Interim progress report on comparison of model estimates and measurements of soil carbon stocks and fluxes • Robertson *et al* . (2003). Evaluation of the C-FLOW and CARBINE carbon accounting models. Section 3 of UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities (2003) (https://www.semanticscholar.org/paper/Comparison-of-the-CFLOW-and-CARBINE-carbon-models-Robertson-Ford-Robertson/22f909599387970eef6b61ff7057151f4b86d76e)

Criteria (or element)	Reference to documentation
QA/QC procedures adopted (including verification and model intercomparison)	**Summary** The QA/QC procedures used in the forest land inventory are summarised in this NIR: • Section 6.2.6. Category-Specific QA/QC and Verification (CATEGORY 4A – FOREST LAND) • Section 6.8.4. Category-Specific QA/QC and Verification (CATEGORY 4G – HARVESTED WOOD PRODUCTS) • Section 6.11. GENERAL COMMENTS ON QA/QC. There is a detailed QA/QC plan for the forest land inventory, which is described in Henshall (2018). Chapter 8 of the CARBINE description report presents some comparisons of parameters referred to in the CARBINE model with standard estimates for these parameters from scientific literature, where relevant, and with any published parameter estimates of particular relevance to UK conditions. The SCOTIA report provides a detailed comparison of the CARBINE SCOTIA soil carbon sub-model estimates and measurements of soil carbon stocks and fluxes. **References** • Matthews et al. (in prep). The CARBINE model. A technical description. Chapter 8. Comparisons with standard parameters and estimates • Matthews et al. (in prep). SCOTIA forest soil carbon model: Interim progress report on comparison of model estimates and measurements of soil carbon stocks and fluxes • Henshall (2018). UK Greenhouse Gas Inventory LULUCF Sector Forest Land QA Plan. Paul Henshall. Forest Research

Criteria (or element)	Reference to documentation
References to peer-reviewed literature	There are several papers describing the C-FLOW model which follows the same theory of combining the FC yield tables with biomass expansion factors and a soil and litter model. There are also non-journal publications that have been reviewed by peers. **Peer reviewed journal publications** • Cannell, M.G.R., Dewar, R.C. (1995). The carbon sink provided by plantation forests and their products in Britain. Forestry 68, 35–48. doi: https://doi.org/10.1093/forestry/68.1.35 • Dewar, R.C. (1990). A model of carbon storage in forests and forest products. Tree Physiol. 6, 417–28 • Dewar, R.C. (1991). Analytical model of carbon storage in the trees, soils, and wood products of managed forests. Tree Physiol. 8, 239–258 • Dewar, Roderick & Cannell, M. (1992). Carbon sequestration in the trees, products and soils of forest plantations: An analysis using UK examples. Tree physiology. 11. 49-71. 10.1093/treephys/11.1.49. **Non- journal publications** • Matthews, R.W. (1996). The influence of carbon budget methodology on assessments of the impacts of forest management on the carbon balance, in: Apps, M.J., Price, D.T. (Eds.), Forest Ecosystems, Forest Management and the Global Carbon Cycle. Springer-Verlag, Berlin, New York, pp. 233–243. • Matthews, R.W. (1994). Towards a methodology for the evaluation of the carbon budget of forests. In: Kanninen, M. (Ed.), Carbon Balance of the World's Forested Ecosystems: Towards a Global Assessment. Proceedings of a Workshop Held by the Intergovernmental Panel on Climate Change AFOS, Joensuu, Finland, 11-15 May 1992. Painatuskeskus, Helsinki, pp. 105–114. • Matthews, R.W. (1992). Forests and arable energy crops in Britain: can they stop global warming? In: Richards, G.E. (Ed.), Wood: Fuel for Thought. Harwell, pp. 39-62. • Matthews, R.W. (1991). Biomass production and carbon storage by British forests. In: Aldhous, J.R. (Ed.), Wood for Energy: The Implications for Harvesting, Utilisation and Marketing: Proceedings - 1991 Discussion Meeting. Institute of Chartered Foresters, Edinburgh, pp. 162-177.

A 3.4.1.3 Forest activity data: management

The activity data for forests comes from different data sources for the public and private forest estates. The public forest estate is as defined in Forestry Statistics and covers the woodland that used to be managed by the Forestry Commission (FC) in Great Britain and that managed by the Northern Ireland Forest Service (NIFS). The public forest estate in Great Britain is now managed by separate organisations in England (Forestry England (FE)), Scotland (Forestry and Land Scotland (FLS)) and Wales (Natural Resources Wales (NRW)). The private forest estate covers all other woodland, including areas of forest managed by local authorities and other public bodies.

Each organisation maintains a Sub-Compartment DataBase (SCDB), containing information on location, size, species, growth rate and management of the forests. Information from the SCDB) was used to create a distribution of species and yield class (an indication of growth rate) for the public forest estate. For the private forest estate, information from the National Forest Inventory (NFI) survey of woodlands was analysed to estimate yield class and species by age class and scaled to represent the whole private forest estate. Data from the Forestry Commission's new planting and wood production statistics were used to assign the areas in an age class to individual years, either as areas restocked or areas newly planted.

Management of forests is represented as one of four options: Clearfell with thinnings, clearfell without thinnings, managed but not clearfelled, and not used for timber production. For the clearfell forests restocking occurs after the rotation period. For non-clearfell productive woodlands it is assumed there is a 30 year overlap of restocking and non-restocked trees. The area of land felled each year was estimated from the wood production statistics separately for both public and private forests. The rotation periods for forests were estimated based on information on the intended management of the public estate. This analysis gave a target rotation period for each modelled species and yield class.

The actual rotations historically applied to the forest estate are unknown and for the private forests the area of woodland used for timber production is also unknown. In order to match production, given the age class distribution of the forest, an algorithm was implemented to adjust the assumed rotations and the percentage of private sector woodland not used for timber production. This algorithm adjusts these assumptions in order to match the modelled wood production with the timber production statistics separately for the public and private forests. It was assumed that the forests would be felled evenly over a period +/-7 years from the target rotation period. A comprehensive description of this algorithm will be presented in a separate technical report.

Information on the management of privately owned forests that is used to inform the inventory estimates, as well as a description of how forest land AD (forest land remaining forest land; land converted to forest land) are derived, is included in the UK National Forest Accounting Plan, which can be found at:

https://www.gov.uk/government/publications/uk-national-forestry-accounting-plan-2021-to-2025

A 3.4.1.4 Forestry activity data: historical and current afforestation rates

Irrespective of species assumptions, the variation in CO_2 removals from 1990 to the present is determined by the afforestation rate in earlier decades, the effect this has on the age structure in the present forest estate, and hence the average growth rate. Afforestation is assumed to occur on ground that has not been wooded for many decades, based on the assumption that if it had previously been woodland it would be in the restocking statistics rather than the new planting statistics as a result of the regulatory framework that applies to forestry in the UK.

A comparison of historical forest census data and the historical annual planting rates has been undertaken. Forest censuses were taken in 1924, 1947, 1965, 1980 and the late 1990s. The latest census (National Forest Inventory) has only just been completed. The comparison of data sources showed that discrepancies in annual planting rates and inferred planting/establishment date (from woodland age in the forest census) are due to restocking of older (pre-1920) woodland areas and variations in the harvesting rotations. However, there is also evidence of shortened conifer rotations in some decades and transfer of woodland between broadleaved categories (e.g. between coppice and high forest). It is difficult to incorporate non-standard management in older conifer forests and broadleaved forests into the Inventory because it is not known whether these forests are on their first rotation or subsequent rotations (which would affect carbon stock changes, particularly in soils). The area of afforestation in a given year is predicted based on applying the yearly distribution from the new planting and restocking statistics to the age class inventory. Age classes prior to the availability of new planting statistics are assigned evenly to individual years. For this inventory submission the assumption was made that we can estimate the area felled for recent years based on the timber production in the year of felling. It is assumed that woodland felled is immediately restocked. As we have an estimate of the area restocked for these years, the remainder of the area for each year was assumed to be restocking or natural regeneration. For years prior to the timber production statistics (i.e. prior to 1976), an estimated ratio between restocking and afforestation was used based on the earliest data. For restocked woodland the forest area was assumed to have been restocked twice and had been managed in the same fashion and on the same rotation.

The planting data used as input to the CARBINE model come from national planting statistics from 1921 to the present (provided by the Forestry Commission) for England, Scotland and Wales and from 1900 to the present (provided by the Northern Ireland Forest Service). For England, Scotland and Wales estimates of area of woodland by species, yield class and broad age class came from analysis of the NFI (for private woodland) and the SCDB (for FC/NRW woodland).

The NFI provides woodland statistics for Great Britain, (England, Wales and Scotland), broken down by region. It comprises a digital woodland map based on comprehensive aerial photography and a field survey using 15,000 one-hectare sample squares. The digital map and field survey cover all woodland areas down to 0.5 hectares. An initial digital woodland map was published in spring 2011. The NFI woodland field survey provides direct assessments of woodland growing stock including species composition, stand structure, tree age (distribution) productivity indices, numbers of trees, and diameter and height distribution. Standing biomass (and carbon) in trees, including above and below ground biomass, can be derived from these assessments using GB-specific conversion factors and allometric equations. A complete 5-year cycle of ground survey has now been completed. NFI data do not allow the carbon stocks of deadwood or litter to be estimated. The NFI has been supplemented by an assessment of the area of small woods (woodland between 0.1 ha and 0.5 ha) to align with the minimum woodland area for UNFCCC reporting as set out in CMP.7 (Forestry Commission, 2017). The analysis of small woods area included no characterisation of the resource. Since there is currently no information on the age-distribution of the area of small woods, it was assumed to have established evenly between 1900 and 1970.

The NFI uses a lower integral open space threshold of 0.5 ha (as opposed to 1 ha), which requires a downward adjustment to areas. However, the main differences in 2010 GB woodland cover between the NFI (2982 kha) and previous estimates (2757 kha, Forestry Statistics 2010) arise from identified errors in the previous woodland survey, particularly the under-estimate of woodland areas between 0.5 and 2 hectares. Estimates of woodland loss have been assessed, which affect the total estimated woodland area in the GHGI (but are not yet reflected in the national Forestry Statistics).

We assumed that the NFI survey gives a distribution of all the private forest area for a base year of 2011, and the SCDB gives a distribution of all the public forest area for a base year of 2014.

The main NFI survey includes areas of woodland >0.5 ha. An adjustment was made to the areas of woodland to account for woods between 0.1 ha and 0.5 ha. For England and Wales, the estimates are derived from a calibration of tree cover plotted in the National Tree Map (NTM) product across England and Wales[19], using a comparison of manual photographic interpretation with the NTM product within a sample of 1 km square tiles. For Scotland, the estimates are derived from a direct evaluation of polygons in the map constructed for the Native Woodlands of Scotland Survey (NWSS)[20], which mapped all woodland polygons in Scotland down to 0.1 hectares in size

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[19] http://www.bluesky-world.com/national-tree-map

[20] http://scotland.forestry.gov.uk/supporting/strategy-policy-guidance/native-woodland-survey-of-scotland-nwss

by photographic interpretation. The areas of small woods used in this inventory were based on data published in 2017 by the Forestry Commission in the report “Tree cover outside woodland in Great Britain”[21].

An algorithm was used to obtain the area of woodland afforested each year by removing the area of felling from the age class distribution. The species were then allocated to this “residual distribution’ by starting in the base year and allocating the shortest rotations first. The planting years for all restocked woodland are assigned by the algorithm to give two rotations of the same length as the assigned rotation, and are thus notional. This approach was undertaken to “spin up” the model in terms of soil and litter in order to reach a state consistent with land that has been forest for a long period. This algorithm will be described in detail in the same technical report as the description of allocation of the management of forests.

As part of implementation of wetland drainage and rewetting accounting, new maps of peat soils have been created for each of the DAs (see **Section A 3.4.6.1**). These maps were combined with a forest map to give areas of conifer and broadleaf forests planted on organic soils for each DA. These total areas were assigned to individual afforestation years by adjusting the previously applied the distribution of organic soil areas and an analysis of recent grant-aided new planting on organic soils and implementation of policies against planting on organic soils in each of the DAs.

As explained above, the planting rates given in **Table A 3.4.3** are derived from administrative records, information on forest age class distribution from NFI field assessments and interim assumptions about the age distribution of ‘small woods’. The planting rates given in **Table A 3.4.3** are therefore significantly different to those reported as official planting statistics supported by grant-aid. The afforestation rates for each planting type in the UK have been calculated from the data and are shown in **Table A 3.4.3.**

Table A 3.4.3 Afforestation rate (kha p.a.) of conifers and broadleaves in the United Kingdom since 1500 based on estimates of woodland area by age from the NFI and administrative records.

Period	Conifers on all soil types	Conifers on organic soil	Broadleaves on all soil types	Broadleaves on organic soils
1501-1600	0.00	0.00	0.02	0.00
1601-1700	0.09	0.00	0.47	0.00
1701-1750	0.29	0.00	1.05	0.00
1751-1800	0.63	0.00	0.89	0.00
1801-1850	1.98	0.00	0.76	0.00
1851-1900	5.11	0.56	1.12	0.02
1901-1910	4.72	0.96	9.27	0.19
1911-1920	3.26	0.63	11.71	0.25

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[21] 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/

Period	Conifers on all soil types	Conifers on organic soil	Broadleaves on all soil types	Broadleaves on organic soils
1921-1930	3.12	0.61	13.61	0.35
1931-1940	3.82	0.65	14.70	0.51
1941-1950	8.20	1.88	18.06	0.78
1951-1960	13.30	3.70	19.35	1.04
1961-1970	20.64	6.70	21.29	1.27
1971-1980	28.11	10.63	14.75	0.96
1981-1990	20.64	7.58	17.09	0.95
1991	14.84	5.01	12.57	0.64
1992	12.74	4.20	14.62	0.75
1993	10.32	3.30	18.22	0.89
1994	14.04	4.43	19.75	1.02
1995	12.72	3.88	16.60	0.81
1996	12.51	3.67	16.08	0.78
1997	12.22	3.39	17.95	0.75
1998	11.66	3.09	17.74	0.74
1999	11.76	2.96	17.79	0.73
2000	10.33	2.47	19.64	0.84
2001	7.19	1.64	15.83	0.73
2002	6.94	1.49	15.56	0.63
2003	6.57	1.39	13.80	0.54
2004	3.23	0.70	13.26	0.45
2005	2.27	0.47	12.08	0.38
2006	2.92	0.55	12.87	0.40
2007	2.18	0.39	10.28	0.32
2008	2.01	0.30	8.25	0.23
2009	1.44	0.19	7.51	0.18
2010	2.68	0.32	9.88	0.21
2011	4.49	0.32	13.16	0.14
2012	2.28	0.08	14.48	0.06
2013	2.31	0.00	12.53	0.00
2014	2.69	0.00	8.83	0.00
2015	2.28	0.00	4.67	0.00

Period	Conifers on all soil types	Conifers on organic soil	Broadleaves on all soil types	Broadleaves on organic soils
2016	3.30	0.00	3.10	0.00
2017	4.85	0.00	3.64	0.00
2018	7.46	0.00	5.01	0.00
2019	7.86	0.00	5.77	0.00
2020	7.41	0.00	5.99	0.00

A 3.4.1.5 Allocation of CARBINE outputs to UNFCCC inventory sub-categories

The CARBINE model output was post-processed using the IPCC default 20-year transition period for Land converted to Forest to move into the Forest remaining Forest category. The area within the Land converted to Forest Land sub-category is split between cropland, pasture grassland, semi-natural grassland, settlement and other areas. Pasture grassland and semi-natural grassland are combined for Grassland reporting in the CRF. This split is based on the relative proportions of historical land use change from these categories to forest. The proportions for each country change over time because the 20-year transition period has a different start date for each reporting year. The CARBINE model outputs take account of forest area loss through conversion to other land uses (deforestation).

A 3.4.1.6 Nitrogen fertilization of forest land

Nitrogen fertilization of forest land is assumed to occur only when absolutely necessary, i.e. new planting on ‘poor’ soils (mining spoil, impoverished brown field sites, or upland organic soils). In terms of the inventory, this means that N fertilisation is assumed for Settlement converted to Forest land and Grassland converted to Forest Land on organic soils. The areas of new planting with these conditions were taken from the same dataset used in the CARBINE model (see **Table A 3.4.3)** for 4.A.2. Land converted to Forest land.

Where fertilisation occurs, an application rate of 150 kg N ha^{-1} is assumed based on Forestry Commission fertilisation guidelines (Taylor, 1991). The guidelines recommend applying fertiliser on a three-year cycle until canopy closure (at approximately 10 years), but this is thought to be rather high (Skiba 2007) and unlikely to occur in reality, so two applications are adopted as a compromise. These applications occur in year 1 and year 4 after planting. The N_2O emission factor for applied nitrogen fertiliser is the default value of 1% used in the IPCC 2006 Guidelines. Emissions of N_2O from N fertilisation of forests are estimated using a Tier 1 methodology and IPCC default emission factors. The emissions have fallen since 1990 due to reduced rates of new forest planting. A GWP of 298 for N_2O is used. Indirect emissions of N_2O from atmospheric deposition also arise from this activity and are reported under Sector 4.

A 3.4.1.7 Non-CO_2 emissions from drainage on forest soils

Emissions from forest on drained soils are calculated for mineral and organic soils separately using a Tier 1 methodology. Emissions of CH_4 and N_2O from organic soils are calculated using Tier 1 EFs (see **Section A 3.4.6**). Emissions of N_2O from mineral soils are calculated using Tier 1 EFs (IPCC 2006) and information on the distribution of forest cover on different soil types (Yamulki *et al*. 2012), adjusted by the amount of forest planted since 1920. The area of forest on mineral soil is adjusted by splitting it between organo-mineral soils, free-draining mineral soils and easily waterlogged mineral soils, which require artificial drainage (based on the current guidance and policy for forest operations and management). The proportion of mineral soils requiring artificial drainage is: 34% in England, 24% in Scotland, 3% in Wales, 68% in Northern Ireland and 26% in the UK as a whole. We assumed all forest on organo-mineral soils is cultivated prior to planting and therefore effectively drained.

A 3.4.2 Land Use Change and Soils (4B, 4C, 4E)

A 3.4.2.1 Estimation of land-use change using Bayesian data assimilation

The tracking of land use and land-use change is fundamental to producing accurate and consistent greenhouse gas inventories for the LULUCF sector. In previous inventories the methodology for land use/land-use change modelling applied Approach 2 (non-spatial LUC matrices) using a combination of ‘snapshot’ Countryside Surveys, forest inventory and administrative statistics. However, this approach has proved to be insufficient for tracking annual land use change, particularly in relation to the reporting requirements of the second commitment period of the Kyoto protocol (as raised by the UNFCCC expert review team in October 2019). Firstly, the non-spatial matrix-based approach is insufficient for tracking annual land-use change: the matrices have no time dimension, and are defined independently each year. There is therefore no possibility of representing a sequence of land-use on the same parcel of land (such as afforestation followed by deforestation, or crop-pasture rotations). Secondly, the data used to estimate these matrices in the UK are rather limited. The Countryside Surveys are only carried out approximately once per decade (and not since 2007), and whilst the geographical extent is very wide, the actual ground area surveyed is a small fraction of the total UK area. The afforestation/deforestation statistics from the Forestry Commission have good national coverage (excluding Northern Ireland) but do not contain any information on the spatial location or land use prior to afforestation or following deforestation.

BEIS commissioned a research project (Land-Use Tracking) to improve tracking of land use change for the LULUCF sector (reference TRN 2384/05/2020), with additional funding for inventory implementation. This built on the successful pilot project that used a Bayesian data assimilation approach to integrate available multiple land-use data sources into vectors, i.e. unique sequences of land use histories and their associated areas (Levy *et al.* 2018). In the pilot study, carbon emissions arising from land-use change were modelled using the vector output, demonstrating the feasibility of using this as a methodology for the LULUCF sector.

Although the UK is well-provided with land-use datasets, UK land-use change occurs on small, fragmented areas and there is no single time-series with sufficient reliability to infer annual land-use change by difference for inventory reporting. Even with advances in satellite sensors, GIS and spatial data handling, the accuracy of change detection from EO-based products is generally too poor; the different EO products are inconsistent (with each other, and with themselves over time), irregular, and infrequent before 2000. Repeat ground-based surveys can detect change more reliably but lack a spatial element or information on gross change (e.g. the annual June Agricultural Census) and survey coverage is often incomplete or at infrequent intervals.

In the 1990-2020 submission the UK has updated the methodology for estimating land use change using a Bayesian data assimilation approach. This constrains estimates of gross land-use change with national-scale census data, whilst retaining the detailed information available from other land-use data sources. A full description of the methodology is given in the project reports (Levy *et al.* 2020, 2021; Rowland *et al.* 2021) and a summary is given here. It has not been possible to fully implement all of the project’s findings in the 1990-2020 inventory submission, so a two-step approach is being pursued:

1. **Improving the activity data used in the 1990-2020 GHG Inventory**, which broadly addresses the recommendation from the 2019 UNFCCC review team;
2. **Moving from independent annual matrices of land-use change to vectors of land-use change** (which improves the representation of rotation management of cropland and improved grassland) in the 1990-2021 GHG inventory, at the earliest.

A 3.4.2.1.1 Land-use change data sets

A range of datasets containing relevant information on land use and land-use change in the UK were assessed for inclusion in the Bayesian assimilation approach:

- Countryside Survey (DAERA 2016, UKCEH 2020a): GB and NI field repeated surveys of stratified 1km sample grid squares giving land-use and land-use change;
- Agricultural census data (DAERA 2021, Defra 2021, Scottish Government 2021, Welsh Government 2021): annual records of the total area in the main agricultural land uses;
- Land Cover Map (UKCEH 2020b): thematic land-cover classification of satellite image data covering the UK;
- Land Cover® plus: Crops (UKCEH 2016): Based on the LCM parcel framework with additional crop information from satellite data
- CORINE Land Cover (CORINE 2020): Survey of European land cover and land cover change from semi-automatic interpretation of high resolution satellite imagery;
- Agricultural holdings data: this is the finest level of detail from the Agricultural census dataset with information on agricultural land areas at the farm level;
- IACS: field-level register of agricultural subsidy claims under the EU Common Agricultural Policy;
- CROME: crop classification of satellite imagery for England, with ground-truth data from agricultural subsidy inspectors;
- Forestry Commission and Forest Service Northern Ireland data: forestry statistics on afforestation and deforestation currently used in the GHGI, forest maps from National Forest Inventory and National Forest Estate Sub-Compartment Database (Forestry Commission 2020);
- FAOStat MODIS data on artificial surfaces: annual area of coverage of artificial surfaces (urban) in the UK 2001-2018 from satellite imagery https://www.fao.org/faostat/en/#data/LC .

The decadal LUC matrices compiled for 1950-1979 from the Monitoring Landscape Change (MLC) dataset for Great Britain (MLC 1986) were also used. The only data available for Northern Ireland pre-1990 are land use areas from The Agricultural Census and The Forest Service (Cruickshank and Tomlinson 2000).

Some datasets were obtained under licence from the different national governments (IACS, agricultural holdings data) as they contain sensitive information. It was not possible to obtain permission for some data within the timescales of the research project (agricultural holdings for England, Wales and Northern Ireland, and IACS data for Scotland, Wales and Northern Ireland) but efforts are continuing to obtain, assess and integrate these datasets in the future.

Table A 3.4.4 Mapping land-use data categories to LULUCF categories (GB: Great Britain, E: England, S: Scotland, W: Wales, NI: Northern Ireland, UK: United Kingdom of Great Britain and Northern Ireland)

Data source	Spatial and temporal coverage	Forest Land	Cropland	Grassland-pasture	Grassland-rough	Settlement	Other	Not included
Countryside Survey	GB 1984, 1990, 1998/99, 2007 NI: ~1990, 1998, 2007	Broadleaved and Mixed; Coniferous woodland	Arable and Horticulture	Improved Grassland	Neutral Grassland; Calcareous grassland; Acid grassland; Fen Marsh and Swamp; Dwarf Shrub heath; Bog; Littoral Sediment	Built Up Areas and Gardens	Inland Rock; Supra-littoral Rock; Supra-littoral sediment; Littoral Rock	Saltwater Freshwater
Agricultural Census	E,S,W,NI: 1951-present	Woodland	Crops; Uncropped arable land	Temporary grass sown in past 5 years; Land used for outdoor pigs; Grass over 5 years old	Common rough grazing; Sole right rough grazing			
Land Cover Map	UK: 1990, 2015, 2017, 2018, 2019,2020 (publicly available), UK: 1994, 1998, 2002, 2006, 2010 created for the BEIS Land-use Tracking project	Broadleaved Woodland; Coniferous Woodland	Arable and Horticulture	Improved Grassland	Neutral Grassland; Calcareous grassland; Acid grassland; Fen Marsh and Swamp; Heather; Heather grassland; Bog; Saltmarsh	Urban; Suburban	Inland rock; Supra-littoral Rock; Supra-littoral sediment; Littoral Rock	Saltwater Freshwater
Land Cover plus Crops	GB: 2015 (partial coverage), 2016, 2017, 2018, 2019		Beet, Field Beans, Maize, oilseed Rape, other crop, Peas, Potatoes,	Grass				

Data source	Spatial and temporal coverage	Forest Land	Cropland	Grassland-pasture	Grassland-rough	Settlement	Other	Not included
			Spring barley, Spring Wheat, Winter barley, Winter oats, Winter wheat					
CORINE land Cover	UK: 2000, 2006, 2012, 2018	Agro-forestry areas; Broadleaved woods; Coniferous woods; Mixed woods	Non-irrigated arable land; Permanently irrigated land; Rice fields; Vineyards; Fruit trees and berry plantations; Olive groves; Annual crops ; associated with permanent crops; Complex cultivation patterns	Green urban areas; Sport and leisure facilities; Pastures	Natural grasslands; Moors and heathland; Sclerophyllous vegetation; Transitional woodland-shrub; Inland marshes; Peat bogs; Salt marshes	Continuous urban fabric; Discontinuous urban fabric; Industrial or commercial units; Road and rail network and associated land; Port areas; Airports; Mineral extraction sites; Dump sites; Construction sites	Beaches dunes sands; Bare rocks; Sparsely vegetated areas; Burnt areas; Glaciers and perpetual snow; Salines	Intertidal flats; Water courses; Water bodies; Coastal lagoons; Estuaries; Seas and ocean; NODATA
Monitoring Landscape Change	GB: 1947, 1969, 1980	Broadleaved wood; Conifer wood; Mixed wood	Crops; Market garden; Orchards	Improved grassland	Upland heath; Upland smooth grassland; Upland coarse grass; Blanket bog; Bracken Lowland rough grass; Lowland heather; Gorse; Neglected grassland; Marsh; Rough pasture; Peat bog; Fresh Marsh; Salt marsh	Built up; Urban open, Transport; Mineral workings; Derelict	Bare rock; Sand/shingle; Inland water; Coastal water	

The agricultural holdings data for Scotland were supplied for 1990-2018 and provide spatial data at the postcode or parish level, rather than the exact location. IACS data use a very large number of classes, which have changed over time, and a table showing the correspondence between these and LULUCF classes is too large to display here but available on request. The IACS data require considerable processing and classification to ensure consistency and only the data for England 2004-2014 were included in the data assimilation, as issues with 2015-2019 data had not been resolved within the timescale of the Land-Use Tracking project.

Ordnance Survey Land Use Change Statistics and LUCAS (Land Use Cover Area Frame Survey) were also assessed but not included in the final data assimilation because of time constraints on data processing and analysis.

The datasets covering multiple land categories were mapped to the LULUCF categories (**Table A 3.4.4**), with a sub-division of grassland between improved pasture and semi-natural rough grazing land. Land-use change information from repeated survey data and decadal land-use change matrices were transformed to annual time series based on interpolation between the survey/decadal start dates.

A 3.4.2.1.2 Bayesian data assimilation methodology

There are three data structures that provide information on land-use change:

- the time series of areas of each land use, **A**

- the transition matrix **B** denoting the areas which have changed from each land use to each of the other land uses, over a given time period

- the 3-D spatio-temporal array **U** which denotes land use at each location in space and time, in a regular gridded format.

The three data structures are inter-related by arithmetic equations (see Levy *et al.* 2018). These equations are used as a model to relate the different observational data via Bayesian data assimilation in a two-stage process.

- Firstly, a Bayesian approach is used to estimate the parameters in ***B***, given prior information and partial observations of ***U*** and ***A***.
- Secondly, the posterior distribution of ***B*** and spatial and probabilistic information on the location of land-use change (***W***) is used to simulate posterior realisations of ***U***.

The maximum a posteriori probability (MAP, the mode of the posterior distribution) realisations represent the best estimate of land-use and land-use change, given the available data. The spread of possible realisations in the posterior distribution provides the uncertainty in our knowledge of the true land-use change.

The output data structure ***U*** has the high temporal and spatial resolution (annual and 100 m) necessary for capturing small-scale land-use. The data cuboid ***U*** contains a lot of repetition and can be summarised efficiently as the set of unique vectors of land use over time, together with their associated areas. This provides an intermediate option for modelling the effects of land-use change in the GHG inventory, without requiring a fully spatially explicit model.

The data assimilation approach produced transition matrix (the gross area changing annually between the different land uses from 1951-2020), the gross gain in area of each land use, the gross loss of area for each land use, and the net change in area occupied by each land use, for each devolved administration (sections 7-10 in Levy et al. 2021). Example outputs are shown in **Figure A 3.4** and **Figure A 3.5**.

Figure A 3.4 **Transition matrix for England, representing the gross area change between land uses 1951-2020, showing the observations and posterior distribution of estimates. The grey shaded band is the 2.5-97.5 percentiles of the posterior distribution, with the MAP the black line within this. (Levy *et al.* 2021).**

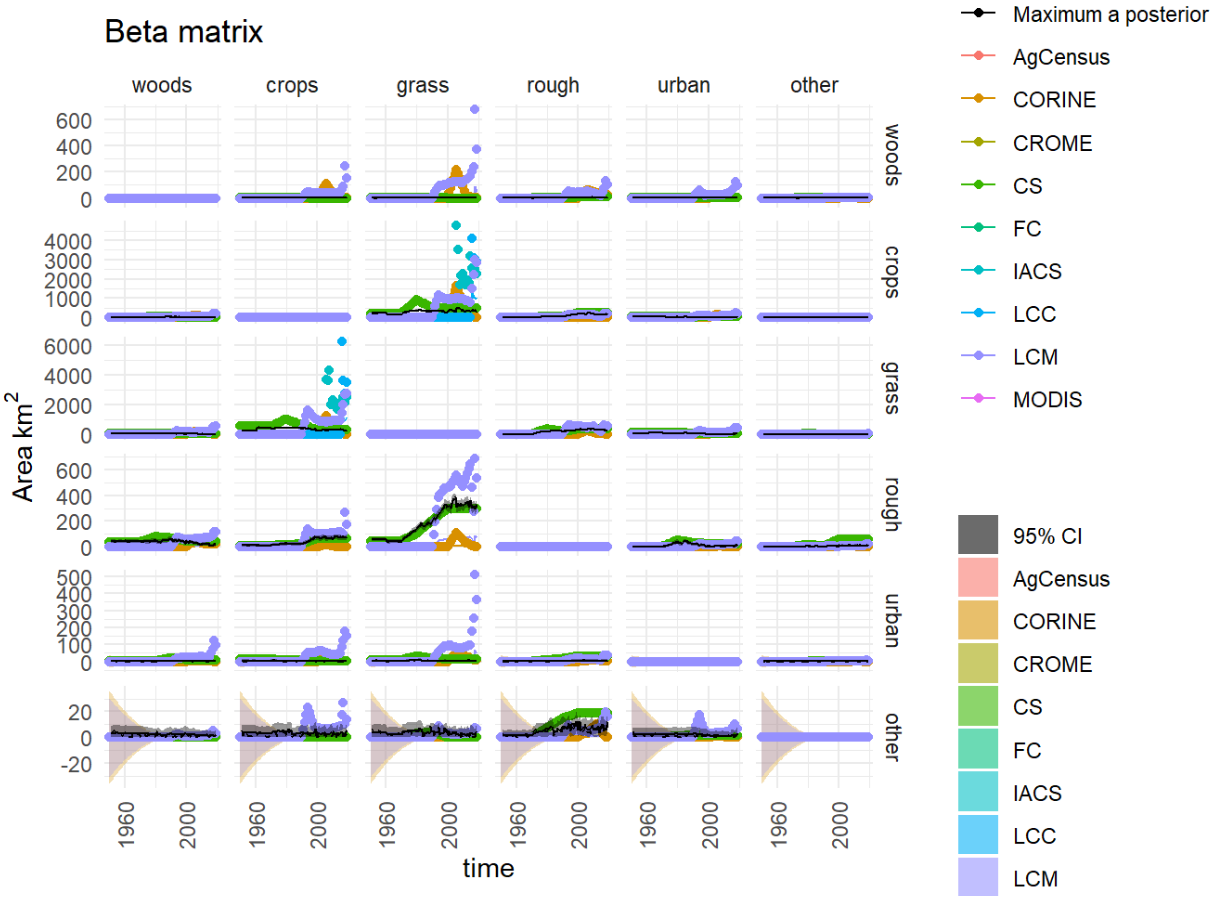
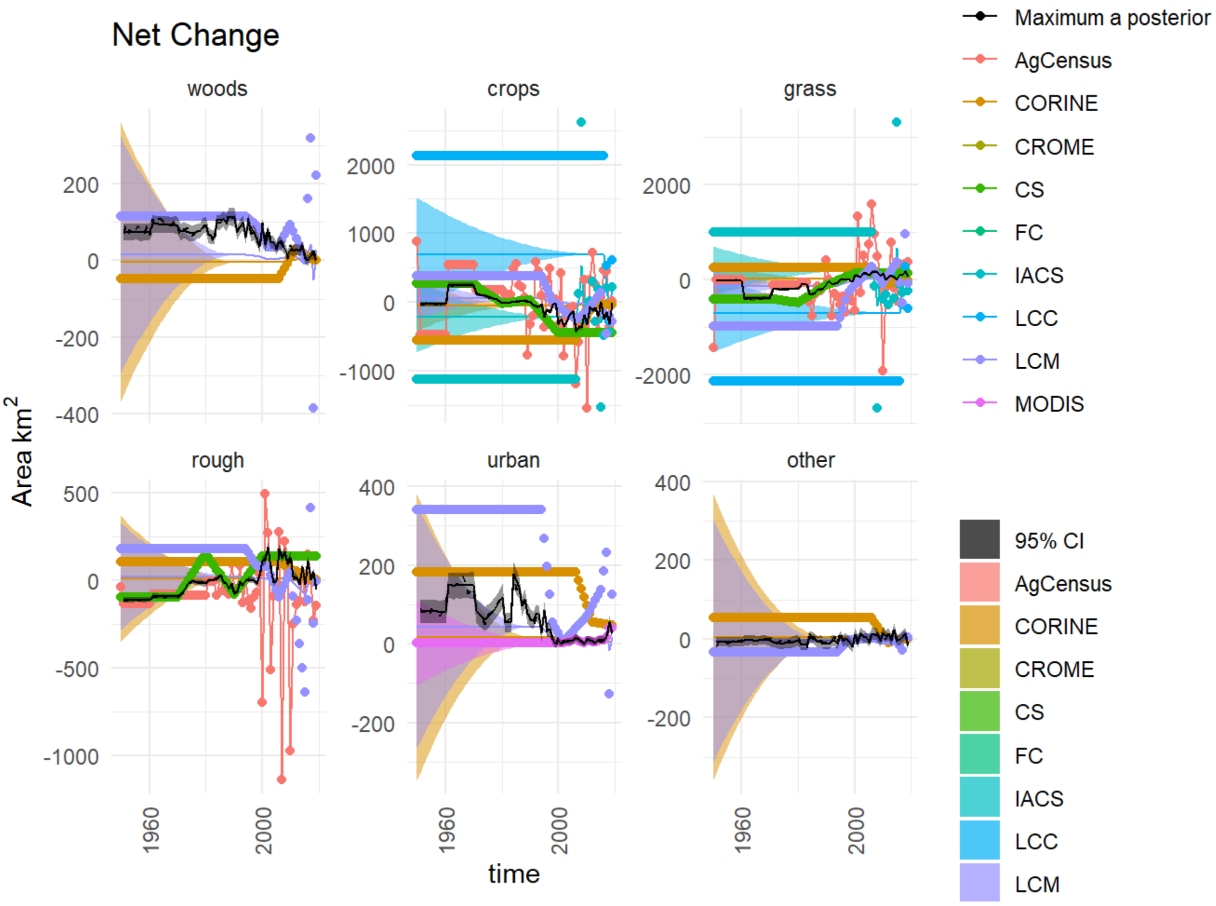


Figure A 3.5 **Time series of the net change in the area of each land use 1950-2020, showing the observations and posterior distribution of estimates. The grey shaded band is the 2.5-97.5 percentiles of the posterior distribution, with the MAP the black line within this. (Levy et al. 2021). The thin coloured lines are the corrected observations, after accounting for systematic uncertainty, and interpolating.**



A 3.4.2.1.3 Uncertainty associated with the different datasets in the Bayesian assimilation

There was a detailed quantification of uncertainty for data included in the assimilation (Levy *et al*. 2021). For every spatial data source, the following contribution to uncertainty were assessed:

- False positive rate, F_p (over-estimation of land-use change that did not happen)
- False negative rate, F_N (under-estimation through missing true land-use change)
- Random uncertainty σ
    - Data-source specific

      $$\sigma^{\text{obs}}$$

    - Sampling frequency (increasing uncertainty as the sampling frequency increases from annual to decadal intervals)

      $$\sigma^{\text{obs}}_{\text{ann}} = \sigma^{\text{obs}}\sqrt{n}$$

    - Sampling coverage (higher uncertainty outside the bounds of the data coverage).

      $$\sigma^{\text{obs}}_{t} = \sigma^{\text{obs}}\Delta_t^2$$

These contributions were included when estimating the likelihood of every land-use transition. For every observation, likelihood was estimated:

$$\mathcal{L} = \frac{1}{\sigma_{ij}^{\text{obs}}\sqrt{2\pi}}\exp(-((1-F_P)\beta_{ij}^{\text{obs}} + A_N F_N - \beta_{ij}^{\text{pred}})^2/2\sigma_{ij}^{\text{obs}^2})$$

Most spatial datasets had high false positives and random uncertainty, which were large in relation to the small signal of true land-use change in the UK. These uncertainties were corrected for in the data assimilation algorithm by correcting for false positives and down-weighting the more uncertain datasets. A preliminary assessment with only a subset of datasets to constrain the land-use change matrix produced fairly similar results.

A 3.4.2.1.4 Land-use change results

The rates of land-use change 1951-2020 estimated by the data assimilation are shown in **Figure A 3.6**, superimposed with the rates of land-use change used in the 1990-2019 inventory. As in previous years, the land-use change activity data uses Approach 2, but with annual input data instead of decadal. Pending further analysis, it has been assumed that gross changes to/from the 4F Other Land category correspond to noise, especially from the EO-derived datasets, and these transitions are not considered (as has been done previously). The UK continues to use the rates of afforestation (whole time series) and deforestation (1990 onwards) from national forest statistics. However, additional information on the proportions of afforestation on cropland, grassland and settlements and information on pre-1990 deforestation from the Land-Use Tracking project is used in the transitions.

Figure A 3.6 **Time series for UK land-use transitions 1951-2020, showing the mean, 95% confidence limits and the 1990-2019 inventory LUC time series, based on Countryside Survey and historic datasets.**

Land use change on organic soils uses the information from Evans et al. (2017) (see **Section A 3.4.6**), but further analysis of land-use vectors on organic soils will be undertaken in the second stage of implementation of the Land-Use Tracking project.

Work was also done to improve the accuracy of representation of crop-grass rotational management, using the idea of "life tables" or age-specific transition probabilities, from population modelling. The life table probabilities are based on an analysis of the available data from IACS, CROME, LCM, and LCC, and these all show consistent patterns. Of these, IACS has much the longest time span of data, and is the dominant source of information. Using this method, the observed frequencies of transitions from crop to grassland as a function of cropland age (and vice versa for grassland) are now reproduced in the land-use vectors, and thereby approximate the observed frequency of crop-grass rotations. Implementing this in the inventory requires re-writing the soils model to use land-use vector data rather than land-use matrices. Work is being done on this, with rigorous QA/QC, with the intention of implementing in later submissions.

The full set of annual land use change matrices 1990-latest inventory year for the GBE, GBK and GBR submissions are provided in in Chapter 6 of the main NIR report, **Section 6.1.1**. The full set of annual matrices is used in the calculation of non-forest biomass carbon stock change. The full set is adjusted to take account of land use change on organic soils (see **Section A 3.4.6**) to produce a set of matrices for changes on non-organic soil only (which includes both mineral and organo-mineral soils) and these are used as input for the soils model described below.

A 3.4.2.2 Soils modelling

A database of soil carbon density for all soils in the UK (Milne & Brown 1997, Cruickshank *et al*. 1998, Bradley *et al*. 2005) is used in conjunction with the land use change matrices. There are three soil surveys covering England and Wales, Scotland and Northern Ireland. The field data, soil classifications and laboratory methods for these surveys have been harmonized to reduce uncertainty in the final joint database. The depth of soil considered was also restricted to 1 m at maximum as part of this process. The dynamic model of carbon stock change requires the change in equilibrium carbon density from the initial to the final land use. The core equation describing changes in soil carbon with time for any land use transition is:

$$C_t = C_f - (C_f - C_0)e^{-kt}$$

Where: C_t is carbon density at time t, C_0 is the assumed equilibrium carbon density initial land use, C_f is the assumed equilibrium carbon density after change to new land use and k is time constant of change.

Differentiating this equation gives the flux f_t (emission or removal) per unit area:

$$f_t = k(C_f - C_o)e^{-kt}$$

This equation gives, for any inventory year, the land use change effects from any specific year in the past. If A_T is area in a particular land use transition in year T considered from 1950 onwards then total carbon lost or gained in an inventory year, e.g. 1990, is given by:

$$F_{1990} = \sum_{T=1950}^{t=1990} kA_T(C_f - C_o)(e^{-k(1990-T)})$$

This equation is used with k, A_T and $(C_f\text{-}C_0)$ chosen by Monte Carlo methods within ranges set by prior knowledge, e.g. literature, soil carbon database, agricultural census, LUC matrices.

The model calculates the change in equilibrium carbon density from the initial to the final land-use for each land-use category as averages for Scotland, England, Wales and Northern Ireland. These are weighted by the area of land-use change occurring in each soil group to account for the actual carbon density where change has occurred. In previous inventories four broad soil groups were used (organic, organo-mineral, mineral, unclassified). With the implementation for the first time of methodologies consistent with chapters 2 and 3 of the 2013 IPCC Wetlands supplement, we now have areas of land use change on organic soils and the emission factors for the associated carbon losses. This would lead to double-counting without the adjustment of the soil carbon model to exclude land use change on organic soils. The equilibrium soil carbon density and weighting is now based on the non-organic soil groups only.

Mean soil carbon density change is calculated as:

$$\overline{C}_{ijc} = \frac{\sum_{s=1}^{6}(C_{sijc}L_{sijc})}{\sum_{s=1}^{6}L_{sijc}}$$

This is the weighted mean, for each country, of change in equilibrium soil carbon when land use changes, where: *i* = initial land use (Forestland, Grassland, Cropland, Settlements), *j* = new land use (Forestland, Grassland, Cropland, Settlements), *c* = country (Scotland, England, N. Ireland & Wales), *s* = soil group (organo-mineral, mineral, unclassified) and C_{sijc} is change in equilibrium soil carbon for a specific land use transition

The land use data (1990 to 1998) is used in the weighting. The average change and range calculated are presented in **Table A 3.4.5**-**Table A 3.4.8**.

Table A 3.4.5 Weighted average change and range (±% from mean value) in equilibrium non-organic soil carbon density (t ha^{-1}) to 1 m deep for changes between different land types in England

From / To	Forestland	Grassland	Cropland	Settlements
Forestland	0	5 (±44%)	30 (±7%)	79 (±4%)
Grassland	-5 (±49%)	0	24 (±0%)	75 (±4%)
Cropland	-30 (±7%)	-24 (±2%)	0	49 (±3%)
Settlements	-79 (±4%)	-73 (±3%)	-50 (±2%)	0

Table A 3.4.6 Weighted average change and range (±% from mean value) in equilibrium non-organic soil carbon density (t ha^{-1}) to 1 m deep for changes between different land types in Scotland

From / To	Forestland	Grassland	Cropland	Settlements
Forestland	0	56 (±4%)	174 (±2%)	235 (±2%)
Grassland	-61 (±4%)	0	101 (±0%)	171(±0%)
Cropland	-180 (±1%)	-101 (±0%)	0	62 (±4%)
Settlements	-242 (±0%)	-168 (±1%)	-54 (±14%)	0

Table A 3.4.7 Weighted average change and range (±% from mean value) in equilibrium non-organic soil carbon density (t ha^{-1}) to 1 m deep for changes between different land types in Wales

From / To	Forestland	Grassland	Cropland	Settlements
Forestland	0	14 (±54%)	51 (±13%)	105 (±12%)
Grassland	-13 (±65%)	0	38 (±11%)	91 (±10%)
Cropland	-48 (±21%)	-39 (±2%)	0	46 (±10%
Settlements	-104 (±12%)	-89 (±6%)	-55 (±6%)	0

Table A 3.4.8 Weighted average change and range (±% from mean value) in equilibrium non-organic soil carbon density (t ha^{-1}) to 1 m deep for changes between different land types in Northern Ireland

From / To	Forestland	Grassland	Cropland	Settlements
Forestland	0	39 (±10%)	106 (±10%)	192 (±10%)
Grassland	-39 (±10%)	0	68 (±10%)	153 (±10%)
Cropland	-106 (±10%)	-68 (±10%)	0	85 (±10%)
Settlements	-192 (±10%)	-153 (±10%)	-85 (±10%)	0

The rate of loss or gain of carbon is dependent on the type of land use transition (**Table A 3.4.9).** For transitions where carbon is lost e.g. transition from Grassland to Cropland, a 'fast' rate is applied, whilst a transition that gains carbon occurs much more slowly. A literature search for information on measured rates of changes of soil carbon due to land use was carried out and ranges of possible times for completion of different transitions were selected, in combination with modelling and expert judgement (Milne and Brown, 1999; Ashman, *et al,* 2000, Salway *et al*, 2001). These are shown in **Table A 3.4.10**. The Scottish carbon gains are slower because Scottish soils generally have a higher equilibrium carbon content.

Table A 3.4.9 Rates of change of soil carbon for land use change transitions

From / To	Forestland	Grassland	Cropland	Settlement
Forestland		*Slow*	*slow*	*slow*
Grassland	*Fast*		*slow*	*slow*
Cropland	*Fast*	*Fast*		*slow*
Settlement	*Fast*	*Fast*	*fast*	

(“Fast” & “Slow” refer to 99% of change occurring in times shown in **Table A 3.4.10**)

Table A 3.4.10 Range of times for soil carbon to reach 99% of a new value after a change in land use in England (E), Scotland (S), Wales (W) and Northern Ireland (NI)

	Low (years)	High (years)	Years to reach 50% of carbon stock change (mean)	Years to reach 90% of carbon stock change (mean)
Carbon loss (“fast”) E, S, W, NI	50	150	15	52
Carbon gain (“slow”) E, W, NI	100	300	29	97
Carbon gain (“slow”) S	300	750	74	247

A Monte Carlo approach is used to vary the rate of change, the area activity data and the values for soil carbon equilibrium (under initial and final land use) for all countries in the UK. The model of change was run 1000 times using parameters selected from within the ranges described above. The mean carbon flux for each region resulting from this imposed random variation is reported as the estimate for the Inventory. An adjustment was made to these calculations for each country to remove increases in soil carbon due to afforestation, as the CARBINE model provides a better estimate of these fluxes in the Land Converted to Forest Land category. Variations from year to year in the reported net emissions reflect the trend in land use change as described by the land-use change time series.

A 3.4.2.2.1 Change in soil carbon stock due to cropland management activities

Change in soil carbon stocks due to cropland management activities is estimated using the methodology developed in Defra project SP1113 (Moxley *et al*, 2014a) which reviewed UK relevant literature on the effects of cropland management practices on soil carbon stocks and attempted to model UK specific emission factors.

Increases in inputs of fertiliser, manure and crop residues were found to increase soil carbon stocks of tillage land, but changes in the tillage regime from conventional tillage to reduced or zero tillage were found to have no significant effect in a UK context. This activity is only relevant for non-organic soils in the UK.

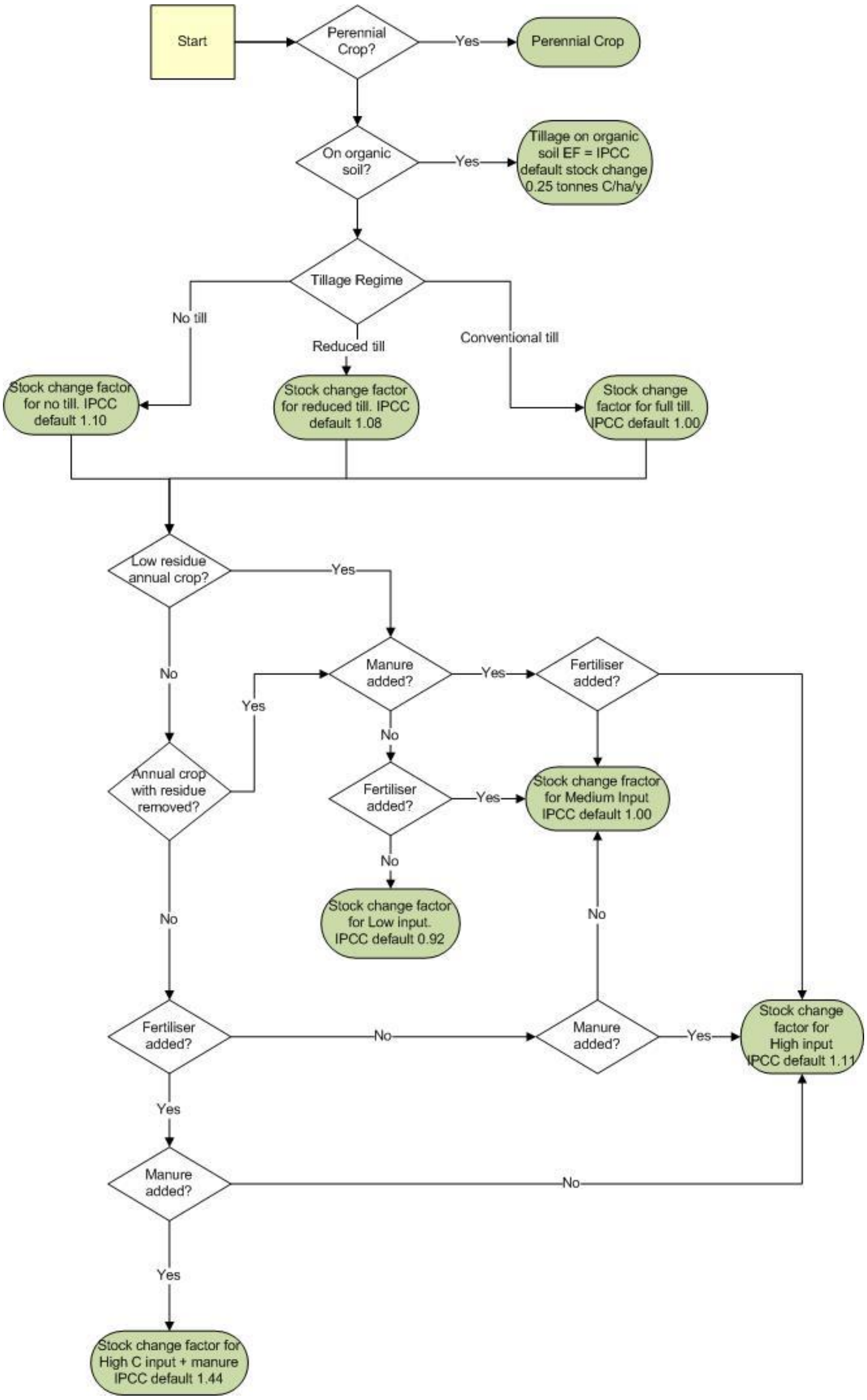
Using this methodology, tillage crops are divided into Medium and Low residue groups based on the data on total crop biomass. Where land receives inputs of fertiliser or manure the inputs moved up a class (e.g. cropland producing a Low residue crop which receives manure is considered to receive Medium inputs, while land producing a Medium residue crop which received manure inputs is considered to receive High inputs). If crop residues are removed from land the input level drops. A decision tree for assessing the effect of cropland management on soil carbon stocks is shown in **Figure A 3.7**.

For most cropland management activities there were insufficient UK field data to develop reliable Tier 2 stock change factors, and so Tier 1 factors have been used (for manure and residue inputs, and for differentiating perennial crops, annual crops and set-aside). These Tier 1 factors have been derived for soil carbon reference stocks of 0-30 cm depth (as opposed to the 1 m depth used in the land use change calculations. The 0-30 cm reference stocks for cropland soils are 70 tC/ha for England and Wales, 100 tC/ha for Northern Ireland and 120 tC/ha for Scotland. These values come from the same database of soil carbon density used for the land use change modelling. However, for tillage reduction both a literature review and modelling work suggested that it did not have a significant effect on soil carbon stocks, and that the Tier 1 stock change factors over-estimated its effect under UK conditions. Therefore, a stock change factor of 1 has been used for tillage reduction.

As changes in soil carbon stocks due to changes in cropland management are smaller than changes due to land use change the IPCC default transition time of 20 years is used.

Data on the areas under the main crop types is obtained from the annual June Agricultural Surveys/Census carried out by each UK administration (Defra; Welsh Government; Scottish Government; DAERA) and the annual Defra report on areas of crops grown for bioenergy. Data on the areas of cropland receiving inputs of manure, fertiliser and crop residues is obtained from the annual British Survey of Fertiliser Practice (Defra).

Figure A 3.7 Decision tree for assessing the effects of cropland management activities on soil carbon stocks.



See Annex 3.4.6

A 3.4.2.2.2 Change in soil carbon stock due to grassland management activities

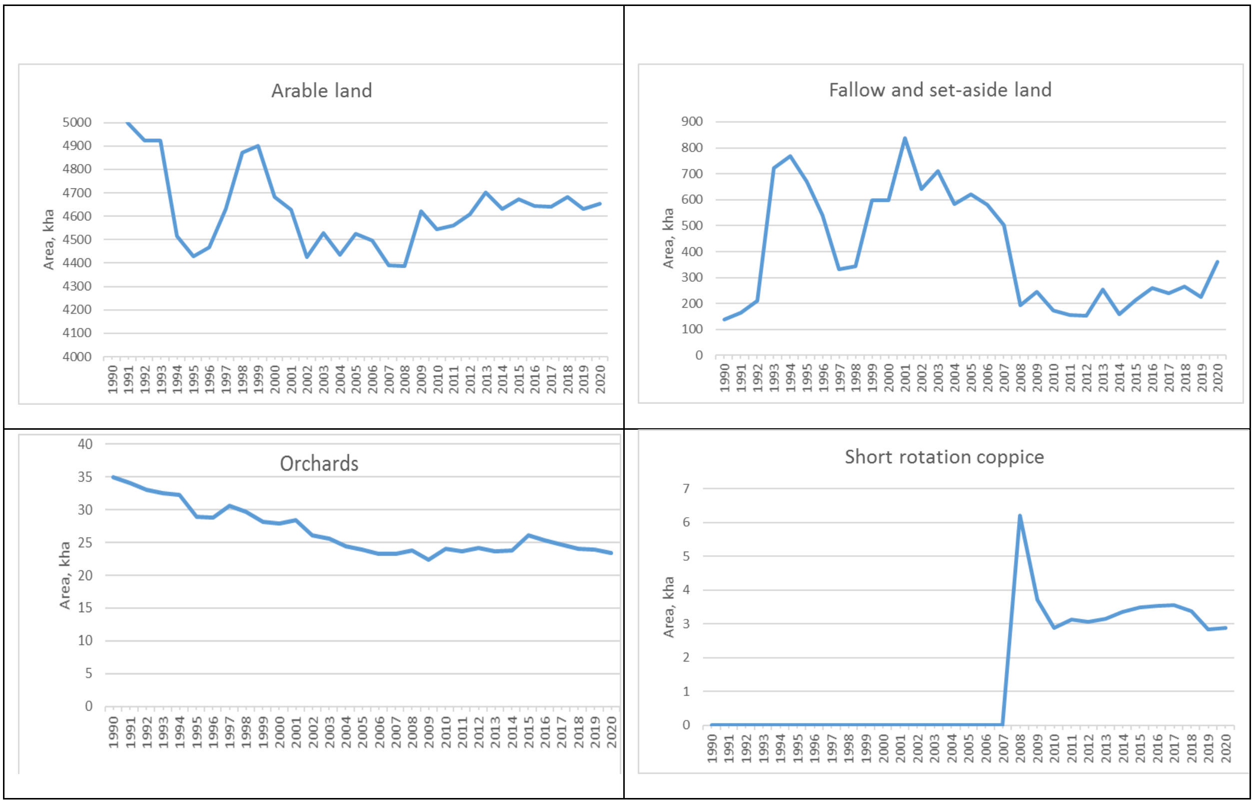
Defra project SP1113 attempted to develop a methodology to allow reporting of changes in soil carbon stocks resulting from grassland management activities. There are reasonable data on the effects of management practices such as liming, reseeding and drainage on improved grassland on mineral soils. However, there are few data on the effect of many management practices if applied to semi-natural grassland or those on organo-mineral or organic soils where there is a risk that more intensive management could increase carbon losses. As semi-natural grassland makes up a large proportion of grassland in the UK the lack of field data makes it impossible to reliably report changes in soil carbon stocks from grassland management activities. BEIS funded a research project to improve understanding of the effect of grassland management practices on soil carbon stock changes, which has not yet been published and work is ongoing in this area.

A 3.4.3 Changes in stocks of carbon in non-forest biomass due to management and land use change (4B2, 4C2, 4E2)

A 3.4.3.1 Change in biomass carbon stock due to change in Cropland and Grassland Management.

Change in Cropland biomass carbon stocks was assessed based on agricultural census data. Areas under different crop types were taken from annual agricultural census data and assigned on one of five categories: annual crops, orchard crops, shrubby perennial crops, perennial grassland used for biomass fuel (*Miscanthus)*, short rotation coppice and set aside and fallow (**Figure A 3.8**). Crop types reported in the agricultural census vary slightly for each administration. **Table A 3.4.11** shows how agricultural census crop types were grouped to assess biomass carbon stocks. Areas of planting of *Miscanthus* and short rotation coppice are only available since 2007, when biomass crop incentives were introduced: any areas before 2007 were very small and for research purposes.

Figure A 3.8 Crop type area in the UK 1990-2020



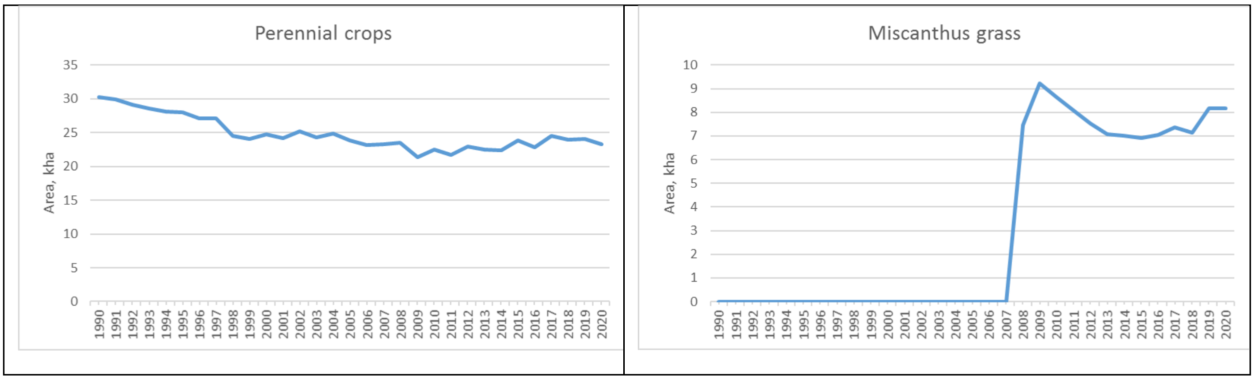


Table A 3.4.11 Aggregation of Agricultural Census crop types for estimating biomass carbon stock changes from Cropland Management

Devolved Administration	Annual Crops	Orchard Crops	Shrubby perennial crops	Set Aside and Fallow
England	Cereals, Other arable not stockfeed, Crops for stockfeeding, Vegetables for Human Consumption	Orchard Fruit	Soft fruit, Hardy nursery stock, bulbs and flowers, Area under glass or plastic covered structures.	Uncropped land
Scotland	Cereals, Oilseed rape, Peas for combining, Beans for combining, Linseed, Potatoes, Crops for stockfeeding, Vegetables for human consumption, Other crops	Orchard fruit	Soft fruit	Fallow , Set Aside
Wales	Cereals, Other arable not for stockfeeding, Crops for stockfeeding, Salad and vegetables grown in the open, Total hardy crops	Commercial orchards, Other orchards	Glasshouse	Bare fallow
Northern Ireland	Cereals, Other arable not for stockfeeding, Vegetables	Fruit	Ornamentals	Fallow and set aside

The areas under each aggregated crop type were multiplied by the biomass carbon stock of each crop type using the biomass carbon stock factors in **Table A 3.4.12**. These factors were generated from a literature review. (Moxley *et al.* 2014b), except for Short Rotation Coppice, where the values came from IPCC 2019 Refinement Tables 4.4 and 5.3.

Table A 3.4.12 Biomass stock factors for UK Cropland types

Crop Type	Total biomass Carbon Stock t C/ha	Uncertainty t C/ha (95% CI)	Root: Shoot ratio
Annual	5	1.2	Assume no Below Ground Biomass.
Orchards	10	6.75	0.24
Shrubby perennial crops	3.7	2.0	Assume no Below Ground Biomass.
Short rotation coppice	7.57	2.54	0.192
Miscanthus grass	9.9	2.48	2.8
Set Aside and Fallow	5	1	4.0

Biomass carbon stock change was assumed to occur in the year in which the change in crop type was reported. Cropland biomass stock changes resulting from land use change to or from Cropland were subtracted from the changes due to change in cropland management, as they are accounted for under land use change.

Change in Grassland biomass carbon stocks was assessed based on Countryside Survey data, which is the most reliable source of change between different habitat types within a land category. Grassland was separated into shrubby, non-shrubby and unvegetated Grassland based on Countryside Survey Broad Habitat types. **Table A 3.4.13** shows which Broad Habitats were allocated to which Grassland type.

Table A 3.4.13 Aggregation of Countryside Survey Broad Habitats for estimating biomass carbon stock changes from Grassland Management

Shrubby Grassland	Non-shrubby Grassland	Unvegetated Grassland
Dwarf Shrub Heath Bracken Montane	Improved Pasture Improved Pasture Neutral Grassland Calcareous Grassland Acid Grassland Bogs	Littoral sediment Supra littoral sediment

The areas under each aggregated Grassland type were multiplied by the biomass carbon stock of each crop types using the biomass carbon stock factors in **Table A 3.4.14**. These factors were generated from literature reviews (Moxley *et al.* 2014b). Only biomass carbon stock changes resulting from change between shrubby and non-shrubby Grassland were considered, as changes to and from unvegetated littoral and supra-littoral sediments were considered unlikely.

Table A 3.4.14 Biomass stock factors for UK Grassland types

Crop Type	Total biomass Carbon Stock t C/ha	Uncertainty t C/ha (95% CI)	Root: Shoot ratio
Non-shrubby Grassland	2.8	1.5	4.0
Shrubby Grassland.	10	3.6	0.53
Unvegetated Grassland	0	0	0
Managed hedge	34.86	68.75	0.3
Unmanaged hedge	175.3	476.6	0.3

Countryside Survey data are only collected on an approximately decadal basis. The annual stock change between survey years was estimated using linear interpolation. Biomass carbon stock change was assumed to occur in the year in which the change in Grassland type occurred. Grassland biomass stock changes resulting from land use change to or from Grassland were subtracted from the changes due to change in grassland management.

Change in Grassland biomass carbon stocks due to change in hedge length are included in the estimate of change in Grassland biomass carbon stock using Countryside Survey data on hedge length and condition. Hedges were divided into managed hedges which are trimmed to prevent the growth of large trees and unmanaged hedges which do not received routine maintenance. Unmanaged hedges do not fall within the UK's definition of Forest, but may contain isolated trees and may also have some gaps in them. The biomass carbon stocks of managed and unmanaged hedges are estimated as the median of UK-relevant values in published literature, based on a literature review commissioned by BEIS (Moxley et al. 2014b) supplemented with more recent data. Full details of these values and data sources are included the Grassland Management Biomass calculation workbook.

A 3.4.3.2 Change in biomass carbon stock due to land use change.

Changes in stocks of carbon in biomass due to land use change are based on the all-soils area matrices (see previous section). The average biomass carbon density for Cropland, Grassland and Settlement are shown in **Table A 3.4.15**: these were derived from the distribution and biomass densities of the different crop and grassland types in each country of the UK**.** For Settlements the biomass stocks from Milne and Brown (1997) and land cover data from the 2007 Land Cover Map was used to assess the proportion of gardens, pasture-type grass (including sports pitches, golf courses and parks) and urban (built over) area within areas identified as Settlements.

The average change in biomass carbon density for each country is shown in **Table A 3.4.16** - **Table A 3.4.19**. Changes between these equilibrium biomass carbon densities were assumed to happen in a single year.

Table A 3.4.15 Mean biomass carbon stock densities, tC/ha

Mean C stock tC/ha	Cropland	Grassland	Settlement
England	5.02	3.37	2.77
Scotland	5.00	4.16	2.91
Wales	5.03	3.61	2.81
Northern Ireland	5.14	2.93	2.64

Table A 3.4.16 Weighted average change in equilibrium biomass carbon density (tC/ha) for changes between different land types in England

From / To	Forestland	Grassland	Cropland	Settlements
Forestland				
Grassland		0	-1.66	0.60
Cropland		1.66	0	2.25
Settlements		-0.60	-2.25	0

(Transitions to and from Forestland are considered elsewhere)

Table A 3.4.17 Weighted average change in equilibrium biomass carbon density (tC/ha) for changes between different land types in Scotland.

From / To	Forestland	Grassland	Cropland	Settlements
Forestland				
Grassland		0	-0.83	1.25
Cropland		0.83	0	2.08
Settlements		-1.25	-2.08	0

(Transitions to and from Forestland are considered elsewhere)

Table A 3.4.18 Weighted average change in equilibrium biomass carbon density(tC/ha) for changes between different land types in Wales.

From / To	Forestland	Grassland	Cropland	Settlements
Forestland				
Grassland		0	-1.42	0.80
Cropland		1.42	0	2.22
Settlements		-0.80	-2.22	0

(Transitions to and from Forestland are considered elsewhere)

Table A 3.4.19 Weighted average change in equilibrium biomass carbon density (tC/ha) for changes between different land types in Northern Ireland.

From / To	Forestland	Grassland	Cropland	Settlements
Forestland				
Grassland		0	-2.21	0.29
Cropland		2.21	0	2.49
Settlements		-0.29	-2.49	0

(Transitions to and from Forestland are considered elsewhere)

Living biomass carbon stocks and Dead Organic Matter (DOM) stocks on Forest Land are modelled using CARBINE and used to calculate changes in carbon stocks due to conversions to and from Forest Land. When land is deforested to another land use, it is assumed that all living biomass and DOM is either converted to Harvested Wood Products or burnt on site in the year in which deforestation takes place. Under KP-LULUCF reporting all HWP from Article 3.3 Deforestation are assumed to be instantaneously oxidised. Increase in biomass carbon and DOM stocks on afforested land is modelled in CARBINE. Full details of CARBINE modelling of carbon stocks on Forest Land are given in **Section A 3.4.1.1.**

A 3.4.4 Carbon stock changes and biomass burning emissions due to Deforestation (4B, 4C, 4E, 4G)

Deforestation is an activity that cuts across LULUCF categories, affecting net emissions and removals in all the land use categories. The process of land use change affects carbon stock changes in biomass and soil, and the woody material left after felling either moves into the harvested wood products pool or is assumed to be burnt on-site, resulting in immediate biomass burning emissions.

Levy and Milne (2004) discuss methods for estimating deforestation since 1990 using a number of data sources. Their approach of combining Forestry Commission felling licence data for rural areas with Ordnance Survey data for non-rural areas was expanded to include new sources of information and to improve coverage of all countries in the UK. Deforestation before 1990 (which contributes to soil carbon stock change from historical land use change) is estimated from the land use change matrices described in **Section A 3.4.2**.

A 3.4.4.1 Types of deforestation activity in the UK

In Great Britain, some activities that involve tree felling require permission from the Forestry Commission, in the form of a felling licence, or a felling application within the various forestry grant schemes. There is a presumption that the felled areas will be restocked with trees, usually by replanting but sometimes by natural regeneration. However, some licences are granted without the requirement to restock – so-called unconditional felling licences. A felling licence is required unless special conditions are met[22].

Felling for urban development, with no requirement to restock, can be allowed under planning permission but only local planning authorities hold documentation for this. Since 2006, remotely sensed data used in the NFI has included this change, but prior to this, the need for collation of data from local authorities makes estimating the national total difficult. However, in England, the Ordnance Survey (the national mapping agency) makes an annual assessment of land use change from the data it collects for map updating and provides this assessment to the Department for Levelling Up, Housing and Communities (DLUHC)[23]. DLUHC provides an extract of this dataset, listing annual land use change from Forest to developed land uses (1990-2008 in the latest submission). This dataset comes from a continuous rolling survey programme, both on the ground and from aerial photography. The changes reported each year may have actually occurred in any of the preceding 1-5 years. The survey frequency varies among areas, and can be up to 10 years for moorland/mountain areas. Consequently, for pre-2006 deforestation to Settlement a five-year moving average is applied to the data to smooth out the between-year variation appropriately, to give a suitable estimate with annual resolution.

A 3.4.4.2 Compilation of activity datasets

Pre-1990 conversion of forest to other land categories is estimated using the land-use change matrices produced from the land-use data assimilation methodology (**Section A 3.4.2**)

For 1990-1999 the deforestation activity dataset is compiled from the felling licence and DLUHC datasets as far as possible, using Countryside Survey (CS) data to fill gaps in the time series, to estimate deforestation in Northern Ireland (for which no direct data are available) and to estimate the conversion to different land use categories. The DLUHC data are used to estimate the area of Forest Land converted to Settlement (4.E.2.1). The unconditional felling licence data are used to estimate the area of Forest Land converted to Cropland (4.B.2.1) and of Forest Land converted to Grassland (4.C.2.1). Only England has any post-1990 forest to cropland conversion: the estimated areas in Scotland, Wales and Northern Ireland are so small that they are thought to be due to survey classification error rather than genuine land use change.

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[22] https://www.gov.uk/guidance/tree-felling-licence-when-you-need-to-apply

[23] http://www.communities.gov.uk/planningandbuilding/planningbuilding/planningstatistics/landusechange/

The land-use change matrices from the data assimilation are used to estimate the relative split of Forest conversion between Grassland, Cropland and Settlements (**Table A 3.4.20**). **Table A 3.4.21** shows the Corrected Forest conversion rates. A correction ratio is used to adjust the estimated deforestation areas, as the Countryside Survey is known to over-estimate deforestation as described in the section above. There are no non-CS data for Northern Ireland so the correction ratios for England or Wales are used, depending on availability.

The annual area of forest converted to other land uses is removed from the area of 4A1 Forest Land remaining Forest Land to maintain consistency in the land area matrix.

Table A 3.4.20 Countryside Survey data for Forest conversion

Years	Land change	England rate of change, kha/yr	Scotland rate of change, kha/yr	Wales rate of change, kha/yr	N Ireland rate of change, kha/yr	Grassland / Cropland split England	Grassland / Cropland split Scotland	Grassland / Cropland split Wales
1990-1998	Forest to Natural Grassland	5.600	4.418	1.099	0.171	0.61	0.86	0.72
	Forest to Pasture Grassland	3.081	0.608	0.418	0.086	0.33	0.14	0.28
	Forest to Cropland	0.545	0.097	0.019	0.008	0.06	0.00	0.00
	Forest to Settlements	1.242	0.293	0.132	0.072	-	-	-
	Forest to Other Land	0.169	0.231	0.058	0.025	-	-	-
1999-2007	Forest to Natural Grassland	2.656	10.327	0.120	0.209	0.86	0.98	0.42
	Forest to Pasture Grassland	0.277	0.186	0.162	0.102	0.09	0.02	0.58
	Forest to Cropland	0.141	0.006	0.001	0.001	0.05	0.00	0.00
	Forests to Settlements	0.617	0.098	0.095	0.142	-	-	-
	Forest to Other Land	0.430	0.695	0.374	0.027	-	-	-

Table A 3.4.21 Corrected Forest conversion rates

Years	Land type	England Correction ratio	Scotland Correction ratio	Wales Correction ratio	England rate of change, kha/yr	Scotland rate of change, kha/yr	Wales rate of change, kha/yr	N Ireland rate of change, kha/yr
1990-1998	Grassland & Cropland	2% [a]	-	-	0.159	0.088[c]	0.026 [c]	0.005 [c]
	Settlements & Other Land	28% [b]	-	-	0.390	0.145 [c]	0.052 [c]	0.027 [c]
1999-2007	Grassland & Cropland	20% [a]	2% [a]	15% [a]	0.602	0.262	0.041	0.045[d]
	Settlements & Other Land	28% [b]	-	-	0.296	0.224 [c]	0.133 [c]	0.048 [c]

[a] Unconditional felling licence data used for correction

[b] Land Use Change Statistics used for correction

[c] England correction ratio used

[d] Wales correction ratio used

For 2000 onward, the area and subsequent land-use of deforestation were estimated based on a combination of data sources:

- observations on forest loss by the National Forest Inventory (internal Forestry Commission analysis) by IPCC category. This inventory includes an analysis of deforestation from 2006 to the current inventory year based on a new analysis of woodland maps (Forestry Commission, 2016);
- unconditional felling licences granted (assumed all converted to Grassland);
- analysis of the FC Sub-Compartment Database for restoration of Forest land to open habitats (conversion to Grassland or Wetland); and
- conversion to non-forest on private sector forest covered by long-term forest plans rather than felling licences (internal Forestry Commission report, assumed all converted to Grassland).

The revision in deforestation was only done from 2000 onwards, partly because there were no suitable data on which to base adjustments for 1990-1999, but also because a number of policy developments came into play in 2000 or shortly beforehand, which affected deforestation to restore open habitats or develop wind-farms. These include the introduction of the UK's climate change policy (2000), and the diversification in relevant forest policies in England, Scotland and Wales following the devolution of forest policy to countries in the late 1990s (Matthews *et al.* 2014). The deforestation information used in this inventory is based on the assumptions used in the previous inventory, updated with the latest available information from the Forestry Commission on deforestation for recent years and to include estimates of areas deforested to allow rewetting to take place.

Soil carbon stock changes associated with deforestation are estimated using the dynamic soil carbon model described in **Section A 3.4.2**. When deforestation occurs, it is assumed that 60% of the standing biomass is removed as timber products and the remainder is burnt in the UNFCCC inventory. The KP-LULUCF reporting of deforestation assumes instantaneous oxidation of HWP. Country-specific forest biomass densities for living and dead organic matter from CARBINE are used. These densities change over time in relation to the forest age and species structure. Biomass losses are reported in the relevant carbon stock change tables, assuming a carbon fraction of 0.5 on a dry weight basis. The carbon removed as timber is reported as Harvested Wood Products (HWP) in 4G (described in **Section 6.8**) or assumed to instantaneously oxidise for KP reporting.

Direct and indirect greenhouse gas emissions from associated biomass burning is estimated using the Tier 1 methodology described in the IPCC 2006 guidelines (IPCC 1997 a, b, c) and the emission ratios for CH_4, CO, N_2O and NO_x from Table 3A.1.15 in the IPCC 2003 GPG for LULUCF. Only immediate losses are considered because sites are normally completely cleared, leaving no debris to decay.

A 3.4.5 Biomass Burning - Forest and Non-Forest Wildfires (4A, 4B, 4C)

A 3.4.5.1 Activity dataset

Data on Forest wildfires prior to 2009 come from the Forestry Commission and the Forest Service of Northern Ireland.

In 2009 the Fire and Rescue Service (FRS) began recording wildfires in England, Scotland and Wales on a new Incidence and Reporting Systems (IRS) which includes wildfires on all land use categories. The IRS database contains 30 attributes for each fire to which a fire appliance was called, including date, spatial location, property type description (e.g. heathland and moorland, standing crop) and an estimate of the area burnt. This dataset is available from 1st April 2009. The original dataset had >126,000 fire records but 99% of these fires were less than 1 ha in size. The IRS database is manually completed by fire service personnel and its use requires some subjective judgement. This is likely to lead to non-systematic differences in the accuracy and precision of the data. The accuracy of the locations is variable, but an assessment of a number of the larger fires suggests that the land cover type attribute is reliable. The accuracy of the FRS burnt area estimates could not be validated using aerial photography as the available imagery was not recent enough, so Landsat images were used to validate the FRS data. However, it was still difficult to find cloud-free, pre- and post-fire images for fires in 2009. In addition, Landsat has been affected by image ‘striping’ since 2003, which affects the quality of the images and causes some data loss. There are issues with re-ignited fires or additional fires in the same area being logged in the database as separate events. Overall, the uncertainty associated with this dataset is high but should be re-assessed once a longer time series is available.

To provide data on non-Forest wildfires prior to 2009, thermal anomaly data from the NASA-operated MODerate Resolution Imaging Spectroradiometer (MODIS) were obtained from the Fire Information Resource Management System (FIRMS) and allocated to land uses using the proportions of fire on each land use type from the Fire and Rescue Service IRS data. The correlation between MODIS data and IRS data breaks down below 25 ha, so for consistency a 25 ha threshold was set for reporting wildfires logged on the IRS.

Thermal anomalies usually represent active fires, but may also detect industrial heat sources, although these are typically masked out by the thermal anomaly processing chain. The IRS dataset records 89 fires > 25 ha occurring in 2010. The FIRMS dataset records 335 fire detections for the same period, however, the FIRMS detections may contain multiple detections for a single fire event and the FIRMS detections are for a single 1 km pixel, and do not have a straightforward conversion to burnt area. Searching the IRS and FIRMS data sets for temporally and spatially coincident events, using a 2 km buffer around the IRS data, suggests that 22 fires were recorded by both the IRS and FIRMS systems. There are wide discrepancies between the two datasets, reflecting their different natures. The IRS data set records fires where a fire service response was required, so does not record controlled burning, unless the fire gets out of control. The FIRMS dataset, however, responds to anomalous heat signatures, so records controlled and uncontrolled fires. However, in the UK controlled burning, which is primarily carried out for heath management, is only permitted between October and mid-April to reduce the risk of these burns running out of control (Natural England, 2014[24]; Scottish Government, 2011[25]). As the FIRMS thermal anomaly data is only collected between March and August it will not detect most fires from controlled burning. FIRMS is only able to detect fires under cloud-free or light cloud conditions and is also only able to detect fires alight at the time of the satellite overpass. The FIRMS data are more likely to detect larger fires than smaller ones, probably due to the stronger heat signature and the longer burn time that larger fires tend to exhibit.

The IRS and FIRMS thermal anomalies give a very different perspective on the extent, timing and duration of fire events in the UK. However, the datasets did show correlation (R^2 = 70-81%) for fires larger than 25 ha, which enabled an empirical relationship to be derived to extend the burnt area record back to 2001. A burnt area threshold of 25 hectares was used to extract a subset of the IRS database: this captured 75% of the IRS wildfire-burnt area in England, 86% in Scotland and 64% in Wales.

As more IRS data become available confidence should increase in the relationship between fires detected by FIRMS and fires logged in the IRS. This may allow FIRMS data to be extrapolated to fires covering less than 25 ha the inventory in future (although annual FIRMS data is no longer collected as of 2020). However to extend this to small fires there would need to be reasonable confidence that the ratio of large to small fires used was valid, and also some investigation of whether the distribution of small fires across land use classes was the same as that of larger fires.

It was assumed that all fires in the IRS database were wildfires: even if they started as controlled burning, because the need for a fire appliance call-out indicates that they are no longer under control. The IRS property type descriptions were assigned to LULUCF sub-categories (**Table A**

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[24] https://www.gov.uk/guidance/heather-and-grass-burning-apply-for-a-licence

[25] http://www.gov.scot/Resource/Doc/355582/0120117.pdf

3.4.22). There is a very small area of wildfires that occur on Settlement types, and these are included in the Grassland category as the IRS land type classification suggests that they occur on grassy areas within Settlements and there is not a separate reporting field for wildfires in Settlements in the CRF.

Table A 3.4.22 IRS database property type descriptions by LULUCF sub-category

Forest	**Cropland**	**Grassland**	**Settlement**
Woodland/forest - conifers/softwood	Straw/stubble burning	Heathland or moorland	Domestic garden (vegetation fire)
Woodland/forest - broadleaf/hardwood	Stacked/baled crop	Grassland, pasture, grazing etc.	Park
	Nurseries, market garden	Scrub land	Roadside vegetation
	Standing crop	Tree scrub	Railway trackside vegetation
			Wasteland
			Canal/riverbank vegetation

A time series of wildfire-burnt areas for each non-forest land use type was constructed for 1990-current inventory year (**Figure A 3.9**). For non-forest wildfires for England, Scotland and Wales the IRS burnt areas were used for 2009 to the current inventory year (previously this was from 2010 using fiscal years but for the 1990-2019 inventory the IRS data had been re-mapped to calendar years for consistency with other activity data) and the burnt area estimated from thermal anomalies from 2000 to 2008. For 1990-2000 the average annual burnt area 2001-2010 was used.

For the 1990-2020 inventory the Scottish Fire and Rescue Service (SFRS) updated their definition of wildfires. The only criterion required for wildfire inclusion in the inventory is area (>25ha). Previously SFRS used minimum thresholds for burn time and number of appliances in attendance in their wildfire definition; for the 1990-2020 inventory these criteria were removed, and wildfire data included was based on area only. The 1990-2020 inventory also includes historical Scottish wildfires (2009 – 2020) not previously captured under the old definition.

In Northern Ireland, where no IRS data were available, it was assumed that the heathland and grassland burning rates were in the same proportions as the Scottish burning rates, using the area of heathland and grassland from the 2007 Northern Ireland Countryside Survey.

Estimates of the forest area burnt in wildfires 1990-2004 are published in different locations (FAO/ECE 2002; FAO 2005) but all originate from either the Forestry Commission (Great Britain) or the Forest Service (Northern Ireland). There is a gap in the time series 2005-2010 for Great Britain but areas of forest wildfires are reported annually for Northern Ireland. The gap was filled using the annual average areas burnt 1995-2005. These areas refer only to fire damage in state forests; no information is collected on fire damage in privately owned forests. The proportion of private-owned forest that was burnt each year was assumed to be the same as the percentage of the state forest that was burnt each year.

Figure A 3.9 **Annual area of FIRMS thermal anomalies for GB for 2001 to 2010 (thermal anomalies were filtered to exclude those recorded over urban/industrial areas).**

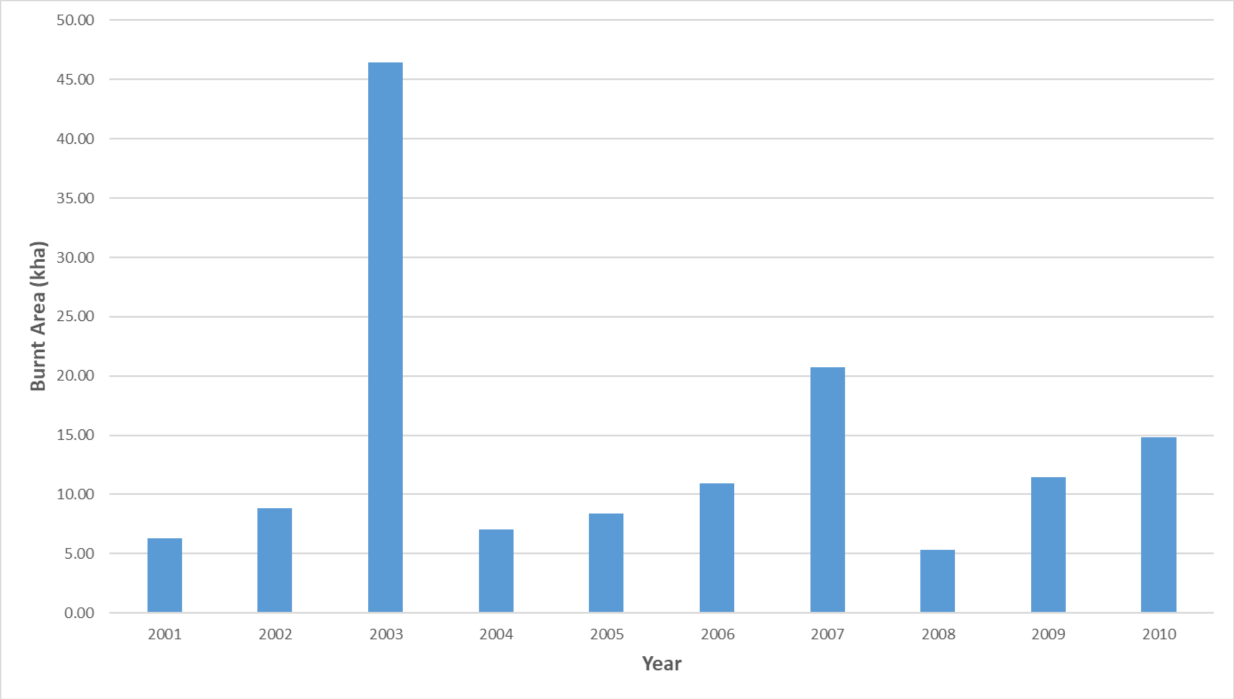
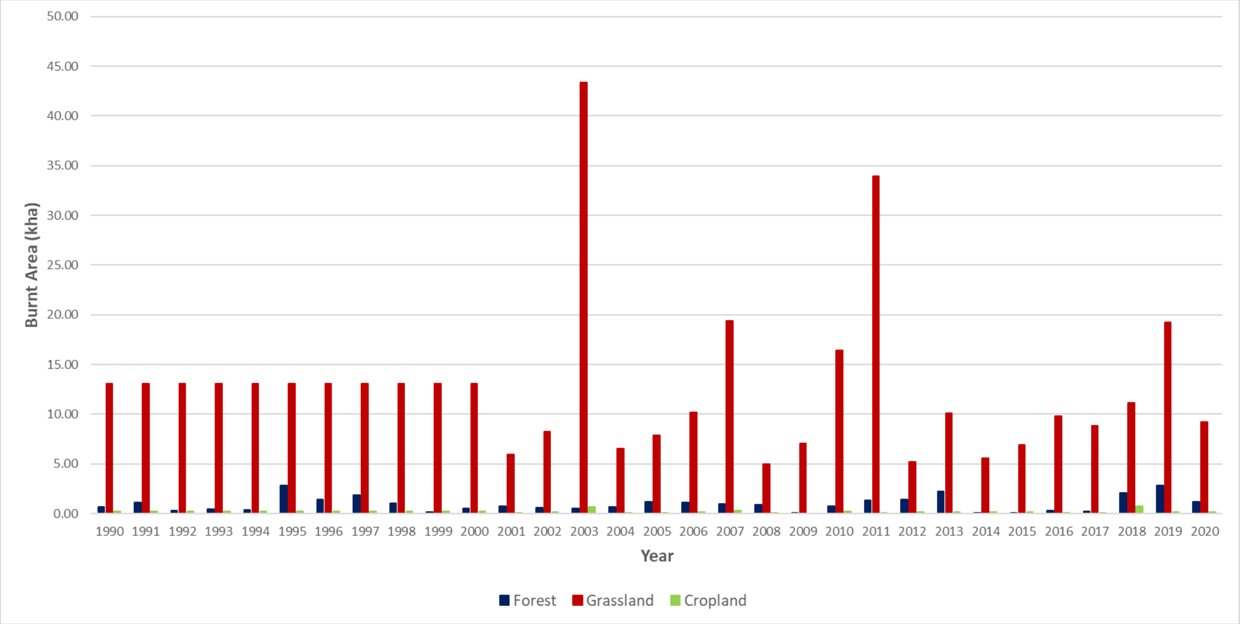


Figure A 3.9 shows the temporal pattern of FIRMS thermal anomalies, with peaks in hot dry years such as 2003. The FIRMS data used only includes thermal anomalies for March – August for each year, as these are the months where the IRS database recorded fires greater than 25 ha. Some FIRMS thermal anomalies were recorded outside these months due to FIRMS detecting both controlled burns and some fires less than 25 ha in size which are not included in the IRS data. As of the 1990-2020 inventory annual FIRMS data is no longer collected as only 2001-2010 data is used in biomass burning calculations and this remains constant. **Figure A 3.10** shows this 2001-2010 data.

Figure A 3.10 Time series of wildfire burnt areas in the UK 1990 to the current inventory year



A 3.4.5.2 Estimation of emissions

The IPCC Tier 1 method is used for estimating emissions of CO_2 and non-CO_2 gases from wildfires (IPCC 2006). The *Calluna* heath fuel biomass consumption factor and grassland emission factors are used for heathland and moorland fires, the agricultural residues EFs for cropland and the “savannah and grassland” EFs for other grassland and settlements.

Country-specific biomass and Dead Organic Matter densities from the CARBINE model are used for estimating fuel consumption in forest fires (as discussed in the deforestation methodology section) and the ‘extra tropical forest’ EFs in the 2006 Guidelines. In line with the default value in the IPCC 2006 Guidelines for AFOLU it is assumed that 45% of the biomass is consumed in a wildfire in an unfelled temperate forest.

Emissions from all wildfires are reported under the ‘Land remaining Land’ categories (i.e. 4A1, 4B1 and 4C1) and IE reporting under 4A2, 4B2 and 4C2.

A 3.4.5.3 Discussion of controlled burning in the Grassland category

The UK does not report emissions from controlled burning on grassland, leading to a recommendation by the 2017 UNFCCC review team. Controlled burning in the UK context occurs in very small (<1 ha) scattered patches, and is undertaken to enhance vegetation productivity and forage quality, and to promote new growth to improve grazing for game species and livestock. Only controlled burning that spreads out of control would be captured in the wildfire reporting statistics.

A literature review of controlled burning in the UK and its Overseas Territories and Crown Dependencies was undertaken in 2018, to identify any new information and estimate GHG emissions if possible. This literature review was presented to the LULUCF Scientific Steering

Committee and was shared with the 2021 UNFCCC review team. Its main findings are summarised here:

- The evidence for the overall impact of managed burning on moorland habitats in the UK is mixed with regard to the longer term GHG balance beyond the immediate combustion of vegetation
- Managed burning following the good practice guidelines should have a minimal impact on soils, with no release of GHGs. The longer term impact on soil carbon stocks is contentious and evidence is not sufficient to produce a simple estimate of GHG emissions or removals from soil due to managed burning.
- Reasonable evidence for burning rates on upland moorland is available for England, but much less is available for Scotland, Wales and Northern Ireland, and it is not possible to construct a robust time series for the UK.
- Rates of burning across all moorland for each administration are low (less than the optimal rotation length for heather regeneration of 8-25 years), and the estimated GHG emissions/removals from biomass burning and regrowth are also low (see below).

An estimate of the GHG emissions from muirburn in each administration in 2015 (see **Table A 3.4.23**) was made using the areas of heather moorland for each country in the Land Cover Map 2015 (a subset of the area in the eastern regions is used for Scotland). An annual burn rate of 1% was used for Scotland, Wales and Northern Ireland and 3.88% for England. These burn rates are on the higher end of the burn rates identified by sources in the literature review. Both the emissions from burning and the carbon stock changes due to regrowth of vegetation are included in the GHG emission calculations. The IPCC 2006 Tier 1 fuel consumption, combustion factor and above-ground biomass for Calluna heathland have been used, with the Tier 1 emission factors for Savannah and grassland for CO_2, CO, CH_4, N_2O and NO_x.

Table A 3.4.23 Estimated GHG emissions from controlled burning on Grassland, Gg

		Emission, Gg gas					Total GHG emissions
	Annual area burnt, ha	CO_2	CH_4	N_2O	CO	NO_x	CO_2e
England	6747	88.86	0.13	0.01	3.58	0.21	95.479
Scotland	4103	54.04	0.08	0.01	2.18	0.13	58.060
Wales	428	5.64	0.01	0.00	0.23	0.01	6.056
Northern Ireland	262	3.45	0.00	0.00	0.14	0.01	3.707
UK	11540	151.99	0.22	0.02	6.12	0.37	163.30

If the burning rate is fixed over time, the CO_2 emissions are largely compensated by the following regrowth, The regrowth of vegetation is assumed to increase linearly over an eight-year cycle, as by eight years burn scars become unidentifiable on aerial photography (this is not relevant if we are only able to assess an average rate of burning but will become so if there is variation in burning rates over time).

A 3.4.6 Emissions from organic soils (4A, 4B, 4C, 4D, 4E, 4(II))

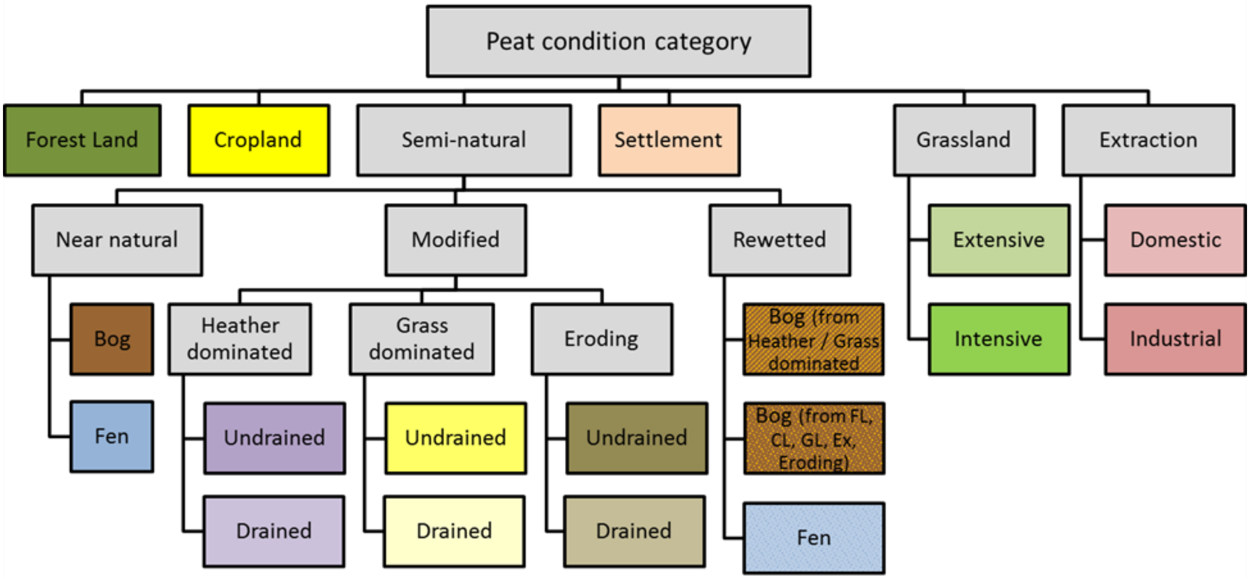
In a natural state, peatlands are important long-term sinks for carbon. However, drainage of peat can drastically alter the carbon balance in these systems, shifting them from a net sink to a net source of carbon. Peatlands comprise a high proportion of the total land area in the UK (~12%) . Of these peatlands, around 76% are in a modified state and no longer functioning as a carbon (C) sink. This ranges from relatively minor changes in vegetation composition and hydrology and GHG emissions, through to deep drainage and replacement of the wetland vegetation for agriculture, forestry, and peat extraction practices that result in large sources of anthropogenic GHG emissions. The remaining 22% of peatlands in the UK are classified as near-natural bog or fen with suitable conditions for C sequestration, and 4% of UK peatlands have undergone restoration actions to restore normal peatland hydrology and biogeochemical functioning.

Prior to the 1990-2019 inventory, the UK's LULUCF inventory reported limited emissions from peatlands, namely direct CO_2 and N_2O emissions arising from domestic and industrial extraction of peat, reservoir creation, conifer plantations on organic soils, and lowland drainage of cropland and agricultural grassland. Following the publication of the 2013 Supplement to the 2006 IPCC Guidelines, which provides methodology and default emission factors to allow calculation of GHG emissions and removals for a wider range of drained and rewetted peatlands (IPCC 2014), the UK elected to report Wetland Drainage and Rewetting (WDR) for the second commitment period of the Kyoto Protocol (KP). A BEIS-funded study on the Implementation of an Emission Inventory for UK Peatlands (Evans et. al. 2017) was undertaken to provide activity data and a UK-specific Tier 2 emissions reporting approach for UK peatlands. This section summarizes the main results used to estimate emissions from organic soils in the LULUCF inventory and full details are available in Evans et al. (2017) on the NAEI website.

A 3.4.6.1 Areas of organic soils

Peatland soils occur in all LULUCF land categories in the UK apart from 4F Other Land. Peatland condition categories comprised near-natural bog and fen, semi-natural peatlands affected by human activity (such as drainage, controlled burning and livestock grazing), cropland, extensive and intensive grassland, woodland, domestic and industrial peat extraction areas and active peatland restoration (rewetted) areas of bog and fen. This classification encompasses peat condition categories in the UK that were sufficiently well mapped to derive emission factors (**Figure A 3.11**, **Table A 3.4.24**). Detailed descriptions of the activity data obtained from unified peat extent and land use maps, including key assumptions in the assignment of peat areas to condition categories, are given in Evans et al. (2017). Updates to activity data since the publication of the Evans et al (2017) peatlands implementation report include: the addition of a Settlement peat condition category; amendment to the Eroded Bog category to include only the actively eroding (bare peat) component of the landscape, with areas of not actively eroding bog captured under Modified Bog areas; and separate Rewetted categories for rewetted semi-natural Modified Bog, and more intensively modified peatlands (e.g. Forest, Cropland, Intensive and Extensive Grassland, Peat Extraction, Eroding Modified Bog) (**Figure A 3.11**), as well as updates due to land use change (detailed below, **Table A 3.4.24**). The peatlands defined in **Figure A 3.11** have all been altered by human interventions and practices to some extent, with natural peatlands managed for their high conservation value (e.g. SSSIs, SACs). Thus, emissions and removals from all managed UK peatlands are reported “*regardless of whether they are anthropogenic or non-anthropogenic”* (IPCC 2014, Section 1.3, Chapter 1).

Figure A 3.11 Final land cover hierarchy used to derive a separate EFs for UK peatlands, amended from Evans et al (2017)



Grey cells represent higher-level categories encompassing two or more sub-categories. Note that there are separate rewetted bog categories for transitions from heavily modified peatlands (Forest Land, Cropland, Grassland, Extraction, Eroding bog), and Semi-natural peatlands (Heather dominated and Grass dominated bogs).

Changes in peat condition were associated with restoration (rewetting) of peatlands, which has largely occurred in the UK since 2000, changes in peat extraction, and forestry. Most large-scale peatland drainage occurred prior to 1990, however some new drainage has occurred due to wind farm or settlement developments, but to date it has not been possible to acquire data to report these effects. Similarly, land-use transitions between cropland and grassland, or change between intensive and extensive grassland on organic soils could not be reliably quantified due to an absence of spatially explicit data.

Changes in peat extraction site area were generated from Google Earth satellite imagery and information on site operations data from Growing Media Association, and applied to the baseline peat extraction areas (Evans et al. 2017) to give a time series of peat extraction area (see section 3.4.8). In contrast to the IPCC Tier 1 assumptions, fuel peat extraction was assumed to occur on nutrient-poor bog peat, and horticultural peat extraction on nutrient-rich fen peat, typical of UK practice (see Evans et al. 2017 for more detail).

Evans et al. (2017) reported spatial datasets of peatland restoration from 2000 to 2013. It was assumed that no rewetting activity took place before 2000 (other than peat extraction sites). An average rate of restoration was applied 2000 – 2013 due to limited temporal information. This annual rate has been extrapolated to the latest inventory year for England, Wales, and Northern Ireland, which is likely an underestimate given that funding for peatland restoration in the UK has increased in recent years. Efforts are underway to provide a reporting mechanism for recent rewetting activities. An annual timeseries of peatland restoration in Scotland 2013- latest inventory year was provided by Peatland Action, NatureScot. Estimates of changes in area of each peat condition due to rewetting between 1990 and 2020 are shown by UK administration in **Table A 3.4.24**. An update to the total organic soil areas occurred in this inventory, which included revisions to the near natural bog areas of -603 ha and -280 ha for England and Scotland, respectively, due to a mis-categorisation of saltmarsh habitat that is not yet implemented in the GHG inventory, and +1,182 ha of near natural bog for Northern Ireland to correct for an area of deep peat that had been mis-recorded as thin peat.

There are also changes in the forest baseline area (see **Section 6.2.4**), which have altered the total peat area.

Table A 3.4.24 Assignment of peat areas (kha) to condition categories for each UK administration in 1990 and 2020.

Country	England				Scotland		Wales		Northern Ireland		UK Total	
Peat category	**Deep peat**		**Wasted peat**		**All**	**All**	**All**	**All**	**All**	**All**	**All**	**All**
Year	**1990**	**2020**	**1990**	**2020**	**1990**	**2020**	**1990**	**2020**	**1990**	**2020**	**1990**	**2020**
Forest, D	47.59	48.91	12.62	13.39	332.68	360.23	9.51	9.45	22.79	25.52	425.19	457.49
Cropland, D	53.78	48.33	132.18	132.18	7.88	4.87	0.10	0.10	3.15	3.15	197.09	188.63
Eroding Modified Bog (bare peat), D	1.25	0.61	0.00	0.00	11.22	8.76	0.00	0.00	0.34	0.31	12.82	9.68
Eroding Modified Bog (bare peat), UD	6.65	6.53	0.00	0.00	29.59	28.53	0.03	0.03	0.59	0.56	36.86	35.65
Modified Bog (H.&G.dom), D	71.03	34.45	0.01	0.00	251.12	217.24	3.19	1.59	16.08	14.53	341.43	267.82
Modified Bog (H.&G.dom), UD	160.35	157.55	1.93	1.89	662.03	638.27	35.37	35.07	27.66	26.38	887.35	859.17
Extensive Grassland (combined bog + fen), D	3.37	0.22	0.52	0.52	31.67	32.69	8.97	2.12	5.28	4.32	49.82	39.87
Intensive Grassland, D	32.15	26.88	35.96	35.28	78.15	70.18	6.52	6.33	32.00	31.10	184.79	169.77
Near Natural Bog, UD	83.33	83.33	2.35	2.35	490.22	490.22	23.53	23.53	36.29	36.29	635.72	635.72
Near Natural Fen, UD	0.00	0.00	0.00	0.00	0.00	0.00	2.67	2.67	0.00	0.00	2.67	2.67
Extracted Domestic, D	4.26	4.25	0.14	0.14	44.90	44.35	0.00	0.00	91.84	87.54	141.14	136.28
Extracted Industrial, DI	6.91	1.29	0.00	0.00	2.89	2.45	0.00	0.00	0.52	0.78	10.33	4.53
Settlement, D	4.56	4.77	5.44	5.40	4.26	6.27	0.18	0.21	1.47	1.48	15.90	18.13
Rewetted Modified (Semi-natural) Bog, UD	0.00	35.73	0.00	0.00	0.00	24.86	0.00	1.57	0.00	0.82	0.00	62.98
Rewetted Bog, UD	0.15	4.02	0.00	0.00	0.02	15.72	0.00	4.91	0.36	4.95	0.53	29.60
Rewetted Fen, UD	10.18	28.67	0.00	0.00	0.00	2.00	0.00	2.49	0.03	0.69	10.21	33.85
Total	**485.55**	**485.55**	**191.15**	**191.15**	**1,946.64**	**1,946.64**	**90.09**	**90.09**	**238.42**	**238.42**	**2,951.84**	**2,951.84**

D= Drained, UD = Undrained, H.&G.dom = Heather and grass dominated

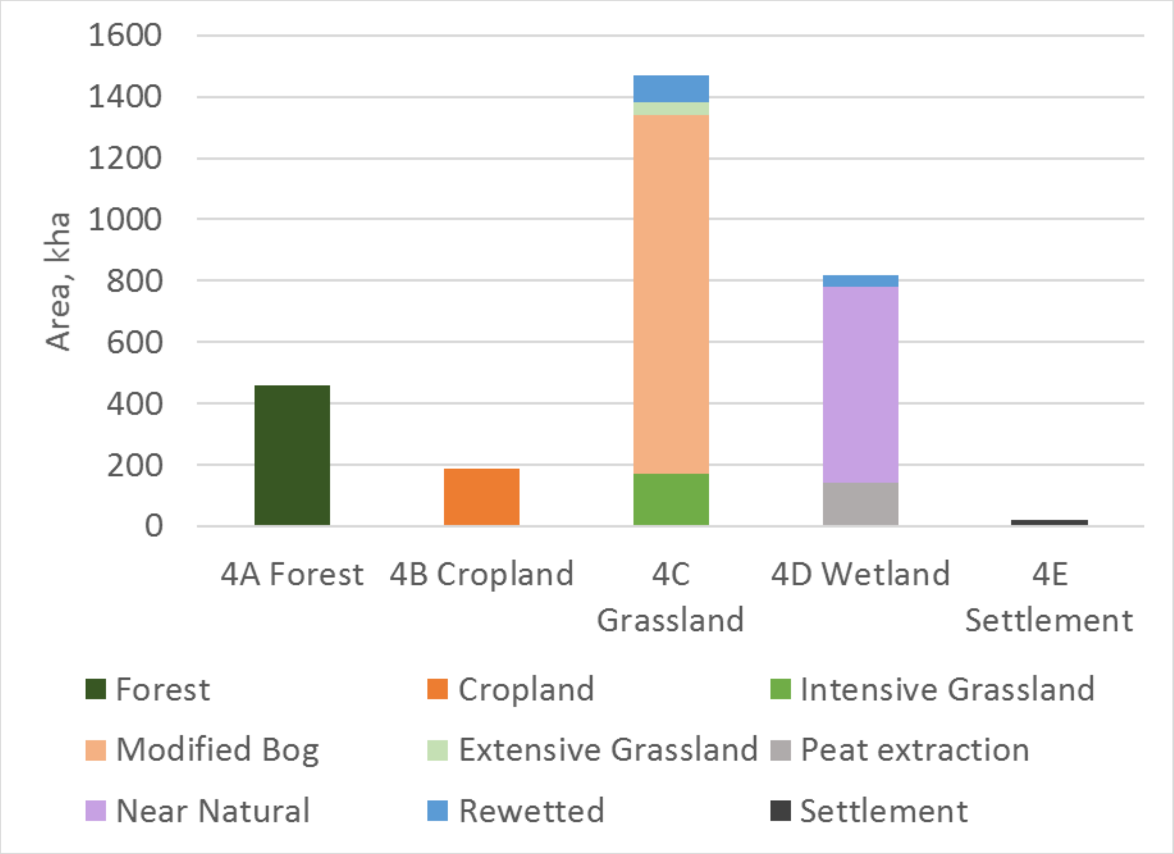
Table A 3.4.25 Estimated changes in area (kha) of each peat condition category due to land-use change, drainage and rewetting between 1990 and 2020

Tier 2 peat condition category	England Deep peat	England Wasted peat	Scotland	Wales	Northern Ireland	UK Total
Forest	1.323	0.766	27.547	-0.056	2.721	32.302
Cropland	-5.452	0.000	-3.010	0.000	0.000	-8.462
Eroding Modified Bog (bare peat)	-0.760	-0.002	-3.521	-0.002	-0.060	-4.345
Modified Bog (Heather + Grass dominated)	-39.370	-0.052	-57.637	-1.896	-2.839	-101.794
Extensive Grassland (combined bog + fen)	-3.154	0.000	1.020	-6.853	-0.961	-9.948
Intensive Grassland	-5.264	-0.679	-7.977	-0.197	-0.901	-15.018
Near Natural Bog	0.000	0.000	0.000	0.000	0.000	0.000
Near Natural Fen	0.000	0.000	0.000	0.000	0.000	0.000
Extracted Domestic	-0.010	0.000	-0.547	0.000	-4.305	-4.862
Extracted Industrial	-5.614	-0.001	-0.439	0.000	0.259	-5.795
Settlement	0.209	-0.033	2.009	0.029	0.013	2.227
Change in drained area	**-58.091**	**-0.002**	**-42.555**	**-8.974**	**-6.072**	**-115.694**
Rewetted Modified (Semi-natural) Bog	35.732	0.000	24.859	1.569	0.822	62.982
Rewetted Bog	3.869	0.000	15.694	4.913	4.588	29.065
Rewetted Fen	18.489	0.001	2.002	2.492	0.663	23.647
Change in rewetted area	**58.091**	**0.002**	**42.555**	**8.974**	**6.072**	**115.694**

The peat condition categories are assigned to the LULUCF land categories with the majority area falling under Grassland or Wetland (**Figure A 3.12**):

- 4A Forest Land: Forest;
- 4B Cropland: Cropland;
- 4C Grassland: Eroding Modified Bog, Modified Bog, Extensive Grassland, Intensive Grassland, Rewetted Modified Bog (from Modified Bog), Rewetted Bog or Fen (from Eroding Modified Bog, Intensive and Extensive Grassland);
- 4D Wetland: Near Natural Bog/Fen, Extracted Domestic, Extracted Industrial, Rewetted Bog or Fen (from Forest Land, Cropland, Extracted Domestic, Extracted Industrial and pre-1990 Rewetted Fen),
  4E Settlement: Settlement.

Figure A 3.12 Area of land-use sub-categories on organic soils in 2020 in the UK



A large area of the cropland organic soil area in England is classified as shallow, wasted peat: former deep peat that has been partly lost through agricultural activity. GHG emissions from wasted peatlands are not well quantified so it is assumed that wasted peat soils continue to emit at the same rate as deep peat, making these emissions estimates particularly uncertain. As such, the EFs for wasted peat are under review, with a BEIS-funded research project underway to measure GHG emissions from wasted peat in England, and emissions from these areas will be updated in the inventory when results become available.

There is currently a significant area of bog in Northern Ireland that is classified as historic (i.e. inactive and pre-1990) domestic peat extraction (88 kha).This area is classified as semi-natural grassland in the Northern Ireland habitat surveys, so has been assigned to Article 3.4 Grazing Land Management activity rather than Article 3.4 Wetland Drainage and Rewetting in KP-LULUCF.

A 3.4.6.2 Emission factors for organic soils

Tier 2 emission factors for the UK-relevant peat condition categories were developed by Evans et al. (2017). The EF literature review and meta-analysis was updated in 2019 to include recent GHG flux measurement publications and generate the Tier 2 EFs given in **Table A 3.4.26**. Tier 2 EFs calculated from at least four different primary study locations were considered reliable enough to replace Tier 1 values (see detailed methods in Evans et al. 2017). Thus, where a Tier 1 EF is used in **Table A 3.4.26**, the Tier 2 EF for that category was not reliable enough to replace the Tier 1 value. A continued tier 3 approach for forestry carbon stock changes and fluxes on organic soils using the CARBINE model has been used, with updates to the areas of organic soils used in the model, documented in **Section A 3.4.1**. Other GHGs from forested peat (CO_2 from dissolved organic carbon (DOC) and particulate organic carbon (POC), CH_4, and N_2O) are estimated using the EFs in **Table A 3.4.26**. A Tier 2 approach was used for most peatland categories for Direct CO_2, CO_2 from POC, and Direct CH_4. Limited studies were available for Direct N_2O, CH_4 from ditches, and CO_2 from DOC, thus a Tier 1 approach was adopted until more UK-specific flux data are available. Comparisons of the emission factors adopted for each UK peat condition category are given in **Figure A 3.13**-**Figure A 3.15**. Furthermore, updates to the tier 2 EFs developed by Evans et al. (2017) include EFs for Settlement, which uses the closest national condition category of drained organic soils assuming 50% garden (heather/shrub) using the EFs for Modified Bog, and 50% impermeable land (no emissions); amendment to the Eroded Modified Bog EF to represent emissions from actively Eroding Modified Bog (bare peat) only, with emissions from the not actively eroding bog captured by the EFs for Modified Bog; and an additional Rewetted EF for Rewetted Modified (Semi-natural Bog), described further in Section 3.4.6.3, which employs the EFs for Near Natural Bog.

Table A 3.4.26 Emission factors for peat condition types updated from Evans et al (2017). All fluxes are shown in $tCO_2e\ ha^{-1}\ yr^{-1}$, a positive EF indicates net GHG emission, and a negative EF indicates net GHG removal. Note that the EFs for Direct CH_4 include a correction for CH_4 lost in ditches (1-fraction of ditches in the landscape) as per Equation 2.6 and Table 2.4 in IPCC (2014).

Peat Condition	Drainage status	Direct CO_2	CO_2 from DOC	CO_2 from POC	Direct CH_4	CH_4 from Ditches	Direct N_2O	Total
Forest	Drained	2.52 to -1.79[c]	1.14[a]	0.3[b]	0.06[a]	0.14[a]	1.31[a]	**5.46 to 1.15**
Cropland	Drained	28.60[b]	1.14[a]	0.3[b]	0.02[b]	1.46[a]	6.09[a]	**37.61**
Eroding Modified Bog (bare peat)	Drained	6.18[b]	1.14[a]	5.0[b]	0.14[a]	0.68[a]	0.14[a]	**13.28**
	Undrained	6.18[b]	0.69[a]	5.0[b]	0.15[a]	0[a]	0.14[a]	**12.17**
Modified Bog (semi-natural Heather + Grass dominated)	Drained	0.13[b]	1.14[a]	0.3[b]	1.26[b]	0.66[a]	0.06[b]	**3.54**
	Undrained	0.13[b]	0.69[a]	0.1[b]	1.33[b]	0[a]	0.06[b]	**2.31**
Extensive Grassland (combined bog/fen)	Drained	6.96[b]	1.14[a]	0.3[b]	1.96[b]	0.66[a]	2.01[a]	**13.03**
Intensive Grassland	Drained	21.31[b]	1.14[a]	0.3[b]	0.68[b]	1.46[a]	2.67[b]	**27.54**
Rewetted Bog	Rewetted	-0.69[b]	0.88[a]	0.1[b]	3.59[b]	0.0[a]	0.04[b]	**3.91**
Rewetted Fen	Rewetted	4.27 [b]	0.88[a]	0.1[b]	2.81[b]	0.0[a]	0[a]	**8.05**
Rewetted Modified (Semi-natural) Bog	Rewetted	-3.54[b]	0.69[a]	0[b]	2.83[b]	0[a]	0[a]	**-0.02**
Near Natural Bog	Undrained	-3.54[b]	0.69[a]	0[b]	2.83[b]	0[a]	0[a]	**-0.02**
Near Natural Fen	Undrained	-5.41[b]	0.69[a]	0[b]	3.79[b]	0[a]	0[a]	**-0.93**
Extracted Domestic	Drained	10.27[a]	1.14[a]	1.01[b]	0.14[a]	0.68[a]	0.14[a]	**13.37**
Extracted Industrial	Drained	6.18[b]	1.14[a]	5.0[b]	0.14[a]	0.68[a]	0.14[a]	**13.28**

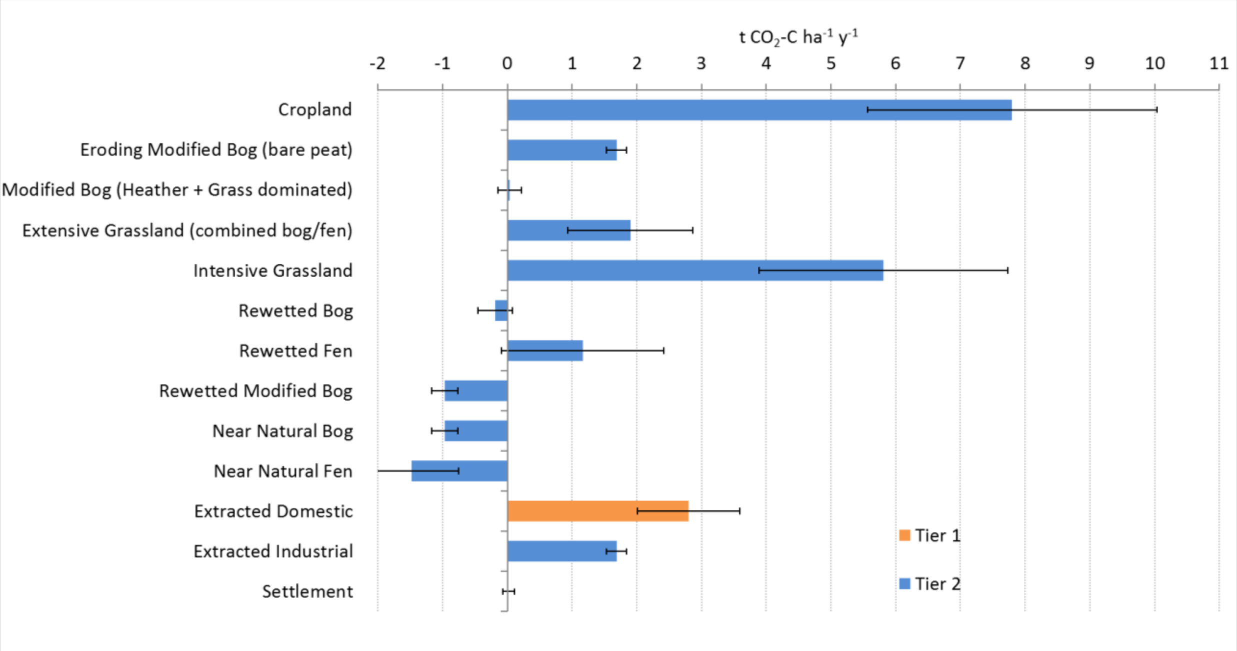
Peat Condition	Drainage status	Direct CO_2	CO_2 from DOC	CO_2 from POC	Direct CH_4	CH_4 from Ditches	Direct N_2O	Total
Settlement	Drained	0.07[b]	0.57[a]	0.15[b]	0.63[b]	0.16[a]	0.03[b]	**1.61**

[a] Tier 1 default EF (IPCC 2014)

[b] Tier 2 EF (updated literature analysis in 2019 incorporating data from Evans et al. 2017)

[c] Tier 3 Forest Research CARBINE model implied EF for 1990 to 2020. The decreasing trend is due to an increase in age of forests on organic soils due to decreasing afforestation on organic soils.

Figure A 3.13 Direct CO_2 emission factors (Tier 1, 2, 3) for UK peat condition types updated from Evans et al (2017) ± standard error. Note that an EF for Forest is not shown as the Tier 3 method employed results in a range of EFs for forests on organic soils, which is due to changes in the age of forests and differences in afforestation over time



(All fluxes are shown in tCO_2-C ha-1 yr-1. Note that a positive EF indicates net GHG emission, and a negative EF indicates net GHG removal)

Figure A 3.14 Direct CH_4 emission factors (Tier 1 and 2) for UK peat condition types updated from Evans et al (2017) ± standard error. (All fluxes are shown in Kg CH_4 ha-1 yr-1)

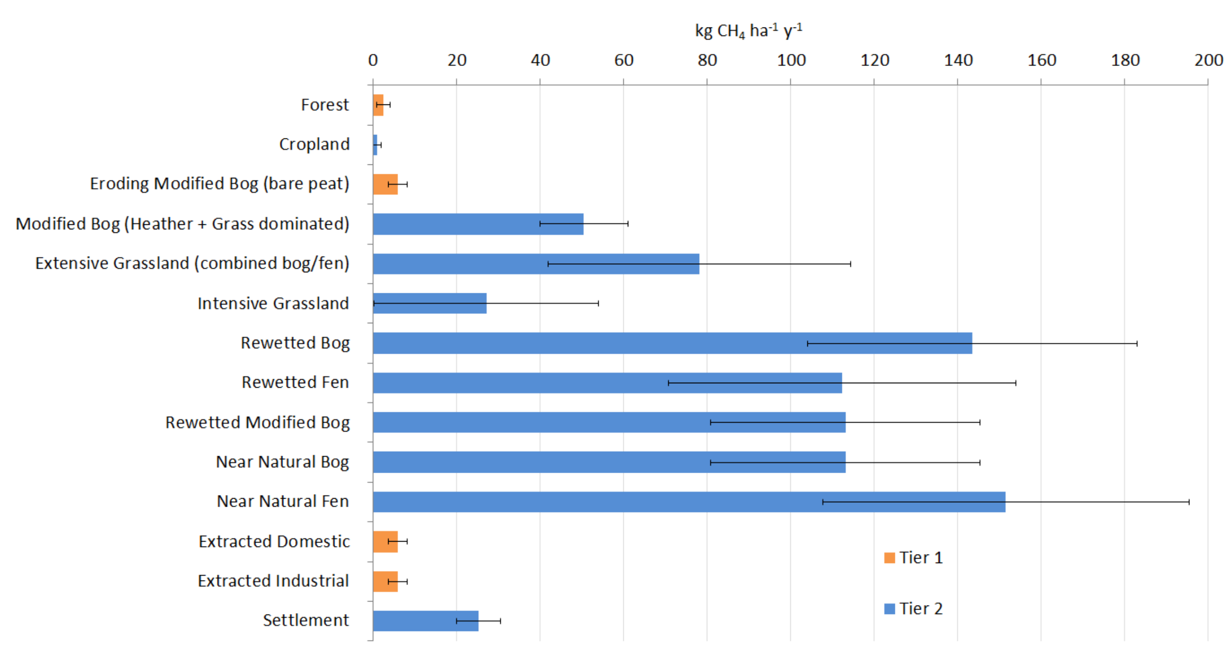
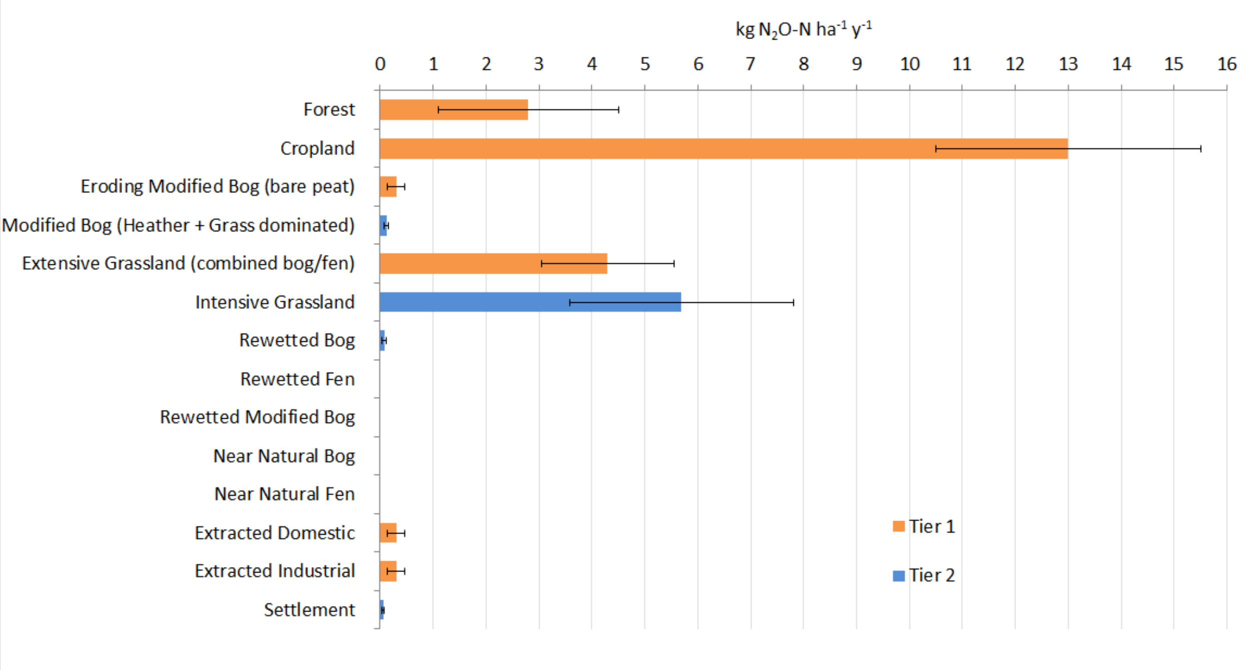


Figure A 3.15 Direct N_2O emission factors (Tier 1 and 2) for UK peat condition types updated from Evans et al (2017) ± standard error. (All fluxes are shown in Kg N_2O-N ha^{-1} yr^{-1})



Off-site CO_2 emissions from fluvial DOC exported from drained areas were estimated following 2014 IPCC Tier 1 methodology which incorporated a large body of UK data. Tier 1 EFs for CO_2 from exported POC are not given in the Wetlands Supplement. However, Tier 2 emissions factors were estimated using flux data from Evans *et al* (2017) and the area of exposed peat associated with each land-use category based on the method outlined in Appendix 2.a.2 of the IPCC Wetlands Supplement. Indirect N_2O emissions associated with nitrate leaching from organic soils were not incorporated at this time due to caution given in the 2006 and 2014 IPCC guidance against double-counting of emissions from fertilisation. A BEIS-funded research project to measure emissions from wasted peat under cropland will help to assess indirect emissions from N_2O from organic soils. Findings from this study are expected in 2022.

A 3.4.6.3 Emissions from drainage and rewetting (4(II))

Large areas of UK peatlands, predominantly semi-natural heather- and grass-dominated bog, are modified by grazing and burning-management practices but remain undrained. As these habitats are a net source of GHG emissions (**Table A 3.4.13**), and no guidance is given in IPCC (2014) for modified undrained peatlands, Tier 2 emissions factors were developed to capture undrained peat condition categories.

Separate emissions factors were developed for rewetted semi-natural, heather and grass dominated bog (rewetted total EF = -0.02 $tCO_2e\ ha^{-1}\ yr^{-1}$), and more intensively modified peatlands, which includes forest, cropland, intensive/extensive grassland, extracted, and eroding modified bog, (total EFs of 3.91 and 8.05 $tCO_2e\ ha^{-1}\ yr^{-1}$ for rewetted bog and fen, respectively) to take account of the different scale of damage to these lands, and the greater ease and effectiveness of rewetting of habitats that already have semi-natural vegetation and are functioning in a near-healthy state (**Table A 3.4.13**).

N_2O emissions from cropland and intensive grassland are calculated using the EFs in **Table A 3.4.26** and reported under the Agriculture sector category of 3.D- Agricultural Soils, as these agricultural land types are considered to be highly cultivated and this is consistent with the approach taken in the Agriculture sector. N_2O emissions from unintensive grassland on organic soils are reported under 4(II)/4.H to ensure completeness, as it is not possible to report these emissions in the 4(II)/4.C rows in the CRF tables.

A 3.4.6.4 Uncertainties

The uncertainties associated with the areas and emission factors from organic soils were assessed as part of the Evans et al. (2017) research and work to implement the results in the LULUCF inventory.

The uncertainties associated with areas were not quantifiable (as there were limited data sources available) so expert judgement was used to assign peatland condition classes to low, medium and high uncertainty: 10%, 30% and 60% respectively.

- Low uncertainty: rewetted Grassland, rewetted and near-natural Wetland;
- Medium uncertainty: drained Cropland, drained intensive Grassland, drained and undrained modified bog Grassland, industrial peat extraction on Wetland;
- High uncertainty: all condition classes on wasted peat, drained extensive grassland, domestic peat extraction on Wetland.

Uncertainties for the Tier 2 emission factors were calculated from the 95% confidence interval for CO_2, CH_4 and N_2O (see Evans et al. 2017), and taken from the IPCC 2013 guidance for Tier 1 factors. The combined uncertainties for organic soils by LULUCF category are included in **Section A 3.4.12** The uncertainties for forest on organic soil are calculated as part of the overall Forest uncertainty, as this uses a Tier 3 model rather than an emission factor approach. Settlements on organic soils were not included in the Evans et al. 2017 research, but their uncertainty is assumed to be Medium/High based on expert judgement.

A 3.4.7 Emissions of N_2O due to disturbance associated with land use conversion and land management changes (4(III))

All land use conversions or land management changes that result in a loss of soil carbon, leading to N mineralization and N_2O emissions, are reported. Direct emissions from soils, and indirect emissions from nitrogen leached from soil and subsequently oxidised are included in the inventory. The UK now includes emissions resulting from the land use conversions: 4A2 Land converted to Forest Land, 4B2 Forest to Cropland and Grassland to Cropland, 4C1 Grassland remaining Grassland, 4C2 Forest to Grassland, 4E1 Settlement remaining Settlement and 4E2 Land converted to Settlement. Emissions of N_2O from 4C1 and 4E1 arise from land use change over 20 years before the inventory reporting year where loss of soil organic matter is still ongoing. Emissions of N_2O from 4B1 Cropland remaining Cropland (resulting from land use change over 20 years before the inventory year) are calculated in the same way by the LULUCF inventory team but are included in the Agriculture sector (category 3D1).

The Tier 1 methodology described in the IPCC 2006 Guidelines is used. The activity data are the areas and soil carbon stock changes reported in the relevant categories in 4A2, 4B, 4C and 4E. Some C:N ratios for UK soil/vegetation combinations are published in the Countryside Survey (with values of 11.7 to 13.4) but only for the top 15 cm of soil. However, the soil carbon stock changes reported in the inventory are from the top 1 m of soil, so these C:N ratios were not felt to be applicable. Therefore, the IPCC default C:N ratio of 15 is used for estimating mineralised N. The emission factor of 1% in the 2006 Guidelines was used to estimate N_2O emissions from mineralised N. Indirect N_2O emissions from mineralisation are also estimated from carbon stock change using Tier 1 methodology.

A 3.4.8 On-site and off-site emissions from peat extraction (4D)

On-site emissions of CO_2 and N_2O from peat extraction activities (for energy and horticultural use) and off-site emissions of CO_2 from the decomposition of horticultural peat are reported in category 4D.

A 3.4.8.1 Activity datasets

Available data sets on peat extraction vary between Northern Ireland and for Great Britain (England, Scotland and Wales). From 2002 onwards Google Earth imagery has been used to estimate the area of peat extraction from sites listed in the Directory of Mines and Quarries and the BritPits online database[26], supplemented with recent ground-truthed site information from Growing Media Association. Prior to the 2002 no Google Earth images are available, and peat

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[26] https://www.bgs.ac.uk/products/minerals/britpits.html

extraction site areas have been estimated from other sources. **Table A 3.4.27** shows the sources of activity data used to estimate emissions from peat extraction.

Table A 3.4.27 Activity data for peat extraction sites in Northern Ireland

Data set	Information contained	Geographic extent	Time period	Publication frequency
Directory of Mines and Quarries (DMQ)/BritPits database	Location of active peat extraction sites	England, Scotland, Wales, Northern Ireland	1984 - present	Online database is continuously updated
Google Earth	Land use images to estimate area of extraction sites identified from DMQ	UK	2002 - present	Variable
Growing Media Association	Location, area estimates, and site history of peat extraction sites.	UK	present	Variable
Cruickshank and Tomlinson (1997)	Area with planning consent for peat extraction Local authority planning consents for peat extraction sites	England, Scotland, Wales	1990/91	One off compilation of data
Tomlinson (2010)	Estimate of peat extraction area in Northern Ireland. Volume of peat extracted (sod cutting and vacuum harvesting)	Northern Ireland	1990 - 1991	One off compilation of data
Mineral Extraction in Great Britain (Annual Minerals Raised Inquiry)	Volume of peat extracted	England, Scotland, Wales	1947 - date	Annual
Cruickshank et al. 1995	Volume of peat extracted (hand cutting)	Northern Ireland	1990 - 1991	One off compilation of data
GMA (2021)	Volume of horticultural peat sold in the UK	England, Scotland, Wales	2011 - 2020	One-off compilation of data

The areas of peat extractions sites listed in the BritPits database were assessed using Google Earth. Polygons were drawn around site boundaries and the area covered by the polygons was calculated in Google Earth. Change over time at individual sites was tracked to give an estimate of the extent of conversion to and from extraction sites. This method is repeated annually to incorporate changes in extraction site areas in new Google Earth images.

It is assumed that extraction areas continue to produce emissions while there is visible evidence of exposed peat soil from Google Earth satellite imagery, and do not convert back to functioning peatlands without restoration intervention. An extraction site is considered to have ceased emissions when there is visible evidence of the re-establishment of vegetation cover on the satellite imagery and evidence of rewetting (ditch blocking) from online documentation of the restoration works and communication with site managers. Additional information on active peat extraction areas and site history are provided by UK Growing Media Association.

Annual peat production in Great Britain (**Table A 3.4.28**) is inferred from extractor sales by volume as published in the annual Mineral Extraction in Great Britain report, formerly known as the Minerals Raised Inquiry (ONS). This gives a breakdown for horticultural and other uses of peat, which are assumed to be fuel, for English regions and for Scotland. No peat extraction is reported in Wales. Annual production is highly variable because extraction methods depend on suitable summer weather for drying peat. Data are available from 1990-2014. For the period 2015-2020, UK sales volumes of horticultural peat are derived from the Growing Media Association report (GMA, 2021).

Table A 3.4.28 Annual peat production, m^3 for England and Scotland (from Annual Minerals Raised Inquiry/Mineral Extraction in Great Britain reports, and GMA, 2021)

Year	England Horticultural	England Fuel	Scotland Horticultural	Scotland Fuel
1990	1,116,940	2,727	293,170	93,163
1991	1,202,000	2,000	241,000	115,000
1992	1,079,000	4,000	332,000	91,000
1993	1,069,820	2,180	306,511	73,489
1994	1,375,000	1,000	498,000	108,000
1995	1,578,000	2,000	657,000	44,000
1996	1,313,000	2,000	517,000	53,000
1997	1,227,000	2,000	332,000	59,000
1998	936,000	0	107,000	32,000
1999	1,224,000	0	392,000	37,000
2000	1,258,000	1,000	336,000	31,000
2001	1,459,000	1,000	325,000	30,000
2002	856,000	1,000	107,000	10,000
2003	1,227,000	1,000	741,000	38,000
2004	902,000	1,000	338,000	21,000

Year	England Horticultural	England Fuel	Scotland Horticultural	Scotland Fuel
2005	927,000	1,000	550,716	26,284
2006	856,000	1,000	712,000	24,000
2007	654,000	0	221,000	10,000
2008	496,000	0	243,000	21,000
2009	476,000	0	390,000	21,000
2010	456,000	1,000	527,000	21,000
2011	429,000	0	369,000	26,000
2012	422,000	0	146,000	20,000
2013	661,000	0	594,000	24,000
2014	294,000	0	501,000	32,000
2015	277,694	0	390,953	22,528**
2016	247,080*	0	347,341*	22,528**
2017	216,465*	0	303,729*	22,528**
2018	185,851	0	260,117	22,528**
2019	134,322	0	243,671	22,528**
2020	253,711	0	282,162	22,528**

*Linear interpolation between 2015-2018 used in absence of measured horticultural peat volume data. ** Actual data for fuel peat are not available 2015-2019. Volumes are 2005-2014 average except for Fuel peat in England which is assumed to be zero as there are no longer any sites licenced for this activity.

A 3.4.8.2 Estimation of emissions

Tier 1 and Tier 2 emission factors are used to estimate on-site emissions for CO_2, CH_4 and N_2O (see section **A 3.4.6.2**).

A value of 0.0641 tonnes C m^{-3} is used for Great Britain to estimate emissions from extracted horticultural peat volumes based on previous work (Thomson *et al*, 2011).

Tomlinson (2010) gives production estimates of horticultural peat production for Northern Ireland for 1990/91 and 2007/2008. These have been interpolated to produce a time series. The total emission from horticultural peat production is the sum of emissions from vacuum harvesting production, sod extraction production and mechanical extraction production.

Emissions from vacuum harvesting production =

area * annual depth of extraction * carbon fraction by volume

where

Annual depth of extraction by vacuum harvesting, m/ha = 0.1

Carbon fraction of air-dry peat by volume, tonnes C/m^3 air-dry peat = 0.0641

Emissions from sod extraction production =

area * sod extraction rate * % dry matter for sods * mean % C

where

Sod extraction rate, tonnes/ha/yr = 200

Sod extraction, mean % dry matter = 35%

Mean % carbon = 49%

Emissions from mechanical extraction production =

area * extraction rate * % dry matter for mechanical extraction * mean % C

where

The mechanical extraction rate was estimated to be 206.45 tonnes/ha in 1990/91 and 243.06 tonnes/ha in 2007/08 (Tomlinson, 2010).

Mechanical extraction, mean % dry matter = 67%

Mean % carbon = 49%

A 3.4.9 Flooded Lands (4D)

Carbon stock changes on land converted to Flooded Land (reservoirs) are included in the inventory, based on the IPCC 2006 Guidance. Data on all reservoirs over 1 km^2 were compiled but only reservoirs established since 1990 were reported (areas of inland water under 1 km^2 are reported under 4D Wetlands remaining Wetlands). Activity data were compiled for England and Wales from the Public Register of Large Raised Reservoirs provided by the Environment Agency, which listed location, surface area and year built. Activity data for Scotland were compiled from the SEPA Water Body Classification database (of water bodies > 0.5 km^2) and the associated Water Body data sheets. Additional information on the year of building was obtained from:

- the Gazetteer for Scotland http://www.scottish-places.info;
- hydro-electric power generators http://sse.com/whatwedo/ourprojectsandassets/ http://www.power-technology.com/projects/glendoehydropowerpla/; and
- local authorities http://www.argyll-bute.gov.uk .

It was established through discussion with local experts that no new large reservoirs had been built in Northern Ireland since the 1950s.

Only five large reservoirs have been established in the UK since 1990, three in England and one each in Scotland and Wales (another five in England are sacrificial floodplains and do not fit the criteria of permanent conversion to Flooded Land). These cover a total of 1.995 kha.

The location of each reservoir was examined using the www.magic.gov.uk geographic information portal. All reservoirs were in upland locations and were assumed to be Grassland prior to their conversion to Flooded Land. (Any forest removed as part of the land conversion will have been captured under the deforestation activity methodology). A Tier 1 methodology was followed, so carbon stock changes in living biomass stock in the year of flooding were estimated, but not carbon stock change in soils. The UK biomass carbon stock of shrubby grassland (10 t C/ha) was used for consistency with other parts of the LULUCF inventory.

A 3.4.10 Harvested Wood Products (4G)

The activity data used for calculating this activity are the annual forest planting rates. CARBINE then applies a forest management regime as given in input to the model. For a given forest stand, carbon enters the HWP pool when thinning is undertaken and when harvesting takes place. Depending on the species, first thinning occurs approximately 20 years after planting.

During wood extraction, conversion losses are assumed to be left as on-site harvest residue and enter the litter pool. The allocation of carbon to wood product categories is estimated by allocating the merchantable stem carbon to woodfuel, paper, wood-based panels and sawnwood, based on yearly proportions derived from reported forestry statistics. The CARBINE model uses standard estimates for oven-dried wood density to derive biomass from the harvested volume (Lavers and Moore, 1983; Jenkins et al., 2011). Carbon content of all oven-dried wood is assumed to be 50% (Matthews, 1993). CARBINE assumes the wood of a tree species all has the same oven-dried wood density and carbon content, irrespective of which semi-finished wood product categories it is assigned to.

The proportions of wood produced which are allocated to different product categories are based on proportions derived from FAO data[27] (prior to 1994) and forestry commission data[28] (after 1993) on production of semi-finished wood products. A carbon retention curve is used to estimate product decay and return of carbon to the atmosphere. Each wood product category has its own carbon retention curve using the default half-lives in the IPCC 2013 Revised Supplementary Methods and Good Practice Guidance, taking into account the decay rate of wood products and the service life as influenced by socio-economic factors. The half-lives are: 35 years for sawn wood; 25 years for wood panels; 2 years for paper. Timber used as woodfuel is assumed to instantaneously oxidise.

In implementing the 2006 IPCC guidelines for HWP the UK has elected to report using the production approach B2, which requires disaggregation of HWP into those produced and consumed domestically and those produced and exported. In the annual Forestry Statistics publication, there is data on the apparent consumption of wood products in the UK. A consistent dataset is available at the product level (i.e. sawnwood, wood panels and paper & paperboard) for 2002 onwards. The ten year average of 2002-2011 was calculated for each product type and those values were used for the years 1990-2001. This dataset was used to assign the HWP output from the CARBINE model into either consumed domestically or exported.

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[27] http://www.fao.org/faostat/en/#data/FO

[28] https://www.forestresearch.gov.uk/tools-and-resources/statistics/statistics-by-topic/timber-statistics/uk-wood-production-and-trade-provisional-figures/

A 3.4.11 Methods for the Overseas Territories (OTs) and Crown Dependencies (CDs)

The UK LULUCF inventory includes direct GHG emissions from UK Crown Dependencies (CDs) and Overseas Territories (OTs) which have joined, or are likely to join, the UK's instruments of ratification to the UNFCCC and the Kyoto Protocol. Currently, these are: Guernsey, Jersey, the Isle of Man, the Falkland Islands, the Cayman Islands, Bermuda, and Gibraltar. Bermuda has not ratified the 2nd Commitment Period of the Kyoto Protocol and is therefore not included in the 'GBK' submission under the Kyoto Protocol.

A web search of statistical publications is undertaken for any updates in datasets for every inventory compilation cycle. This work builds on an MSc project to calculate LULUCF net emissions/removals for the OTs and CDs undertaken during 2007 (Ruddock 2007).

Gibraltar has a very small land area (6 km^2) with no agricultural land. The only area of woodland (dense Mediterranean scrub) occurs within the Upper Rock Nature Reserve/park, and is not managed for production[29]. The whole land area of Gibraltar is categorised as Settlement remaining Settlement and has not undergone any land use change since 1970. It is therefore estimated that there are no net LULUCF emissions from this territory.

An assessment of flooded land was undertaken for the Overseas Territories and Crown Dependencies. No flooded land areas exceed the area threshold of 1 km^2 used for the UK, so the area of Flooded Land remaining Flooded Land has been included with the Inland Water area in the Wetlands remaining Wetlands category.

Peat organic soils occur in the Falkland Islands and Isle of Man but not in the other Overseas Territories and Crown Dependencies. Emissions from the drainage and rewetting of organic soils on the Isle of Man are included for the first time in the 1990-2020 inventory submission. The reporting of drainage and rewetting of organic soils on the Isle of Man uses the same methodology (e.g. peatland classification and EFs) for the UK given in **section A 3.4.6** above, with further details given in Evans et al. (2017). The organic soil area reported for the Isle of Man uses the British Geological Survey 1:50,000 superficial geology map, which employs a peat depth threshold of 1 m, and thus reports a small area (475 ha) all occurring in the lowlands, which is an underestimate of the true area (**Table A 3.4.29**). A Manx Wildlife Trust survey is currently underway to map peat extent >40 cm, which will be used to complement the area estimates provided below. Data on land use change on organic soils is currently unavailable for reporting in the inventory. Peatland restoration activities are likely to increase in the near future; however, Isle of Man are a few years away from reporting outcomes (Shaun Gelling Uplands Manager, IoM Government, pers. comm., 28/09/21).

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[29] https://www.gibraltar.gov.gi/new/sites/default/files/1/15/Upper_Rock_Nature_Reserve_Management_Action_Plan.pdf

Table A 3.4.29 Assignment of peat areas (kha) to condition categories for the Isle of Man in 1990 and 2020.

Crown Dependency	**Isle of Man**	
Peat category	**All**	**All**
Year	**1990**	**2020**
Forest	118	118
Cropland	41	41
Drained Eroding Modified Bog (bare peat)	1	1
Undrained Eroding Modified Bog (bare peat)	0	0
Drained Modified Bog (Heather + Grass dominated)	0	0
Undrained Modified Bog (Heather + Grass dominated)	13	13
Extensive Grassland (combined bog + fen)	99	99
Intensive Grassland	204	204
Near Natural Bog	0	0
Near Natural Fen	0	0
Extracted Domestic	0	0
Extracted Industrial	0	0
Settlement	0	0
Rewetted Modified (Semi-natural) Bog	0	0
Rewetted Bog	0	0
Rewetted Fen	0	0
Total	**475**	**475**

A small area of deforestation occurs in Guernsey, obtained from habitat surveys in 1999, 2010 and 2018. The change in forest cover is a result of the changed areas losing sufficient tree cover to be reclassified as dense scrub or parkland, rather than conversion to settlement land or agriculture, therefore changes in soil carbon stocks do not occur. Deforestation in the Cayman Islands arises from mangrove conversion to urban development (Jurn et al. 2018) and occurs on organic soils.

The UK has assessed the available information on wildfires in the OTs and CDs, and will repeat this procedure for future inventories. The procedure included reviewing available published government data on fire occurrence and contact with local experts for all CDs and OTs, which brought up no relevant information. We also conducted searches on global fire data portals (Global Forest Watch, Global Fire Emissions Database, and Global Wildfire Information System (GWIS)). All of these portals record zero occurrences of fires and zero burnt area for 2002-2019 for the Cayman Islands, Jersey, Guernsey and the Isle of Man.

The GWIS portal does record a total of 11 fires between 2002 and 2019 in the Falkland Islands with an estimated total area of 5,024 ha based on pixel size, although the total burnt area is recorded as zero.

Due to the lack of publicly available data in wildfires in the OTS and CDS we estimate the extent of biomass burning 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. The estimated rate of grassland wildfire occurrence in the Falklands, using the geographical proxy, is 944 ha p.a., which has been assessed as a plausible annual area by local experts. 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 no forest in the Falkland Islands so no wildfire occurrence there. The estimated rate of grassland wildfire occurrence in the Falklands, using the geographical proxy, is 944 ha p.a., which has been assessed as a plausible annual area by local experts.

Information on the area of each IPCC land category, dominant management practices, land use change, soil types and climate types were compiled for each OT/CD from statistics and personal communications from their government departments (**Table A 3.4.30**). This allowed Tier 1 level inventories to be constructed for the OT/CDs for all land use categories. The assumptions and factors used for the estimation of emissions are given in **Table A 3.4.31**. The estimates have high uncertainty and may not capture all relevant activities, but given the size of the territories any missing sources are likely to be small.

Table A 3.4.30 Information sources for estimating LULUCF emissions from the Overseas Territories and Crown Dependencies

Territory	LULUCF category	Time period	Reference
Isle of Man	4A	1970-2011	Personal communication from Isle of Man Department of Agriculture, Fisheries and Forestry (Peter Williamson) FAO (2010) Global Forest Resources Assessment: Isle of Man
	4B, 4C, 4D	2002-2018	Isle of Man Agricultural and Horticultural Census: completed by all farmland occupiers on an annual basis Isle of Man Digest of Economic and Social Statistics
	4B, 4C	2012 - 2013	Isle of Man Digest of Economic and Social Statistics
	4B, 4C	2014	The Isle of Man in Numbers
	4E	1991-1994	Isle of Man Ecological Habitat Survey, Phase 1 Report (Sayle et al, 1995)
	4D	1990-present	Evans et al. 2017
Guernsey	4A	1990-2010	FAO Global Forest Resources Assessment 2010: Guernsey
	4A, 4B, 4C, 4D, 4E	1998/9, 2005, 2018	Guernsey Habitat Survey (1998, 2010, 2018), Sustainable Guernsey 2005, 2009; Guernsey Facts and Figures 2018
Jersey	4A	1990-2010	FAO Global Forest Resources Assessment 2010: Jersey
	4B	1990 - 2018	Jersey Agricultural Statistics
	4A, 4B, 4C, 4D, 4E	2006, 2008, 2012, 2015	Jersey In Figures 2006-present
Falkland Islands	4A	1990-2011	Department of Mineral Resources, personal communication FAO Global Forest Resources Assessment 2010: Falkland Islands
	4B, 4C	1991-present	Falkland Islands Agricultural Statistics
	4E	1990-2005	Falkland Islands Environment and Planning Department, personal communication

Territory	LULUCF category	Time period	Reference
	4E	1986 – 2001 with projections 2006 - 2016	Stanley Town Plan, Environmental Planning Dept, Falkland Islands Government.
Cayman Islands	4A, 4B, 4C, 4D, 4E	2013	Cayman Island Compendium of Statistics- Land Cover 2013; Agricultural Land Capability of the Cayman Islands (1996)
	4E	1965-2013	Jurn et al. (2018); Information provided by Cayman Islands Government to Aether for GHGI (2017)
Bermuda	4A, 4B, 4D, 4E	1989-present	Bermuda Biodiversity Study[30], Bermuda Environmental Statistics Compendium

Table A 3.4.31 Assumptions and EFs used in applying the Tier 1 methodology to the Overseas Territories and Crown Dependencies

Land Use category	Sub-category	Isle of Man	Guernsey	Jersey	Falkland Islands	Cayman Islands	Bermuda
Soil C density, tC/ha	Mineral soil	95	95	95	87	35	47

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[30] https://environment.bm/country-study

Land Use category	Sub-category	Isle of Man	Guernsey	Jersey	Falkland Islands	Cayman Islands	Bermuda
Forest land fluxes	Living biomass, DOM, Mineral soils, Organic soils	Tier 1 temperate oceanic forest and temperate oceanic plantation EFs used. Area increased 1961-1990, but stable since. Gains and losses (thinning management) in living biomass are calculated, deadwood, litter and mineral soil CSC are assumed to be zero under Tier 1. Emissions from organic soil use Tier 2 EFs (not CARBINE).	Tier 1 temperate oceanic forest and temperate oceanic plantation EFs used. All forest is on mineral soil. Area increased 2000-present. Gains in living biomass are calculated, deadwood, litter and mineral soil CSC are assumed to be zero under Tier 1.	Assumed in equilibrium	No forest on Falklands	Tier 1 tropical dry forest and tropical dry mangrove EFs used. All forest is on mineral soil, all mangrove is on organic soil. The forest area is stable 1990-2005. Assumed that any gains in biomass are lost in the same year, keeping the carbon stock changes in balance. Deadwood, litter and mineral and mangrove soil CSC are assumed to be zero under Tier 1	Tier 1 tropical dry forest and tropical dry mangrove EFs used. All forest is on mineral soil, all mangrove is on organic soil. Assumed that any gains in biomass are lost in the same year, keeping the carbon stock changes in balance. Deadwood, litter and mineral and mangrove soil CSC are assumed to be zero under Tier 1
	Wildfires	Use proxy rate of burning in UK forests (0.030% p.a.). Tier 1 EFs for “All other temperate forests”.	Use proxy rate of burning in UK forests (0.030% p.a.) Tier 1 EFs for “All other temperate forests”.	Use proxy rate of burning in UK forests (0.030% p.a.) Tier 1 EFs for “All other temperate forests”.	N/A	Use proxy rate of burning in Cuba forests (0.15% p.a.). Tier 1 EFs for “Primary tropical forest”.	No reported wildfires

Land Use category	Sub-category	Isle of Man	Guernsey	Jersey	Falkland Islands	Cayman Islands	Bermuda
Crop remaining crop	Living biomass	N/A. Only for perennial crops	Orchards only. 10 tC/ha	N/A. Only for perennial crops	N/A. Only for perennial crops	There is no land use data to distinguish the cropland within the man-modified area, so it is included with the settlement area.	Agricultural land is predominantly cropland and the small area of agricultural grassland (dairy/forage) has been included here. Assumed stable with no net emissions
	Dead organic matter	N/A	N/A	N/A	N/A		
	Mineral soils	No change in SOC	No change in SOC	No change in SOC	N/A		
	Organic soils	Emissions from organic soil use Tier 2 EFs	N/A	N/A	Default (-5 tC/ha)		

Land Use category	Sub-category	Isle of Man	Guernsey	Jersey	Falkland Islands	Cayman Islands	Bermuda
Land converted to Crop	Living biomass	UK shrubby grass to crop values(5 tC/ha)	UK non-shrubby grass to crop value (2.2 tC/ha)	UK non-shrubby grass to crop value (2.2 tC/ha)	UK non-shrubby grassland to crop value (2.2 tC/ha)	There is no land use data to distinguish the cropland within the man-modified area, so it is included with the settlement area.	N/A
	Dead organic matter	N/A	N/A	N/A	N/A		
	Mineral soils	Conversion from natural grassland (-1.7347 tC/ha). Crop F_{LU}=0.69, Crop F_i=0.92	Conversion from natural grassland (-0.95 tC/ha). Crop F_{LU}=0.8, Crop F_i=1	Conversion from natural grassland (-0.95 tC/ha). Crop F_{LU}=0.8, Crop F_i=1	N/A		
	Organic soils	Emissions from organic soil use Tier 2 EFs	N/A	N/A	Default (-5 tC/ha)		
	N_2O emissions	Default (0.001817 t N_2O/ha)	Default (0.000995 t N_2O/ha)	Default (0.000995 t N_2O/ha)	Default (0.012571 t N_2O/ha)		

Land Use category	Sub-category	Isle of Man	Guernsey	Jersey	Falkland Islands	Cayman Islands	Bermuda
Grass remaining grass	Living biomass	N/A	N/A	N/A	N/A	The grassland area is stable 1990-2005. Biomass, dead organic matter and soil CSC are assumed to be zero under Tier 1.	Included with Cropland
	Dead organic matter	N/A	N/A	N/A	N/A		
	Mineral soils	No change in SOC	No change in SOC	No change in SOC	N/A		
	Organic soils	Emissions from organic soil use Tier 2 EFs	N/A	N/A	Assume no soil C stock change		
	Wildfires	Use proxy rate of burning in UK grassland (0.093% p.a.). Tier 1 EFs for “Calluna heath (temperate)”	Use proxy rate of burning in UK grassland (0.093% p.a.). Tier 1 EFs for “Calluna heath (temperate)”	Use proxy rate of burning in UK grassland (0.093% p.a.). Tier 1 EFs for “Calluna heath (temperate)”	Use proxy rate of burning in UK grassland (0.093% p.a.) .Tier 1 EFs for “Calluna heath (temperate)”	Use proxy rate of burning in UK grassland (0.093% p.a.). Tier 1 EFs for “Tropical/sub-tropical grassland (mid-late dry season burn)”	No reported wildfires

Land Use category	Sub-category	Isle of Man	Guernsey	Jersey	Falkland Islands	Cayman Islands	Bermuda
Land converted to grass	Living biomass	UK crop to non-shrubby grass values (-2.2 tC/ha)	UK settlement to non-shrubby grass value (0 tC/ha), Forest to grass assume 120 t DM/ha in forest	Crop to Grassland: UK crop to non-shrubby grass value (-2.2 tC/ha) Settlement to Grassland: assume increase from 0 in glasshouses (2.8 tC/ha)	Use crop to non-shrubby grassland value (-2.2 tC/ha)	Only dry forest is converted to grassland. Tier 1 tropical dry grassland and tropical dry forest EFs are used	N/A
	Dead organic matter	N/A	Forest to grass assume 16 t DM/ha in forest	N/A	N/A	T1 tropical dry forest litter stocks, N/A for dead wood	N/A
	Mineral soils	Assume conversion from cropland (1.7347 tC/ha)	Assume conversion from settlement, assume same soil C as for cropland (0.95 tC/ha)	Cropland to Grassland: assume conversion from cropland (0.95 tC/ha) Settlement to Grassland: assume no change	N/A	Fmg- tropical moderately degraded factor (0.97)	N/A
	Organic soils	Emissions from organic soil use Tier 2 EFs	N/A	N/A	Default (-0.25 tC/ha)	N/A	N/A
	N_2O emissions	N/A	N/A	N/A	N/A	Tier 1 EFs with EF2 for tropical cropland/grassland	N/A

Land Use category	Sub-category	Isle of Man	Guernsey	Jersey	Falkland Islands	Cayman Islands	Bermuda
Wetlands remaining Wetlands	N/A	N/A	N/A	N/A	N/A	The area of inland water is stable 1990-2005. The tropical shrubland values (IPCC 2006) are used for mangroves.	There is a small area of protected peat marsh reported in the Biodiversity Study (assumed stable). Areas of fresh/brackish ponds are very small and have been included in Other Land.
Land converted to Wetlands	Living biomass losses	N/A	N/A	N/A	N/A	T1 tropical dry forest EFs for conversion to inland water	N/A
	Dead organic matter	N/A	N/A	N/A	N/A	Only dry forest is converted to flooded land. T1 tropical dry forest EFs for conversion to inland water	N/A
Settlements remaining Settlements	Living biomass, DOM, Mineral soils	N/A	N/A	N/A	N/A	It is assumed that any settlement area that existed before 1965 was on mineral soil. Any settlement area converted from mangrove post-1965 is assumed to be on organic soil. T1 EF for cultivated organic soils (IPCC 2013)	All settlement is assumed to be on mineral soil. Assumed stable.

Land Use category	Sub-category	Isle of Man	Guernsey	Jersey	Falkland Islands	Cayman Islands	Bermuda
	Organic soils	N/A	N/A	N/A	N/A		

Land Use category	Sub-category	Isle of Man	Guernsey	Jersey	Falkland Islands	Cayman Islands	Bermuda
Land converted to Settlements	Living biomass	UK values, shrubby grass to settlement (-7.2 tC/ha)	UK non-shrubby grass to settlement value (0 tC/ha)	Grassland to Settlement, UK non-shrubby grass to settlement value (0 tC/ha) Cropland to Settlement: use cropland to settlement value (-2.2 tC/ha)	Use shrubby grass to settlement value (-7.2 tC/ha)	Tier 1 EFs for tropical dry mangrove forest and tropical mangrove shrubland converted to settlement	Conversion to settlement is assumed to occur on forest land and agricultural land at an overall rate of 9.2 ha per year (Bermuda Biodiversity Study value for previous 10 years). Assume 41.6% paved over and 20% soil C lost, 27.3% turf grass with 117% change in soil C, 31.1% wooded with no change in soil C. Assume Crop F_{LU}=0.48 (long-term cultivated on tropical moist soil)
	Dead organic matter	N/A	N/A	N/A	N/A		

Land Use category	Sub-category	Isle of Man	Guernsey	Jersey	Falkland Islands	Cayman Islands	Bermuda
	Mineral soils	Default SOC = 95 tC/ha, assume conversion from grassland and all soil C lost (-4.75 tC/ha)	Default SOC = 95 tC/ha, assume 30% of land is paved over and the rest is turf grass (-1.14 tC/ha)	Default . SOC = 95 tC/ha, Grassland to Settlement: assume 30% of land is paved over and the rest is turf grass (-1.14 tC/ha) Cropland to Settlement: assume 30% of land is paved over and the rest is turf grass (0.95 tC/ha)	N/A	N/A	
	Organic soils	N/A	N/A	N/A	Default - assume cropland (-5 tC/ha)	T1 EF for cultivated organic soils (IPCC 2013)	N/A
	N_2O emissions	Default (0.004976 t N_2O/ha)	Default (0.00119 t N_2O/ha)	Default (0.00119 t N_2O/ha)	N/A	Tier 1 EFs with EF2 for tropical cropland/grassland (for Wetland to Settlement) and EF2 for tropical forest for F2S	
Other land remaining other land	Living biomass, DOM, Mineral soils, Organic soils	N/A	N/A	N/A	N/A	Area assumed to remain constant over time	Area assumed to remain constant over time

Land Use category	Sub-category	Isle of Man	Guernsey	Jersey	Falkland Islands	Cayman Islands	Bermuda
Land converted to other land	Living biomass	N/A	Assume loss of grassland to standing water or cliff (-10 tC/ha)	Assumed loss of grassland to standing water (-2.8 t C/ha)	N/A	N/A	N/A
	Dead organic matter	N/A	N/A	N/A	N/A	N/A	N/A
	Mineral soils	N/A	Assume no change in soil stocks	N/A	N/A	N/A	N/A
	Organic soils	N/A	N/A	N/A	N/A	N/A	N/A
	N_2O emissions	N/A	0	N/A	N/A	N/A	N/A
Harvested wood products		N/A	N/A	N/A	N/A	Instantaneous oxidation assumed for any timber from deforestation.	N/A

A 3.4.12 Uncertainty analysis of the LULUCF sector

The purpose of carrying out uncertainty analysis within the LULUCF inventory is to quantify where the largest sources of errors lie, and to identify areas to be targeted in future work so as to reduce the uncertainties. In the 1990-2010 inventory report (2012) a sensitivity analysis of the whole of the existing inventory methodology was undertaken, applying uncertainty quantification more widely and rigorously to all model parameters and empirical conversion factors, in order to quantify the impact of those uncertainties on the inventory. This work was revisited in 2019/2020 (Henshall and Watterson 2020, not yet published), to re-assess the uncertainties and sensitivities associated with the forest land modelling and update the uncertainties for the non-forest parts of the LULUCF sector.

In 2010 parameterisation of the forest model was assessed as the second largest source of uncertainty. This has been addressed with the move to CARBINE, as 19 tree species are now modelled instead of the two used in previous submissions. Results from the National Forest Inventory (NFI) and small woods dataset will also provide additional information on carbon stocks in trees (e.g. Forestry Commission 2015[31]). The choice of soil carbon model and its parameters are also important because the time course of the flux following land use change may be quite different, depending on the equations used to represent this, and how carbon is distributed between fast- and slow-turnover pools. The choice of forest model is less important, largely because all the UK forest models are based on the same yield table data.

The updated uncertainty assessment of the Forest Land inventory and Harvested Wood Products (Henshall and Watterson 2020) (outputs derived from the CARBINE model) undertook a Monte Carlo analysis. The probability density functions (PDFs) assigned to the various CARBINE input parameters were based on information from the literature and expert judgement. A selection of 100 sets of input parameters were generated using Latin hypercube sampling, as this was considered to be the minimum number of model runs to get a reasonable estimate of the uncertainty considering the number of parameters adjusted.

The analysis of the carbon emissions/removals predicted by the model gave an uncertainty estimate at the 95% confidence interval of approximately 25% for both forest land and harvested wood products (rounded to the nearest 5%) in both the base year (1990) and the latest inventory year and 20% when both categories are considered in conjunction. This is smaller than what was assumed in the previous uncertainty analysis (around 40% uncertainty for those categories). While this may come in part from the improvement in the stratification of forest land obtained by the change of forest model, this is likely mostly a technical re-evaluation from a more up to date analysis of uncertainties range for the different parameters and the absence of characterisation of structural uncertainties in the model. In relative terms, carbon net emissions estimates for land converted to forest are assessed as considerably more uncertain (85% in the 1990 and 145% in 2020) than for forest remaining forest (20% in both 1990 and 2020). The activity data uncertainty for biomass, dead wood, litter and mineral soils is assessed as being 1%, but as 5% for forest organic soils.

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[31] This survey is preliminary and the carbon stocks have been estimated using the same relationships and calculation parameters that underlie CARBINE; they are therefore not an independent validation of the LULUCF estimates.

In 2010 and the updated assessment the area undergoing land use change was assessed as being the single biggest uncertainty in the inventory. This uncertainty in the land use change areas has been addressed by the development of a new vector-based approach (see **Section A 3.4.2.1**), combining multiple sources of land use data and land cover data from administrative, survey and earth observation datasets. This has allowed better estimation of the uncertainties associated with the activity data and enabled the separate calculation of the uncertainties associated with carbon stock changes in non-forest Land remaining in the same land category and Land converted to another land category. The activity data uncertainty for Land remaining in the same category is relatively stable across the 1990-2020 time series, but more variable for Land converted to other land categories, due to the complex contribution of different data sources in the data assimilation across the inventory time period.

In general, compared to the previous inventory submission, the overall uncertainties did not change greatly for 1990 and the latest inventory year. For CO_2 the 4A Forest Land and 4G Harvested Wood Product categories have not changed (20%), 4B Cropland has reduced slightly (25% to 20%), 4C Grassland has decreased slightly (30% to 20%), 4D Wetland decreased slightly for 2020 (25% to 20%) and 4E Settlements have increased (25% to 45%). There have been some changes in the CH_4 uncertainties (4C Grassland 40% to 45% uncertainty in 1990, and 4A Forest Land 70% to 85% in 2020). There are also some changes in the N_2O uncertainties since the last inventory submission: 4A Forest Land has decreased by 5% in 1990 and increased by 5% in 2020 (80% to 75%, and 80% to 85% respectively); 4B Cropland has decreased 40% to 35%, 4D Wetlands has increased from 65% to 90% in 2020, and Indirect N_2O emissions increased from 160% to 165% in 1990. A summary table of the combined uncertainties in the LULUCF sector is shown in **Table A 3.4.32**.

Table A 3.4.32 Summary uncertainties for LULUCF sector activities

LULUCF sub-category	Variable	CO_2	CH_4	N_2O
4A1 Forest remaining Forest	Forest biomass and mineral soils	20%[a]		
4A1 Forest remaining Forest	Forest organic soils	21%[a]		
4A2 Land converted to Forest	Forest biomass and mineral soils	86-146 %[a]		
4A2 Land converted to Forest	Forest organic soils	86-146 %[a]		
4A Forest Land/4(I)	Forest fertilisation			34%[a]
4A Forest Land/4(II)	Mineral soil drainage			140%[b]
4A Forest Land/4(II)	Organic soil drainage		95%[c]	97%[c]
4A Forest Land/4(III)	N_2O from land use change			135%[b]
4A Forest Land/4(V)	Biomass burning	54%[d]	54%[d]	54%[d]
4B1 Cropland remaining Cropland	LUC mineral soil carbon change	22-24%[e]		
4B1 Cropland remaining Cropland	LUC biomass carbon	36-37%[e]		
4B1 Cropland remaining Cropland	Cropland management (soils and biomass)	12%[b]		
4B1 Cropland remaining Cropland	Organic soils	52%[c]		
4B2 Forest Land converted to Cropland	LUC mineral soil carbon change	33-153%[e]		
4B2 Forest Land converted to Cropland	LUC biomass carbon	36-154%[a]		

LULUCF sub-category	Variable	CO_2	CH_4	N_2O
4B2 Forest Land converted to Cropland	LUC DOM carbon stock change	36-154%[a]		
4B2 Forest Land converted to Cropland	Organic soils	60-161%[c]		
4B2 Grassland converted to Cropland	LUC mineral soil carbon change	18-24%[e]		
4B2 Grassland converted to Cropland	LUC biomass carbon	34-37%[e]		
4B2 Grassland converted to Cropland	Organic soils	52%[c]		
4B2 Settlements converted to Cropland	LUC mineral soil carbon change	186-196% [e]		
4B2 Settlements converted to Cropland	LUC biomass carbon	188-197% [e]		
4B2 Settlements converted to Cropland	Organic soils	52% [c]		
4B Cropland/4(II)	Organic soil drainage		91% [c]	71% [c]
4B Cropland/4(III)	N_2O from land use change			36%[a]
4B Cropland/4(V)	Biomass burning (wildfires and controlled burning after deforestation)	54% [d]	54% [d]	54% [d]
4C1 Grassland remaining Grassland	LUC mineral soil carbon change	27-30%[e]		
4C1 Grassland remaining Grassland	LUC biomass carbon	39-42%[e]		
4C1 Grassland remaining Grassland	Grassland management (biomass)	13% [b]		
4C1 Grassland remaining Grassland	Organic soils	42% [c]		
4C2 Forest Land converted to Grassland	LUC mineral soil carbon change	42-156%[e]		
4C2 Forest Land converted to Grassland	LUC biomass carbon	36-155%[a]		
4C2 Forest Land converted to Grassland	LUC DOM carbon stock change	20-155%[a]		
4C2 Forest Land converted to Grassland	Organic soils	52-159%[c]		
4C2 Cropland converted to Grassland	LUC mineral soil carbon change	21%[e]		
4C2 Cropland converted to Grassland	LUC biomass carbon	35%[e]		
4C2 Cropland converted to Grassland	Organic soils	42%[c]		
4C2 Settlements converted to Grassland	LUC mineral soil carbon change	135-142%[e]		
4C2 Settlements converted to Grassland	LUC biomass carbon	138-145%[e]		
4C2 Settlements converted to Grassland	Organic soils	42%[c]		
4C Grassland/4(II)	Organic soil drainage		40-43% [c]	53-55% [c]
4C Grassland/4(III)	N_2O from land use change			135% [b]
4C Grassland/4(V)	Biomass burning (wildfires and controlled burning after deforestation)	54% [d]	54% [d]	54% [d]
4D Wetlands	Peat extraction offsite emissions	32%[a]		
4D Wetlands	Organic soils (extraction and rewetting)	49% [c]		
4D Wetlands/4(II)	Organic soil drainage		36-39% [c]	111-120% [c]
4D Wetlands	Flooded land biomass carbon	75% [b]		
4D2 Forest Land converted to Other wetlands	LUC biomass and DOM loss after rewetting	36-155% [a]		

LULUCF sub-category	Variable	CO_2	CH_4	N_2O
4D Wetlands/4(V)	Biomass burning (controlled burning after deforestation)	54% [d]	54% [d]	54% [d]
4E1 Settlements remaining Settlements	LUC mineral soil carbon change	67-73%[e]		
4E1 Settlements remaining Settlements	LUC biomass carbon	72-79%[e]		
4E1 Settlements remaining Settlements	Organic soils	60% [c]		
4E2 Forest Land converted to Settlements	LUC mineral soil carbon change	32-150% [e]		
4E2 Forest Land converted to Settlements	LUC biomass and DOM carbon stock change	36-151% [a]		
4E2 Forest Land converted to Settlements	Organic soils	67-161% [c]		
4E2 Cropland converted to Settlements	LUC mineral soil carbon change	87-119% [e]		
4E2 Cropland converted to Settlements	LUC biomass carbon	91-121% [e]		
4E2 Cropland converted to Settlements	Organic soils	60% [c]		
4E2 Grassland converted to Settlements	LUC mineral soil carbon change	70-129% [e]		
4E2 Grassland converted to Settlements	LUC biomass carbon	76-132% [e]		
4E2 Grassland converted to Settlements	Organic soils	60% [c]		
4E Settlements/4(II)	Organic soil drainage		60% [c]	60% [c]
4E Settlements/4(III)	N_2O from land use change			135% [b]
4E Settlements/4(V)	Biomass burning (wildfires and controlled burning after deforestation)	54% [d]	54% [d]	54% [d]
4G HWP	Harvested wood products	15-19%[a]		
4	Indirect N_2O (atmospheric deposition)			240% [b]
4	Indirect N_2O (leaching)			163% [b]

[a] Updated uncertainty assessment (Henshall and Watterson, 2020); [b] IPCC default; [c] Analysis of uncertainties for the reporting of drainage and rewetting of peatlands recommended by Evans et al. 2017 (see **Section A 3.4.6.4**); [d] Uncertainty assessment 2012, [e] Uncertainty assessment 2020.

A 3.5 WASTE (CRF SECTOR 5)

A 3.5.1 Solid Waste Disposal on Land (5A)

A 3.5.1.1 Input data

Because waste sent to landfill is now evaluated using individual waste consignments by EWC code, there is no need to make assumptions regarding waste composition, other than for two waste categories. These EWC codes are 19.12.12 (residues from waste sorting) and 20.03.01 (mixed municipal waste). Wastes with these codes were allocated in accordance with the findings of a survey carried out on behalf of Defra (Resource Futures, 2012), as set out in **Table A 3.5.1**. This waste composition data is considered to be representative of current national circumstances, in absence of new data sources for the composition of mixed waste. Data on DOC, DOCf and material compositions are provided in **Table A 3.5.2**.

The model allocates waste to two types of landfill – old, closed sites which last received waste in 1979, and modern engineered landfills that came into operation from 1980. Only these latter sites have gas management systems. The old closed sites have no gas control. The distribution of waste between these types of site is the same as used for compiling the previous NIR.

The quantities of waste sent to landfill are shown in **Table A 3.5.3**. The amounts of methane generated, recovered, used for power generation, flared, oxidised and emitted to the atmosphere are shown in **Table A 3.5.4**.

Table A 3.5.1 Composition of waste sorting residues and mixed municipal waste

Material	**19.12.12 (residues from waste sorting)**	**20.03.01 (mixed municipal waste**
Paper	10.3%	10.6%
Card	9.1%	7.7%
Plastic film	9.4%	8.4%
Dense plastics	13.2%	9.6%
Sanitary waste	1.3%	3.1%
Wood	10.0%	5.3%
Textiles and shoes	5.9%	5.6%
Glass	1.3%	3.0%
Food waste	8.2%	21.3%
Garden waste	1.8%	3.5%
Other organic	1.3%	2.1%
Metals	3.2%	3.7%
WEEE	1.4%	1.5%
Haz waste and batteries	1.1%	0.9%
Carpet, underlay & furniture	7.0%	5.0%
Other combustibles	2.7%	1.4%
Bricks, plaster and soil	7.9%	4.1%
Other non-combustible	1.7%	1.5%
Fines <10mm	3.3%	1.8%
Total	100%	100%

Table A 3.5.2 DOC, DOCf and composition of waste materials

Component	Lignin biodegradability DOCf	Non-lignin biodegradability DOCf	Moisture, %fresh matter	Lignin, % dm	Hemicellulose, %dm	Cellulose, %dm	Starch, %dm	Sugar, % dm	Fat, %dm	Proteins, %dm	Fibre, %dm	Readily soluble, %dm	Other (inert), % dm
Carbon contents (DOC)			**0%**	**65.1%**	**44.6%**	**40.0%**	**44.4%**	**42.1%**	**76.0%**	**40.0%**	**45.0%**	**45.0%**	**0.0%**
Paper	5%	65%	15%	15%	9%	61%							15.00%
Card	5%	65%	20%	15%	9%	61%							15.00%
Nappies	5%	65%	65%			47%							52.70%
Textiles and footwear	5%	65%	20%		15%	15%							69.68%
Miscellaneous combustible	5%	65%	20%		25%	25%							50.00%
Wood	5%	65%	17%	26%	12%	42%							21.00%
Food	15%	70%	70%	6%	4%	27%	13%	7%	14%	15%	14%	0%	0.00%
Garden	10%	65%	55%	20%	16%	20%			2%			26%	17.10%
Soil and other organic	5%	65%	30%		1%	1%							98.60%
Furniture	5%	65%	12%	1%	10%	11%	0%	0%	0%	0%	0%	0%	77.25%
Mattresses	5%	65%	20%		15%	15%							69.68%
Non-inert Fines		50%	40%		25%	25%							50.00%
Inert													100.00%
Commercial	5%	65%	37%		8%	76%							16.00%

Component	Lignin biodegradability DOCf	Non-lignin biodegradability DOCf	Moisture, %fresh matter	Lignin, % dm	Hemicellulose, %dm	Cellulose, %dm	Starch, %dm	Sugar, % dm	Fat, %dm	Proteins, %dm	Fibre, %dm	Readily soluble, %dm	Other (inert), % dm
Paper and Card	5%	65%	15%	15%	9%	61%							15.00%
General industrial waste	5%	65%	37%		8%	76%							16.00%
Food and Abattoir	15%	70%	70%	5%	11%	11%	36%	7%	6%	18%			6.00%
Food effluent	15%	70%	65%		55%	7%							37.40%
Construction and demolition	5%	65%	30%		9%	9%							83.00%
Miscellaneous process waste	5%	65%	20%		10%	10%							80.00%
Other waste	5%	65%	20%		25%	25%							50.00%
Sewage sludge	5%	65%	70%		14%	14%							72.00%
Textiles / Carpet and Underlay	5%	65%	20%	0%	15%	15%	0%	0%	0%	0%			69.68%
Sanitary	5%	65%	65%	0%	0%	47%	0%	0%	0%	0%			52.70%
Other	5%	65%											100.00%

Table A 3.5.3 Amount of waste landfilled (Mt) (1945 to 2020)

Year	England	Scotland	Wales	Northern Ireland	Total	Year	England	Scotland	Wales	Northern Ireland	Total
1945	70.9	9.0	4.6	2.3	86.9	**1983**	77.1	8.5	4.6	2.6	92.8
1946	71.2	9.0	4.6	2.4	87.2	**1984**	77.2	8.5	4.6	2.6	92.8
1947	71.5	9.0	4.6	2.4	87.4	**1985**	77.2	8.4	4.6	2.6	92.8

Year	England	Scotland	Wales	Northern Ireland	Total
1948	71.7	9.0	4.6	2.4	87.7
1949	72.3	9.0	4.6	2.4	88.4
1950	72.9	9.1	4.6	2.4	89.1
1951	73.6	9.1	4.6	2.5	89.8
1952	74.2	9.1	4.7	2.5	90.5
1953	74.2	9.1	4.7	2.5	90.4
1954	74.2	9.0	4.6	2.4	90.3
1955	74.2	9.0	4.6	2.4	90.3
1956	75.7	9.1	4.7	2.5	92.0
1957	77.2	9.2	4.8	2.5	93.7
1958	78.6	9.3	4.8	2.6	95.4
1959	80.1	9.5	4.9	2.6	97.1
1960	81.5	9.6	5.0	2.6	98.8
1961	81.1	9.7	4.9	2.7	98.4
1962	80.9	9.6	4.9	2.7	98.0
1963	84.5	10.0	5.1	2.8	102.4
1964	84.6	9.9	5.1	2.8	102.4
1965	85.7	10.0	5.1	2.8	103.6
1966	85.3	9.9	5.1	2.8	103.2
1986	77.3	8.4	4.6	2.6	92.9
1987	77.3	8.3	4.6	2.6	92.9
1988	77.4	8.3	4.6	2.6	92.9
1989	77.4	8.3	4.6	2.6	92.9
1990	77.7	8.3	4.7	2.6	93.3
1991	77.7	11.3	4.7	2.6	96.3
1992	77.7	12.2	4.7	2.6	97.2
1993	77.6	14.0	4.6	2.6	98.8
1994	77.6	15.9	4.6	2.6	100.7
1995	81.8	15.0	4.9	2.8	104.5
1996	80.7	15.0	4.8	2.8	103.3
1997	81.1	14.0	4.8	2.8	102.7
1998	75.0	11.9	4.5	2.6	93.9
1999	69.3	10.9	4.1	2.4	86.6
2000	67.4	11.2	4.0	2.3	84.9
2001	71.4	8.9	4.2	2.4	86.9
2002	66.8	8.2	3.9	2.3	81.3
2003	65.4	7.9	3.8	2.2	79.4
2004	64.9	7.8	3.8	2.2	78.7

Year	England	Scotland	Wales	Northern Ireland	Total	Year	England	Scotland	Wales	Northern Ireland	Total
1967	85.0	9.8	5.1	2.8	102.7	**2005**	60.0	7.1	3.5	2.0	72.6
1968	84.8	9.7	5.1	2.8	102.4	**2006**	61.7	7.1	4.0	2.0	74.8
1969	84.0	9.6	5.0	2.8	101.4	**2007**	60.7	7.4	3.2	1.9	73.2
1970	83.8	9.5	5.0	2.8	101.0	**2008**	53.9	6.1	2.9	1.6	64.5
1971	82.8	9.3	4.9	2.7	99.8	**2009**	44.0	4.7	2.5	1.1	52.3
1972	81.8	9.2	4.8	2.7	98.5	**2010**	43.6	4.6	2.3	1.0	51.4
1973	81.3	9.1	4.8	2.7	97.9	**2011**	44.7	4.7	2.2	1.0	52.5
1974	79.9	9.0	4.8	2.6	96.3	**2012**	41.8	4.5	2.2	1.1	49.6
1975	80.1	9.0	4.8	2.6	96.5	**2013**	41.1	4.1	2.2	1.1	48.4
1976	78.8	8.8	4.7	2.6	94.9	**2014**	41.3	4.1	1.5	1.3	48.2
1977	78.4	8.8	4.7	2.6	94.5	**2015**	43.9	4.2	1.3	1.6	51.0
1978	78.8	8.8	4.7	2.6	95.0	**2016**	44.7	3.7	2.0	1.9	52.3
1979	78.7	8.8	4.7	2.6	94.7	**2017**	45.4	3.8	1.8	1.7	52.7
1980	78.6	8.7	4.7	2.6	94.6	**2018**	44.1	3.7	1.4	1.5	50.7
1981	77.0	8.5	4.6	2.5	92.7	**2019**	45.9	3.0	1.1	1.5	51.4
1982	77.1	8.5	4.6	2.5	92.7	**2020**	39.8	2.6	1.0	1.4	44.8

A 3.5.1.2 Methane emissions

The right-most column of **Table A 3.5.4** shows the current estimate of methane emitted from UK landfills, according to the approach outlined in **Chapter 7**, taking account of recovery and oxidation.

Table A 3.5.4 Amount of waste landfilled and methane generated, captured, utilised, flared, oxidised and emitted

Year	Waste Landfilled Mt	Methane generated Kt	Methane captured kt	Methane captured %	Methane used for power generation kt	Methane used for power generation %	Methane flared kt	Methane flared %	Residual methane oxidised kt	Residual methane oxidised %	Methane emitted kt	Methane emitted %
1990	93.25	2,709	33	1%	33	1%	0	0%	268	10%	2408	89%
1991	96.32	2,752	50	2%	50	2%	0	0%	270	10%	2432	88%
1992	97.18	2,797	90	3%	90	3%	0	0%	271	10%	2436	87%
1993	98.85	2,837	107	4%	107	4%	0	0%	273	10%	2457	87%
1994	100.75	2,878	124	4%	124	4%	0	0%	275	10%	2479	86%
1995	104.50	2,939	135	5%	135	5%	0	0%	280	10%	2524	86%
1996	103.26	2,983	170	6%	170	6%	0	0%	281	9%	2532	85%
1997	102.70	3,022	218	7%	218	7%	0	0%	280	9%	2524	84%
1998	93.85	3,038	278	9%	278	9%	0	0%	276	9%	2484	82%
1999	86.63	3,032	394	13%	394	13%	0	0%	264	9%	2374	78%
2000	84.85	3,028	500	17%	500	17%	0	0%	253	8%	2275	75%
2001	86.92	3,040	566	19%	566	19%	0	0%	247	8%	2227	73%
2002	81.28	3,021	599	20%	598	20%	1	0%	242	8%	2180	72%
2003	79.38	2,981	723	24%	723	24%	0	0%	226	8%	2032	68%
2004	78.71	2,937	874	30%	874	30%	0	0%	206	7%	1857	63%
2005	72.59	2,870	926	32%	926	32%	0	0%	194	7%	1750	61%
2006	74.83	2,753	950	35%	944	34%	6	0%	180	7%	1622	59%
2007	73.21	2,645	989	37%	987	37%	2	0%	166	6%	1490	56%
2008	64.51	2,528	1065	42%	980	39%	85	3%	146	6%	1316	52%
2009	52.33	2,400	1112	46%	1015	42%	97	4%	127	5%	1159	48%
2010	51.38	2,278	1200	53%	1066	47%	134	6%	108	5%	971	43%

Year	Waste Landfilled Mt	Methane generated Kt	Methane captured kt	Methane captured %	Methane used for power generation kt	Methane used for power generation %	Methane flared kt	Methane flared %	Residual methane oxidised kt	Residual methane oxidised %	Methane emitted kt	Methane emitted %
2011	52.54	2,159	1178	55%	1075	50%	103	5%	98	5%	883	41%
2012	49.55	2,041	1124	55%	1042	51%	82	4%	92	4%	825	40%
2013	48.43	1,929	1144	59%	1035	54%	109	6%	78	4%	706	37%
2014	48.15	1,820	1142	63%	1007	55%	136	7%	68	4%	610	34%
2015	50.98	1,716	1065	62%	974	57%	90	5%	65	4%	587	34%
2016	52.31	1,627	1007	62%	941	58%	67	4%	62	4%	558	34%
2017	52.75	1,544	916	59%	857	56%	59	4%	63	4%	565	37%
2018	50.70	1,468	829	56%	783	53%	53	4%	63	4%	568	39%
2019	51.25	1,396	765	55%	725	52%	48	4%	62	4%	560	40%
2020	44.84	1,325	758	57%	699	53	58	4%	57	4%	511	39%

Notes

a. Methane generated is based on the MELMod model.

b. Methane captured is the sum of methane used for power generation and methane flared.

c. Methane used for power generation is calculated from official figures on landfill gas electricity generation (Digest of UK Energy Statistics (BEIS, 2016), in GWh/year, assuming a net calorific value for methane of 50 GJ/tonnes and a conversion efficiency between methane use and electricity export of 30% rising to 36%, which includes parasitic losses and on-site use of electricity, e.g. for gas blowers, leachate treatment and site offices.

d. Methane flared is calculated from site-specific data provided by the Environment Agency at regulated sites for 2009 to 2013, from SEPA for 2013, from a study carried out during 2014, and from site-specific data provided voluntarily by site operators.

e. Methane oxidised is based on the IPCC default oxidation factor of 10%, applied to methane remaining after subtraction of the amount captured.

f. Methane emitted = (methane generated – methane captured) x (1-oxidation factor).

A 3.5.1.3 Overseas Territories and Crown Dependencies

For the overseas territories and crown dependencies, the IPCC landfill model is used. Where available, country-specific waste generation and composition data have been applied and appropriate defaults chosen e.g. taking into account climatic variation. There are no landfill emissions for Gibraltar as waste is exported. **Table A 3.5.5** below gives the parameters used.

Table A 3.5.5 Parameters used in landfill emission estimates for overseas territories and crown dependencies

Region	Methodology	Activity data	MCF	DOC	k value
Guernsey	IPCC Landfill Model	2005 onwards: total MSW to landfill data and percentage that is plastics, other inert. Prior to 2005: flat-lined 2005 data	IPCC default values; waste management type is unmanaged, deep (results from expert consultation, 2014)	IPCC default values	Region: Europe: Western Climate: Wet Temperate
Jersey	N/A, all MSW is incinerated for energy from waste	N/A	N/A	N/A	N/A
Gibraltar	N/A, all MSW used to be incinerated, now all waste is exported to be landfilled in Spain.	N/A	N/A	N/A	N/A
Isle of Man	IPCC Landfill Model	2004 onwards: all waste incinerated for energy from waste. Prior to 2004: population and IPCC default waste per capita for Western Europe	IPCC default values; waste management type is 50% unmanaged, deep and 50% managed, semi-aerobic (results from expert consultation, 2014)	IPCC default values	Region: Europe: Western Climate: Wet Temperate
Bermuda	IPCC Landfill Model	Total MSW to landfill (Environmental Statistics Compendium)	IPCC default values; no information on management system so assume unmanaged deep	IPCC default values	Region: Caribbean Climate: Moist and wet tropical

Region	Methodology	Activity data	MCF	DOC	k value
Cayman Islands	IPCC Landfill Model	2000 onwards: Total MSW to landfill (Department of Environmental Health). Prior to 2000: flat-lined 2000 data	IPCC default values; landfill sites are lined and managed to some degree, but with limited information, "Uncategorised" considered appropriate	IPCC default values	Region: Caribbean Climate: Moist and wet tropical
Falkland Islands	IPCC Landfill Model	1998: Halcrow Report. Other years: flat-lined after advice in personal communication from environmental officer	IPCC default values; waste management type is unmanaged, shallow (results from expert consultation, 2014)	IPCC default values	Region: America: South Climate: Wet Temperate

A 3.5.2 Biological Treatment of Solid Waste (5B)

The annual amount of waste treated in the composting process (fresh weight) are reported in **Table A 3.5.6**. Fresh weight can be converted to dry mass by using the IPCC default a factor of 0.4 dry matter/fresh weight.

Table A 3.5.6 Activity Data: Inputs in the composting process

Year	Composting (Non-household) (Mg fw)	Composting (Household) (Mg fw)	MBT - Composting (Mg fw)
1990	-	181,322	-
1991	229,036	181,756	-
1992	458,072	182,146	-
1993	687,108	182,638	-
1994	916,144	183,213	-
1995	1,145,181	183,654	-
1996	1,374,217	184,132	-
1997	1,603,253	184,643	-
1998	1,832,289	185,364	-
1999	2,061,325	185,979	-
2000	2,290,361	186,676	-
2001	2,519,397	187,441	67,882
2002	2,748,433	187,373	62,537
2003	2,977,469	187,300	57,192
2004	3,206,506	238,235	37,179
2005	3,435,542	289,058	88,917
2006	3,664,578	339,909	110,618
2007	3,893,614	390,804	542,678
2008	3,720,016	441,622	629,269
2009	4,655,911	492,393	438,011
2010	4,802,584	496,077	1,282,060
2011	4,9327,08	500,008	1,898,570

Year	Composting (Non-household) (Mg fw)	Composting (Household) (Mg fw)	MBT - Composting (Mg fw)
2012	5,385,239	503,005	1,719,118
2013	5,495,532	505,833	2,138,366
2014	6,129,050	509,350	2,439,341
2015	5,874,538	513,040	2,740,317
2016	6,142,963	517,007	3,041,292
2017	6,228,356	519,898	3,342,268
2018	5,744,604	522,778	3,643,244
2019	5,510,427	525,570	3,944,219
2020	5,202,459	527,590	4,245,195

Table A 3.5.7 Activity Data: Inputs in the anaerobic digestion process

Year	Anaerobic digestion – non-agricultural residue (Mg)	Anaerobic digestion - MBT (Mg)
1990	0	0
1991	1,678	0
1992	1,678	0
1993	1,678	0
1994	5,435	0
1995	5,435	0
1996	5,435	0
1997	6,061	0
1998	6,061	0
1999	6,061	0
2000	6,124	0
2001	6,187	16,970
2002	56,155	15,634
2003	56,155	14,298
2004	87,513	37,179

Year	Anaerobic digestion – non-agricultural residue (Mg)	Anaerobic digestion - MBT (Mg)
2005	191,153	17,783
2006	206,481	27,655
2007	226,519	40,847
2008	250,438	66,664
2009	373,793	365,570
2010	736,055	72,262
2011	1,314,758	104,815
2012	1,882,010	795,961
2013	3,050,437	600,692
2014	4,709,801	703,455
2015	6,080,995	806,218
2016	7,820,574	908,982
2017	9,068,438	1,011,745
2018	9,342,902	1,114,508
2019	9,378,614	1,217,272
2020	9,532,894	1,320,035

A 3.5.3 Waste Incineration (5C)

Table A 3.5.8 Activity Data: UK Waste Incineration

Year	Municipal Waste Incineration[a] (Mt)	Clinical Waste Incineration (Mt)	Chemical Waste Incineration (Mt)	Sewage Sludge Incineration (Mt)
1990	2.093	0.350	0.290	0.075
1991	2.069	0.350	0.290	0.069
1992	1.945	0.330	0.290	0.072
1993	1.677	0.310	0.290	0.084
1994	1.148	0.290	0.289	0.072
1995	0.996	0.270	0.289	0.082

Year	Municipal Waste Incineration[a] (Mt)	Clinical Waste Incineration (Mt)	Chemical Waste Incineration (Mt)	Sewage Sludge Incineration (Mt)
1996	1.062	0.250	0.288	0.088
1997	-	0.230	0.287	0.081
1998	-	0.236	0.287	0.185
1999	-	0.242	0.286	0.189
2000	-	0.248	0.285	0.194
2001	-	0.254	0.285	0.198
2002	-	0.260	0.284	0.203
2003	-	0.221	0.263	0.207
2004	-	0.182	0.241	0.212
2005	-	0.143	0.220	0.216
2006	-	0.105	0.199	0.220
2007	-	0.111	0.192	0.215
2008	-	0.115	0.167	0.192
2009	-	0.121	0.153	0.199
2010	-	0.114	0.159	0.231
2011	-	0.107	0.153	0.224
2012	-	0.107	0.154	0.209
2013	-	0.101	0.179	0.200
2014	-	0.103	0.184	0.174
2015	-	0.092	0.168	0.169
2016	-	0.093	0.173	0.148
2017	-	0.092	0.171	0.133
2018	-	0.092	0.139	0.112
2019	-	0.096	0.148	0.088
2020	-	0.092	0.153	0.071

a Note that all MSW incinerators were either closed or converted to extract power by 1997. In the latter case they were then considered to be power generation and so emissions were reported in 1A1a.

Table A 3.5.9 Emissions Data: UK Waste Incineration (kt)

Pollutant	Year	Chemical Waste Incineration	Accidental Fires	MSW Incineration[a]	Clinical Waste Incineration	Sewage Sludge Incineration	Total
CO_2	1990	444	NE	604	308	NA	1355
	1995	442	NE	365	238	NA	1044
	2000	404	NE	NO	218	NA	622
	2005	339	NE	NO	126	NA	465
	2010	188	NE	NO	101	NA	288
	2015	164	NE	NO	81	NA	245
	2017	176	NE	NO	81	NA	257
	2018	159	NE	NO	81	NA	240
	2019	158	NE	NO	84	NA	242
	2020	167	NE	NO	81	NA	248
CH_4	1990	0.144	1.009	4.179	0.009	0.029	5.370
	1995	0.143	0.984	2.205	0.007	0.032	3.372
	2000	0.103	0.772	NO	0.006	0.076	0.957
	2005	0.068	0.708	NO	0.004	0.084	0.865
	2010	0.030	0.366	NO	0.003	0.090	0.488
	2015	0.027	0.279	NO	0.002	0.066	0.375
	2017	0.029	0.277	NO	0.002	0.052	0.360
	2018	0.027	0.271	NO	0.002	0.044	0.344
	2019	0.027	0.257	NO	0.002	0.034	0.321
	2020	0.027	0.238	NO	0.002	0.028	0.296
N_2O	1990	0.029	NE	0.056	0.011	0.074	0.169
	1995	0.029	NE	0.029	0.008	0.081	0.148
	2000	0.029	NE	NO	0.007	0.192	0.228
	2005	0.022	NE	NO	0.004	0.214	0.240
	2010	0.016	NE	NO	0.003	0.229	0.248
	2015	0.017	NE	NO	0.003	0.167	0.187
	2017	0.017	NE	NO	0.003	0.131	0.151
	2018	0.014	NE	NO	0.003	0.110	0.127

Pollutant	Year	Chemical Waste Incineration	Accidental Fires	MSW Incineration[a]	Clinical Waste Incineration	Sewage Sludge Incineration	Total
	2019	0.015	NE	NO	0.003	0.087	0.105
	2020	0.015	NE	NO	0.003	0.070	0.088

a Note that all MSW incinerators were either closed or converted to extract power by 1997. In the latter case they were then considered to be power generation and so emissions were reported in 1A1a.

A 3.5.4 Wastewater Handling (5D)

A 3.5.4.1 5D1 Domestic and Commercial Wastewater Handling and Sludge Disposal

Table A 3.5.10 UK Domestic and Commercial Waste Water Treatment (5D1) Activity Data

Process stage	Process type	unit	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Total Sludge		kt tds	1634	1657	1682	1768	1666	1597	1669	1688	1687	1654
Population Equivalent		million	68.3	69.2	70.2	70.5	69.3	73.0	73.4	73.8	75.2	75.5
Additional Treatment	Digested	kt tds	400	432	467	795	823	657	681	656	594	596
	Advanced Digested	kt tds	102	109	117	331	374	454	596	668	805	808
	Composted	kt tds	7	8	8	15	24	7	14	2	4	4
Disposal route	Farmland	kt tds	508	547	590	1216	1282	1422	1479	1548	1556	1525
	Landfill	kt tds	160	153	110	131	35	7	8	0.4	4	4
	Incineration	kt tds	68	80	211	252	238	161	168	137	124	121
	Sea	kt tds	782	721	611	0	0	0	0	0	0	0
	Composted	kt tds	2	2	2	13	23	7	14	2	4	4
	Land Reclamation	kt tds	31	30	30	96	44	0	0	0	0	0
	Other	kt tds	84	124	129	61	44	0	0	0	0	0

Where tds is total dissolvable solids; this is assumed to be comparable to Biochemical Oxygen Demand (BOD)

Table A 3.5.11 UK Domestic and Commercial Waste Water Treatment (5D1) Implied Emission Factors

Process stage	Process type	unit	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Mechanical treatment and storage[1]		kt/Mt tds	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70

Process stage	Process type	unit	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Additional Treatment	Digested[2]	kt/Mt tds	16.54	16.28	16.46	16.93	16.48	15.63	13.26	13.19	0.00	0.00
	Advanced Digested	kt/Mt tds	4.54	4.54	4.54	4.54	4.54	4.52	4.57	4.55	4.55	4.55
	Composted	kt/Mt tds	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Disposal route	Farmland[3]	kt/Mt tds	1.36	1.36	1.36	1.44	1.41	1.30	1.22	1.16	0.96	0.96
	Landfill	kt/Mt tds	15.09	15.09	15.09	15.09	15.09	15.09	15.09	15.09	15.09	15.09
	Incineration	kt/Mt tds	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sea[4]	kt/Mt tds	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
	Composted	kt/Mt tds	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	Land Reclamation[5]	kt/Mt tds	1.36	1.36	1.36	1.36	1.36	1.29	1.22	1.16	0.96	0.96
	Other[6]	kt/Mt tds	1.19	1.19	1.19	1.19	1.19	1.22	1.16	1.07	0.92	0.92
Total[7]		kt/Mt tds	29.81	28.54	30.98	13.47	13.48	11.68	11.05	10.76	10.99	11.13

1. All waste is mechanically treated and stored, so the emission factor is applied to total sludge.
2. Implied emission factor after methane capture.
3. Emission factor varies depending on how the waste is treated.
4. Not an IEF, this is the default IPCC factor for sea, river and lake discharge.
5. Land reclamation hasn't got associated reported emissions, so the factor is based on a weighted average of other waste to land (farmland, composting) IEFs.
6. Other hasn't got associated reported emissions; the factor is based on a weighted average of all other disposal IEFs.
7. For information, IEF when dividing total emissions by total activity.

Table A 3.5.12 UK Domestic and Commercial Waste Water Treatment (5D1) Emission Estimates (kt CH_4)

Process stage	Process type	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Mechanical treatment and storage[1]		4.41	4.47	4.54	4.77	4.50	4.31	4.51	4.56	4.55	4.46
Additional Treatment	Digested[2]	6.62	7.03	7.68	13.46	13.56	10.27	9.13	8.76	8.74	8.71
	Advanced Digested	0.46	0.50	0.53	1.50	1.70	2.06	2.72	3.04	3.66	3.67

Process stage	Process type	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
	Composted	0.07	0.08	0.08	0.15	0.24	0.07	0.14	0.02	0.04	0.04
Disposal route	Farmland[3]	0.68	0.73	0.79	1.71	1.81	1.84	1.81	1.79	1.49	1.46
	Landfill	2.41	2.30	1.66	1.97	0.53	0.10	0.12	0.01	0.05	0.05
	Incineration	-	-	-	-	-	-	-	-	-	
	Sea[4]	33.92	31.99	36.63	-	-	-	-	-	-	
	Composted	0.001	0.001	0.001	0.01	0.01	0.00	0.01	0.001	0.002	0.002
	Land Reclamation[5]	0.04	0.04	0.04	0.13	0.06	-	-	-	-	
	Other[6]	0.10	0.15	0.15	0.07	0.05	-	-	-	-	
Total[7]		48.72	47.29	52.11	23.81	22.46	18.66	18.44	18.17	18.53	18.40

Table A 3.5.13 UK Private Waste Water Management System Emission Estimates Parameters (5D1)

Data	Unit	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Estimated population connected to private wastewater management systems	population (thousands)	1417.18	1440.63	1438.67	1465.29	1525.78	1577.77	1605.40	1605.79	1606.95	1625.52
BOD value applied	g/person/day	66.33	66.33	66.33	68.73	65.90	59.96	62.30	62.69	61.41	59.97

A 3.5.4.2 5D2 Industrial Wastewater Handling and Sludge Disposal

Table A 3.5.14 UK Industrial Wastewater Treatment Activity Data, total industrial product per sector (5D2)

Industry	Units	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Alcohol refining	Kilotonnes	469	469	446	552	554	634	680	573	727	754
Beer & malt	Kilotonnes	7,983	7,983	6,709	7,211	6,499	6,557	6,849	5,794	5,881	5,585

Industry	Units	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Coffee	Kilotonnes	11	11	63	74	80	83	81	86	85	92
Dairy Products	Kilotonnes	6,924	6,924	6,172	6,223	8,539	10,446	8,809	9,095	8,594	8,370
Fish processing	Kilotonnes	191	191	362	363	269	227	230	185	171	152
Iron and Steel manufacturing	Kilotonnes	214	214	177	98	293	810	109	99	99	198
Meat & Poultry	Kilotonnes	2,706	2,706	2,617	2,832	2,603	3,284	3,563	3,593	3,578	3,451
Organic chemicals	Kilotonnes	158	158	129	65	1,192	316	369	306	228	244
Petroleum Refineries	Kilotonnes	86,131	86,131	81,129	80,145	68,599	57,577	56,407	54,853	55,248	55,248
Nitrogen fertiliser	Kilotonnes	1,020	1,021	1,021	1,021	1,076	1,703	2,104	1,850	1,972	3,255
Plastics & resins	Kilotonnes	1,413	1,413	1,334	1,741	1,390	1,780	1,676	1,851	1,710	1,653
Pulp & Paper	Kilotonnes	8,590	8,590	8,138	7,349	8,207	6,822	8,017	5,967	6,219	6,408
Soap & detergents	Kilotonnes	202	202	248	278	291	259	326	285	302	194
Starch production	Kilotonnes	23	23	10	57	163	25	18	18	15	130
Sugar Refining	Kilotonnes	35	35	40	25	22	18	16	15	13	7
Vegetable Oils	Kilotonnes	302	302	288	346	411	574	433	397	386	337
Vegetables, Fruits & Juices	Kilotonnes	990	990	1,052	1,083	820	1,077	845	1,024	885	729
Wine & Vinegar	Kilotonnes	55	559	604	702	685	965	1,108	1,333	1,011	843

A 3.6 UK CROWN DEPENDENCIES AND OVERSEAS TERRITORIES

A 3.6.1 Overview of Data Sources

Fuel use data for Isle of Man, Guernsey and Jersey are assumed to be included in UK national energy statistics (see **Section 1.1.2.2**), so fuel thought to be used in these territories are split out from UK total consumption unless otherwise stated in **Section A 4.2.1**.

Activity data including fuel use data for other territories are obtained from government departments for those territories, specifically:

- The Cayman Islands Government Department of Environment Sustainable Development Unit;
- The Department of Energy Bermuda; and,
- The Falkland Islands Government Policy Unit.

Activity and emissions data estimates from LULUCF sources and sinks have been researched via the FAOSTAT database, to supplement data available from the OTs. The LULUCF data for Cayman Islands from FAOSTAT (FAO, 2018) indicates zero emissions, using Tier 1 methods. The data sources and methodologies used for other sectors are described in the main methodology sections of the NIR.

A 3.6.2 Activity and Emissions Data

Table A 3.6.1 Isle of Man, Guernsey and Jersey – Emissions of Direct GHGs (Mt CO_2 equivalent)

Sector	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
1. Energy	1.48	1.66	1.72	1.40	1.31	1.17	1.18	1.23	1.31	1.05
2. Industrial Processes and Product Use	0.00205	0.0052	0.0186	0.0359	0.0615	0.0779	0.0773	0.0758	0.0721	0.0721
3. Agriculture	0.180	0.186	0.186	0.168	0.156	0.146	0.146	0.143	0.140	0.141
4. LULUCF	-0.0243	-0.0269	-0.0228	-0.0138	-0.00865	-0.0138	-0.0222	-0.024	-0.0254	-0.0249
5. Waste	0.114	0.116	0.119	0.119	0.105	0.0901	0.0859	0.0839	0.0817	0.0773
7. Other	-	-	-	-	-	-	-	-	-	-
Total	**1.76**	**1.93**	**2.02**	**1.71**	**1.62**	**1.47**	**1.47**	**1.51**	**1.58**	**1.32**

Table A 3.6.2 Isle of Man, Guernsey and Jersey - Combustion activity data

Fuel	Fuel Unit	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Aviation spirit	TJ	95.6	109	157	163	85.8	44.8	30.2	28.9	18	2.35
Aviation turbine fuel	TJ	1,270	1,220	1,540	1,670	1,480	1,350	1,500	1,450	1,490	520
Burning oil	TJ	2,880	3,360	4,620	3,970	3,750	3,210	3,270	3,390	3,210	3,280
Coal	TJ	329	210	149	100	8.2	8.84	8.81	8.81	8.81	8.81
DERV	TJ	1,060	1,340	1,910	1,690	1,790	1,920	2,020	2,040	2,000	1,830
Fuel oil	TJ	6,350	7,850	5,900	1,060	1,210	812	452	884	1,700	220
Gas oil	TJ	3,380	3,650	3,630	3,090	2,230	1,890	1,980	2,050	1,900	1,570
LPG	TJ	810	806	1,960	1,240	1,090	670	643	674	642	566
MSW	TJ	268	374	479	866	795	1,050	1,040	1,080	1,060	1,040
Natural gas	TJ	-	-	-	3,370	4,020	3,700	4,040	4,140	4,940	4,780
Petrol	TJ	3,510	3,400	3,230	3,270	2,850	2,520	2,370	2,310	2,270	1,950
Urea consumption	Mt	-	-	-	-	0.00029	0.000677	0.000776	0.000792	0.000782	0.000698

Table A 3.6.3 Isle of Man, Guernsey and Jersey - Animal numbers

Livestock Category	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Dairy	15,888	15,729	16,186	13,127	11,511	10,846	11,451	11,192	10,807	10,687
Non-dairy	28,663	28,333	29,176	16,770	28,821	26,643	24,601	23,927	22,910	23,334
Sheep	151,764	160,228	176,259	87,537	138,251	133,666	129,139	126,029	129,171	129,171

Livestock Category	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2017**	**2018**	**2019**	**2020**
Pigs	4,854	5,411	4,609	1,148	4,086	2,861	2,364	2,188	2,154	2,391
Poultry	84,048	46,481	46,448	58,160	54,400	62,916	62,537	59,485	59,734	60,408
Goats	333	347	376	141	288	539	396	458	484	452
Horses	2,785	2,785	2,785	2,822	3,236	2,891	2,705	2,536	2,591	2,591

Table A 3.6.4 Isle of Man, Guernsey and Jersey – Total emissions from Agricultural Soils (Mt CO_2 equivalent)

Territory	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2017**	**2018**	**2019**	**2020**
Isle of Man	0.0451	0.0455	0.0412	0.0338	0.0291	0.0268	0.0266	0.0263	0.0262	0.0263
Guernsey	0.0035	0.0036	0.0031	0.0027	0.0028	0.0027	0.0028	0.0028	0.0028	0.0027
Jersey	0.0091	0.0097	0.0094	0.0080	0.0078	0.0075	0.0075	0.0074	0.0073	0.0071

Table A 3.6.5 Cayman Islands, Falklands Islands, and Bermuda - Emissions of Direct GHGs (Mt CO_2 equivalent)

Sector	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2017**	**2018**	**2019**	**2020**
1. Energy	1.23	1.25	1.40	1.59	1.58	1.69	1.66	1.67	1.64	1.51
2. Industrial Processes and Product Use	0.000379	0.00238	0.0148	0.0881	0.220	0.383	0.440	0.457	0.452	0.452
3. Agriculture	0.274	0.265	0.249	0.222	0.184	0.181	0.185	0.175	0.180	0.169
4. LULUCF	0.0943	0.0928	0.100	0.101	0.238	0.135	0.139	0.140	0.133	0.134
5. Waste	0.115	0.100	0.0831	0.0833	0.128	0.109	0.111	0.114	0.117	0.122
7. Other	-	-	-	-	-	-	-	-	-	-
Total	**1.72**	**1.71**	**1.85**	**2.08**	**2.35**	**2.50**	**2.53**	**2.56**	**2.52**	**2.39**

Table A 3.6.6 Cayman Islands, Falklands Islands, and Bermuda - Combustion activity data

Fuel	Fuel Unit	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Aviation spirit	TJ	1.88	-	-	-	-	-	-	-	-	-
Aviation turbine fuel	TJ	3,990	2,850	2,950	2,630	2,870	2,590	2,860	2,840	2,900	1,280
Burning oil	TJ	63.3	78.3	90.2	117	105	129	118	128	137	137
DERV	TJ	2,160	1,850	1,540	3,400	1,450	1,300	1,310	1,310	1,310	1,310
Fuel oil	TJ	1,970	2,060	3,600	4,140	4,270	4,300	5,110	4,500	4,550	4,320
Gas oil	TJ	5,670	6,370	6,130	6,750	7,770	8,140	8,090	8,630	8,970	8,770
LPG	TJ	263	294	326	377	386	422	452	471	507	503
MSW	TJ	0.931	453	453	453	426	362	435	465	461	455
Natural gas	TJ	1.57	1.94	2.24	2.8	3.32	3.65	3.52	3.37	3.43	3.43
Petrol	TJ	2,830	2,870	3,200	2,540	2,940	2,120	2,360	2,620	2,610	2,210
Urea consumption	kg	-	-	-	-	212,000	563,000	597,000	598,000	594,000	590,000
Lubricants	TJ	63.9	76	75.8	73.8	69.3	60.5	63.5	59.4	61.1	45.6
Petroleum waxes	kg	83,500	71,700	58,400	139,000	72,700	88,100	80,100	75,300	95,400	81,300

Table A 3.6.7 Cayman Islands, Falklands Islands, and Bermuda - Animal numbers

Livestock Category	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Dairy Cattle	2,161	1,862	1,911	1,145	868	675	647	598	595	580
Non-dairy Cattle	5,256	4,861	5,077	7,845	6,360	4,748	4,913	4,772	4,860	5,003

Livestock Category	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Sheep	739,999	717,571	669,905	580,864	478,625	482,131	490,213	462,245	476,867	444,834
Goats	405	867	1,286	1,704	2,251	1,812	2,337	2,546	2,689	2,689
Horses	2,217	2,069	1,703	1,417	1,269	1,223	1,244	1,221	1,227	1,184
Swine	1,116	1,174	1,376	1,384	1,233	1,058	1,301	1,485	1,579	1,502
Poultry	15,319	14,664	20,890	27,164	32,293	39,458	26,710	30,019	31,805	33,844
Deer	0	0	0	0	184	0	0	0	0	0

Table A 3.6.8 Cayman Islands, Falklands Islands, and Bermuda ‐ Total emissions from Agricultural Soils (Mt CO_2 equivalent)

Territory	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Bermuda	0.0007	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008
Cayman Islands	0.0008	0.0010	0.0011	0.0013	0.0013	0.0012	0.0011	0.0012	0.0012	0.0014
Falkland Islands	0.1083	0.1045	0.0978	0.0860	0.0717	0.0715	0.0727	0.0688	0.0708	0.0663

Table A 3.6.9 Cayman Islands, Falklands Islands, and Bermuda - Amount of synthetic fertilizer applied

Country	kg N applied
Cayman Islands	28,834
Falkland Islands	0
Bermuda	1,480

Table A 3.6.10 Gibraltar ‑ Emissions of Direct GHGs (Mt CO_2 equivalent)

Sector	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
1. Energy	0.217	0.214	0.240	0.276	0.287	0.335	0.307	0.309	0.303	0.188
2. Industrial Processes and Other Product Use	0.000488	0.00112	0.00218	0.00417	0.00714	0.0105	0.0114	0.01140	0.0108	0.0108
3. Agriculture	-	-	-	-	-	-	-	-	-	-
4. LULUCF	-	-	-	-	-	-	-	-	-	-
5. Waste	0.00721	0.00873	0.0117	0.0015	0.00316	0.0018	0.00191	0.00191	0.0019	0.00187
7. Other	-	-	-	-	-	-	-	-	-	-
Total	**0.224**	**0.224**	**0.254**	**0.281**	**0.297**	**0.348**	**0.320**	**0.322**	**0.315**	**0.200**

Table A 3.6.11 Gibraltar ‑ Combustion activity data

Fuel	Fuel Unit	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Aviation spirit	TJ	1.07	-	-	-	-	-	-	-	-	-
Aviation turbine fuel	TJ	384	339	256	399	329	415	563	380	440	197
Clinical waste	Mt	-	-	-	-	0.00181	0.000306	0.000356	0.000356	0.000356	0.000356
DERV	TJ	82.2	67.7	141	329	347	491	491	624	623	623
Fuel oil	TJ	12,000	12,200	20,600	30,300	34,800	34,000	37,800	33,300	31,700	31,500
Gas oil	TJ	1,510	1,680	2,320	3,170	3,790	4,570	4,330	4,420	3,360	2,360
LPG	TJ	382	382	382	382	382	384	402	402	426	420
MSW	TJ	109	126	160	-	-	-	-	-	-	-

Fuel	**Fuel Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2017**	**2018**	**2019**	**2020**
Petrol	TJ	298	254	352	353	329	250	286	326	325	325
Petroleum waxes	Mt	0.0000297	0.0000206	0.0000147	0.0000348	0.0000184	0.0000233	0.0000208	0.0000194	0.0000236	0.0000207
Lubricants	TJ	22.7	21.8	19.1	18.5	17.5	16.0	16.5	15.3	15.1	11.6

Table A 3.6.12 Isle of Man, Guernsey and Jersey – Total Municipal Solid Waste activity data (Gg)

Territory	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2017**	**2018**	**2019**	**2020**
Isle of Man	39.4	40.4	43.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guernsey	56.7	56.7	56.7	56.7	35.0	29.5	27.2	27.2	4.16	3.73
Jersey	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table A 3.6.13 Cayman Islands, Falklands Islands, and Bermuda – Total Municipal Solid Waste activity data (Gg)

Territory	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2017**	**2018**	**2019**	**2020**
Cayman Islands	34.0	34.0	34.0	144	94.1	63.0	106	108	136	136
Falklands Islands	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bermuda	64.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

ANNEX 4: National Energy Balance

A 4.1 UK ENERGY BALANCE

The UK energy balance is produced and published annually by the Department of Business, Energy & Industrial Strategy in the Digest of UK Energy Statistics – DUKES. This is available online from:

https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

The aggregate energy balance for the latest year is presented below (Table 1.1 in DUKES). The following sections explain how the energy balance is used for the UK inventory for individual fuel types, and how the data are supplemented with other statistics that may lead to deviations from the DUKES statistics.

The UK energy statistics (detailed breakdown) are presented on a mass basis for liquid and solid fuels, and on a gross energy basis for gaseous fuels (including derived gases). The UK inventory is calculated using these data directly, and for the purposes of reporting in the CRF and NIR, activity data and emission factors are converted to energy units, on a net basis.

The scope of the UK energy balance, as shown below, is fuel use in the United Kingdom and its Crown Dependencies (Jersey, Guernsey and the Isle of Man), as described in the NIR **Section 1.1.2.2**.

The fuel use estimates for Overseas Territories (OTs) are not included within DUKES, and are obtained through direct communications with the respective government contacts in each of the OTs.

Table A 4.1.1 UK Energy Balance for 2020 (thousand tonnes of oil equivalent, gross energy basis)

	Coal	Manufactured fuel(1)	Primary oils	Petroleum products	Natural gas(2)	Bioenergy & waste(3)	Primary electricity	Electricity	Heat sold	Total
Supply										
Production	1,158	-	53,648	-	37,706	12,715	18,914	-	-	124,140
Imports	3,139	812	43,006	26,741	41,117	5,652	-	1,925	-	122,392
Exports	-862	-8	-43,593	-20,287	-9,106	-404	-	-385	-	-74,645
Marine bunkers	-	-	-	-2,010	-	-	-	-	-	-2,010
Stock change*(4)*	+1,427	+5	+183	-664	-918	-12	-	-	-	+22
Primary supply	**4,862**	**809**	**53,244**	**3,781**	**68,799**	**17,951**	**18,914**	**1,540**	**-**	**169,899**
Statistical difference*(5)*	-19	+1	+3	-38	-446	-	-	-8	-	-506
Primary demand	**4,881**	**808**	**53,241**	**3,818**	**69,245**	**17,951**	**18,914**	**1,548**	**-**	**170,406**
Transfers	-	-1	-992	+652	+527	-544	-8,194	+8,194	-	-359
Transformation	**-3,692**	**167**	**-52,248**	**51,657**	**-22,434**	**-11,662**	**-10,720**	**18,513**	**1,584**	**-28,837**
Electricity generation	-1,471	-515	-	-321	-19,915	-11,453	-10,720	18,513	-	-25,883
Major power producers	-1,461	-	-	-99	-17,761	-5,392	-10,720	15,354	-	-20,079
Autogenerators	-10	-515	-	-222	-2,154	-6,062	-	3,159	-	-5,804
Heat generation	-4	-1	-	-46	-2,520	-209	-	-	1,584	-1,195
Petroleum refineries	-	-	-52,661	52,533	-	-	-	-	-	-128

	Coal	Manufactured fuel(1)	Primary oils	Petroleum products	Natural gas(2)	Bioenergy & waste(3)	Primary electricity	Electricity	Heat sold	Total
Coke manufacture	-1,273	1,202	-	-	-	-	-	-	-	-71
Blast furnaces	-838	-660	-	-	-	-	-	-	-	-1,498
Patent fuel manufacture	-107	141	-	-55	-	-	-	-	-	-20
Other(7)	-	-	413	-454	-	-	-	-	-	-41
Energy industry use	**-**	**384**	**-**	**3,391**	**5,121**	**-**	**-**	**1,884**	**329**	**11,110**
Electricity generation	-	-	-	-	-	-	-	1,231	-	1,231
Oil and gas extraction	-	-	-	632	4,394	-	-	54	-	5,080
Petroleum refineries	-	-	-	2,759	146	-	-	398	329	3,632
Coal extraction	-	-	-	-	7	-	-	29	-	35
Coke manufacture	-	137	-	-	-	-	-	2	-	139
Blast furnaces	-	247	-	-	26	-	-	15	-	288
Patent fuel manufacture	-	-	-	-	-	-	-	-	-	-
Pumped storage	-	-	-	-	-	-	-	40	-	40
Other	-	-	-	-	547	-	-	116	-	663
Losses	**-**	**80**	**-**	**-**	**236**	**-**	**-**	**2,272**	**-**	**2,588**
Final consumption	**1,188**	**509**	**-**	**52,736**	**41,981**	**5,745**	**-**	**24,099**	**1,255**	**127,512**
Industry	**837**	**318**	**-**	**2,166**	**8,126**	**1,676**	**-**	**7,195**	**682**	**21,001**
Unclassified	-	-	-	1,258	0	303	-	-	-	1,561
Iron and steel	16	318	-	6	333	-	-	190	-	864

	Coal	Manufactured fuel(1)	Primary oils	Petroleum products	Natural gas(2)	Bioenergy & waste(3)	Primary electricity	Electricity	Heat sold	Total
Non-ferrous metals	14	-	-	6	236	-	-	335	-	592
Mineral products	360	-	-	163	1,155	296	-	474	-	2,449
Chemicals	32	-	-	127	1,736	152	-	1,274	230	3,551
Mechanical engineering etc	7	-	-	0	734	1	-	443	1	1,186
Electrical engineering etc	3	-	-	1	254	-	-	483	-	740
Vehicles	29	-	-	174	404	-	-	306	-	913
Food, beverages etc	37	-	-	107	1,673	73	-	936	17	2,843
Textiles, leather etc	36	-	-	39	239	-	-	204	-	517
Paper, printing etc	50	-	-	27	368	512	-	772	0	1,729
Other industries	251	-	-	34	563	340	-	1,678	434	3,299
Construction	3	-	-	222	431	-	-	100	-	757
Transport *(6)*	**9**	**-**	**-**	**38,355**	**27**	**1,638**	-	**431**	**-**	**40,461**
Air	-	-	-	5,514	-	-	-	-	-	5,514
Rail	9	-	-	577	-	-	-	384	-	970
Road	-	-	-	31,792	27	1,638	-	48	-	33,505
National navigation	-	-	-	473	-	-	-	-	-	473
Pipelines	-	-	-	-	-	-	-	-	-	-
Other	**342**	**141**	-	**6,069**	**33,439**	**2,430**	**-**	**16,472**	**573**	**59,466**
Domestic	320	141	-	2,550	25,735	987	-	9,273	269	39,276

	Coal	Manufactured fuel(1)	Primary oils	Petroleum products	Natural gas(2)	Bioenergy & waste(3)	Primary electricity	Electricity	Heat sold	Total
Public administration	13	-	-	696	2,999	40	**-**	1,410	79	5,237
Commercial	4	-	-	1,496	3,782	1,272	**-**	5,443	221	12,218
Agriculture	-	-	-	910	87	130	**-**	346	4	1,477
Miscellaneous	5	-	-	418	835	-	-	-	-	1,258
Non energy use	-	**49**	-	**6,146**	**389**	-	-	-	-	**6,584**

(1) Includes all manufactured solid fuels, benzole, tars, coke oven gas and blast furnace gas.

(2) Includes colliery methane.

(3) Includes geothermal, solar heat, and heat pumps.

(4) Stock fall (+), stock rise (-).

(5) Primary supply minus primary demand.

(6) See DUKES 2020 paragraphs 5.21 regarding electricity use in transport and 6.44-6.49 regarding renewables use in transport.

(7) Back-flows from the petrochemical industry.

A 4.2 FUELS DATA

The fuels data are taken from DUKES - the Digest of UK Energy Statistics (BEIS, 2021), so the fuel definitions and the source categories used in the NAEI reflect those in DUKES.

IPCC Guidelines (IPCC, 2006) lists fuels that should be considered when reporting emissions. **Table A 4.2.1** lists the fuels that are used in the GHGI (based on DUKES) and indicates how they relate to the fuels listed in the IPCC Guidelines. In most cases the mapping is obvious but there are a few cases where some explanation is required.

Table A 4.2.1 Mapping of fuels used in IPCC and the NAEI

Category	IPCC Fuel Name	NAEI Fuel Name
Liquid	Motor Gasoline	Petrol
	Aviation Gasoline	Aviation Spirit
	Jet Kerosene	Aviation Turbine Fuel[1] (ATF)
	Other Kerosene	Burning Oil
	Gas/Diesel Oil	Gas Oil/ DERV
	Residual Fuel Oil	Fuel Oil
	Orimulsion	Orimulsion
	Liquefied Petroleum Gases	Liquefied Petroleum Gas (LPG)
	Naphtha	Naphtha
	Petroleum Coke	Petroleum Coke
	Refinery Gas	Other Petroleum Gas (OPG)
	Other Oil: Other Petroleum Products	Refinery Miscellaneous
	Lubricants	Lubricants
Solid	Anthracite	Anthracite
	Coking Coal	Coal[2]
	Other Bituminous Coal	Coal
		Slurry[3]
	Coke Oven Coke	Coke
	Patent Fuel	Solid Smokeless Fuel (SSF)
	Coke Oven Gas	Coke Oven Gas
	Blast Furnace Gas	Blast Furnace Gas

Category	**IPCC Fuel Name**	**NAEI Fuel Name**
Gaseous	Natural Gas	Natural Gas
		Sour Gas[4]
		Colliery Methane[5]
Other Fuels	Municipal Solid Waste	Municipal Solid Waste
	Industrial Waste: Scrap Tyres	Scrap Tyres
	Waste Oils	Waste Oil
Peat	Peat	Peat
Biomass	Wood/Wood Waste	Wood
	Other Primary Solid Biomass	Straw
		Poultry Litter, Meat & bone meal
	Landfill Gas	Landfill Gas
	Sludge Gas	Sewage Gas
	Charcoal	Charcoal
	Other liquid biofuels	Liquid Biofuels
	Other biogas	Biogas

1 Includes fuel that is correctly termed jet gasoline.

2 Used in coke ovens.

3 Coal-water slurry used in some power stations

4 Unrefined natural gas used on offshore platforms and some power stations

5 IPCC Guidelines (IPCC, 2006) specifies coal seam methane is included in Natural Gas.

A 4.2.1 Reallocations of energy data and differences from UK energy statistics

The main source of energy consumption data used in the UK inventory is the Digest of UK Energy Statistics (DUKES; BEIS, 2021). This annual publication gives detailed sectoral energy consumption broken down by fuel type, and covering the entire time period of the inventory. In many cases, these data are used directly in the inventory without modification. However, there are instances where the activity data used are not based directly on DUKES, instead utilising alternative data sources which provide supplementary information to the allocation of fuel to individual sectors and sources. In general, the UK inventory totals by fuel are kept consistent with the DUKES national totals for each fuel. There are some exceptions where the UK total may be different to that presented in DUKES due to different scopes and reporting requirements.

The reasons for any deviations from use of DUKES data in the inventory are discussed within the source category methodological descriptions in Section 3 of the main report. The main reasons for reallocations or modifications are:

- To account for differences in geographical scope (e.g. to account for energy use in OTs)
- To make best use of EU ETS data (this data is only used indirectly in producing UK energy statistics)

- To utilise other operator reported data (e.g. direct to the Inventory Agency, or to environmental or industry regulators).
- When bottom-up models are available providing fuel consumption data on a more granular level and are considered to be a higher quality estimate by the Inventory Agency.

The fuel reconciliation tables (**Table A 4.2.2** - **Table A 4.2.6**) show how the deviations are applied and how the energy data for the major fuels in the UK inventory are reconciled against the energy demand data from DUKES. The tables show:

1. Where fuels are re-allocated between sectors, but the overall annual fuel consumption across all UK sectors is kept consistent with the data in DUKES; and
2. Where deviations are made to DUKES figures for total UK consumption of a given fuel, and in which source categories these deviations are made.

The Inventory Agency presents data below for the fuel allocations for coal, natural gas, fuel oil, gas oil (including DERV) and petroleum gases (LPG, OPG) for the latest inventory year. Together these fuels constitute the majority of the UK inventory 1A sector emissions total.

Deviations to the energy balance are made in consultation with the authors of the energy statistics.

A 4.2.1.1 Coal

Total coal use within the GHG inventory is consistent with the DUKES total and in most cases, coal use at the sectoral level is also consistent with the DUKES data. However, there are several instances where operator-reported data, either via trade associations such as the Mineral Products Association, or through EU ETS, indicates slight differences from the DUKES statistics. In those cases, the Inventory Agency deviates from DUKES to ensure higher accuracy for those source categories. Overall, however, the DUKES demand total is regarded as complete and accurate and therefore the 1A2gviii Other Industrial Combustion is used as the ‘residual’ source category, to deliver exact reconciliation between GHGI activity and the DUKES demand total. **Table A 4.2.2** below presents the comparison between UK inventory estimates with DUKES estimates for the latest inventory year.

Table A 4.2.2 Fuel reconciliation: Coal use in the latest year (Mtonnes)

DUKES Category	Activity (Mt)	GHGI	IPCC Sector	Activity (Mt)	Difference	Comment
Major power producers	2.308	Power Stations	1A1ai	2.308	0.000	
Autogenerators	0.016	Autogenerators (inc. exports to grid)	1A2b	0.016	0.000	
Heat generation	0.006	n/a	n/a	0.000	0.006	Heat generation emissions are considered to be included within the 'Other' section below under sources like public and misc. combustion
Coke manufacture	1.675	Coke manufacture	2C1	1.638	0.037	Operator-provided data used in preference to DUKES

DUKES Category	**Activity (Mt)**	**GHGI**	**IPCC Sector**	**Activity (Mt)**	**Difference**	**Comment**
Blast furnaces	1.102	Blast furnaces	1B1b	1.102	0.000	
Patent fuel manufacture	0.166	Solid smokeless fuel production	1B1b	0.166	0.000	
Coal extraction	0.000	Collieries - combustion	1A1ciii	0.000	0.000	
Other industries	1.048	Other industrial combustion	1A2gviii	0.527		NAEI other industry used to reconcile overall consumption to DUKES total.
Iron and steel	0.024	Iron and steel - combustion plant	1A2a	0.024		
Non-ferrous metals	0.024	Non-ferrous metal (combustion)	1A2b	0.024		
Minerals	0.000	Cement and lime processes	1A2f	0.558		Cement and lime sector data from MPA and EU ETS used in preference to DUKES
Chemicals	0.050	Chemicals (combustion)	1A2c	0.050		
food beverages	0.054	Food & drink, tobacco (combustion)	1A2e	0.055		
Paper printing	0.087	Pulp, Paper and Print (combustion)	1A2d	0.087		
TOTAL industry	1.287	**TOTAL industry**	∑1A2	1.326	- 0.039	Some operator data used, also some re-allocation of heat generation data.
Rail	0.013	Rail transport	1A3c	0.013	0.000	
Domestic	0.468	Domestic combustion	1A4bi	0.468	0.000	
Public Administration	0.018	Public sector combustion	1A4ai	0.022	- 0.004	Some reallocation from industry and heat-generation
Commercial	0.005	Miscellaneous industrial/commercial combustion	1A4ai	0.012	0.000	
Miscellaneous	0.007					
Agriculture	0.000	Agriculture (mobile & stationary combustion)	1A4ai	0.000	0.000	
TOTAL (all)	**7.072**	**TOTAL (all)**		**7.072**	**0.000**	**Fully reconciled to DUKES demand total.**

Notes: Rows are shaded to help illustrate reconciliation between sectors.

A 4.2.1.2 Natural Gas

Data for natural gas use is largely taken directly from DUKES and the national total is consistent between the inventory and the energy statistics, other than a small additional use of natural gas at a number of (international) gas pipeline inter-connectors and also on the Isle of Man (IoM) which is added to the inventory, as natural gas use on IoM is not included in DUKES demand totals. Operator estimates for ammonia production (both fuel and feedstock), and ETS data for gas separation plant lead to minor reallocations of the DUKES data, these are summarised below in **Table A 4.2.3**. In addition, the NAEI model doesn't include any accounting for losses compared to DUKES tables.

Table A 4.2.3 Fuel reconciliation: Natural gas and Colliery Methane use in the latest year (TJ net)

DUKES Category	Activity (TJ net)	GHGI	IPCC Sector	Activity (TJ net)	Difference	Comment
NATURAL GAS						
Major power producers	671,065	Power Stations (UK)	1A1ai	671,065	0.000	Note that one site in the GHGI, the fuel is termed sour gas based on EU ETS.
		Power Stations (CDs)	1A1ai	3,799	- 3,799	Isle of Man gas use is additional, as it is not reported within DUKES
Oil and gas extraction	166,037	Upstream Oil/Gas production	1A1cii	168,670	- 2,632	EU ETS natural gas use in upstream facilities exceeds DUKES reported total. Inventory uses EU ETS in preference and the difference is regarded as additional to the data in the UK energy stats. (See additional commentary in MS for 1A1cii).
Coal extraction	256	Collieries - combustion	1A1ciii	256	0.000	
Blast furnaces	1,001	Blast furnaces	2C1b	1,001	0.000	No change in AD from DUKES to GHGI but note change in allocation; previously 1A2a now 2C1b.
Other	20,683	Gas production	1A1ciii	21,916	- 1,233	Gas use to drive international gas interconnector pipelines are excluded from DUKES; they are added from EU ETS data.
Petroleum refineries	21,693	Petroleum Refineries	1A1b	46,892		Re-allocation in the GHGI of gas use from autogeneration to the refinery sector
Autogenerators	80,784	Autogeneration (inc. exports to grid)	1A2gviii	56,592		
	1,044	Railways - stationary combustion	1A4ai	39		
	103,522			103,522	0.000	Reconciled over these sources.

DUKES Category	Activity (TJ net)	GHGI	IPCC Sector	Activity (TJ net)	Difference	Comment
Agriculture	3,450	Agriculture - stationary combustion	1A4ci	3,450		
Commercial	158,367	Miscellaneous industrial/commercial combustion	1A4ai	189,932		GHGI total is the sum of DUKES Commercial and Miscellaneous.
Miscellaneous	31,565			-		
Domestic	972,375	Domestic combustion	1A4bi	973,359		
Public Administration	129,794	Public sector combustion	1A4ai	129,794		
Subtotal	**1,295,551**	*Subtotal*		1,296,535	- 984	Domestic gas use on the Isle of Man is additional, as it is not included in DUKES
Iron and steel	14,106	Iron and steel - combustion plant	1A2a	14,166		
Non-ferrous metals	9,747	Non-Ferrous Metal (combustion)	1A2b	9,747		
Chemicals	85,499	Chemicals (combustion)	1A2c	85,499		
Paper, printing, etc.	19,371	Pulp, Paper and Print (combustion)	1A2d	19,371		
Food, beverages, etc.	68,271	Food & drink, tobacco (combustion)	1A2e	68,271		
		Cement processes	1A2f	4,545		
Other	155,899	Other industrial combustion	1A2gviii	127,214		
Subtotal	**352,892**	*Subtotal*		**328,813**	24,079	Reduced to account for greater NEU implied by alternative NAEI data sources
NEU	14,694	Ammonia production	2B1	29,351		
		Other NEU (non-emissive)	n/a	9,422		
Subtotal	14,694			38,773	- 24,079	Offset by industrial combustion reductions
Losses	8,908	Losses			8,908	GHGI doesn’t report a ‘losses’ category in energy units, but directly reports gas transporter estimates of leakage in mass of methane terms.
TOTAL	**2,634,610**		**TOTAL**	**2,634,351**	**259**	
TOTAL Excl. Losses	**2,625,702**		**TOTAL Excl. Losses**	**2,634,351**	**- 8,649**	GHGI allocation for combusted gas is higher than DUKES due to the addition of gas use in the Isle of Man and at gas interconnectors and upstream oil and gas.

DUKES Category	Activity (TJ net)	GHGI	IPCC Sector	Activity (TJ net)	Difference	Comment
COLLIERY METHANE						
Autogenerators	599	Collieries - combustion	1A1ciii	599	0.000	
Unclassified industry	16	Other industrial combustion	1A2gviii	16	0.000	
TOTAL	**615**		**TOTAL**	**615**	0.000	Exact reconciliation

Notes: Rows are shaded to help illustrate reconciliation between sectors. Note that DUKES activity data is originally in gross energy terms. Reconciliation has been calculated by net terms using a net/gross ratio derived from sources external to DUKES (i.e. from information provided by the GB's gas network operators).

A 4.2.1.3 Fuel Oil

For shipping, a major research project was completed in 2017 and the results were incorporated from the 2018 submission onwards. The estimated total fuel oil consumption derived from this research is greater than as reported for shipping in DUKES, and any deviations from the national navigation sector are considered additional and are not reconciled elsewhere in the inventory. Additional sectoral deviations are also made to account for known use of fuel oil in power stations, and the Crown Dependencies.

Table A 4.2.4 Fuel reconciliation: Fuel oil use in latest year (Mtonnes)

DUKES Category	Activity (Mt)	GHGI	IPCC Sector	Activity (Mt)	Difference	Comment
Major power producers	0.045	Power Stations	1A1ai	0.055	- 0.010	EU ETS data used for AD for UK power stations. For CDs, local datasets are used
Autogenerators	0.022	Autogenerators (inc. exports to grid)	1A2gviii	0.000	0.022	Fuel reallocated to iron and steel works and other industry on the basis of data provided by BEIS
Oil gas extraction	0.050	Upstream Oil/Gas production	1A1ciii	0.000	0.050	Fuel oil allocated to oil and gas extraction in DUKES is reallocated to other industrial combustion
Petroleum refineries	0.088	Refineries - combustion	1A1b	0.088	0.000	
Other industries	0.054	Other industrial combustion	1A2gviii	0.105	- 0.052	Calculated as a residual, to account for differences (e.g. from EU ETS) in power stations, and allocation of autogeneration
Iron and steel	0.006	Iron and steel - combustion plant	1A2a	0.016	-0.011	Increased to account for share of autogeneration and to include fuel allocated to blast furnaces
Non-ferrous metals	0.000	Non-ferrous metal (combustion)	1A2b	0.000	0.000	

DUKES Category	**Activity (Mt)**	**GHGI**	**IPCC Sector**	**Activity (Mt)**	**Difference**	**Comment**
Chemicals	0.009	Chemicals (combustion)	1A2c	0.009	0.000	
food beverages	0.002	Food & drink, tobacco (combustion)	1A2e	0.002	0.000	
Paper printing	0.001	Pulp, Paper and Print (combustion)	1A2d	0.001		
TOTAL industry	0.072	TOTAL industry	∑1A2	0.134	- 0.062	GHGI allocates residual fuel oil to industry hence this higher GHGI figure reflects no specific allocation to oil and gas, autogeneration etc.
National navigation	0.003	Shipping - coastal	1A3d	0.146		
		Shipping between UK and CDs	1A3d	0.000		
		Shipping between UK and OTs	1A3d	0.006		Shipping between the UK and overseas territories (Incl. Gibraltar, Bermuda) so outside of DUKES scope.
		Fishing vessels	1A4ciii	0.008		
		TOTAL National navigation		0.160	-0.157	GHGI shipping/fishing activity data is based on bottom-up methodology. This activity data is additional to DUKES Also GHGI accounts for CD/OT activity which is outside of DUKES scope.
Marine bunkers	0.546	Marine bunkers	Memo item	0.540	0.006	
Public Administration	0.011	Public sector combustion	1A4ai	0.011	-	
Commercial	0.020	Miscellaneous industrial/commercial combustion	1A4ai	0.021	0.000	
Miscellaneous	0.002					
Agriculture	0.006	Agriculture (mobile & stationary combustion)	1A4ci	0.006	0.000	
TOTAL (all sectors)	0.864	TOTAL (all sectors)		1.015	-0.151	Higher overall reported FO use in the GHGI due to coastal shipping and fishing estimates.

notes: Rows are shaded to help illustrate reconciliation between sectors.

A 4.2.1.4 Gas Oil

Gas oil is used in both off-road transport and machinery diesel engines, and as a fuel for stationary combustion. The varied use of this fuel and the complexity of the supply chain complicates the means of allocating consumption across the wide range of sectors that use the fuel in the inventory. DUKES provides a breakdown of gas oil consumption in different economic sectors, but the data resolution in DUKES does not distinguish between use of the fuel for stationary combustion and off-road machinery, a distinction which is necessary for the inventory.

The GHGI estimates consumption of gas oil and emissions for off-road machinery using a bottom-up method based on estimates of population and usage of different types of machinery. However, this has led to a situation where the total amount of gas oil consumption across sectors exceeds that which is available as given in DUKES. Therefore, consumption figures, mainly for stationary combustion in industry sectors, have had to be adjusted to obtain a total fuel balance.

In addition to off-road mobile machinery, gas oil allocations are also required for other sources such as vessels on the UK's inland waterways (Walker et al, 2011). Research into fuel use on inland waterways indicates that not all vessels with diesel engines use gas oil, but that some also use road diesel; this may also apply to other off-road machinery sources, especially those that consume small amounts of fuel on an irregular basis, e.g. for private or recreational use rather than commercial use. There are also inconsistencies in terminology used to define types of fuel; the research indicated that the terms "gas oil", "red diesel" and "diesel" are used interchangeably by fuel suppliers and consumers and this confuses the situation when considering fuel allocations across different sectors.

To address these issues, an inventory improvement task was commissioned (Murrells et al., 2011), to develop an inventory methodology that is retained in the current submission.

Several fuel suppliers and experts in the petroleum industry and at the Department for Transport were consulted to understand terminologies used, the physical differences between gas oil and DERV, and to gauge opinions on what determines where the fuels are mainly used where it is possible to use either gas oil or DERV. The study concluded that while the majority of agricultural and industrial machinery will be using low tax gas oil (red diesel), a small amount of DERV is likely to be used by private recreational boat users and by equipment with small engines used for private or small-scale commercial use on an irregular basis and the gas oil fuel supply infrastructure makes it more convenient to use DERV.

The study provided new estimates of the amount of DERV and petrol consumed by non-road transport sources with small internal combustion engines. This reduces the overestimation of gas oil consumption and relieves the pressure on how much gas oil consumption by other sources has to be adjusted to match the total amount available as given in DUKES.

The study also considered the allocation of gas oil given in DUKES to different industry and other sectors and how these can be mapped to inventory reporting categories. The detailed bottom-up method is used to estimate gas oil consumption by different off-road machinery and marine vessel types. Independent sources were used to estimate gas oil used by the rail sector while data provided by industrial sites reporting under emission trading schemes (EU ETS) were used to derive an allocation of gas oil consumption by stationary combustion sources in different industry, commercial and other sectors. Also, the UK energy statistics now include an allocation of gas oil for consumption by the oil and gas sector, but since only a partial time series was made available, the study included making estimates of gas oil for this category back to 1990.

A method of re-allocation was developed using an over-arching condition that the total sum of gas oil consumption across all sectors was consistent with the total consumption figures given in DUKES across all years. The method allowed the consumption estimates for industrial off-road machinery and stationary combustion by industry, commercial and public sector activities to vary in order to align the total consumption estimates with DUKES on the basis that the estimates for these sources are the most uncertain.

As with fuel oil, the introduction of the results of a major research project into the shipping sector in the 2018 submission, whereby Automatic Identification System (AIS) data was used to calculate shipping movements along the coast of the UK and the Crown Dependencies, however suggested that gas oil consumption reported by DUKES is an underestimate. As a result, total gas oil use (not including DERV) deviates from DUKES as any further consumption in the national navigation sector are considered additional to DUKES and are not reconciled elsewhere in the inventory.

Table A 4.2.5 below summarised the DUKES and GHGI allocations for the latest inventory year.

Table A 4.2.5 Fuel reconciliation: Gas oil use in latest year (Mtonnes)

DUKES Category	Activity (Mt)	GHGI	IPCC Sector	Activity (Mt)	Difference	Comment
Major power producers	0.049	Power Stations	1A1ai	0.049	0.000	
Autogenerators	0.042	Autogenerators (inc. exports to grid)	1A2gviii	0.000	0.042	Fuel reallocated to iron and steel works and other industries on the basis of data provided by BEIS
Oil gas extraction	0.533	Upstream Oil/Gas production	1A1ciii	0.533	0.000	
Petroleum refineries	0.000	Refineries - combustion	1A1b	0.000	0.000	
Other industries	1.072	Other industrial combustion	1A2gviii	0.040		Calculated as a residual to accommodate bottom-up estimates in other sectors.
Iron and steel	0.000	Iron and steel - combustion plant	1A2a	0.002		Data provided by operators
Non-ferrous metals	0.006	Non-ferrous metal (combustion)	1A2b	0.000		
Mineral products	0.000	Cement production	1A2f	0.004		Data provided by cement operators
Chemicals	0.108	Chemicals (combustion)	1A2c	0.005		GHGI estimates for AD in several 1A2 stationary combustion sectors are lower than DUKES, to accommodate estimates for off-road machinery.
Food, beverages	0.027	Food & drink, tobacco (combustion)	1A2e	0.002		
Paper printing	0.025	Pulp, Paper and Print (combustion)	1A2d	0.001		
		Off-road industrial machinery	1A2gvii	1.391		

DUKES Category	Activity (Mt)	GHGI	IPCC Sector	Activity (Mt)	Difference	Comment
		Aircraft - support vehicles	1A3eii	0.176		Inventory Agency estimates. No such DUKES categories.
TOTAL industry (inc. heat generation)	1.239	TOTAL industry	∑1A2, 1A3eii	1.620	- 0.381	Many sector re-allocations but overall GHG allocates more gas oil to industrial sources, to cover mobile machinery use.
Road	19.693	Road transport		19.236	0.457	Reduced to offset consumption from off-road DERV applications
Rail	0.530	Rail transport	1A3c	0.439	0.091	Inventory Agency estimates
National navigation	0.432	Inland and small vessels, and domestic shipping	1A3d	1.223	-0.791	GHGI shipping/fishing activity data is based on bottom-up methodology; some categories are inventory estimates and additional to DUKES (e.g. motorboats and inland-goods carrying vessels). This activity data is considered additional to DUKES. Also, GHGI accounts for CD/OT activity which is outside of DUKES scope.
		Fishing vessels	1A4ciii	0.142	- 0.142	
		Naval shipping	1A5b	0.119	- 0.119	
		TOTAL National navigation		1.484	-1.052	
Marine bunkers	1.327	Marine bunkers	Memo item	1.327	0.000	
Domestic	0.125	Domestic combustion	1A4bi	0.125	0.000	
		Off-road domestic machinery	1A4bii	0.011	- 0.011	Inventory Agency estimates; no such DUKES category.
Public Administration	0.258	Public sector combustion	1A4ai	0.018	0.240	Fuel use offset to account for to inventory estimates of various off-road machinery and vehicles
Commercial	0.444	Miscellaneous industrial/commercial combustion	1A4ai	0.039	0.637	Fuel use offset to account for to inventory estimates of various off-road machinery and vehicles
Miscellaneous	0.232					
Agriculture	0.376	Agriculture (stationary combustion)	1A4ci	0.000	0.376	Fuel use offset to account for to inventory estimates of various off-road machinery and vehicles

DUKES Category	Activity (Mt)	GHGI	IPCC Sector	Activity (Mt)	Difference	Comment
	0.000	Agriculture (mobile combustion)	1A4cii	1.290	-1.290	Inventory Agency estimates
TOTAL (all sectors)	25.281	TOTAL (all sectors)		26.171	-0.891	Overall, the GHGI reports more gas oil use than DUKES, due to the shipping research and fuel use in OTs.

Notes: Rows are shaded to help illustrate reconciliation between sectors

A 4.2.1.5 Petroleum gases

For petroleum gases (LPG, OPG), the total fuel use in the inventory is greater than the national statistics in several years, to reflect information from other sources (such as EU ETS data) that indicate potential under-reports in the UK energy statistics. These modifications to the energy balance are set out in **Table A 4.2.6.** They mostly relate to refineries, use of feedstock as fuel in the petrochemicals sector, and fuel use for upstream oil and gas production.

Table A 4.2.6 Fuel reconciliation: Use of Petroleum Gases in the latest year (Mt)

DUKES Category	Activity (Mt)	GHGI	IPCC Sector	Activity (Mt)	Difference	Comment
Liquefied Petroleum Gas (LPG) – *in DUKES this fuel is reported as propane and butane*						
Petroleum refineries	0.009	Refineries - combustion	1A1b	0.009	0.000	
Iron and steel	0.000	Iron and steel - combustion plant	1A2a	0.001		Several re-allocations from DUKES to accommodate other data. Overall a higher GHGI allocation to industry, lower allocation to ‘other’ sources such as commercial, but reconciles to DUKES across industry and ‘other’ combustion, together.
Food, beverages, etc.	0.049	Food & drink, tobacco (combustion)	1A2e			
Other industry	0.320	Other industrial combustion	1A2gviii	0.779		
Subtotal industry	0.370	*Subtotal industry*		0.780	- 0.410	
Agriculture	0.081	Agriculture - stationary combustion	1A4ci	-		
Commercial / Miscellaneous	0.313	Miscellaneous/Commercial combustion	1A4ai	-		
Domestic	0.250	Domestic combustion	1A4bi	0.250		
Public administration	0.017	Public sector combustion	1A4bi	-		
Subtotal other	0.660	*Subtotal other*		0.250	0.410	
Road transport	0.058	Road transport	1A3bv	0.058	0.000	

DUKES Category	**Activity (Mt)**	**GHGI**	**IPCC Sector**	**Activity (Mt)**	**Difference**	**Comment**
TOTAL (LPG)	**1.097**	**TOTAL (LPG)**		**1.097**	**0.000**	Exactly reconciled
Other Petroleum Gases (OPG) – ***includes Refinery Fuel Gas (RFG). In DUKES, reported as Ethane, Other gases and Naphtha.***						
Petroleum refineries	1.608	Refineries - combustion	1A1b	1.999	- 0.391	Refinery (and on-site refinery autogen) AD derived from EU ETS and deviates from DUKES
Autogeneration	0.130				0.130	
Subtotal	1.738	*Subtotal*		1.999	- 0.261	
Other transformation	0.178				0.178	
		Chemicals (combustion)	2B8g	1.019	-1.019	Use of process off-gases as fuel in petrochemical plant are added to the GHGI, from EU ETS reporting. In DUKES these materials are reported (correctly) as Non Energy Use process feedstocks, other than a small component of naphtha reported as unclassified industry use.
TOTAL (OPG)	**1.916**	**TOTAL (OPG)**		**3.017**	**- 1.101**	GHGI fuel use a lot higher than DUKES due to the reporting of activity and emissions from process off-gases, from NEU materials in DUKES.

Notes: Sequences of shaded rows indicate categories which are grouped for purposes of data reconciliation, and should be considered together.

1 Mtherm = 105.51 TJ

ANNEX 5: Additional Information to be Considered as Part of the Annual Inventory Submission and the Supplementary Information Required Under Article 7, paragraph 1, of the Kyoto Protocol Other Useful Reference Information.

A 5.1 ANNUAL INVENTORY SUBMISSION

No additional information.

A 5.2 SUPPLEMENTARY INFORMATION UNDER ARTICLE 7, PARAGRAPH 1

No additional information.

ANNEX 6: Comparison of Inventory and Emissions Estimated using Atmospheric Observations

This Annex describes the verification of the reported UK emissions through comparison with UK emissions estimated through the use of atmospheric observations and modelling.

A 6.1 MODELLING APPROACH USED FOR COMPARISON WITH THE UK GHGI

Comparison of the UK GHGI (Greenhouse Gas Inventory) with emission estimates made using atmospheric observations is considered to be best practice by the UNFCCC as it allows for an independent assessment of the GHG emissions from the UK using a comprehensively different approach. Significant differences in the emissions estimated using the two methods are a means of identifying areas worthy of further investigation, for example as occurred with a re-assessment of the emissions of HFCs for refrigeration.

In order to provide a comparison to the UK GHGI, BEIS (UK government department of Business, Energy and Industrial Strategy) supported the establishment and maintenance of a high-quality remote observation station at **Mace Head (MHD)** on the west coast of Ireland as part of the Advanced Global Atmospheric Gases Experiment (AGAGE) (Prinn et al., 2018). The station reports high-frequency concentrations of the key greenhouse gases and is under the supervision of Prof. Simon O'Doherty of the University of Bristol (O'Doherty et al. 2004, 2014, Stanley et al. 2018, Stavert et al. 2019).

BEIS extended the measurement programme in 2012 with three new tall tower stations across the UK, collectively called the UK DECC (Deriving Emissions linked to Climate Change) network: **Tacolneston (TAC)** near Norwich; **Ridge Hill (RGL)** near Hereford; and **Tall Tower Angus (TTA)** near Dundee, Scotland (decommissioned in 2015). Two additional stations, **Heathfield (HFD)** in Southern England and **Bilsdale (BSD)** in North Yorkshire, were established through the NERC GAUGE (Greenhouse gAs UK and Global Emissions) programme. BSD replaced TTA in 2015 in the UK DECC network and is funded by BEIS. A fire at BSD in August 2021 destroyed the tower and measurements have therefore been discontinued until a replacement tower is available. HFD is supported by the National Physical Laboratory (NPL). Methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O) and sulphur hexafluoride (SF_6) are measured at all stations across the UK DECC network. The hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are measured at MHD and TAC, and nitrogen trifluoride (NF_3) is only measured at MHD.

With permission of the data providers, observations were also obtained from:

- **Carnsore Point (CSP)** on the east coast of Ireland (2005-2010), funded by the Irish Environmental Protection Agency.
- **Weybourne (WAO)** in East Anglia, England (2013-present) supported by the University of East Anglia and the National Centre for Atmospheric Sciences.

- **Cabauw (CBW)** in the Netherlands (1993-2019) supported by the Netherlands Organisation for applied scientific research (TNO), funded by the Dutch Ministry of Infrastructure and Water Management.
- **Jungfraujoch (JFJ)** in the Swiss Alps (2007-present) supported by the Federal Office for the Environment (FOEN) through the project HALCLIM/CLIMGAS-CH, by the International Foundation High Altitude Research Stations Jungfraujoch and Gornergrat (HFSJG), and by the Swiss Federal Laboratories for Materials Science and Technology (Empa).
- **Monte Cimone (CMN)** in the Italian Apennine mountains (2007-present) supported by the University of Urbino.
- **Taunus (TOB)** in central Germany (2013-present) supported by the Goethe University Frankfurt.

For the global hemispheric concentration analysis, data were kindly provided from the **Cape Grim observatory (CGO)** in Tasmania, Australia by CSIRO (The Commonwealth Scientific and Industrial Research Organisation, an Australian Government agency).

The Met Office, under contract to BEIS, employs the Lagrangian dispersion model NAME (Numerical Atmospheric dispersion Modelling Environment) (Ryall et al. 1998, Jones et al. 2007) driven by three-dimensional modelled meteorology to interpret the observations. NAME determines the history of the air arriving at each station at the time of each observation. Estimates of UK emissions are made by firstly estimating the underlying background trend (Northern Hemisphere, mid-latitude, atmospheric concentrations with the short-term impact of regional pollution removed from the data) and secondly by modelling the impact of where the air has passed over on route to the observation stations at a regional scale. A methodology called Inversion Technique for Emission Modelling (InTEM) has been developed that uses a minimisation technique, Non-Negative Least Squares (NNLS) (Lawson and Hanson, 1974), to determine the emission distribution that most accurately reproduces the observations (Manning et al. 2003, 2011, 2021 and Arnold et al. 2017).

For each reported gas, the Northern and Southern (estimated using observations from Cape Grim) Hemisphere background concentrations and the UK emission estimates are presented. InTEM uses all of the available observations. Two-year inversion windows are used up until 2013 due to the paucity of UK observations prior to this year. Each inversion is performed for a two-year period and then the period is incremented by one-year e.g. 1989 – 1990, 1990 – 1991 etc., from which a mean for each year is estimated. From 2013, with the additional data from the other stations (principally TAC), the inversion time window is shortened to one year or smaller (1 month for CH_4, N_2O and SF_6 as all of the DECC network stations measure these gases).

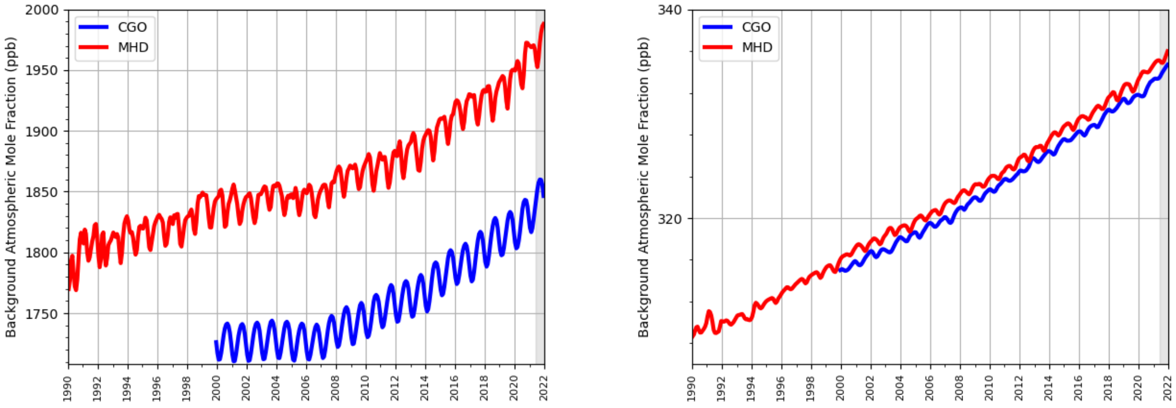
The geographical spread of the UK DECC (and other stations) network allows the spatial distribution of the emissions across the UK to be better constrained by InTEM. The InTEM estimates of UK emissions using the atmospheric observations are compared to the reported GHGI estimates. For each gas the InTEM estimated geographical distribution is presented as an average for 2018-2021. For CH_4 and N_2O this is shown as seasonal averages for 2018-2021. The time-series of UK emissions from 1990 are given showing the comparison between the GHGI and InTEM (2-year and 1-year or monthly) estimates.

The uncertainty of the InTEM estimates are calculated through the Bayesian framework. The GHGI uncertainties have been linearly interpolated between the reported 1990 and 2019 Approach 2 uncertainty values given in the 2021 submission of the UK NIR. As the values in the GHGI should represent a 95% confidence interval, the uncertainties have been halved so they are comparable to ±1σ, consistent with the error bars presented in this chapter. The most recent GHGI uncertainty assessment is not completed in time to allow for inclusion in the analysis presented in this chapter, but as the assessments for uncertainty by gas do not generally change substantially between submissions, the use of the previous year's GHGI uncertainty values is a good approximation.

All of the comparisons have been made in units of CO_2-equivalence using global warming potentials (GWP) over a 100-year timeframe (WMO ozone assessment (Montzka et. al., 2018) and where necessary the IPCC 5th assessment (Myhre et. al., 2013)). Note that while these GWPs differ from those used elsewhere in the report, the comparisons presented here all use consistent GWPs and therefore the verification exercise presented here remains valid.

A 6.2 METHANE

Figure A 6.1 Background Northern Hemisphere monthly concentrations of (a) CH_4, and (b) N_2O, estimated from Mace Head, Ireland observations are shown in red, and background Southern Hemisphere monthly concentrations from Cape Grim, Tasmania are shown in blue.



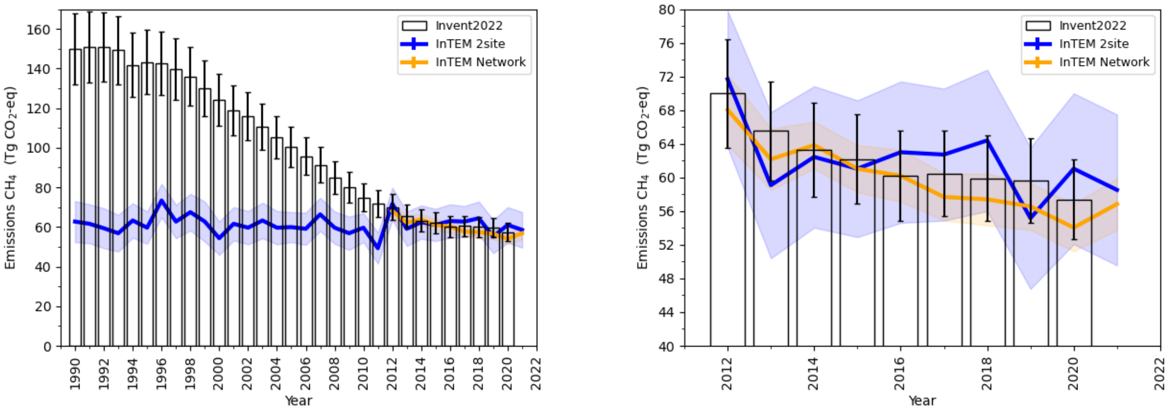
(a) Methane (b) Nitrous Oxide

Figure A 6.1 (a) shows the background atmospheric concentration of CH_4 from 1990 onwards. As with all of the background plots for each different gas, it shows how the overall atmospheric concentration of the gas in question is changing as a result of global emissions and atmospheric loss processes. For CH_4, the underlying background trend is positive. In 2021, the Northern Hemisphere (NH) concentration grew by 16.7 ppb, the SH by 12.4 ppb.

The CH_4 emission estimates made for the UK using the InTEM methodology are compared to the GHGI emission estimates for the period 1990 onwards and shown in **Figure A 6.2**. It is important to note that although the UK GHGI CH_4 emissions are estimated to have fallen since 1990, the global atmospheric concentration of methane has increased, indicating that global emissions of methane are still outperforming the global natural removal of methane from the atmosphere.

Methane has a natural (biogenic) component and it is estimated that 22% of the annual global emission is released from wetlands (Nilsson et al. 2001). Usually, natural emissions are strongly dependent on a range of meteorological factors such as temperature and also growth and decay cycles. Such non-uniform emissions will add to the uncertainties in the InTEM modelling, although in northwest Europe the natural emissions are thought to be small compared to the anthropogenic emissions (<5%, Bergamaschi *et al* 2005). Due to the relatively strong local (within 20km) influence of emissions at some of the stations, observations taken when local emissions are thought to be significant (low boundary layer heights, low wind speeds, stable atmospheres) have been removed from the InTEM analysis.

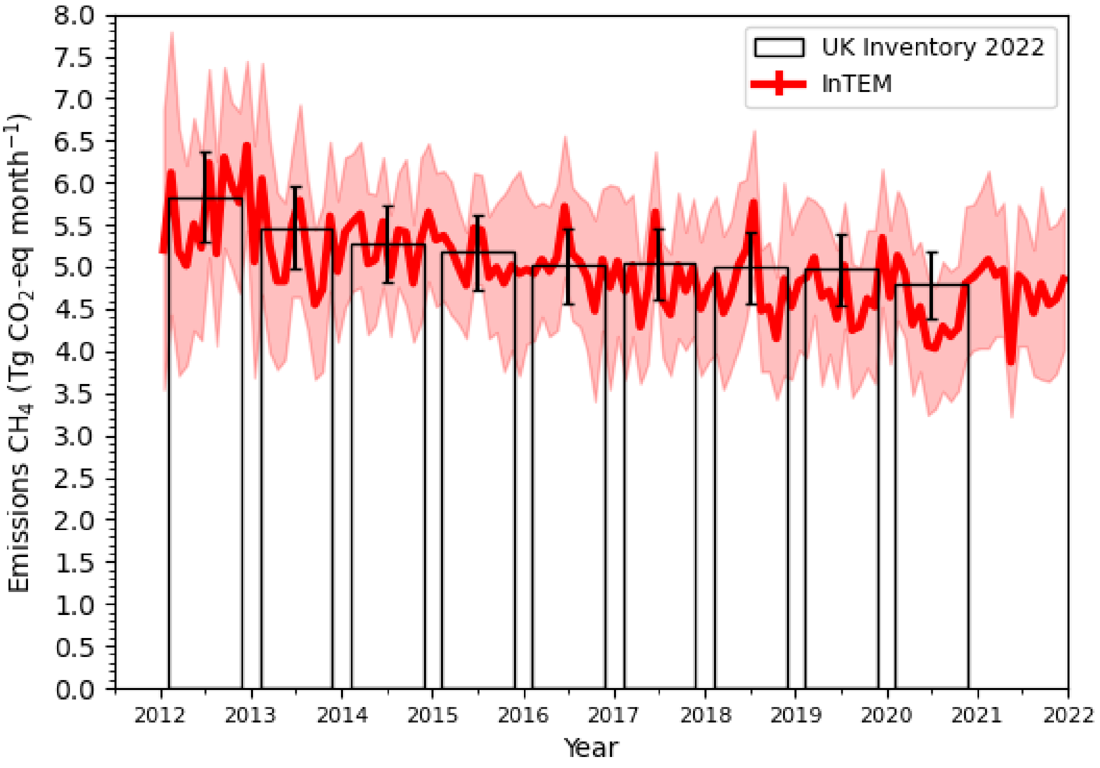
Figure A 6.2 **Verification of the UK emission inventory estimates for methane in Tg CO_2-eq yr^{-1} (a) from 1990 and (b) from 2012. GHGI estimates are shown in black. InTEM 2-site, 3-month annualised estimates are shown in blue (±1σ). InTEM full network, 1-month annualised, estimates are shown in orange (±1σ).**



(a) 1990-2021

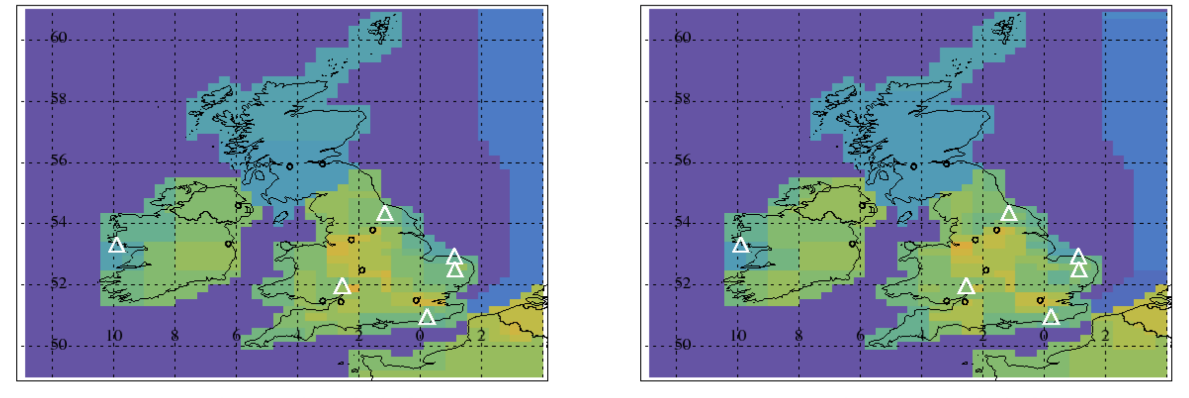
(b) 2012-2021

Figure A 6.3 **Verification of the UK emission inventory estimates for methane in Tg CO_2-eq month^{-1} from 2012. GHGI estimates are shown in black. InTEM 1-month estimates are shown in red (±1σ).**

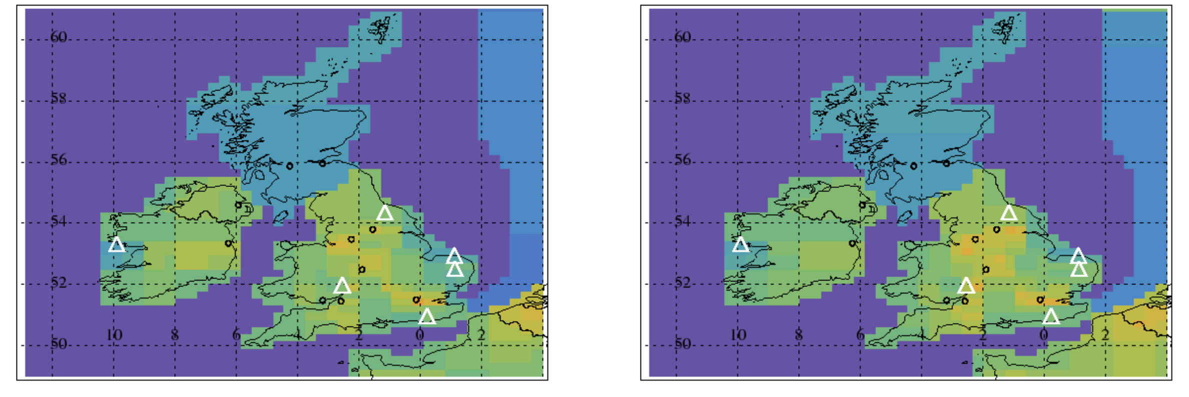


The UK GHGI trend is monotonically downwards from 1990 whereas the InTEM estimates is relatively flat, in comparison across the time-series. Prior to 2012 the InTEM estimate is based only on MHD and CBW observations. From 2012 onwards, observations from MHD, TAC, RGL, HFD, TTA, BSD, WAO and CBW are available and the InTEM estimates show a modest (-1.5 % yr^{-1}) annual decline 2013-2020, similar to the GHGI (-1% yr^{-1}) over the same period. The InTEM 1-month estimates (**Figure A 6.3**) using the full network of observations do not show a strong seasonal cycle in UK methane emissions. **Figure A 6.4** shows the geographical distribution of methane emissions (average over 2018-2021) as estimated by InTEM per season, Winter (Dec-Feb), Spring (Mar-May), Summer (Jun-Jul) and Autumn (Sep-Nov), each of the plots show elevated emissions in highly populated areas. Scotland is poorly resolved due to the paucity of observations after 2015.

Figure A 6.4 **Four-year average CH_4 InTEM emission estimates (kg km^{-2} yr^{-1} of gas) 2018-2021 by season: (a) Winter (b) Spring (c) Summer (d) Autumn. The observation stations are shown as white triangles. Major cities are shown as black circles.**



(a) Spring (b) Summer



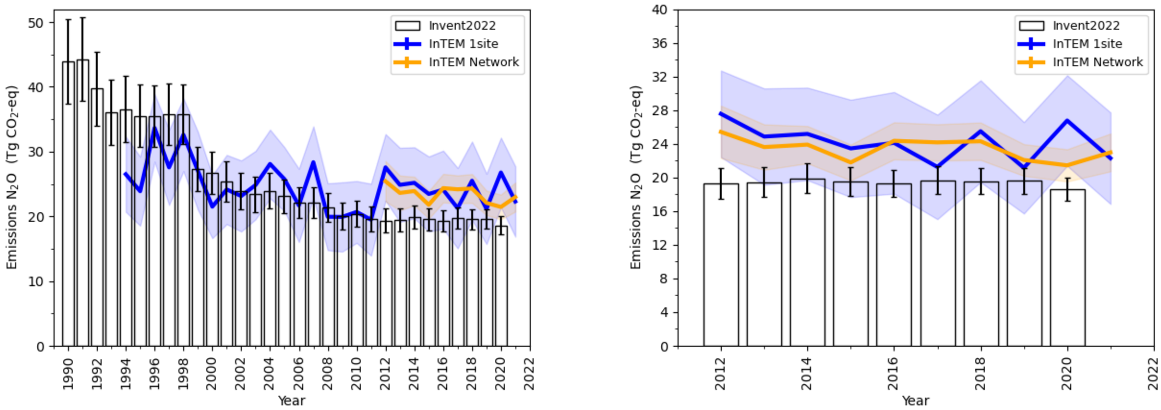
(c) Autumn (d) Winter

A 6.3 NITROUS OXIDE

Figure A 6.1 (b) shows the Hemisphere background atmospheric concentration of nitrous oxide (N_2O) from 1990 onwards. The background trend is monotonic and positive. The Northern Hemispheric background concentration is increasing by ~1 ppb yr^{-1}.

The main activities in Europe resulting in the release of N_2O are: agricultural practices resulting in emissions from soils (~60%), chemical industry (~20%) and combustion (~15%) (UNFCCC 1998 figures). The amount emitted from soils has significant uncertainty and has a diurnal and seasonal release cycle. It is driven by the availability of nitrogen, temperature and the soil moisture content.

Figure A 6.5 **Verification of the UK emission inventory estimates for N_2O in Tg CO_2-eq yr^{-1} (a) from 1990 and (b) from 2012. GHGI estimates are shown in black. InTEM 1-site, 3-month annualised estimates are shown in blue (±1σ), InTEM full network, 1-month, annualised, estimates are shown in orange (±1σ).**



(a) 1990-2021 (b) 2012-2021

Figure A 6.5 shows the InTEM and GHGI emission estimates comparison for N_2O for the UK. The annual InTEM estimates (2012-2020) are, on average, 4.2 (2.4 – 5.7) Tg CO_2-eq higher than those reported by the GHGI, although the 1σ uncertainties mostly overlap. Neither the InTEM estimates (2012-2020) or the GHGI (2012-2020) are showing a statistically significant trend in UK N_2O emissions. The GHGI estimates show a sharp decline (~9 Tg CO_2-eq) between 1998 and 1999 in line with the introduction of clean technology at an adipic acid plant in Wilton, northeast England. It is estimated that they cut their emissions of N_2O by 90%, from 12 Tg CO_2-eq yr^{-1} to around 1.6 Tg CO_2-eq yr^{-1}. The improved network of observations from 2012 onwards allows a very strong seasonal cycle (~1.8 Tg CO_2-eq mth^{-1}) in UK emissions to be highlighted. **Figure A 6.6** shows there is a peak in UK emissions in spring-summer (~2.9 Tg CO_2-eq mth^{-1}) and a minimum in the winter months (~1.1 Tg CO_2-eq mth^{-1}), aligned with the traditional fertiliser application period. There is however a strong year-to-year variability in this seasonal pattern demonstrating the impact of varying meteorology on the emissions of N_2O. The spatial pattern of emissions in each season is show in **Figure A 6.7** revealing a more widely distributed emission pattern than for CH_4.

The nature of the N_2O emissions challenges the InTEM assumption of uniformity of release both in time and space. Also, the point of release to the atmosphere may not be coincidental with the activity ultimately responsible for generating the N_2O e.g. the N_2O, or its precursors, may be transported from its source, for example by rivers, prior to its release to the atmosphere.

Figure A 6.6 **Verification of the UK emission inventory estimates for N_2O in Tg CO_2-eq month^{-1} from 2012. GHGI estimates are shown in black. InTEM 1-month estimates are shown in red (±1σ).**

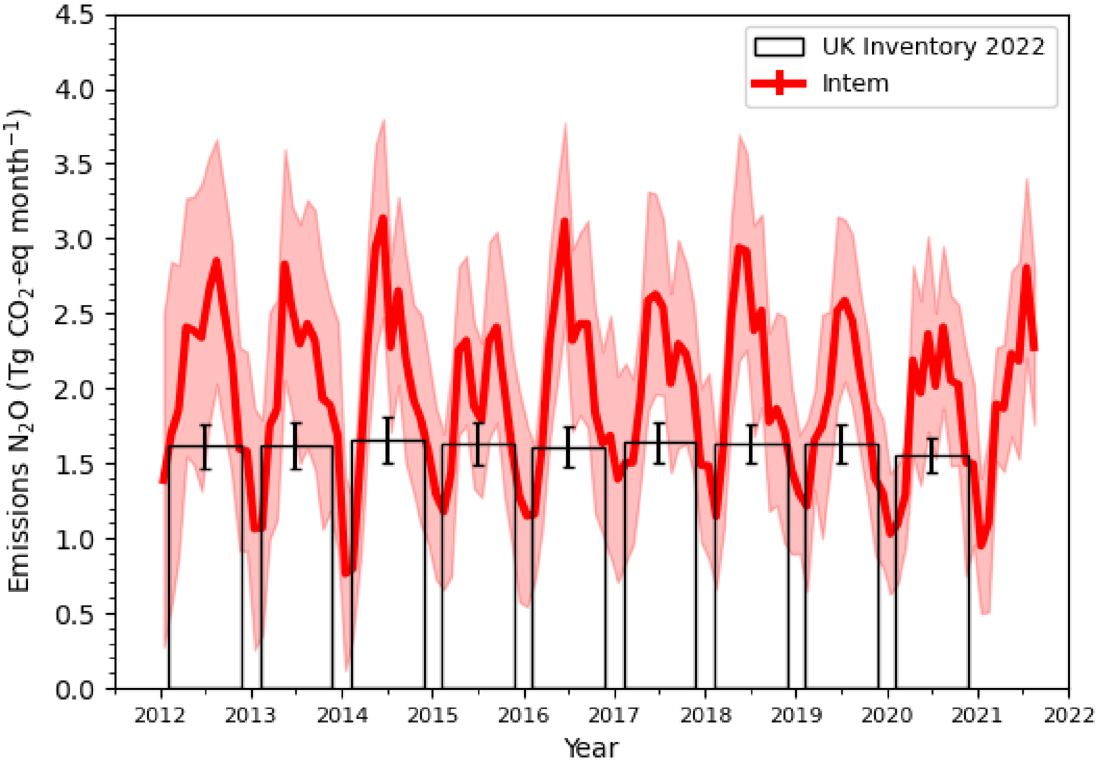
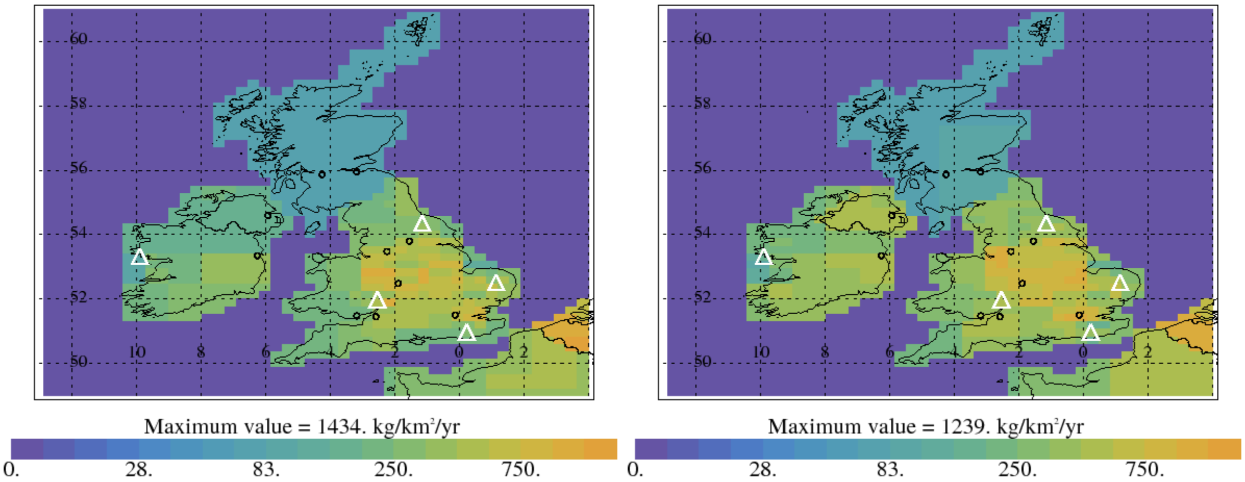
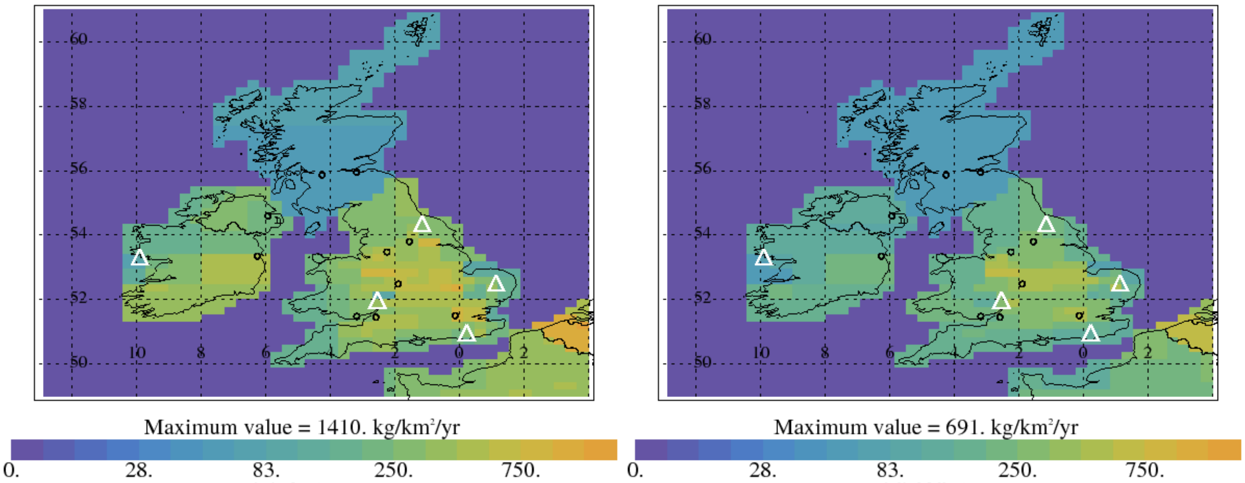


Figure A 6.7 **Four-year average N_2O InTEM emission estimates (kg km^{-2} yr^{-1} of gas) 2018-2021 by season: (a) Winter (b) Spring (c) Summer (d) Autumn. The observation stations are shown as white triangles. Major cities are shown as black circles.**



(a) Spring (b) Summer



(c) Autumn (d) Winter

A 6.4 HYDROFLUOROCARBONS

Figure A 6.8 shows the sum of all the HFCs, (HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-23, HFC-32, HFC-227ea, HFC-245fa, HFC-365mfc and HFC-43-10mee) in Tg CO_2-eq yr^{-1}. The GHGI is shown in black and InTEM annualised 2-year in blue and the 1-year in orange. The total InTEM HFC is consistently lower than the GHGI, with the best agreement between 2008-2012. From 2013 the InTEM estimate remains largely flat before dropping sharply from 2018 to 2020 in the 1-year data. There is a slight upturn in total HFC emissions from 2020 to 2021, and it will be interesting to see if this is sustained in 2022.The largest discrepancies between the model estimate (InTEM 1-year) and the GHGI are in 2019 and 2020, with differences of 4.5 and 4.3 Tg CO_2-eq yr^{-1} respectively. Note, the GHGI reports uncertainty for the HFCs collectively, they are not available for the individual gases.

There is a notable drop in the InTEM HFC estimates in 2019 and to a smaller extent in 2020. Only a small decline is estimated in the GHGI between 2018 and 2019. The UK is committed to phasing down the use of HFCs to 21% by 2030, based on the average use between 2009-2012. Comparison of the total InTEM UK HFC emissions in 2021 (1-year InTEM) with the average from 2009-2012 (2-year InTEM) shows a drop of 26.3%, indicating good progress toward the target of a 79% decrease by 2030, however it will be important to see if the 2021 upturn in emissions is an anomaly in the downwards trend in UK HFC emissions, or if it is sustained.

Figure A 6.8 **Sum of UK HFC emission estimates (HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-23, HFC-32, HFC-227ea, HFC-245fa, HFC-365mfc and HFC-43-10mee) in Tg CO_2-eq yr^{-1} from the GHGI (black) and InTEM, annualised 2-year inversion (blue) and 1-year inversion (orange). Note HFC-43-10mee (< 0.2 Tg CO_2-eq yr^{-1}) included from 2011 when the observations start. The uncertainty bars represent ±1σ.**

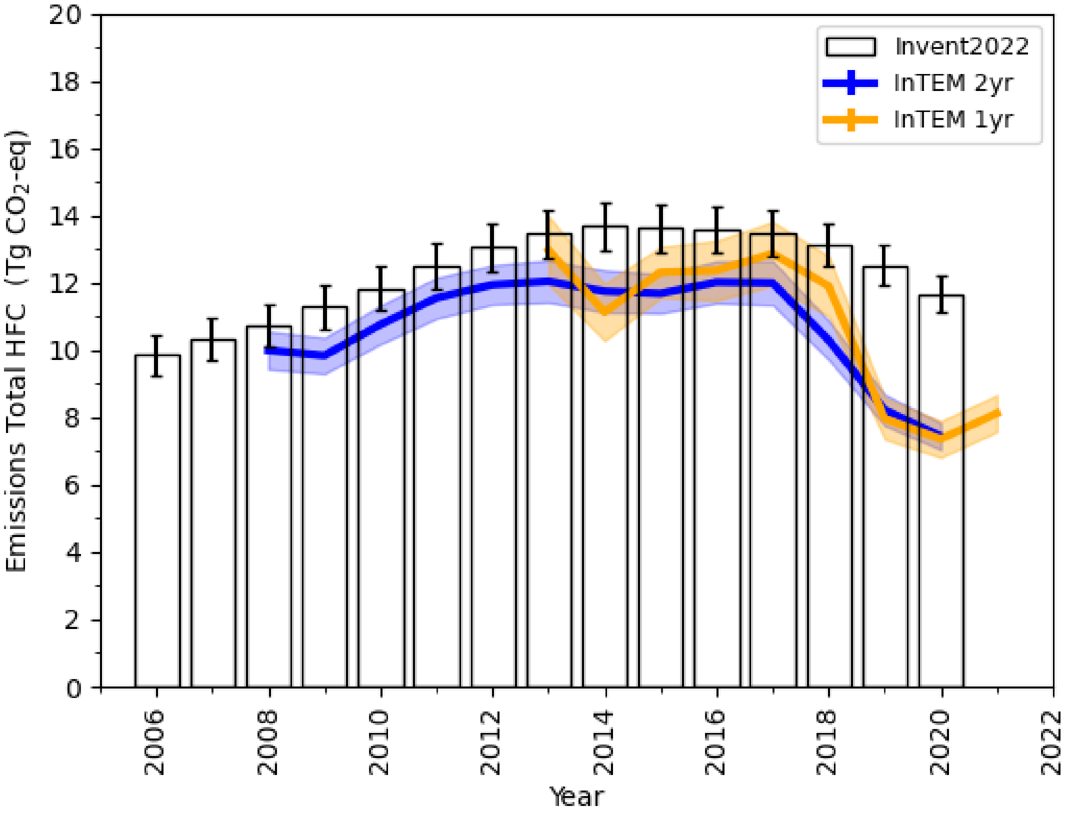
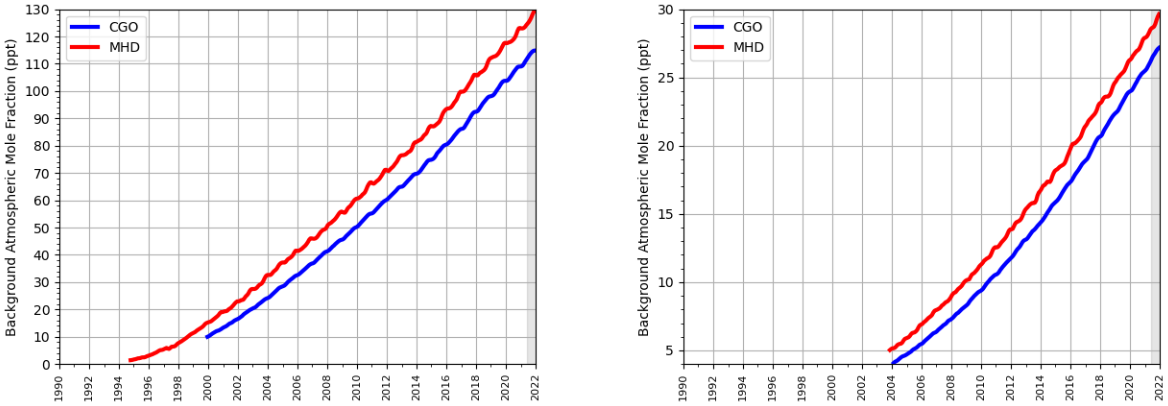
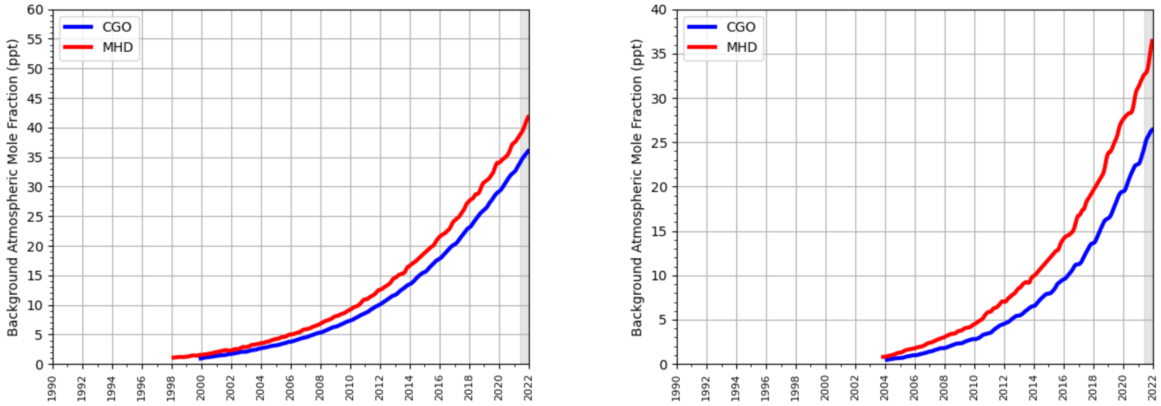


Figure A 6.9 **Background Northern Hemisphere monthly concentrations of six HFCs estimated from Mace Head, Ireland observations are shown in red, and background Southern Hemisphere monthly concentrations from Cape Grim, Tasmania are shown in blue.**



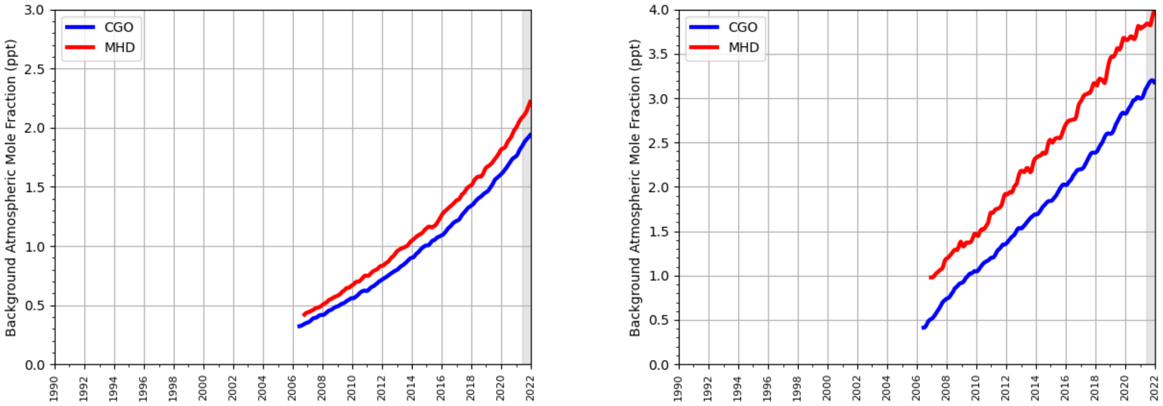
(a) HFC-134a

(b) HFC-143a



(c) HFC-125

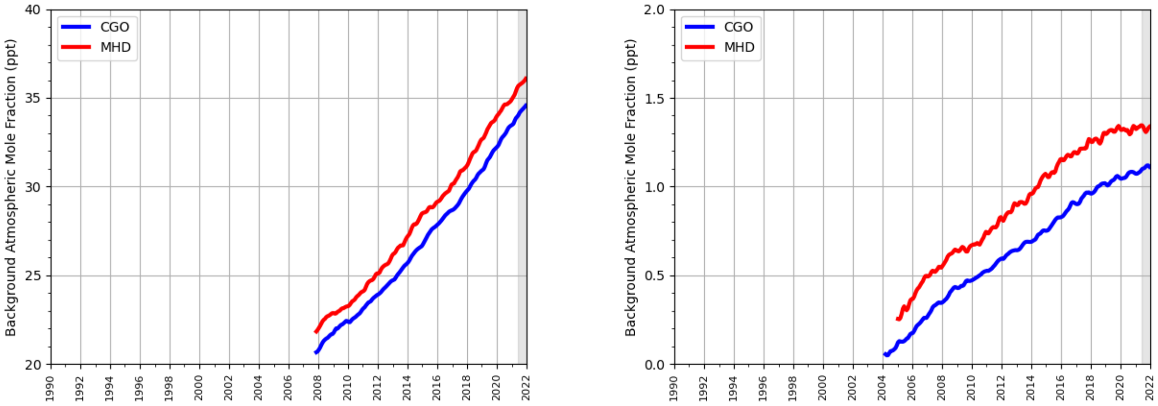
(d) HFC-32



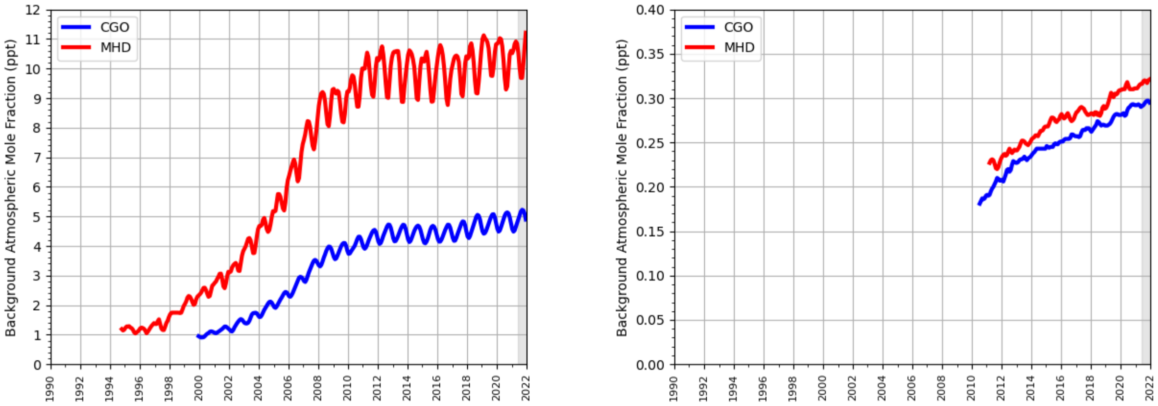
(e) HFC-227ea

(f) HFC-245fa

Figure A 6.10 **Background Northern Hemisphere monthly concentrations of four HFCs estimated from Mace Head, Ireland observations are shown in red, and background Southern Hemisphere monthly concentrations from Cape Grim, Tasmania are shown in blue.**

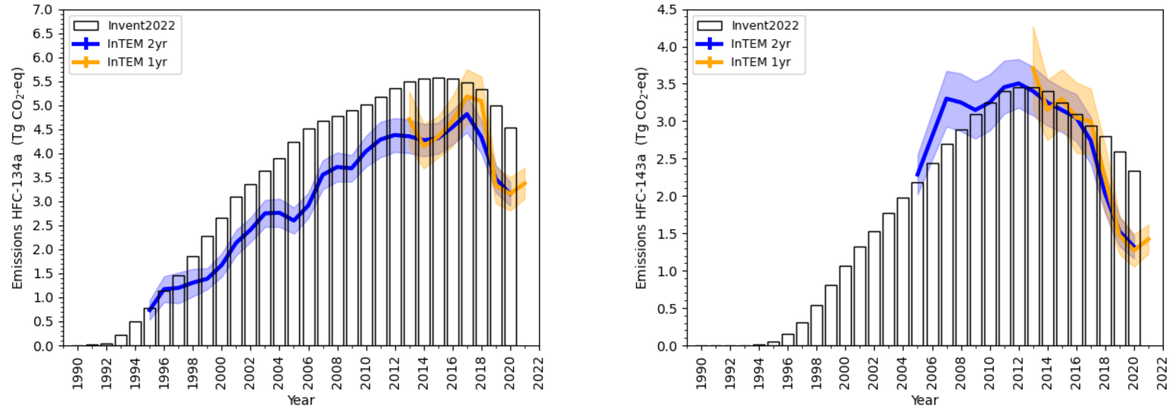


(a) HFC-23 (b) HFC-365mfc

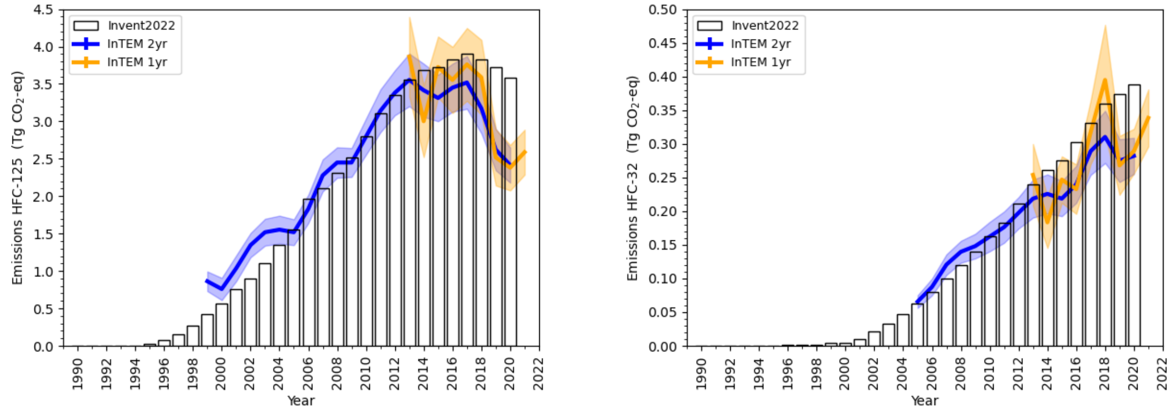


(c) HFC-152a (d) HFC-43-10-mee

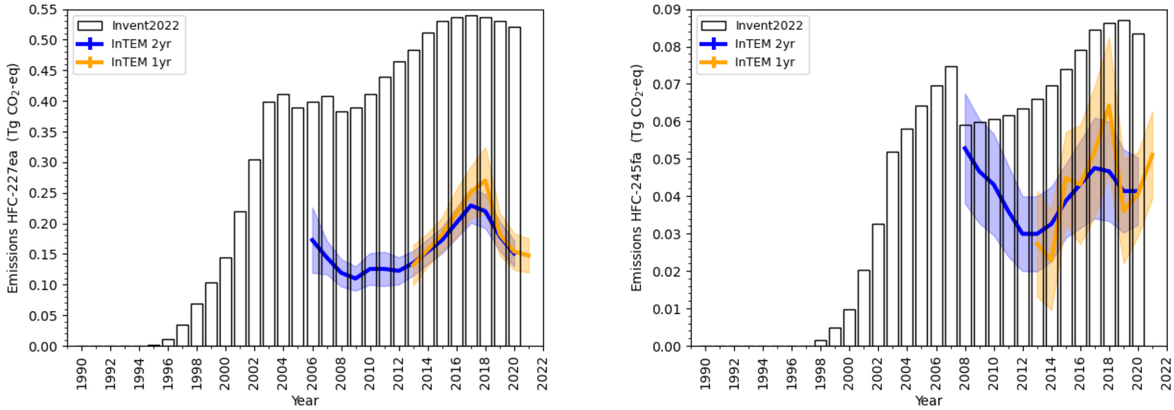
Figure A 6.11 Verification of the UK emission inventory estimates for individual HFC's in Tg CO_2-eq yr^{-1} from 1990. GHGI estimates are shown in black. InTEM 2-year estimates are shown in blue (±1σ), InTEM 1-year estimates are shown in orange (±1σ).



(a) HFC-134a (b) HFC-143a

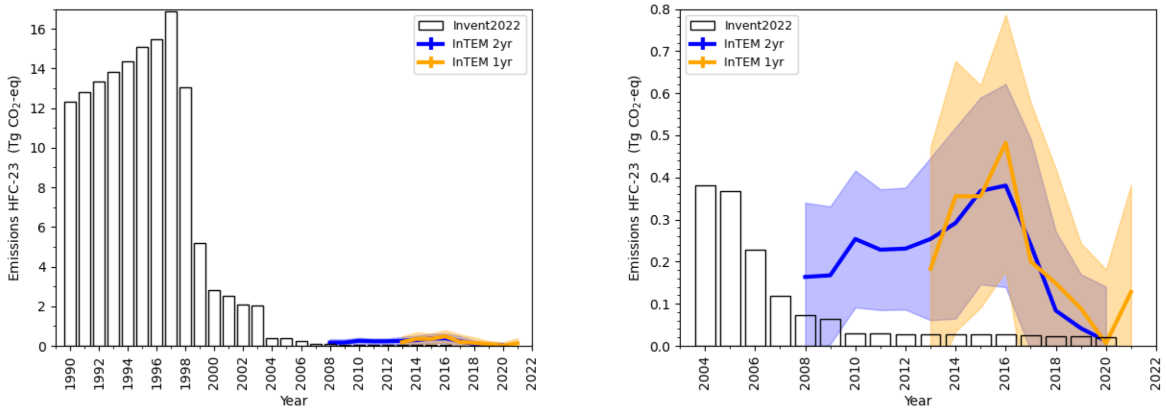


(c) HFC-125 (d) HFC-32



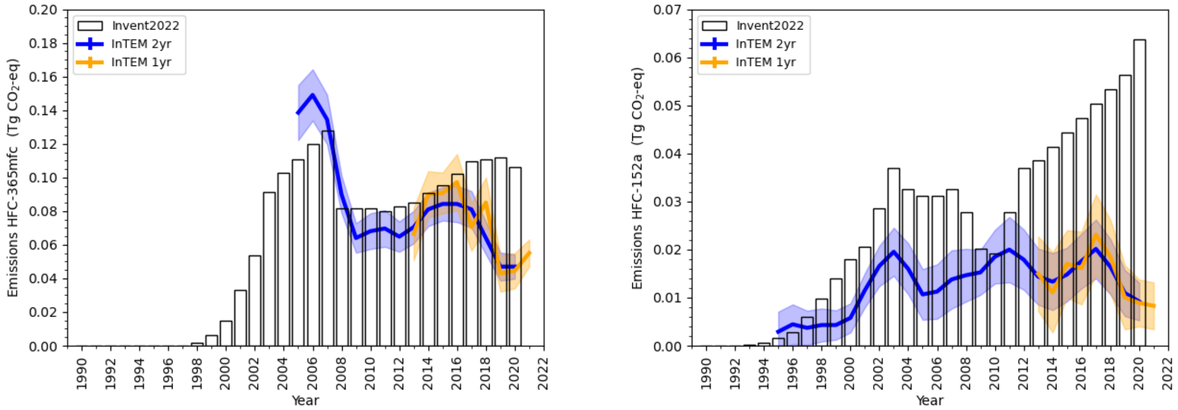
(e) HFC-227ea (f) HFC-245fa

Figure A 6.12 **Verification of the UK emission inventory estimates for individual HFC's in Tg CO_2-eq yr^{-1} from 1990. GHGI estimates are shown in black. InTEM 2-year estimates are shown in blue (±1σ), InTEM 1-year estimates are shown in orange (±1σ).**



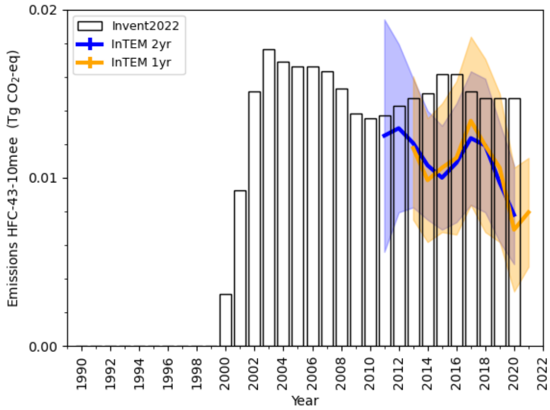
(a) HFC-23

(b) HFC-23



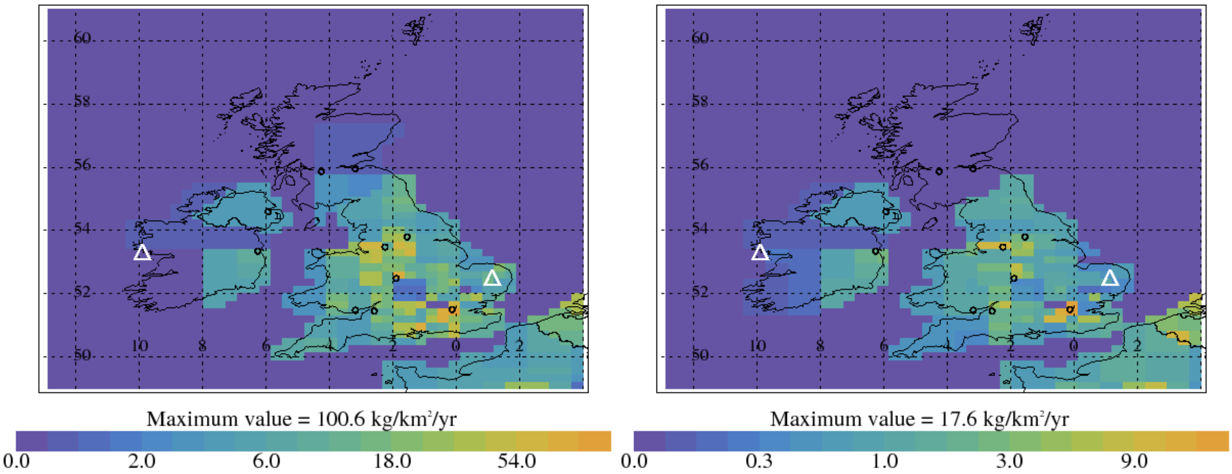
(c) HFC-365mfc

(d) HFC-152a

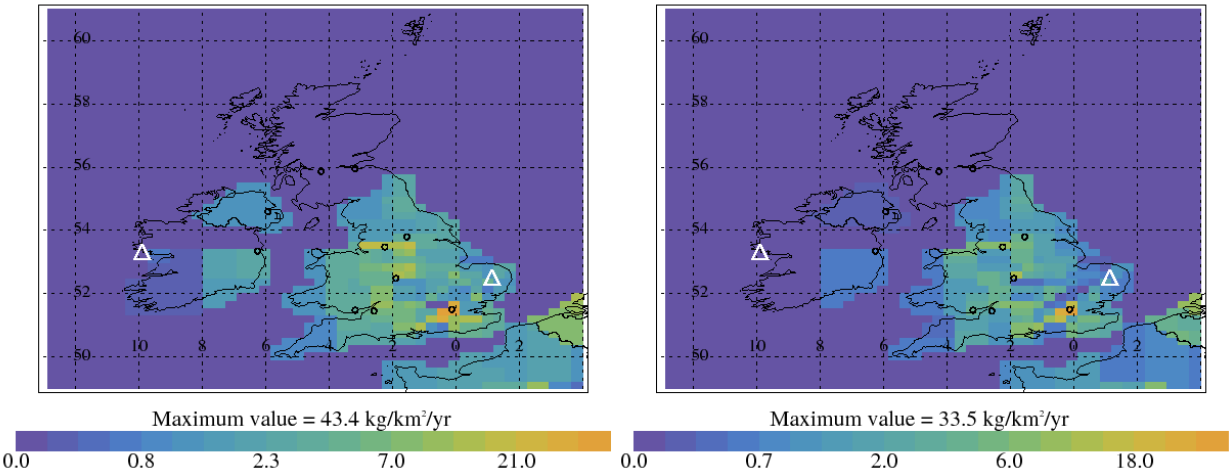


(e) HFC-43-10mee

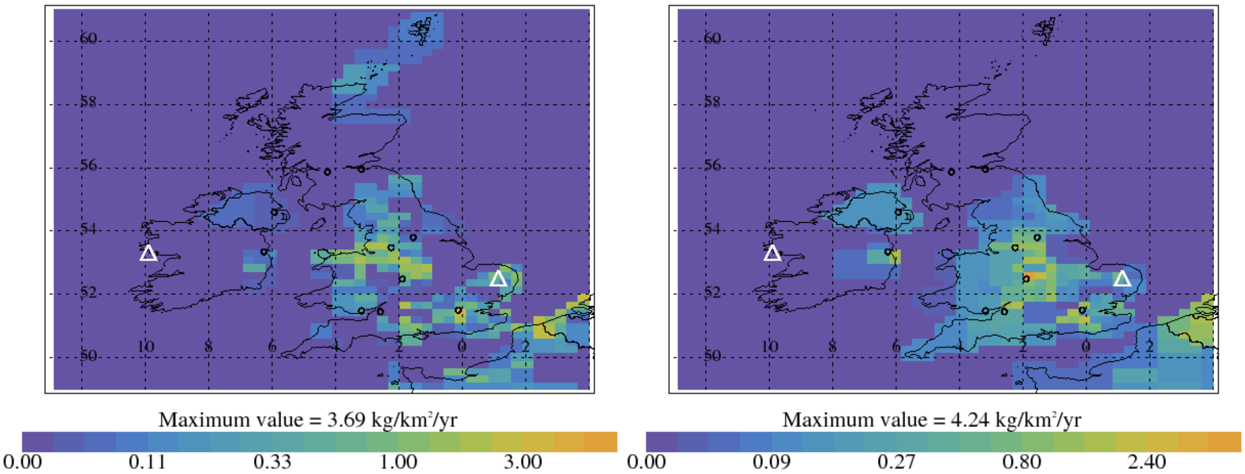
Figure A 6.13 Four-year average HFC-134a InTEM emission estimates (kg km^{-2} yr^{-1}) 2018-2021. The observation stations are shown as white triangles. Major cities are shown as black circles.



(a) HFC-134a (b) HFC-143a

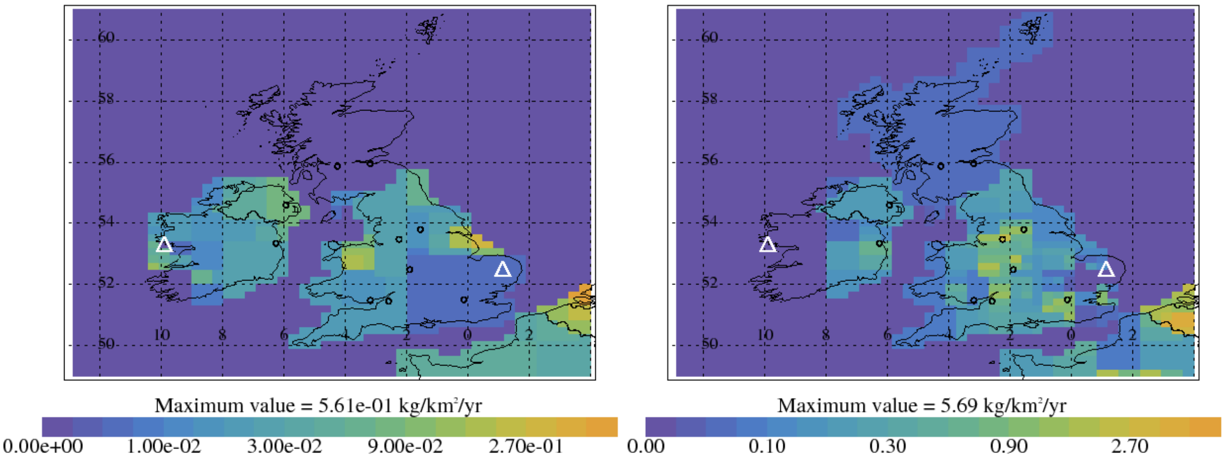


(c) HFC-125 (d) HFC-32

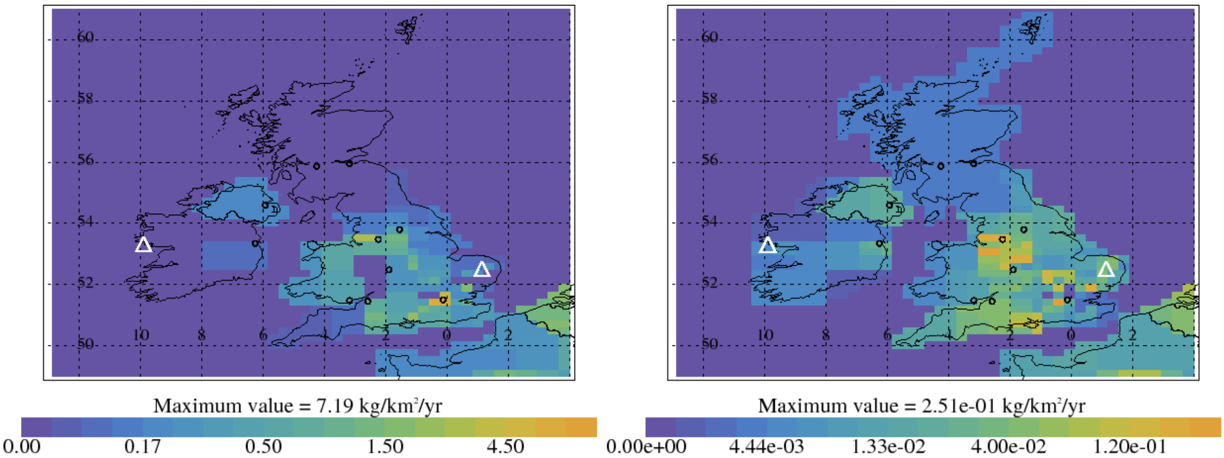


(e) HFC-227ea (f) HFC-245fa

Figure A 6.14 **Four-year average HFC InTEM emission estimates (kg km^{-2} yr^{-1}) 2018-2021. The observation stations are shown as white triangles. Major cities are shown as black circles.**



(a) HFC-23 (b) HFC-365mfc



(c) HFC-152a (d) HFC-43-10mee

A 6.4.1 HFC-134a

Figure A 6.9 (a) shows the Hemisphere background atmospheric concentration of HFC-134a from 1995 onwards. The background trend is monotonic and positive, in 2021 the Northern Hemisphere background increased by 5.4 ppt.

Figure A 6.11 (a) shows the InTEM and GHGI emission estimates for the UK for HFC-134a for the period 1990 onwards. The GHGI shows a stronger increase in emission compared to the InTEM estimates. The InTEM estimates have risen at about 70% of the rate of the GHGI. Throughout the time series the trend agreement between the GHGI and InTEM is good but the InTEM estimates are consistently lower than the GHGI estimates, with the difference well outside the InTEM uncertainty range except for the 1-year estimates in 2017 and 2018. From 2018, the InTEM 1-year estimate drops sharply and is approximately 40% lower than the GHGI in 2019 and continues to drop in 2020, before a slight increase in 2021, perhaps indicating that the sharp decrease has now levelled off or that emissions in 2020 were impacted by the Covid lockdowns. Since the implementation of phase three of the EU MAC directive (2006), on 1st January 2017, the use of fluorinated greenhouse gases with GWPs$_{100}$ higher than 150 (mainly HFC-134a) in all new models of cars and light vans sold in the EU has been banned. The impact of this policy is seen both in InTEM and the GHGI, with InTEM implying a more rapid phase-out is occurring than modelled in the GHGI.

Figure A 6.13 (a) shows the average spatial InTEM emissions estimate for HFC-134a over the UK in kg $km^{-2}yr^{-1}$, for the four-year period 2018-2021. The variable grid resolution of InTEM produces a patchwork of different resolutions dependant on source signal at the measurement site. For HFC-134a, the highest emissions are generally focused on the more populated areas, with the highest emission region appearing over London and in the south of the UK with significant emissions also indicated in the populated regions around Birmingham, Leeds and Manchester.

A 6.4.2 HFC-143a

Figure A 6.9 (b) shows the hemispheric background atmospheric concentrations of HFC-143a from 2004 onwards. The hemispheric background trend is positive, in 2021 the Northern Hemisphere background increased by 1.6 ppt.

InTEM emission estimates for the UK for HFC-143a for the period 2004 onwards are shown in **Figure A 6.11** (b**)** and are compared to the GHGI estimates. UK emissions, as estimated by the GHGI, increased year-on-year from the early 1990s until a peak in 2012-2013, and thereafter estimated a gradual decline. The InTEM estimates show reasonable agreement with the GHGI, though is slightly higher from 2005-2009. Between 2010-2012 there is excellent agreement, and then InTEM follows the slope of the declining GHGI very closely and is just slightly lower from 2013-2017. After 2017, the InTEM estimates drops much more rapidly than the GHGI and is approximately 60% of the GHGI by 2019. The decline in InTEM estimates between 2019 and 2020 is very similar to the decline in the GHGI, maintaining the InTEM estimate as approximately 60% of the GHGI in 2020. InTEM then shows a slight upturn in emissions for 2021, indicating a levelling off of the previously declining emissions of HFC-143a.

Figure A 6.13 (b) shows the average spatial InTEM emissions estimate for HFC-143a over the UK in kg km^{-2} yr^{-1}, for the four-year period 2018-2021. The highest emissions are generally focused around populated regions, with the highest emission area estimated to be over London and in the highly populated regions in the north of the England, in a similar distribution to that seen for HFC-134a.

A 6.4.3 HFC-125

Figure A 6.9 (c) shows the hemispheric background atmospheric concentrations of HFC-125 from 1998 onwards. The background trend is monotonic and exponentially increasing, in 2021 the Northern Hemisphere background increased by 3.5 ppt.

InTEM emission estimates for the UK for HFC-125 for the period 1999 onwards are shown in **Figure A 6.11** (c). Both the InTEM and UK GHGI estimates suggest that the emissions of HFC-125 from the UK increased significantly from the 1990s. The InTEM estimates are slightly higher than the GHGI between 1999-2004, but between 2005-2013 there is excellent agreement. From 2014-2017, the 2-year InTEM estimates remain fairly flat, whilst the GHGI continues to rise, and the agreement is less good. There is better agreement between the 1-year model and the GHGI between 2015-2017, however there is a significant discrepancy in 2014. From 2018 to 2020, both the 2-year and 1-year model estimates drop sharply, in contrast to the slowly declining GHGI, leading to a significant difference by 2020. As with HFC-134a and HFC-143a, there is a slight increase in the 1-year InTEM estimate for 2021.

Figure A 6.13 (c) shows the average spatial InTEM emissions estimate for HFC-125 over the UK in kg km^{-2} yr^{-1}, for the four-year period 2018-2021. Similarly, to HFC-134a and HFC-143a the highest emissions are generally focused in the more populated areas, with the highest emission region estimated to be over the London area.

A 6.4.4 HFC-32

Figure A 6.9 (d) shows the hemispheric background atmospheric concentration of HFC-32 from 2004 onwards. The background trend is monotonic and positive, in 2021 the Northern Hemispheric background increased by 3.7 ppt.

InTEM emission estimates for the UK for HFC-32 from 2005 onwards are shown in **Figure A 6.11** (d). The InTEM emission estimates match the GHGI estimates extremely well up until 2013. Between 2014-2018 the agreement is less good with the InTEM estimates lower than the GHGI, except for the 1-year InTEM estimate for 2018. Up until 2018 the InTEM model and the GHGI had upward trends, however, from 2018 InTEM decreases, remaining approximately level for 2019 and 2020 whilst the GHGI continues to rise. The InTEM 1-year estimate for 2021 is a sharp increase from the 2020 value. This could be an indication that the previous upward trend in this gas is continuing, however given the year-to-year variability seen with the 1-year HFC-32 estimates, it is hard to draw a firm conclusion without another year of data.

Figure A 6.13 (d) shows the average spatial InTEM emissions estimate for HFC-32 over the UK in kg km^{-2} yr^{-1}, for the four-year period 2018-2021. The highest emissions are generally focused on the more populated areas, with the highest emission region estimated to be over London.

A 6.4.5 HFC-227ea

Figure A 6.9 (e) shows the hemispheric background atmospheric concentrations of HFC-227ea from 2007 onwards. There is a positive trend in the background; in 2021 the Northern Hemispheric baseline increased by 0.19 ppt.

The GHGI estimates (**Figure A 6.11** (e)) are significantly (~3 times) higher than those estimated by InTEM. The trend in emission estimates is similar between the GHGI and InTEM, although the InTEM estimates decline more rapidly than the GHGI. The InTEM 2021 estimate shows a slowing in this decline and is approximately a third of the magnitude of the GHGI emission estimate for 2021.

Figure A 6.13 (e) shows the average spatial InTEM emissions estimate for HFC-227ea over the UK in kg km^{-2} yr^{-1}, for the four-year period 2018-2021. The geographic distribution appears to largely follow population with the notable exception of the area around TAC. This is thought to be due to local emissions near to the station and is worthy of further investigation.

A 6.4.6 HFC-245fa

Figure A 6.9 (f) shows the hemispheric background atmospheric concentrations of HFC-245fa from 2007 onwards. There is a positive trend in the background; in 2021 the Northern Hemispheric background increased by 0.14 ppt.

UK emissions of HFC-245fa are small in both the GHGI and InTEM. The InTEM estimates (**Figure A 6.11** (f)) have significant uncertainty and are consistently lower than the GHGI estimates, with the exception of 2008 where there is reasonable agreement. The GHGI estimates show a significant decline between 2007 to 2008 and then a steady annual increase up to and including 2019, before a decrease in 2020. The 2-year InTEM estimates show a strong rise in emissions starting 2014 and peaking in 2017, and then starting to decline from 2018 in contrast to the GHGI. The 1-year InTEM estimates follow the same trend as the 2-year, as would be expected, however there is high year-to-year variability in the estimated emissions of this gas making it hard to conclude whether the upturn in 2021 is significant or not.

Figure A 6.13 (f) shows the average spatial InTEM emissions estimate for HFC-245fa over the UK in kg km^{-2} yr^{-1}, for the four-year period 2018-2021. HFC-245fa emissions follow the distribution of population over the UK.

A 6.4.7 HFC-23

Figure A 6.10 (a) shows the hemispheric background atmospheric concentrations of HFC-23 from 2008 onwards. The background trend is monotonic and positive, in 2021 the Northern Hemispheric background increased by 1.1 ppt.

Figure A 6.12 (a) and (b) show the GHGI and InTEM emission estimates for the UK for HFC-23 from 1990 (a) and from 2009 (b) on a different scale. The InTEM estimates from 2009 onwards are higher than the emissions estimated by the GHGI until 2020 where they agree. It should be noted however that the InTEM uncertainties are large and often extend down to zero . From the observations it is clear that some intermittent emissions of HFC-23 occur in the UK.

Figure A 6.14 (a) shows the average spatial InTEM emissions estimate for HFC-23 over the UK in kg km^{-2} yr^{-1}, for the four-year period 2018-2021. The levels of HFC-23 are fairly uniform over the UK, with areas of higher emissions indicated near Hull on the east coast of England and north Wales.

A 6.4.8 HFC-365mfc

Figure A 6.10 (b) shows the hemispheric background atmospheric concentration of HFC-365mfc from 2004 onwards. There was a positive trend in the Hemispheric backgrounds up until 2019 but no growth was estimated in the Northern Hemisphere in 2021.

The GHGI (**Figure A 6.12** (c)) shows a sharp decline in emissions in 2008 and the InTEM 2-year estimates show a similar response. The InTEM 2-year estimates are larger than the GHGI in 2005 and 2006, and then lower from 2009 onwards, but matches the rise in emissions from 2012 to 2016 before declining sharply. The 1-year InTEM estimates more closely match the GHGI between 2014-2016. The InTEM estimates level off in 2019 and 2020 at about half the magnitude of the GHGI. There is a slight increase in emissions in 2021.

Figure A 6.14 (b) shows the average spatial InTEM emissions estimate for HFC-365mfc over the UK in kg km^{-2}yr^{-1}, for the four-year period 2018-2021. The levels of HFC-365mfc emission are relatively uniform over England and Wales, areas of higher population do show slightly enhanced emissions. Higher emissions are indicated on the near continent in Belgium.

A 6.4.9 HFC-152a

Figure A 6.10 (c) shows the background atmospheric concentration of HFC-152a from 1995 onwards. The Northern Hemispheric background concentration shows a strong rise from the mid-1990s until 2008, then a much-reduced annual increase until 2012. Between 2012-2017 a small decline is observed (Simmonds et al., 2016), followed by a rise, peaking in 2019. The Northern and Southern Hemispheric differences are exacerbated for this gas because of its relatively short atmospheric lifetime (1.6 years). In 2021 the Northern Hemispheric background decreased by 0.13 ppt. **Figure A 6.12** (d) shows the InTEM and the GHGI emission estimates for the UK for HFC-152a for the period 1990 onwards. Between 1999-2008 and from 2012 onwards, the GHGI estimates are significantly larger than those estimated from InTEM. It is also interesting to note that the positive trend between 2011 and 2020 in the UK GHGI conflicts with a much flatter InTEM trend followed by a sharp decline from 2017 to 2021. The InTEM estimate is < 20% of the GHGI in 2020.

Figure A 6.14 (c) shows the average spatial InTEM emissions estimate for HFC-152a over the UK in kg km^{-2} yr^{-1}, for the four-year period 2018-2021. Similar to HFC-134a, the highest emissions are generally focused on the more populated areas, with the highest emission region estimated to be over the London area.

A 6.4.10 HFC-43-10mee

Figure A 6.10 (d) shows the hemispheric background atmospheric concentration of HFC-43-10mee from 2011 onwards. There is a positive trend in the background, in 2021 the Northern Hemispheric baseline concentration increased by 0.01 ppt.

As estimated by both methods, the UK emissions of this gas are small (**Figure A 6.12** (e)). The GHGI estimates are initially in agreement with those estimated by InTEM, but the GHGI then has a small rise in 2015 and 2016, just as the InTEM emission drops sharply to a low point in 2014 and 2015, before rising back up until 2017, before dropping sharply until 2020. The 1-year InTEM estimate shows a slight rise in 2021. Throughout the InTEM uncertainty estimate is large relative to the emission. The spatial distribution is shown in **Figure A 6.14** (d) and is largely similar to other HFC's spread by population, though it perhaps shows a more widely spread distribution over the UK with an elevated region on the south coast as well as the region from Birmingham up to Leeds and Manchester.

A 6.5 PERFLUOROCARBONS

Figure A 6.15 shows the sum of all UK emissions of PFCs, (PFC-14, PFC-116, PFC-218, PFC-318) in Tg CO_2-eq yr^{-1}. The GHGI is shown in black and InTEM annualised 2-year in blue and the 1-year in orange. The InTEM PFC estimate is considerably higher than the GHGI until 2011 when the agreement starts to improve. In 2020 the total PFC InTEM estimates are within a factor of two of the GHGI estimate. Note, the GHGI reports uncertainty for the PFCs collectively, uncertainties are not available for the individual gases.

Figure A 6.15 **Sum of UK PFC emission estimates (PFC-14, PFC-116, PFC-218, PFC-318) in Tg CO_2-eq yr^{-1} from the GHGI (black) and InTEM, annualised 2-year inversion (blue) and 1-year inversion (orange). The InTEM uncertainty bounds represent 1-σ.**

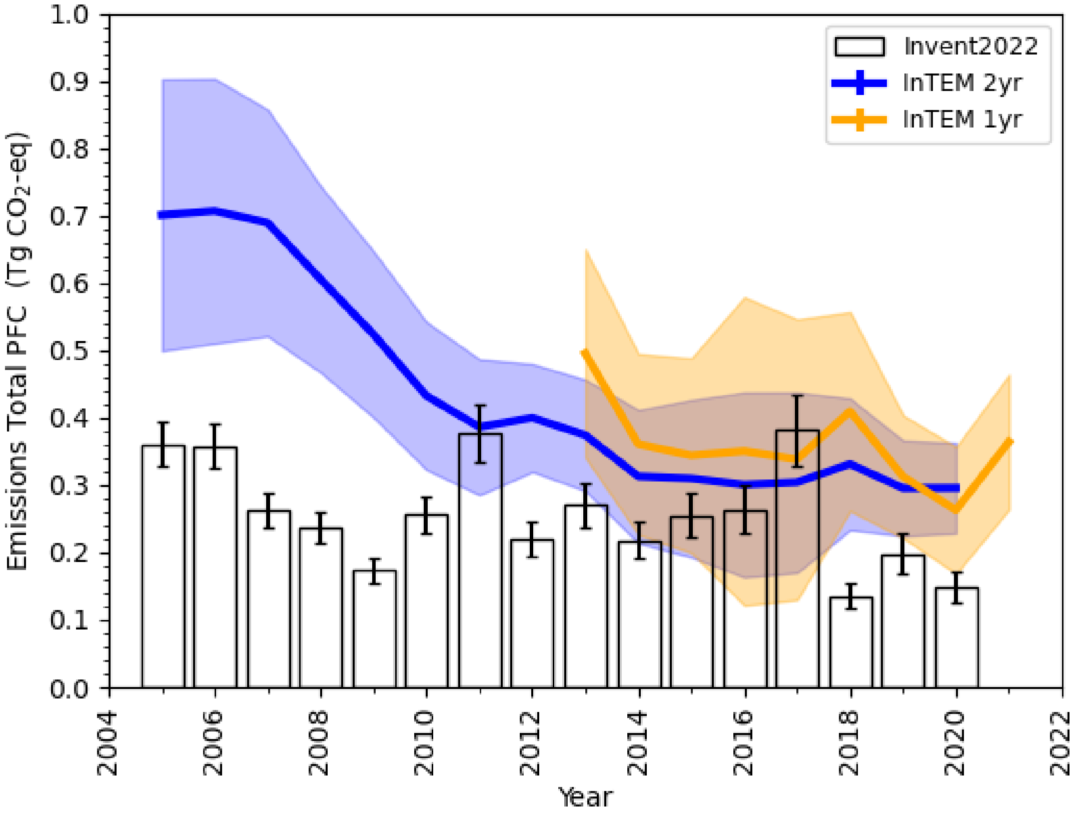
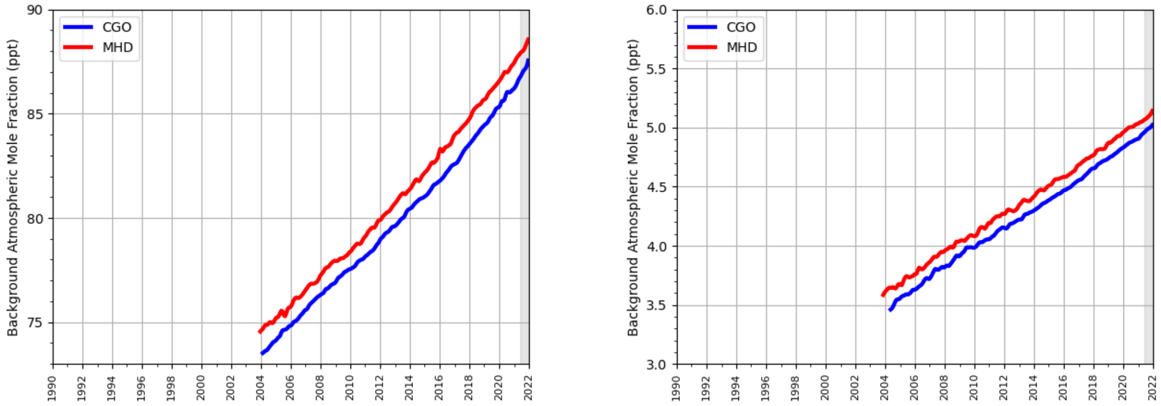
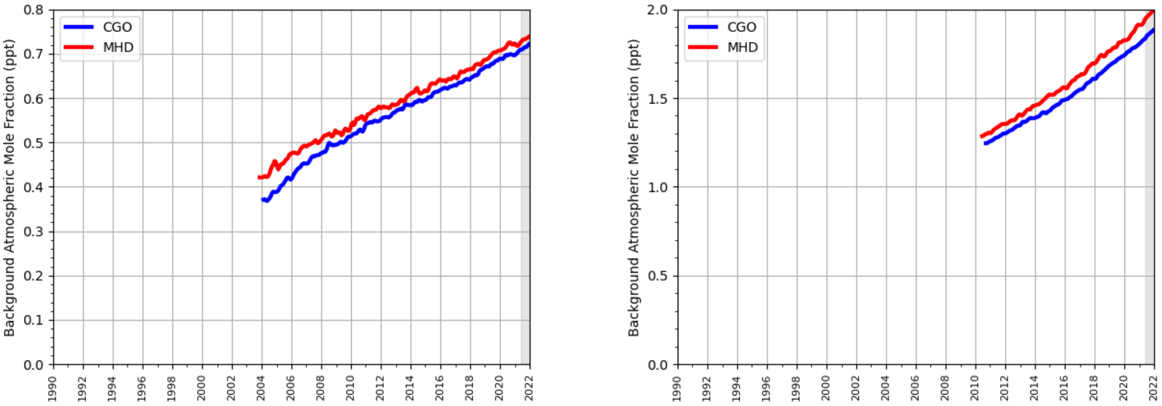


Figure A 6.16 **Background Northern Hemisphere monthly concentrations of four PFCs estimated from Mace Head, Ireland observations are shown in red, and background Southern Hemisphere monthly concentrations from Cape Grim, Tasmania are shown in blue.**

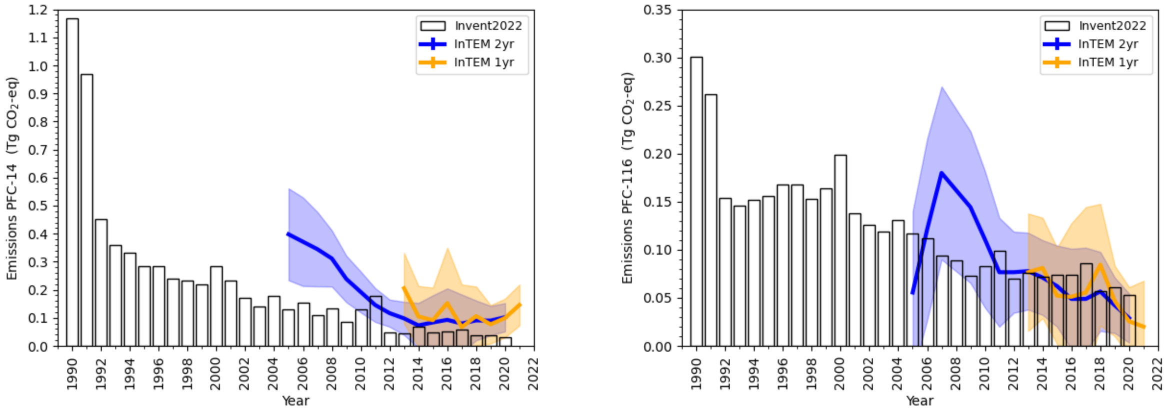


(a) PFC-14 (b) PFC-116



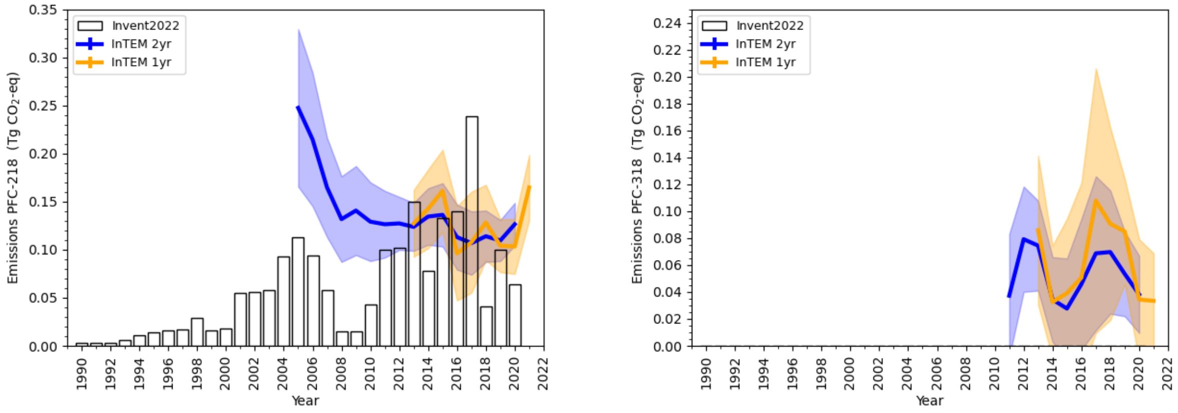
(c) PFC-218 (d) PFC-318

Figure A 6.17 **Verification of the UK emission inventory estimates for PFCs in Tg CO_2-eq yr^{-1} from 1990. GHGI estimates are shown in black. InTEM 2-year estimates are shown in blue (±1 σ), InTEM 1-year estimates are shown in orange (±1 σ).**



(a) PFC-14

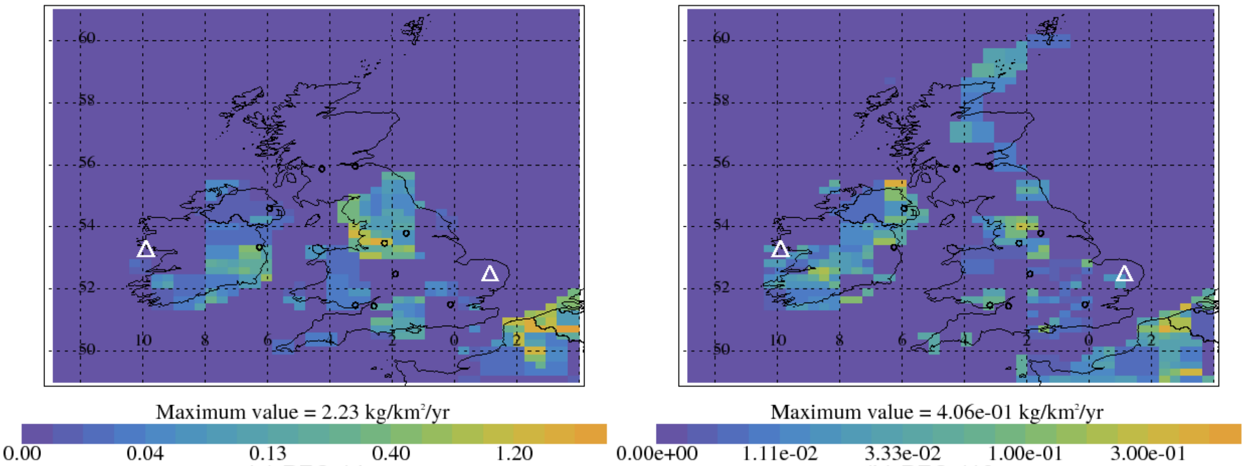
(b) PFC-116



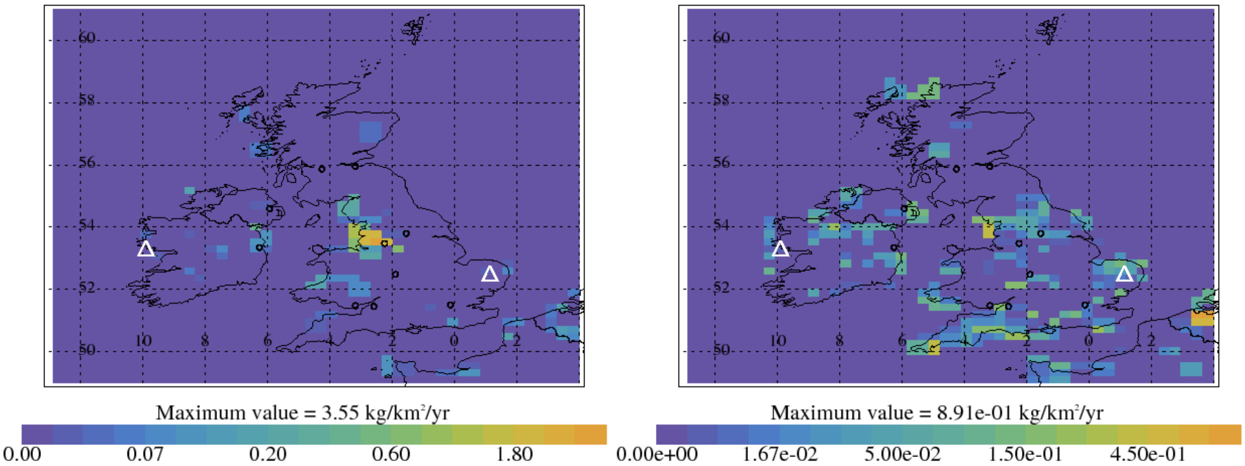
(c) PFC-218

(d) PFC-318

Figure A 6.18 **Four-year average PFC InTEM emission estimates (kg km^{-2} yr^{-1}) 2018-2021. The observation stations are shown as white triangles. Major cities are shown as black circles.**



(a) PFC-14 (b) PFC-116



(c) PFC-218 (d) PFC-318

A 6.5.1 PFC-14

Figure A 6.16 (a) shows the hemispheric background atmospheric concentrations of PFC-14 from 2004 onwards. The background trend is positive, in 2021 the Northern Hemispheric background concentration increased by 0.9 ppt.

The drop in emissions in 2012 seen in the GHGI (**Figure A 6.17** (a)) reflects the closure of a large aluminium production plant in the UK. The InTEM uncertainty ranges are large and the estimates are approximately double the GHGI from 2005 to 2010. InTEM estimates then gradually fall more in line with the GHGI although the estimated uncertainties are still large and often extend down to zero, probably because the majority of emissions come from intermittently emitting point sources. Overall there is reasonable agreement between the GHGI and the InTEM estimates in the last ten years, however it does look as if the slight decreasing trend in 2018, 2019 and 2020 in the GHGI is at odds with a slightly increasing trend emerging in the InTEM estimates.

Figure A 6.18 (a) shows the average spatial InTEM emissions estimate for PFC-14 over the UK in kg km^{-2} yr^{-1}, for the four-year period 2018-2021. The spatial distribution of PFC-14 shows sources in the NW of England, around Dublin and on the near-continent.

A 6.5.2 PFC-116

Figure A 6.16 (b) shows the hemispheric background atmospheric concentrations of PFC-116 from 2004 onwards. The background trend is monotonic and positive and in 2021 the Northern Hemispheric background concentration increased by 0.08 ppt.

The UK InTEM estimates have large uncertainties that generally overlap with the GHGI estimates (**Figure A 6.17** (b)) in the last ten years. The InTEM data is showing a downward trend which appears to agree with the GHGI in the last two years, although the decrease is slower. The 2018-2021 geographical spread of emissions (**Figure A 6.18** (b)) shows the most significant sources are in the southern Republic of Ireland, north of Belfast, Northern Ireland, and northwest England. There are also sources on the near-continent.

A 6.5.3 PFC-218

Figure A 6.16 (c) shows the hemispheric background atmospheric concentrations of PFC-218 from 2004 onwards. The background trend is monotonic and positive and in 2021 the Northern Hemispheric background concentration increased by 0.01 ppt.

The InTEM estimates are higher than those reported in the GHGI from 2005 to 2012 (**Figure A 6.17** (c)), though the very clear fall in UK GHGI emissions between 2005 and 2008 is replicated by the InTEM estimates. There is better agreement from 2013 with the InTEM estimates remaining largely flat whilst the GHGI shows strong year-to-year variation, most notably in 2017. The InTEM 1-year estimate shows a sharp increase from 2020 to 2021. The 2018-2021 geographical distribution of emissions (**Figure A 6.18** (c)) shows that the most significant source is clearly northwest England, the home of the UK's only PFC-218 production facility.

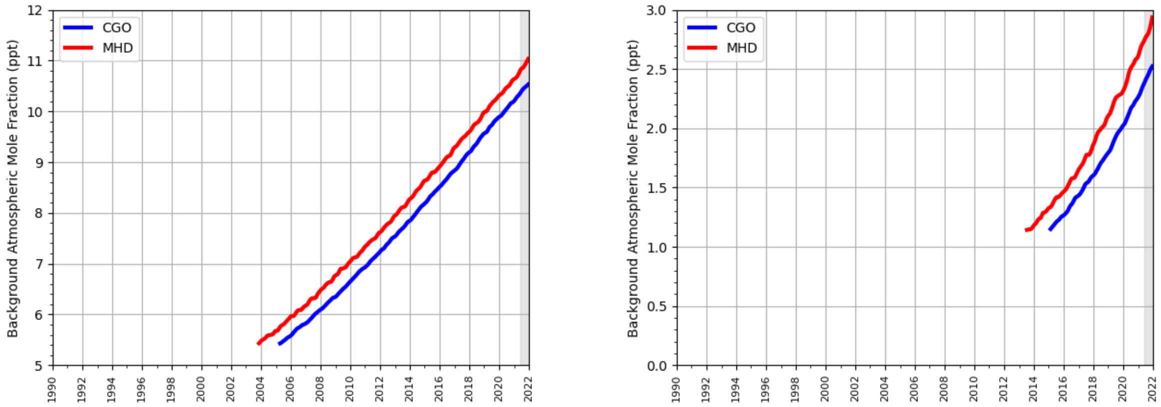
A 6.5.4 PFC-318

Figure A 6.16 (d) shows the hemispheric background atmospheric concentrations of PFC-318 from 2011 onwards. The background trend is monotonic and positive and in 2021 the Northern Hemisphere background concentration increased by 0.08 ppt.

The UK InTEM estimates are between 0.03 and 0.11 Tg CO_2-eq yr^{-1} significantly higher than emissions reported in the GHGI at ~0.00007 Tg CO_2-eq yr^{-1} (**Figure A 6.17** (d)). However, the InTEM estimated quantities have large uncertainties sometimes extending down to zero emissions. The geographical spread of emissions is shown in **Figure A 6.18** (d), and emissions over the UK are very low, with the most significant source on the near continent.

A 6.6 SULPHUR HEXAFLUORIDE

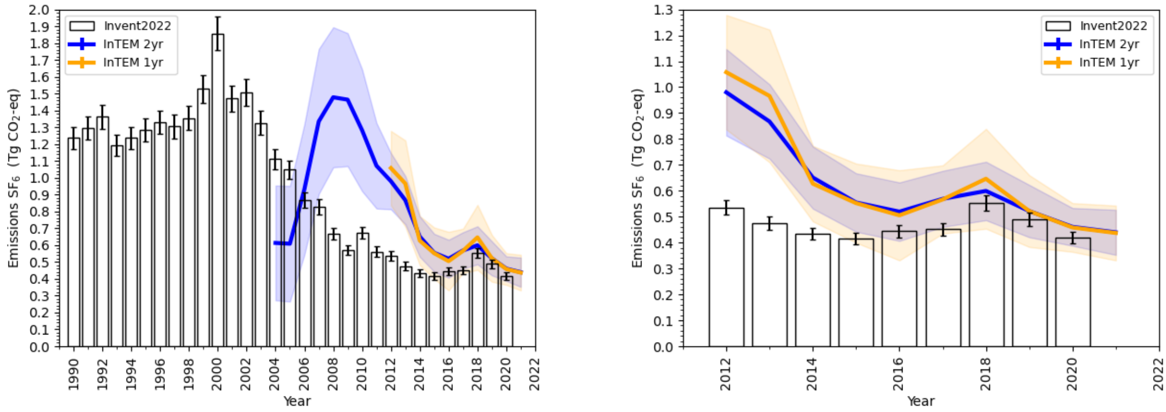
Figure A 6.19 Background Northern Hemisphere monthly concentrations of (a) SF_6 and (b) NF_3 estimated from Mace Head, Ireland observations are shown in red, and background Southern Hemisphere monthly concentrations from Cape Grim, Tasmania are shown in blue.



(a) Sulphur Hexafluoride (b) Nitrogen Trifluoride

Figure A 6.19 (a) shows the hemispheric background atmospheric concentrations of sulphur hexafluoride (SF_6) from 2004 onwards. The background trend is monotonic and positive and in 2021 the Northern Hemispheric background concentration increased by 0.33 ppt.

Figure A 6.20 Verification of the UK emission inventory estimates for SF_6 in Tg CO_2-eq yr-1 from 1990, (a) and 2012 (b). GHGI estimates are shown in black. InTEM 2-year estimates are shown in blue (±1 σ), InTEM 1-year estimates are shown in orange (±1 σ).



(a) 1990-2021 (b) 2012-2021

The UK 2-yr InTEM estimates (**Figure A 6.20**) show a sharp rise from 2005 until 2008 and then a steep decline until 2016. From 2002 until 2009 the GHGI shows a steady decline from ~1.2 Tg CO_2-eq yr^{-1} to ~0.7 Tg CO_2-eq yr^{-1}, a small rise in 2010 and then a slow decline up to 2015 and a rise until 2018. Whilst there is poor agreement between the GHGI and InTEM from 2004-2015, from 2016 there is good agreement especially from 2018-2020 following the decreasing trend. Looking at the monthly emissions (**Figure A 6.21**) such elevations appear to be linked to specific events in individual months e.g. Dec 2016. There is no evidence of a strong seasonal cycle in UK SF_6 emissions, although there are months with very elevated estimated emissions. The observations themselves reveal some very large, short-lived, pollution events that are worthy of further investigation. The estimated spatial distribution of emissions 2018-2021 from InTEM is shown in **Figure A 6.22**. The emissions do not appear to be distributed by population or from a single emission source. The main reported sources of emissions in the UK are from use in high-voltage switchgear which is widespread across the UK.

Figure A 6.21 Verification of the UK emission inventory estimates for SF_6 in Tg CO_2-eq yr^{-1} from 2012. GHGI estimates are shown in black. InTEM 1-month estimates are shown in red (±1 σ).

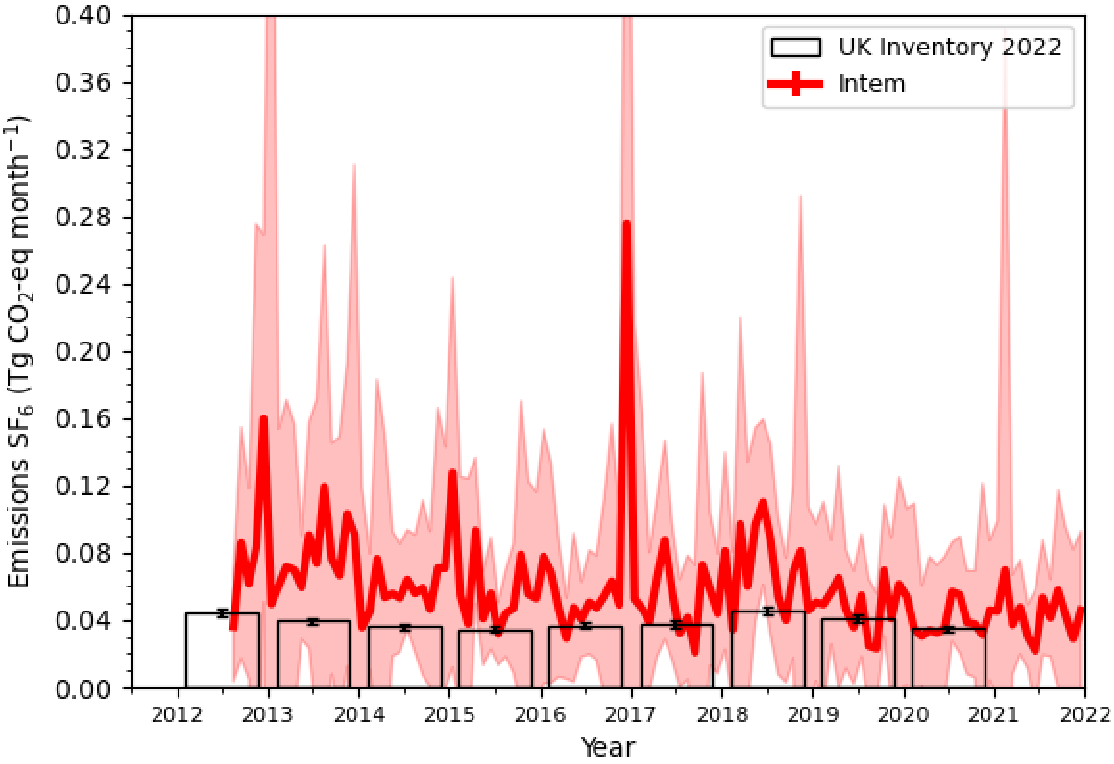
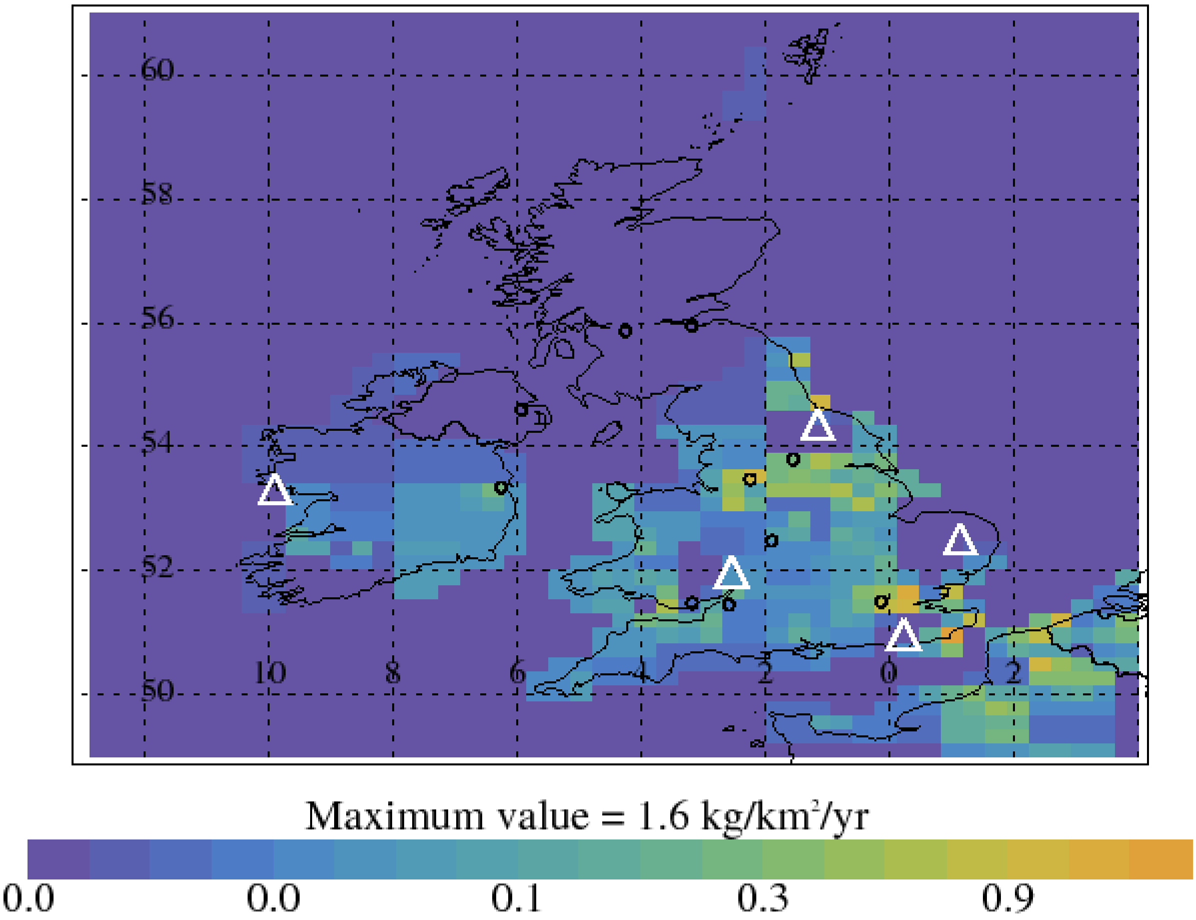


Figure A 6.22 **Four-year average SF_6 InTEM emission estimates (kg km^{-2} yr^{-1} of gas) 2018-2021. The observation stations are shown as white triangles. Major cities are shown as black circles.**

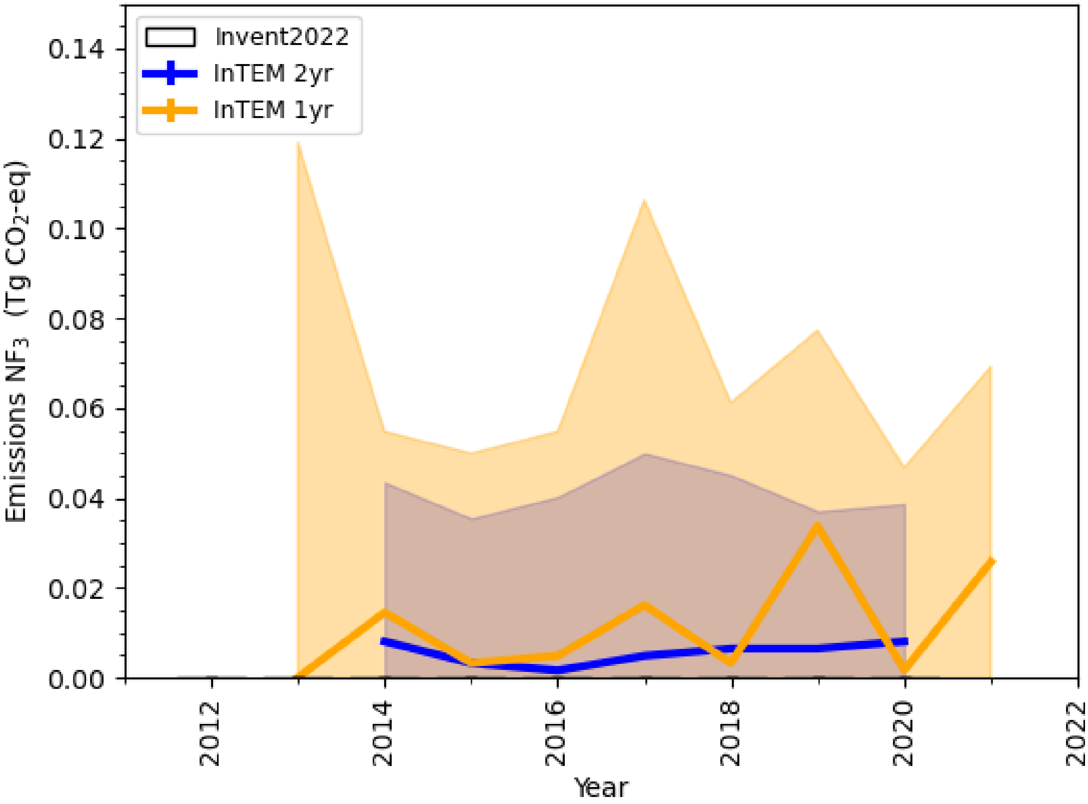


A 6.7 NITROGEN TRIFLUORIDE

Figure A 6.19 (b) shows the hemispheric background atmospheric concentrations of nitrogen trifluoride (NF_3) from 2014 onwards. The background trend is monotonic and positive, and the Northern Hemispheric atmospheric concentration increased by 0.27 ppt in 2021.

NF_3 is only measured at MHD and JFJ. The InTEM emission estimates for the UK are ~0.005-0.02 Tg CO_2-eq yr^{-1} (**Figure A 6.23**) but with uncertainties that extend down to zero. The GHGI estimate for 2020 is 0.00036 Tg CO_2-eq yr^{-1}.

Figure A 6.23 **Verification of the UK emission inventory estimates for NF_3 in Tg CO_2-eq yr^{-1} from 2012. GHGI estimates are too small to see. InTEM 2-year estimates are shown in blue (±1 σ), InTEM 1-year estimates are shown in orange (±1 σ).**



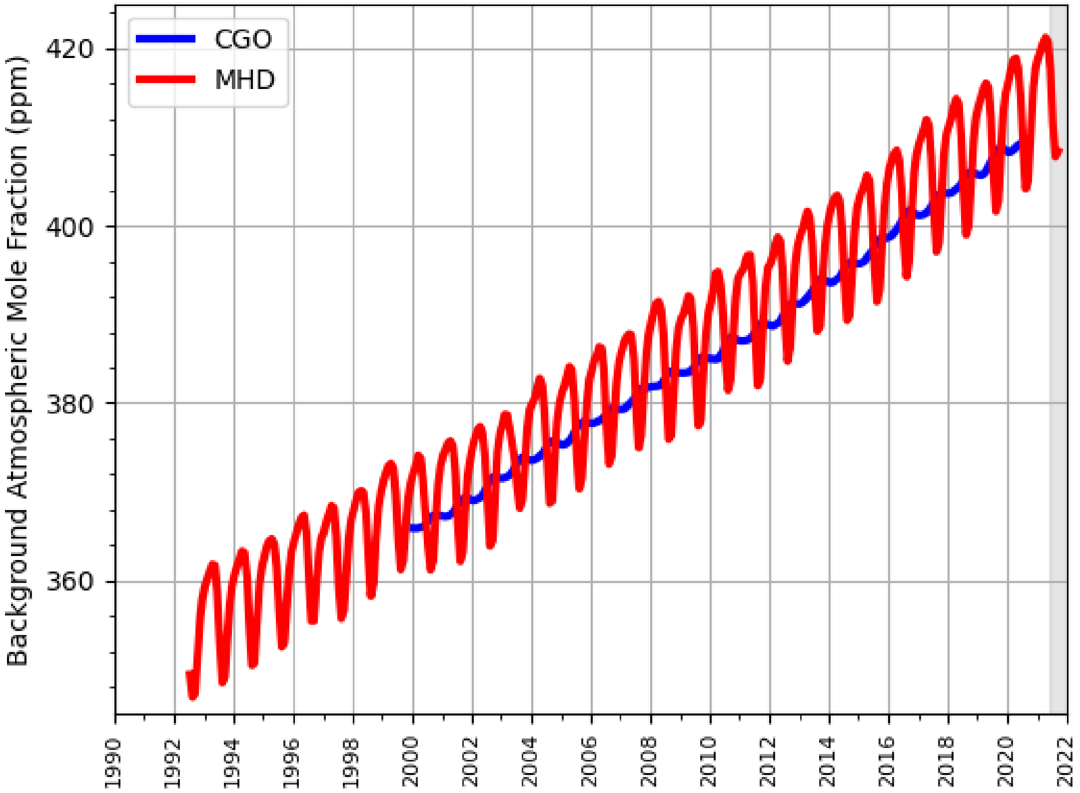
A 6.8 CARBON DIOXIDE

High precision, high frequency measurements of carbon dioxide (CO_2) are made across the UK DECC network. The Northern Hemisphere background trend is positive; in 2021 it increased by 2.6 ppm, as it also did in 2020, up from 2.5 ppm in 2019. The background has a strong seasonal cycle due to the influence of the biosphere with a maximum in early spring and a minimum in late summer.

The CO_2 observed has three principle components:

1. Northern hemisphere background (**Figure A 6.24**).
2. Anthropogenic (man-made)
3. Non-anthropogenic (natural)

Figure A 6.24 Background Northern Hemisphere monthly concentrations of CO_2 estimated from Mace Head, Ireland observations (data obtained from LSCE equipment through a data sharing agreement) are shown in red, and background Southern Hemisphere monthly concentrations from Cape Grim, Tasmania are shown in blue.



Since plants both produce CO_2 through respiration and absorb CO_2 through photosynthesis, the CO_2 flux from vegetation has a strong diurnal and seasonal cycle and switches from production to absorption on a daily basis. This unknown natural (biogenic) component of the observed CO_2 is significant when compared to the anthropogenic (man-made) component and cannot be ignored. It is difficult to use CO_2 measurements directly in an inversion to estimate anthropogenic emissions because (a) it is not possible to distinguish between biogenic and anthropogenic CO_2, and (b) the diurnally varying biogenic CO_2 flux is at odds with a key assumption of the inversion method, namely that emissions do not strongly vary in time over the inversion time-window (say monthly). Methods are under development to attempt to over-come these challenges, such as: the use of isotopic observations, through ratios with respect to anthropogenic carbon monoxide (CO), and tracking at what time of day air passes over the ground and using biogenic process models. The uncertainties associated with each of these methods are predicted to be significant.

The estimated uncertainties in the CO_2 GHGI are very small compared to inversion results. Work is on-going to seek to improve our methods of verifying inventory CO_2 emission estimates.

ANNEX 7: Analysis of EU ETS Data

A 7.1 INTRODUCTION

This annex summarises the analysis of the 2020 European Union Emissions Trading System (EU ETS) energy and emissions data that is used within the compilation of the UK GHG inventory. The EU ETS data are used to inform activity data estimates for heavy industry sectors, carbon dioxide emission factors of UK fuels within those sectors, and for comparison of fuel allocations to specific economic sectors against data presented in the *Digest of UK Energy Statistics* (DUKES), published by the Department of Business, Energy and Industrial Strategy (BEIS).

The EU ETS data are used in the UK GHGI compilation as follows:

- EU ETS raw data on energy and emission estimates are processed and checked to enable integration of the activity data, implied emission factors and installation emission estimates as far as practicable within the UK GHG inventory compilation. Emission sources reported in EU ETS are allocated to inventory fuels and source codes, outliers are identified, and clarifications of data inconsistencies are sought with the regulatory agencies;
- EU ETS activity data are closely compared against the UK national energy balance (DUKES) published by BEIS, and any inconsistencies are researched, seeking to resolve these through consultation with BEIS wherever possible;
- The verified EU ETS data provides up to date high quality fuel compositional analysis of UK fuels, and these data are used to improve inventory emission estimates across the highly energy intensive sources such as power stations, refineries, cement kilns, and oil and gas sources;
- The EU ETS dataset for offshore oil and gas installations are checked to assess data consistency in emissions reporting between the EU ETS and the EEMS dataset which is also used within the UK GHGI compilation;
- Overall, the Inventory Agency approach seeks to minimise data discrepancies between EU ETS and the GHGI as far as practicable, in order that the derivation of traded and non-traded emission estimates from the UK GHGI are as accurate as possible. Close consistency between the EU ETS and GHGI is an important aspect of the development of a complete and consistent evidence base for policy development and tracking progress towards UK GHG reduction targets in the non-traded sector under the EU Effort Sharing Decision.

The scope of reporting under EU ETS increased from the 2013 dataset onwards. Phase II of the EU ETS ran from 2008-2012 inclusive. Phase III reporting began in 2013, with some new emission sources and new installations reporting for the first time on their GHG emissions; in particular, the definition of combustion has now been extended to cover installations such as furnaces, driers, and other plant where heat is used directly. A handful of industrial process sources of CO_2 are also included from 2013, such as soda ash production. In the UK, the changes in reporting in Phase III are most significant for the chemicals sector, where the scope of reporting is larger than previously and now encompasses both new industrial process emission sources, and additional energy use. There is also a notable shift towards estimation methods that are based on mass balance calculations (e.g. for chemical manufacturing) within the UK operator reporting to EU ETS. Other sectors with significant increases in reporting are food and drink manufacture, where installations such as driers, ovens etc. were included for the first time thus adding to the emissions from boilers and CHP plant that were reported in previous years, and roadstone coating, a sector which has not been present in the dataset before.

Analysis of the phase III data enabled the Inventory Agency to improve estimates of emissions from the combustion of waste residues and process off-gases within the chemical and petrochemical sectors (which are all reported under IPPU sector 2B10), as well as to generate improved estimates for the IPPU component of several specific manufacturing processes, such as for soda ash (2B7), and titanium dioxide (2B6). In addition, following a review of methodology for all IPPU sources, EU ETS data for phase II onwards has been used to improve emission estimates for glass production (2A3), brickmaking (2A4) and reductant use in electric arc furnaces (2C1).

The key findings from the analysis and use of the EU ETS data include:

- In the 2020 EU ETS dataset, a very high coverage of Tier 3 emissions data is evident for all fuel use in the power sector, and for solid, liquid and waste-derived fuels used in the cement and lime sectors. The proportion of Tier 3 data is somewhat lower for refinery fuel use, but still sufficiently high for the ETS to be considered the most reliable data available. All of the fuel quality data for these sources and fuels are therefore used within the UK GHGI, as the EU ETS fuel quality data is the most representative dataset available to inform UK carbon dioxide emission factors in the inventory;
- EU ETS emissions data from refineries are higher than estimates derived from DUKES activity data for all but two years within the time series, with a discrepancy evident in OPG emissions. Consultation with the industry trade association, UKPIA, and cross-checking with their data shows that the EU ETS data are felt to more accurately reflect estimates of CO_2, and therefore UK GHGI estimates are based on EU ETS data rather than refinery fuel use data reported in the UK energy balance;
- There are a range of other activity data discrepancies when compared to DUKES within the oil & gas, cement and lime, other industry and iron and steel sectors. Revisions to fuel allocations within the UK GHGI have been implemented for a number of sources, whilst further research is needed in some instances to clarify the issues where the reporting format of EU ETS does not map explicitly to energy balance and GHG inventory reporting requirements;
- EU ETS data for fuel use at chemical and petrochemical production facilities has helped to identify and quantify the combustion of process off-gases that are derived from Natural Gas Liquid (NGL) feedstock to petrochemical production processes, and from combustion of carbon-containing process residues. Analysis of “fuel gas” calorific values and carbon content informs the calculations to estimate emissions from NGL-derived gases and other residues.

The use of EU ETS data in the UK GHG inventory is summarised in **Table A 7.1.1**.

Table A 7.1.1 Summary of the use of EU ETS data in the UK inventory

Category	Sub-categories	Factors	Activity	Emissions	Comments
1A1a	Power stations - coal, fuel oil natural gas, sour gas	✓			
1A1a	Power stations – petcoke			✓	Some additional data is sourced from process operators.
1A1b	Refineries – petcoke & OPG			✓	EU ETS figures only used where higher than DUKES-based emissions.
1A1b	Refineries – natural gas	✓			
1A1c 1B2	Upstream oil and gas production – Gas oil, natural gas, LPG, OPG			✓	
1A1c	Gas industry – natural gas		✓		
1A1c 1B1b 1A2a 2C1	Integrated steelworks	✓	✓		Use of various EU ETS data in complex carbon balance – factors for some fuels, activity data for others
1A1c	Collieries – Colliery methane	✓			
1A2b	Autogenerators - coal	✓			
1A2f	Lime - coal			✓	
1A2f	Lime – natural gas		✓		
1A2g	Industry - petcoke & waste solvents			✓	No alternative data available for this emission source.
1A2g	Industry – colliery methane	✓			
2A1	Cement			✓	Data used is actually from industry trade-association, but this is based on EU ETS returns
2A2	Lime			✓	
2A3	Glass			✓	
2A4	Bricks			✓	
2B7	Soda ash			✓	

Category	Sub-categories	Factors	Activity	Emissions	Comments
2B8g	Ethylene & other petrochemicals			✓	
2C1	Electric arc furnaces - reductants			✓	

A 7.2 BACKGROUND

A 7.2.1 EU ETS Data and GHG Inventories

The European Union Emissions Trading System (EU ETS) data provides annual estimates of fuel use and fuel quality data from the most energy intensive sites in the UK, and provides a source of data, or can be used to cross-check data held in the UK Greenhouse Gas Inventory (GHGI), and to inform the carbon contents of current UK fuels. The EU ETS has operated since 2005, and data has been available on an annual basis since this time across major UK industrial plants.

The data reported under the EU ETS includes quantities of fuels consumed (or other activity data for process sources of CO_2), carbon contents of fuels and other inputs, calorific values (fuels only) and emissions of carbon dioxide, all presented by installation and by emission source. Activity data are also given for many biofuels, although emissions of CO_2 from these fuels are not included in the emissions data. This is useful though, since PI/SPRI/WEI/NIPI emissions data for CO_2 often include biocarbon as well as fossil carbon, and the EU ETS data on biofuels helps to explain differences between CO_2 emissions reported in EU ETS and in those regulator inventories. EU ETS data for individual installations are treated as commercially confidential by the UK regulatory authorities and so only aggregated emissions data are reported in inventory outputs.

As part of the UK's annual reporting requirements to the MMR and UNFCCC, the UK must include a comparison of the EU ETS data against the national inventory dataset within the National Inventory Report. Furthermore, the analysis of the inventory against the EU ETS dataset is coming under increasing scrutiny due to the development of domestic GHG reduction targets that are based on non-traded[32] emissions data only, and the growing need to understand the UK non-traded sector emissions for future reporting under the Effort Sharing Decision.

The EU ETS dataset helps to improve the UK GHG inventory in a number of ways:

- Identifying new sources, therefore improving completeness;
- Helping assess true levels of uncertainty in fuel- and sector-specific data;
- Providing fuel quality data and oxidation factors for complex processes;
- Providing information on process-specific emissions that are not apparent from the national energy balances;
- Reducing uncertainty in the GHGI; and

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[32] All GHG emissions that are regulated within the EU ETS are defined as "traded" emissions, whilst all other GHG emissions are defined as "non-traded". The EU Effort Sharing Decision will lead to the UK adopting a new target for GHG reductions by 2020 for all of the non-traded emissions (i.e. everything outside of EU ETS), and progress towards this target will be monitored through the UK GHG inventory.

- Acting as a source of quality assurance to inventory data.

In the 1990-2020 inventory cycle, the Inventory Agency has updated and extended the EU ETS analysis conducted for inventory compilation, using the 2020 EU ETS dataset, which is the eighth and last year of reporting under the Phase III EU ETS scope. This annex presents a comprehensive review of the sixteen years of EU ETS data, indicating where the data have already been used in the improvement of the GHGI, as well as highlighting outstanding issues which could be investigated further, with potential for further revision and improvement of the GHGI.

The Inventory Agency has also been provided with details of all offshore oil and gas installations from EU ETS data since 2011, which are regulated by BEIS OPRED. Access to these detailed data has enabled a more thorough review of the fuel/gas quality and reported emissions from combustion and flaring sources at offshore installations, and has directly improved the completeness and accuracy of the sector estimates within the UK GHGI.

The analysis of the EU ETS data for use in the UK GHGI necessitates a detailed review of the available data, in order to ensure correct interpretation and application of the available data. The study team prioritises effort to the sources and sites that are the most significant in UK GHGI terms, and/or where data reporting discrepancies have been identified from previous work. For those sectors where EU ETS data are used in the GHGI, it is important to review emission factors from all major installations to ensure that any outliers are identified and checked prior to their inclusion in inventory calculations.

Wherever possible, consistent assumptions are made when interpreting data across all years of the EU ETS. For instance ensuring that each site is allocated to the same inventory sector in each year (unless there is reason to change it – some industrial combustion plants in recent years have been converted into power stations, and so these sites do need to be allocated to different sectors in different years), and that there is consistency in the way in which site-specific names for fuels are interpreted across the entire period. The information on the EU ETS method “Tier” used for each of the data dictates whether they are used in inventory compilation. The highest tier EU ETS data are assumed to be subject to the lowest level of uncertainty, and so only tier 3 and tier 4 emission factor data are used. Occasionally there are internal inconsistencies in the EU ETS data between the data on consumption of a given fuel and emissions from the use of that fuel. These need to be resolved before the data can be used in the UK GHGI. As emissions data are verified, we cross-check the detailed emissions data against the final verified emissions for each site. As a general rule it is found that the most appropriate solution to inconsistencies is to assume that the EU ETS emissions data are correct as EU ETS reporting requirements are well regulated, and that it is the activity data that need to be amended instead.

A 7.2.2 Scope of the UK EU ETS and Implications for the GHG Inventory

There are a number of limitations to the EU ETS data that affect the data usefulness in GHG inventory compilation, including:

- The EU ETS data are only available from 2005 onwards, whilst the UK GHG inventory reports emission trends back to 1990. The additional information that EU ETS provides (e.g. year-specific emission factors for many fuels in energy intensive sectors) helps to reduce the uncertainties in inventory emission estimates for the later years, but care is needed where revisions to the time series are made back to 2005. A consistent approach to inventory compilation across the time series is a key tenet of IPCC good practice guidance, and care is needed to ensure that the use of EU ETS data does not introduce a systematic reporting step-change in the UK GHGI;

- Further to this point, it is important to note that the scope of EU ETS reporting has evolved through the years, from Phase I (2005 to 2007) into Phase II (2008 to 2012 data) and now to Phase III (2013 onwards). The comparability of EU ETS data for many sectors is poor between these three phases. For example, many cement kilns did not report to EU ETS until Phase II: several sectors including cement were reporting under Climate Change Agreements and were opted-out of EU ETS during Phase I. Therefore, in several sectors, more complete coverage of EU ETS reporting is evident in Phase II and data from 2008 onwards are therefore much more useful for UK GHGI reporting. The scope of coverage of chemical industry emissions has gone through two step changes – in 2008, and again in 2013, and some sectors (such as roadstone coating) only appear for the first time in the 2013 EU ETS data. Less significantly for the GHGI, many small installations, mostly in the public sector, were removed from EU ETS at the end of phase I. It is vital that the GHGI takes full account of such changes and that UK inventory data do not include trends that merely result from the increase (or decrease) in scope of EU ETS. The changes in EU ETS scope have made the data set increasingly useful, and there are now five years' worth of Phase II data and eight years of data under Phase III, hence the EU ETS dataset is now an important source of information for the UK inventory;
- In the UK during EU ETS Phases I and II, the regulators adopted a "medium" definition of the term "combustion", and as a result there were many sectors where fuel use in specific types of combustion unit were not included in the EU ETS reporting scope until the start of Phase III (2013 onwards). Examples of this include flaring on chemical sites, and fuel use in heaters, dryers, fryers and stenters in industry sectors such as: chemicals, food and drink, textiles, paper and pulp. Hence the total fuel use and GHG emissions from these sectors have typically been under-reported within the EU ETS historically compared with the UK inventory, with many sites and sources excluded from the scope of EU ETS. However, the EU ETS data for these sectors is also incomplete both in Phase II and Phase III because small installations are not covered by EU ETS. Therefore, while the change in scope for combustion installations in phase III is a positive step, it has relatively little impact on the data used in GHGI compilation. Some Phase III data has been used to improve the estimates of emissions from combustion of process wastes / off-gases in the chemical and petrochemical sector in the recent submissions.
- Phase III also brought an increased scope for industrial process sources of CO_2, and data appeared for the first time for soda ash production, and titanium dioxide manufacture.
- When using the EU ETS data, assumptions and interpretations are required to be made regarding the fuel types used by operators; assumptions are made on a case by case basis depending on knowledge of the site or industry and expert judgement. Operators are free to describe fuels as they wish in their returns, rather than choosing from a specific list of fuels, and so assumptions occasionally need to be made where the fuel type used is not clear from the operator's description. This issue was more significant in the earlier years of EU ETS reporting, with operators often using terms such as "Fuel 1". The assumption then made about fuel type was based both on the other data the operator provided on the fuel such as calorific value, but also by comparison with later data for the same site, since operators now tend to use more recognisable fuel names, and the use of wholly ambiguous terms is now very rare.

Note that:

- The direct use of EU ETS data (e.g. fuel use data by sector) to inform UK GHGI estimates is limited to where the EU ETS is known to cover close to 100% of sector installations. For example, the EU ETS is regarded as representative and 100% comprehensive in coverage of refineries, power stations (except in the case of some small power stations burning biomass, gas oil, or burning oil as the main fuel), integrated steelworks, cement and lime kilns, soda ash plant, titanium dioxide plant, petrochemical works and glassworks (container, flat, wool & continuous filament fibre only – small lead glass and frit producers are not included). Coverage is very close to 100% for brickworks and tileries. For many other industrial sectors (such as chemicals, non-ferrous metals, food and drink, engineering) the EU ETS is not comprehensive and therefore the data are of more limited use, mainly providing a de-minimis fuel consumption figure for these sectors.
- EU ETS Implied Emissions Factors (IEFs) can be used within the UK GHGI, but only where the evidence indicates that EU ETS data are representative of the sector as whole and provides more comprehensive and accurate data than alternative sources. The key criteria to consider in the assessment of EU ETS IEF usefulness is the percentage of annual fuel use by sector where operator estimates use Tier 3 emission factors.
- Review of the EU ETS IEFs for different fuels across different sites provides a useful insight into the level of Tier 3 reporting within different sectors, the progression of higher-Tier reporting within EU ETS through the time series and the level of variability in fuel quality for the different major fuels in the UK. As a general rule, those energy-intensive sectors with near 100% coverage in EU ETS also report a very high proportion of emission factor data at Tier 3. Those sectors with incomplete coverage tend to report most emission factor data below Tier 3. As a result, in all cases where the level of sectoral coverage is high, the quality of reported data is also sufficiently high to be used with confidence in the UK inventory.

A 7.2.3 Limitations of EU ETS Data Integration with GHG Inventory: Autogeneration

Despite detailed research there remain some fundamental limitations in the use of EU ETS data within national inventories where the sector allocation of energy use and emissions cannot be resolved against the national energy statistics that underpin the GHG inventory compilation. One key example is that of the division between fuel use in autogeneration (or heat generation) and direct fuel use within a specific sector. For example, based on the data available from EU ETS, it is impossible to differentiate between gas use in autogeneration on a chemical installation, and gas used directly to heat chemical production processes. In this example, the allocation of EU ETS energy use and emissions between 1A2c (chemicals) and 1A2f (autogenerators) is uncertain, and therefore comparison of EU ETS and GHGI estimates is uncertain. The EU ETS data are not sufficiently detailed and transparent to enable accurate allocation, and so in all cases fuels and emissions are allocated to the industry sector, and not to autogeneration.

It is worth noting here that the UK energy statistics are also subject to some uncertainty, however small, and that there is likely to be more uncertainty in estimates at industrial sector-level, rather than at more aggregated levels. For example, while fuel producers and suppliers will be able to quantify total fuel demand with a high level of certainty, it would be far more difficult for them to estimate fuel use by specific industrial sectors. This will be reflected in the quality of UK energy statistics which are used to estimate emissions from 1A2c etc. We consider that a high proportion of fossil fuel use by the UK chemical industry will be included in the EU ETS, on the basis that most industrial chemical processes will require sufficiently large combustion installations to exceed the threshold for EU ETS. Therefore, we consider that it is reasonable to assume that EU

ETS emissions for the chemical sector should cover most of the sector and therefore be similar in magnitude to those estimated from UK energy statistics and even, given the uncertainty in fuel allocation for autogeneration, to exceed them. For other sectors such as metals, paper, and food and drink, we would assume that the level of sectoral coverage by the EU ETS would be lower, so that emission estimates based on EU ETS would probably be lower than those based on energy statistics, even taking into account the uncertainty regarding autogeneration.

A 7.2.4 Data Processing

BEIS provided the detailed EU ETS regulator data from the Environment Agency, Natural Resources Wales, Scottish Environment Protection Agency and Northern Ireland Environment Agency during April & May 2021, and the Inventory Agency industrial emissions experts progressed the analysis, combining the datasets to generate a UK-wide EU ETS dataset. The work built on analysis conducted in previous years, as the EU ETS has been in place since 2005, but this latest analysis, while focussing on the latest year of data, did involve review of the data for earlier years, to ensure a consistent approach to the interpretation of energy and emissions data across the time series.

The initial step in the analysis is the allocation of all sites in the dataset to one of the economic sectors as reported within the DUKES Commodity Balance tables. Next, the reported fuels for every UK installation have to be allocated to one of the GHGI fuel names, which are also aligned with the fuel types reported within DUKES. This enables a direct comparison of EU ETS fuel totals against sector fuel allocations within DUKES and therefore used within the GHGI.

Most of the allocations have been made as part of previous years' work, and do not need to be revisited. However, several new installations included in the 2020 EU ETS data had to be allocated to DUKES' sectors, and all of the fuel data for 2020 also has had to be allocated to DUKES/GHGI fuel types. In a very small number of cases, we have revised data for earlier years, for example when it has become apparent that existing assumptions are likely to be incorrect. The allocation process does rely upon some expert judgement, with the Ricardo team using the reported EU ETS fuel names as well as the reported fuel quality data such as calorific values and carbon emission factors in order to make the fuel-type allocation for each entry in the EU ETS spreadsheet. The allocation is, occasionally, quite uncertain, particularly with the allocation of petroleum-based fuels such as the GHGI fuel categories LPG, OPG, gas oil and fuel oil, often because of the use of abbreviations or other slightly ambiguous names for fuels within the EU ETS reporting system. Cross-checking of data across the time series for each installation has been used to ensure as much consistency in fuel allocations as possible, although in some cases, operators of installations use different fuel terminology in different years, and the possibility of the use of different fuels in different years at a site cannot always be ruled out.

The quality checking and allocation process is very resource-intensive and essentially an open-ended task for such a large dataset, and hence the Inventory Agency focuses on the highest emitters and the known "problem" sites and fuel types. Where uncertainties arise in allocations, the most important allocation decisions are copied across to the BEIS DUKES team, for their information and input, as ultimately the EU ETS analysis by the Inventory Agency is taken into account to some degree within the compilation of DUKES for the following year.

As a data verification step, the installation emissions (broken down by fuel) from the EU ETS regulator spreadsheets are then compared against the total installation emissions for 2020 on the European Union Transaction Log (EUTL) which is a central website that holds the verified EU ETS emissions totals for all EU installations in the scheme. Each year we have noted that for some sites the regulator data does not match the EUTL dataset, and therefore some “residual” emissions allocations are generated, from the difference between EUTL and regulator information. In cases where these residual emissions are large, these are fed back to the regulator contacts, for their consideration and to request any insights into the likely fuels that the residual emissions should be allocated against. Minor residual emissions are ignored for the purposes of the analysis reported here.

A final data set is then available for fuel combustion emission sources, which includes the following data fields:

- GHGI Source Category;
- GHGI Fuel Category;
- Fuel Consumed;
- Fuel Calorific Value;
- Fuel Carbon Emission Factor; and
- Related Emissions of CO_2

The Inventory Agency then combines the data by sector and/or fuel category to provide data for comparison against GHGI emissions data, and energy statistics published in DUKES. In this way, the analysis can:

- provide improved CO_2 emission factors for highly energy-intensive industrial sectors covered by the GHGI through the use of verified data;
- provide a comparison with UK energy statistics, allowing the identification of inconsistencies between EU ETS and DUKES;
- Identify any emission sources that are not contained in the GHGI.

The analysis of the EU ETS data for all onshore facilities was completed by May 2021 and provided to the BEIS team of energy statisticians, in time for them to consider the EU ETS dataset during compilation of the UK energy balance for 2020, as published within DUKES (published in July 2021).

The EU ETS data for offshore oil and gas installations was provided in May 2021 and were used directly in the compilation of emission estimates for the upstream oil and gas sector, after the UK energy balance had been compiled by BEIS. Access to these EU ETS data for offshore facilities provided more fuel-specific information (GCV, carbon content) to help improve completeness and accuracy of the upstream oil and gas estimates in the UK GHGI, augmenting the EEMS dataset which is a more comprehensive dataset (i.e. EEMS covers more emission sources than EU ETS) but does not provide the same level of fuel-specific data.

A 7.3 EU ETS DATA COVERAGE

The coverage of the EU ETS data has changed over the 16 years for which data are available. Major changes have been outlined in **Section A 7.1**, and these changes in scope have an impact on the usefulness of data for some sectors, with data generally being more complete for Phase II (2008-12) and Phase III (2013-2020) of EU ETS. In addition, smaller combustion installations in the industrial, commercial and public sectors are outside the scope of EU ETS, and in fact coverage was decreased after 2007 due to the exemption of certain 'small emitters' from the UK EU ETS. For some source sectors in the GHGI, the EU ETS data therefore only includes a small proportion of the sector and the EU ETS data are not useful to directly inform the GHGI.

The following GHGI source sectors are well represented in the EU ETS data sets in the UK, with all UK installations included:

- Power stations burning coal, gas, and fuel oil as the principal fuel;
- Oil refineries;
- Coke ovens & Integrated steelworks;
- Cement kilns (from Phase II onwards); and
- Lime kilns (from Phase II onwards)
- Glassworks - container, flat, wool & continuous filament glass fibre subsectors only (from phase II onwards)
- Brickworks and other sites manufacturing heavy ceramic goods (from Phase II onwards)
- Titanium dioxide and soda ash manufacture (from Phase III onwards).

However, GHGI sectors such as industrial combustion, autogeneration, and public sector combustion are only partially represented in the EU ETS data. An indication of the actual level of coverage of the EU ETS data can be seen in **Table A 7.3.1**. The number of sites in each sector which are included in the ETS dataset for 2005 and 2020 are given, together with the Inventory Agency's estimate of the total number of installations in that sector throughout the UK in those years.

Table A 7.3.1 Numbers of installations included in the EU ETS data

Sector	EU ETS installations in 2005	Total installations in 2005	EU ETS installations in 2020	Total installations in 2020
Power stations (fossil fuel, > 75MWe)	60	60	51	51
Power stations (fossil fuel, < 75MWe)	23	27	21	37
Power stations (nuclear)	12	12	7	7
Coke ovens	4	4	2	2
Sinter plant	3	3	2	2
Blast furnaces	3	3	2	2
Cement kilns	8	15	11	11
Lime kilns	4	15	13	13
Refineries	12	12	8	8
Combustion – iron & steel industry	11	200[a]	25	200[a]
Combustion – other industry	171	5000[a]	445	5000[a]
Combustion – commercial sector	28	1000[a]	100	1000[a]
Combustion – public sector	169	1000[a]	93	1000[a]

Sector	EU ETS installations in 2005	Total installations in 2005	EU ETS installations in 2020	Total installations in 2020
Glassworks (flat, special, container & fibre)	6	32	23	24
Brickworks	18	80[b]	48	48
Soda ash & titanium dioxide	0	4	4	4

[a] These estimates are 'order of magnitude' figures, based on expert judgement of the inventory team, to show that the number of installations in the UK is likely to be considerably higher than the number of installations reporting in the EU ETS.

[b] Numbers of brickworks are not certain in 2005 but will have been significantly higher than in 2008 (when there were about 70) since many brickworks were closed or mothballed in the second half of 2007. All brickworks are believed to be covered by EU ETS in 2020.

Data are included in EU ETS for all coke ovens, refineries, sinter plant and blast furnaces. Power stations are divided into three categories in the table in order to show that, although a few stations are not included in the EU ETS data for 2020, these are all small (in most cases, very small diesel-fired plant supplying electricity to Scottish islands). In comparison, coverage is quite poor in 2005 for cement and lime kilns (due to CCA participants opting out during Phase I) and for combustion processes (due to CCA/UKETS opt-outs and the fact that numerous combustion plant are too small to be required to join the EU ETS). All cement kilns and all lime kilns are included in 2020. Coverage of glassworks and brickworks was very limited during Phase I, but since 2008 has been very good: all large glassworks have been included since 2008, and all but one brickworks were included in Phase II, with that remaining site being added for Phase III. UK totals for brickworks are subject to some uncertainty however, and may be revised in future should more data be obtained. Both soda ash plant and both plants manufacturing titanium dioxide via the chloride process have only been included in EU ETS since the start of Phase III.

For most emission sources the level of detail given in the EU ETS data matches well with the structures of the GHGI, allowing comparison of like with like. Only in the case of coke ovens and integrated steelworks is this not the case, since the EU ETS reporting format does not provide a breakdown of emissions for the sectors reported within the GHGI: i.e. estimates of emissions from coke ovens, blast furnaces and sinter plants are not provided explicitly. However, for these sectors, additional detailed analysis, including the collection of other industry data, has allowed for far greater use of EU ETS data for the inventory.

A 7.4 EU ETS DATA USE IN THE UK GHGI

The use of EU ETS data in the UK GHGI may conveniently be divided into two classes:

- Instances where activity data and, in most cases, emission totals as well are taken from EU ETS;
- Instances where emission factors only are taken from EU ETS and then used in the UK GHG Inventory with activity data from other sources such as DUKES.

A 7.4.1 Activity and Emissions Data

A 7.4.1.1 Crude Oil Refineries

The comparison of EU ETS emissions data against GHGI data based on DUKES fuel use allocations for petcoke, natural gas, fuel oil and OPG use is inconsistent to varying degrees in different years. Previous EU ETS analysis indicated that petcoke data in DUKES were too low; the BEIS energy statistics team have investigated this matter with the refinery operators and have revised data for a number of sites that had been misreporting through the DORS system used to compile DUKES. In recent years, therefore, the EU ETS and DUKES data are closely consistent for petcoke use by refineries.

Data inconsistencies between DUKES and EU ETS remain for other fuels, however, in some cases, this will be due to misallocation of fuel use data within the EU ETS analysis, where fuel names are unclear, e.g. “fuel gas” could be interpreted solely as refinery use of OPG or to also cover the use of natural gas as a back-up fuel within the refinery fuel gas system.

The fuel oil activity data in most years is around 10% higher in EU ETS than in DUKES. Natural gas is a relatively minor fuel in the sector; whilst the EU ETS allocations indicate an over-report in DUKES, there is considerable uncertainty over the allocations of gases in the EU ETS dataset, as noted above. However, DUKES data for natural gas used in autogeneration includes some fuel burnt at refineries, thus the difference between refinery fuel use as given in EU ETS, and that derived from DUKES data can be reduced by taking this into account. Consumption of naphtha reported in DUKES as “unclassified industry” is allocated to refineries as the only known consumers in the UK. However, in the case of OPG, there is typically an under-report in DUKES, although the data in DUKES is higher in two years. **Table A 7.4.1** below presents the emissions allocated to OPG for those years (2004 onwards except 2005, 2012) where UKPIA and EU ETS data indicates that DUKES data are too low. Note that the GHGI estimates also include the assumption that all of the OPG allocation to “autogenerators” within the DUKES commodity balance tables (in the column “Other gases”) is used within the refinery sector. Consultation with the BEIS DUKES team has indicated (Personal Communication, Evans, 2010) that the “Other gases” column in the Commodity Balance tables is the OPG on the refinery basis, with CHP plant on site allocated to the autogeneration line. We have therefore retained this assumption in the current analysis, including the autogenerator allocation of “other gases” within the refinery sector.

To resolve the refinery sector under-report, we have compared DUKES data against EU ETS data, and also considered the total carbon dioxide emissions for the refinery sector provided annually by UKPIA. At the installation level, the UKPIA and EU ETS data show very close consistency for recent years (typically within 1%). The close consistency of the EU ETS and UKPIA data further strengthens the case for using EU ETS data as the primary dataset to inform the UK GHG inventory, in preference to the DUKES energy statistics.

At the fuel-specific level, the greatest disparity is evident in the reporting of OPG use at refineries; the reporting disparity has therefore been resolved through a top-down emissions comparison between DUKES-derived data and the best available operator data from EU ETS (2005 onwards) and UKPIA (pre-2005), with the difference between the two then allocated to OPG use in the UK GHGI. UK inventory estimates of emissions for the sector are therefore aligned with EU ETS totals back to 2005, and with UKPIA data prior to 2005, unless the estimates derived from DUKES data are higher than those from UKPIA or EU ETS (i.e. in 2005 and 2012).

No deviations from UK energy statistics have been made prior to 2004, as the data from UKPIA and GHGI estimates based on DUKES are closely consistent with the DUKES-derived data being slightly higher; therefore, a conservative approach is adopted, using DUKES-derived GHG estimates.

The time series of emissions data and the additional OPG and petroleum coke emissions data (where DUKES data are low) for the sector are shown below.

Table A 7.4.1 Refinery Emissions Data Comparison and Revision to OPG Activity

Year	Best Operator Data[1] kt C	Refinery emissions total (if based on DUKES) kt C	Additional emissions assumed from OPG kt C	Additional emissions assumed from Petcoke kt C
2000	3,467	4,718	-	-
2001	3,669	4,665	-	-
2002	4,118	5,244	-	-
2003	4,052	5,084	-	-
2004	3,980	4,925	74	-
2005	5,007	5,275	-	150
2006	4,910	4,674	160	76
2007	4,857	4,729	77	50
2008	4,709	4,348	240	121
2009	4,492	4,000	366	126
2010	4,632	4,349	207	76
2011	4,739	4,490	249	-
2012	4,287	4,299	-	-
2013	4,002	3,852	148	2
2014	3,678	3,558	120	-
2015	3,682	3,610	26	47
2016	3,708	3,497	155	56
2017	3,698	3,511	174	12
2018	3,559	3,506	33	19
2019	3,444	3,432	13	-
2020	3,030	2,819	211	-

[1] For 2005 onwards, the EU ETS data are verified by third parties and regarded as the best available sector estimates; prior to 2005 the best available operator emissions data are from the trade association, UKPIA.

[2] For 2005, DUKES activity data for petroleum coke are somewhat lower than the corresponding figure in the EU ETS, so even though CO_2 emission estimates based on DUKES figures for all fuels exceed the CO_2 figure given in the EU ETS, we use the higher (EU ETS) figure for petroleum coke, with the result that for 2005, the UK inventory figure for refinery CO_2 is higher (at 5422 kt C) higher than either the operator or DUKES based totals.

There is some level of uncertainty in the allocation of fuels in EU ETS to specific “DUKES” fuels, although the OPG use in refineries seems to be reported quite consistently as “Refinery Gas”, "Refinery Off-Gas", or "OPG/RFG". The BEIS DUKES team have reviewed the year to year consistency of OPG use in refineries through the DORS system.

A 7.4.1.2 Natural Gas Use by Downstream Gas Supply Installations

The EU ETS data includes natural gas use by large gas compressor and storage sites that operate on the UK gas transmission and distribution network, as well as the three operational LNG terminals and a small number of other downstream gas industry sites.

The gas use reported in EU ETS for these sites throughout Phase II and III has been notably higher than the allocation of gas within DUKES Commodity Balance Table 4.2 (Energy Industry Use, Other). This has been evident in the traded / non-traded analysis for the gas supply sector in the UK and Devolved Administrations GHGI.

As this gas use arises from the downstream network, the Inventory Agency and the BEIS DUKES team consider that the DUKES data indicate a small misallocation of gas use, rather than a gap in reported gas use. For 2005 to 2019, therefore, the EU ETS data for this source are used within the UK GHG inventory, and the overall gas use data are balanced by reducing the allocation of gas use to "other industrial combustion" (IPCC source 1A2g); the EU ETS data since 2005 shows good consistency with the data from DUKES for earlier years.

The increased gas use for this sector based on EU ETS data is expected to still be a small under-report for the sector as a whole, as the EU ETS scope only includes around 35 of the larger gas compressors, LNG terminals and storage sites on the UK network, and it is likely that additional gas use on smaller sites also occurs. However, the Inventory Agency has no data to inform such estimates.

A 7.4.1.3 Other Industry OPG use

There are a number of "other industry" sites where OPG use has been allocated by the Inventory Agency from EU ETS data, where the fuel is defined as either a specific gas (e.g. ethane, propane, butane) or more generic terms such as "OPG", "High Pressure Refinery Gas", "Low Pressure Refinery gas", "fuel gas" or "RFG/OPG/ROG" within the EU ETS forms.

In refinery complexes, the use of RFG for autogeneration (for the refinery and/or for co-located plant) is reported within the energy balance (allocated to "OPG"). At a number of other UK installations, commodities that are used initially as feedstocks in chemical and petrochemical production (e.g. naphtha, ethane, LPG, gas oil) are allocated to "non-energy use" in the UK energy statistics; any subsequent use of process off-gases (derived from these NEU feedstocks) as a fuel is not reflected in DUKES. Therefore, the Inventory Agency uses other data from industry, primarily from EU ETS, to generate estimates of the use of such secondary fuels. For a small number of sites, consultation with the DUKES team, regulators and operators has clarified that the EU ETS energy and emissions data are the best available dataset for use in the UK GHGI.

In the 1990-2020 inventory cycle, EU ETS data for fuel use at petrochemical production facilities helped to identify and quantify the combustion of process off-gases that are derived from Natural Gas Liquid (NGL) feedstock to petrochemical production processes. Analysis of "fuel gas" calorific values and carbon content informs the calculations to estimate emissions from NGL-derived gases and other residues.

A 7.4.1.4 Industrial Processes

The EU ETS dataset contains data on several industrial processes for which alternative data sources are either unavailable or of low quality. The EU ETS data therefore constitute the most reliable set of emissions data for these processes and are used in the UK inventory. In almost all cases, the EU ETS activity data are difficult to use directly, largely because different operators provide activity data and emission factors on a different basis (e.g. some may provide input material and emission factors on a consumption basis, others will provide production data and emission factors on a production basis). Therefore, for all of the industrial process sources, the EU ETS emissions data are adopted, and activity data are generally back-calculated from the emissions using a suitable IPCC emission factor. The industrial process sources where EU ETS data have been used to generate estimates of emissions included within the UK GHGI in this submission, include:

- Emissions from the manufacture of lime. UK activity data for limestone and dolomite consumption in lime production would yield much lower emission estimates than is suggested by EU ETS returns therefore, as a conservative approach, the EU ETS data are used instead. Activity data are back-calculated using the IPCC default factor for lime production. See **Section 4.3** for further details.
- Emissions from the use of carbonates in the manufacture of glass. As with lime production, the available data on consumption of limestone and dolomite for glass production are suspect, being very inconsistent across the time series, and so EU ETS data are used in the generation of the inventory time series, as detailed in **Section 4.4**.
- Emissions from the use of clays, carbonate minerals and other additives in the manufacture of bricks and roofing tiles, as detailed in **Section 4.5**. The EU ETS data are very detailed, with separate lines for different input materials such as different types of clay, carbonate minerals used in the bricks or in scrubbers used to abate fluoride emissions, and coke oven coke/petroleum coke used as an additive in certain bricks. UK brick production data are used as activity data.
- Estimates for emissions from the use of limestone in flue-gas desulphurisation (FGD) plant for the years 2005-2020 are taken from EU ETS data, because UK activity data (for gypsum produced from the FGD plant) are incomplete for those years. Activity data for 1990-2004 are available from non-EU ETS sources and are back-calculated from the EU ETS CO_2 emissions for 2005 onwards assuming an emission factor of 253 kg CO_2 per tonne gypsum produced (which is based on an assumed 100% conversion of limestone and SO_2 into gypsum and CO_2).
- EU ETS Phase III saw the introduction of data for soda ash manufacturing sites and EU ETS data, and CO_2 emissions reported for earlier years in the PI, are used as the basis of UK inventory emissions data for that sector. See **Section 4.12** for more details.
- Titanium dioxide production was also included in Phase III of the EU ETS, but full data for the UK plant are not included in the data set provided, and so emission estimates are generated using an alternative, more conservative method.
- For 2020, a stand-alone model was developed to estimate carbon emissions from the operation of Electric Arc Furnaces (EAFs). The objective of the model was to derive a time series of Emission Factors (EFs) per unit steel production to estimate annual GHG emissions, 1970 – latest year, for inclusion in the UK GHGI, to ensure completeness and to address any risk of under-reporting when comparing the UK GHGI against other data sources, including the EU ETS. See **Section 4.16** for further details.

A 7.4.2 Implied Emission Factors

A 7.4.2.1 Power Stations

Table A 7.4.2 summarises EU ETS data for fuels burnt by major power stations and coal burnt by autogenerators. The percentage of emissions based on Tier 3 emission factors is given (Tier 3 factors are based on fuel analysis and are therefore more reliable than emission factors based on default values), as well as the average emission factor for EU ETS emissions based on Tier 3 factors.

Table A 7.4.2 EU ETS data for Fuels used at Power Stations and Autogenerators (Emission Factors in kt / Mt for Coal & Fuel Oil, kt / Mth for Gases)

Year	Fuel	% Tier 3	Average Carbon Emission Factor (Tier 3 only)
2005	Coal	99	615.3
2006		100	615.0
2007		100	614.7
2008		100	612.4
2009		100	607.2
2010		100	609.0
2011		100	608.9
2012		100	611.7
2013		100	612.5
2014		100	611.8
2015		100	607.9
2016		94	612.3
2017		100	613.0
2018		100	601.4
2019		100	608.9
2020		100	612.0
2005	Fuel oil / Waste oil^{s}	59	860.3
2006		66	873.0
2007		68	871.1
2008		91	869.5

Year	Fuel	% Tier 3	Average Carbon Emission Factor (Tier 3 only)
2009		94	872.7
2010		95	873.3
2011		94	875.0
2012		96	873.4
2013		93	871.3
2014		92	871.8
2015		89	872.8
2016		91	876.9
2017		88	877.1
2018		81	874.2
2019		89	873.8
2020		89	877.3
2005	Natural gas	52	1.443
2006		76	1.465
2007		95	1.464
2008		97	1.467
2009		100	1.464
2010		99	1.460
2011		99	1.456
2012		100	1.461
2013		99	1.464
2014		100	1.461
2015		100	1.462
2016		99	1.462
2017		99	1.466
2018		99	1.465
2019		99	1.463

Year	**Fuel**	**% Tier 3**	**Average Carbon Emission Factor (Tier 3 only)**
2020		100	1.459
2005	Coal - autogenerators	100	594.3
2006		100	596.3
2007		100	594.5
2008		100	581.3
2009		100	600.6
2010		100	599.9
2011		100	594.9
2012		100	598.3
2013 onwards		0[b]	N/A

[a] It is not possible to distinguish between fuel oil and waste oil in the EU ETS data, so all emissions have been reported under fuel oil.

[b] Plant operated as a power station after 2012 and included in the figures for power stations burning coal

The EU ETS data shown are regarded as good quality data, since a high proportion of emissions are based on Tier 3 emission factors (i.e. verified emissions based on fuel analysis to ISO17025). The factors are also very consistent across the time-series, which would be expected for this sector. As shown in Section 3, the EU ETS data for power stations also cover almost all UK installations in this sector, and certainly cover all of the installations which burn coal, fuel oil and natural gas.

A few power stations burn small quantities of petroleum coke as well as coal. One supplies data to ETS for coal/petroleum coke blends i.e. there are no separate emissions data or carbon factors for the coal and the petroleum coke at that site. We therefore back-calculate the coal IEF in those blends by using an assumed default for the petroleum coke carbon content and more detailed activity data on the constituents of the fuel blends, obtained directly from the operator.

The EU ETS based emission factors presented above for power stations are used directly as the emission factors in the GHGI, with the exception of the 2005 figure for gas, where Tier 3 factors were only used for about half of the sector's emissions reported in EU ETS. Small quantities of sour gas were burnt at one power station in 2005-2007 and 2009 and EU ETS Tier 3 emission factors are available and therefore used. [Due to the confidentiality of the data, the emission factors are not shown]. Prior to 2005, the emission factors for these sectors are based on the methodology established by Baggott *et al*, 2004, since it has been concluded that this represents the most reliable approach.

The EU ETS factors for coal-fired autogenerators are slightly different to the factors for the power stations in that, although the EU ETS data are exclusively Tier 3, they only represent about 80-90% of total fuel used by the sector.

A 7.4.2.2 Crude Oil Refineries

Table A 7.4.3 below summarises the EU ETS data for the major fuels burnt by refineries in the UK.

The main fuels in refineries are fuel oil and OPG and emissions also occur due to the burning off of ‘petroleum coke’ deposits on catalysts used in processes such as catalytic cracking. In the latter case, emissions in the EU ETS are not generally based on activity data and emission factors but are instead based on direct measurement of carbon emitted. This is due to the technical difficulty in measuring the quantity of petroleum coke burnt and the carbon content. Refineries also use natural gas, although it is a relatively small source of emissions compared to other fuels.

Table A 7.4.3 Refinery EU ETS Data for Fuel Oil, OPG and Natural Gas (Emission Factors in kt / Mt for Fuel Oil and kt / Mth for OPG and Natural Gas)

Year	Fuel	% Tier 3	Average Carbon Emission Factor (Tier 3 sites only)
2005	Fuel Oil	25	860.9
2006		65	873.8
2007		78	877.2
2008		91	871.6
2009		91	876.2
2010		97	878.2
2011		85	45.3
2012		82	887.1
2013		95	874.3
2014		96	875.8
2015		61	876.7
2016		66	876.1
2017		25	860.9
2018		65	873.8
2019		78	877.2
2020		100	871.8
2005	OPG	56	1.494
2006		54	1.468
2007		65	1.587
2008		78	1.482
2009		78	1.494

Year	Fuel	% Tier 3	Average Carbon Emission Factor (Tier 3 sites only)
2010		79	1.509
2011		68	1.433
2012		61	1.463
2013		77	1.493
2014		64	1.508
2015		62	1.492
2016		61	1.470
2017		66	1.481
2018		70	1.476
2019		73	1.463
2020		74	1.442
2005	Natural Gas	n/a	-
2006		43	1.460
2007		45	1.462
2008		98	1.475
2009		98	1.480
2010		97	1.465
2011		81	1.375
2012		63	1.442
2013		89	1.459
2014		87	1.459
2015		87	1.465
2016		81	1.456
2017		84	1.462
2018		87	1.462
2019		87	1.459
2020		91	1.462

There has been some variation in the proportion of Tier 3 reporting for all three fuels, which will adversely affect the quality of the emission factors, although coverage is still in excess of 50% for all fuels.

Emission factors for **fuel oil** generated from EU ETS data have been adopted in the GHGI, with the exception of data for 2005, where Tier 3 methods were used for only 25% of fuel.

Carbon factors can be derived for **OPG** based on moderate levels of Tier 3 reporting for 2005-2007 and 2011-2019 but 80% for 2008-2010, which gives us a high confidence in the representativeness of the carbon factors for 2008-10. There is some uncertainty regarding the allocation of EU ETS fuels to the OPG fuel category, and the derived emission factors do cover a wider spread of values than for many other fuels in EU ETS. However, this reflects the nature of this fuel, and the data for all years have been used in the inventory.

Carbon factors for natural gas are based on a low % of Tier 3 reporting until 2008; in 2008 to 2010 over 90% of gas use is reported at Tier 3 and over 80% in 2011 and 2013-2019. Within the UK GHGI, the EU ETS factors for 2008 to 2016 are used directly, whilst emission factors for earlier years are derived from gas network operator gas compositional analysis.

EU ETS emission data for **petroleum coke** are higher in 2005-2010, when compared against the estimates derived from DUKES activity data and the industry-recommended emission factor. This is especially noticeable for 2005, where the petroleum coke consumption given in DUKES would have to be more than 100% carbon in order to generate the carbon emissions given in the EU ETS. Consultation with BEIS energy statisticians has identified that the figures given in DUKES are subject to uncertainty and hence the EU ETS data are used directly within the UK GHGI for those years.

A 7.4.2.3 Integrated Steelworks & Coke Ovens

Table A 7.4.4 summarises EU ETS data for the major fuels burnt at integrated steelworks and coke ovens. The data exclude one independent coke oven which calculated emissions using a detailed mass balance approach which makes it more difficult to assess the data in the same way as the other installations. This site closed at the end of 2014.

Table A 7.4.4 EU ETS data for fuels used at integrated steelworks & coke ovens (Emission Factors in kt/Mt for solid & liquid fuels, kt/Mth for gases)

Year	Fuel	% Tier 3	Average Carbon Emission Factor (Tier 3 sites only)
2005	Blast furnace gas	0	n/a
2006		100	6.873
2007		90	6.920
2008		92	6.945
2009		92	7.029
2010		100	6.949
2011		94	6.990
2012		96	6.815
2013		91	6.766

Year	Fuel	% Tier 3	Average Carbon Emission Factor (Tier 3 sites only)
2014		91	6.776
2015		100	7.653
2016		100	7.578
2017		90	7.219
2018		100	7.426
2019		100	7.587
2020		96	7.479
2005	Coke oven gas	0	n/a
2006		0	n/a
2007		0	n/a
2008		53	1.093
2009		96	1.140
2010		96	1.117
2011		96	1.089
2012		96	1.094
2013		96	1.103
2014		100	1.143
2015		100	1.216
2016		48	1.659
2017		100	1.068
2018		100	1.133
2019		72	1.094
2020		56	1.055
2005	Natural gas	0	n/a
2006		3	1.479
2007		2	1.478
2008		0	n/a
2009		58	1.425
2010		68	1.441
2011		64	1.441

Year	Fuel	% Tier 3	Average Carbon Emission Factor (Tier 3 sites only)
2012		64	1.443
2013		27	1.447
2014		23	1.445
2015		0	n/a
2016		12	1.445
2017		33	1.446
2018		33	1.456
2019		35	1.436
2020		37	1.432
2005	Fuel oil	0	n/a
2006		0	n/a
2007		0	n/a
2008		84	878
2009		89	885
2010		83	888
2011		88	889
2012		67	877
2013		33	846
2014		30	845
2015		32	845
2016		0	n/a
2017		0	n/a
2018		0	n/a
2019		0	n/a
2020		0	n/a

Most of the ETS data for coke ovens and steelworks are now used in the GHGI, although not the emission factors shown above. Instead, the Inventory Agency have used the EU ETS data and other detailed, site-specific and fuel-specific data, provided by the process operators to refine the carbon balance model used to generate emission estimates for the sector. Details of the revisions to the carbon balance model can be found in the research report from the 2013-2014 inventory improvement programme (Ricardo-AEA, 2014).

A 7.4.2.4 Cement Kilns

Table A 7.4.5 summarises EU ETS data for the major fuels burnt at cement kilns.

Table A 7.4.5 EU ETS data for Fuels used at Cement Kilns (kt / Mt)

Year	Fuel	% Tier 3	Average Carbon Emission Factor (Tier 3 sites only)
2005	Coal	8	671.1
2006		100	546.2
2007		100	664.3
2008		100	655.8
2009		99	658.3
2010		100	637.7
2011		100	645.8
2012		100	662.4
2013		100	694.2
2014		100	673.9
2015		100	675.3
2016		98	682.1
2017		100	683.3
2018		100	663.5
2019		100	664.1
2020		92	660.1
2005	Petroleum coke	0	n/a
2006		100	820.8
2007		100	830.2
2008		100	819.1
2009		71	796.8
2010		57	750.8
2011		100	738.4
2012		100	770.2
2013		100	811.1
2014		100	793.4
2015		100	824.6

Year	Fuel	% Tier 3	Average Carbon Emission Factor (Tier 3 sites only)
2016		100	822.2
2017		100	823.1
2018		100	798.1
2019		100	782.0
2020		100	770.5

The EU ETS dataset also provides a detailed breakdown of cement sector process emissions from the decarbonisation of raw materials during the clinker manufacturing process. These data are useful to compare against statistics provided by the Mineral Products Association (MPA) regarding clinker production and the non-combustion emissions associated with UK cement production. The MPA data on clinker production are commercially confidential.

The two data sets show significant differences for 2005-2007; however, the EU ETS data cover only a fraction of the sector, so differences might be expected. From 2008 onwards, there is close agreement (average of 0.5% difference) between the two data sets. The coal IEF data across the time series are also fairly consistent, other than in 2006 where the ETS value is very much lower than in other years. Because of the good agreement in both activity data and emission factors for 2008 onwards, the industry-wide estimates provided by the MPA and used within the GHGI show very close comparison with the EU ETS estimates. The difference between the EU ETS and those reported to the GHGI are consistently less than 1%, as outlined below in **Table A 7.4.6**.

Table A 7.4.6 Comparison of Cement Sector Carbon Dioxide Emissions* within the UK GHGI and the EU ETS

	2008	2010	2015	2016	2017	2018	2019	2020
GHGI CO_2 emissions (kt)	8,298	5,791	6,566	6,820	6,571	6,529	6,638	5,820
Sum of EU ETS CO_2 emissions (kt)	8,259	5,792	6,543	6,800	6,560	6,517	6,613	5,824
EU ETS / GHGI	99.5%	100.0%	99.7%	99.7%	99.8%	99.8%	99.6%	100.1%

*The data in this table include fuel combustion emissions (reported under IPCC 1A2f) and process emissions (reported under IPCC sector 2A1) from UK cement kilns.

A 7.4.2.5 Lime Kilns

Table A 7.4.7 summarises data given in the EU ETS datasets for the major fuels burnt at lime kilns. Unlike cement kilns, which often burn a variety of fuels, many lime kilns burn just a single fuel, often natural gas. The data below exclude coke oven coke used in lime kilns at soda ash plant since these kilns were not covered by EU ETS until Phase III, and the small number of sites make the data confidential in any case.

Table A 7.4.7 EU ETS data for Fuels used at Lime Kilns (Emission Factors in kt / Mt for Solid Fuels and kt / Mth for Gases)

Year	Fuel	% Tier 3	Average Carbon Emission Factor (Tier 3 sites only)
2005	Coal*	-	N/A
2006		-	N/A
2007		34	846.9
2008		79	701.4
2009		100	698.9
2010		100	634.4
2011		100	703.9
2012		100	725.6
2013		100	689.1
2014		100	680.2
2015		100	693.1
2016		100	688.8
2017		100	677.1
2018		100	683.7
2019		100	655.3
2020		100	684.3

*Coal used in the lime industry in the UK includes a proportion of anthracitic coal, and hence some of these IEFs are notably higher than for coal used in other sectors of UK industry.

The EU ETS data for lime kilns vary across the time series, both in terms of the proportion of emissions based on Tier 3 factors, and in the emission factors themselves. EU ETS based factors are currently used for coal and petroleum coke from 2008 onwards, as the EU ETS data do include all lime kilns burning those fuels and almost all those data are Tier 3 and hence are regarded as highly reliable.

EU ETS data for natural gas use in the lime industry does cover all installations burning this fuel, however the proportion of emissions based on Tier 3 factors is very low. Therefore, the EU ETS emission factors are not used in the UK GHGI, and the emission factors for natural gas continue to be based on the methodology given in Baggott *et al,* 2004.

Table A 7.4.8 shows implied emission factors for process-related emissions from lime kilns that are used within the UK GHG inventory. The lime industry can be sub-divided into those installations where lime is the primary product, and carbon dioxide is an unwanted by-product; and those installations where both lime and carbon dioxide are utilised. The latter include kilns in the sugar industry (where carbon dioxide is used in the purification stages) and soda ash production (where carbon dioxide is combined with other chemicals to produce sodium carbonate), and in these kilns, the carbon dioxide from decarbonisation of the limestone or dolomite feedstock is assumed to be fully consumed in the process, rather than emitted to atmosphere. **Table A 7.4.8** therefore does not cover these installations. None of the emission factors in EU ETS are Tier 3, so the table shows the overall emission factors for all tiers of data.

Table A 7.4.8 EU ETS emission factor data for production of lime (kt / Mt lime produced)

Year	Activity	EU ETS
2005	Lime production	200.4
2006		201.2
2007		201.3
2008		195.6
2009		195.0
2010		194.0
2011		195.6
2012		195.7
2013		194.4
2014		194.6
2015		195.3
2016		196.9
2017		196.0
2018		196.3
2019		195.1
2020		196.5

These factors compare with a theoretical emission factor based on the stoichiometry of the lime manufacturing process of 214 kt / Mt lime, assuming use of pure limestone. We note that the EU ETS factors are all lower than the theoretical emission factor and this is despite some use of dolomitic limestone in the UK industry which would be expected to further increase the emission factor above the 214 kt/Mt lime factor. The EU ETS data are subject to third party verification, and therefore the emissions data are assumed to be accurate. It is assumed that the reason for this deviation from the theoretical emission factor is due to the production activity data being inflated by either the products containing some proportion of slaked lime (i.e. hydrated product and hence containing a lower proportion of carbon than pure lime) and/or other additives to the lime product which decrease the % carbon content of the lime product.

A 7.4.2.6 Other Industrial Combustion

Table A 7.4.9 summarises EU ETS data for coal, fuel oil and natural gas used by industrial combustion installations.

At first sight, the data for coal looks like it should be reliable enough to be used in the GHGI with 90% or more of emissions based on Tier 3 factors in each year, with the exception of 2010. However, it must be recalled that numerous smaller industrial consumers will not be represented in EU ETS and that the EU ETS data are not fully representative of UK fuels as a whole – see **Section A 7.3** for details. This is also true for EU ETS data for fuel oil and natural gas but here, in addition, very little of the EU ETS data are based on Tier 3 factors. Therefore, none of these data have been used directly in the compilation of the GHGI estimates.

Table A 7.4.9 EU ETS data for Coal, Fuel Oil and Natural Gas used by Industrial Combustion Plant (Emission Factors in kt / Mt for Coal & Fuel Oil, kt / Mth for Natural Gas)

Year	Fuel	% Tier 3	Average Carbon Emission Factor (Tier 3 sites only)	GHGI Carbon Emission Factor
2005	Coal	98	607.1	647.8
2006		98	603.0	648.6
2007		99	615.7	662.9
2008		94	598.6	656.8
2009		92	595.4	668.8
2010		88	576.5	674.5
2011		91	589.0	653.7
2012		90	599.2	653.9
2013		95	653.4	653.5
2014		98	654.3	651.5
2015		100	645.8	652.4
2016		100	624.9	651.1
2017		100	647.4	651.5
2018		100	653.1	651.5
2019		100	640.7	651.5
2020		100	639.0	651.5
2005	Fuel oil	48	864.7	879.0
2006		74	865.3	879.0
2007		50	872.3	879.0
2008		35	871.4	879.0
2009		39	871.3	879.0
2010		40	873.0	879.0
2011		51	874.2	879.0

Year	Fuel	% Tier 3	Average Carbon Emission Factor (Tier 3 sites only)	GHGI Carbon Emission Factor
2012		49	875.1	879.0
2013		44	871.3	879.0
2014		48	875.0	879.0
2015		55	872.1	879.0
2016		63	876.2	879.0
2017		65	880.0	879.0
2018		70	872.3	879.0
2019		88	875.5	879.0
2020*		-	-	879.0
2005	Natural gas	16	1.593	1.477
2006		37	1.470	1.476
2007		42	1.466	1.476
2008		29	1.496	1.475
2009		43	1.499	1.473
2010		40	1.503	1.472
2011		39	1.466	1.469
2012		40	1.469	1.469
2013		37	1.472	1.473
2014		35	1.474	1.472
2015		34	1.479	1.470
2016		34	1.473	1.463
2017		35	1.485	1.465
2018		33	1.476	1.465
2019		32	1.477	1.460
2020		34	1.473	1.455

* No emissions where reported under Tier 3 for this fuel for 2020 in the reported EU ETS data.

Emission factors can also be derived from EU ETS where a high percentage of Tier 3 analysis is evident, for a number of other minor fuels. Due to the very low number of sites that report data for each fuel type, these EU ETS-derived emission factors are confidential and are not tabulated here. The source/activity combinations for which EU ETS emission factor data are used within the inventory are:

- Other industrial combustion / petroleum coke
- Other industrial combustion / waste solvents
- Other industrial combustion / colliery methane

The EU ETS-derived emission factors for colliery methane for each year (2005-2020) are also applied to all other sources using these fuels.

ANNEX 8: UK Domestic Emissions Reporting Requirements

In addition to the reporting requirements of the UNFCCC, Kyoto Protocol (KP) and EU MMR, UK Greenhouse Gas Inventory statistics are published annually in a Department for Business, Energy and Industrial Strategy National Statistics release[33]. The geographical coverage of these estimates differs from the UNFCCC, KP and EU MMR coverage, with the totals mainly covering emissions from the UK only (i.e. excluding overseas territories and crown dependencies), although progress towards the Kyoto Protocol is still reported.

The UK has domestic targets for reducing greenhouse gas emissions under the Climate Change Act 2008 (CCA)[34]. The CCA established a long-term legally binding framework to reduce emissions, initially committing the UK to reducing emissions by at least 80% below base year[35] emissions by 2050. In June 2019, following the IPCC's Special Report on Global Warming of 1.5°C and advice from the independent Committee on Climate Change, the CCA was amended to commit the UK to achieving a 100% reduction in emissions (to net zero) by 2050.

The CCA also introduced carbon budgets, which set legally binding limits on the total amount of greenhouse gas emissions the UK can emit for a given five-year period. The UK has met its first and second carbon budgets covering the periods 2008-2012 and 2013-2017 respectively.

Summary tables of the National Statistics release data are presented below. The data are presented in the nine categories used in UK Official Statistics (National Communication Categories). Note that the scope of emissions used for calculating Carbon Budgets differs slightly from those presented here, for example Carbon Budgets currently exclude NF_3.

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[33] https://www.gov.uk/government/collections/final-uk-greenhouse-gas-emissions-national-statistics

[34] https://www.legislation.gov.uk/ukpga/2008/27/contents

[35] Under the Kyoto Protocol, the UK uses 1990 as the base year for carbon dioxide, methane and nitrous oxide emissions, and 1995 as the base year for the fluorinated gases (or F-gases: hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride). To ensure consistency with our international obligations, the same base year for each greenhouse gas is used under the Climate Change Act.

A 8.1 NATIONAL STATISTICS

Table A 8.1.1 Summary table of GHG emissions by NC Category, including net emissions/removals from LULUCF (Mt CO_2eq) ‐ National Statistics coverage (UK only)

NC category	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Energy supply	279.5	237.4	222.8	231.4	207.4	145.2	111.1	104.0	95.6	84.0
Business	113.2	110.9	113.3	105.3	89.3	82.8	80.8	79.9	77.1	73.4
Transport	128.1	129.7	133.4	136.1	124.5	123.4	126.0	124.4	122.3	98.8
Public	13.3	13.2	12.1	11.2	9.5	8.0	7.7	7.8	7.5	7.4
Residential	80.0	81.6	88.9	85.7	87.5	67.3	66.3	68.4	65.7	66.3
Agriculture	53.6	53.0	50.8	48.9	45.5	46.2	46.7	46.1	46.4	44.8
Industrial processes	60.4	51.4	27.5	21.0	12.8	12.7	11.2	10.3	10.4	9.5
LULUCF[36]	13.1	10.8	8.2	5.4	3.5	3.1	3.0	3.6	4.0	3.7
Waste management	64.9	67.6	61.2	47.5	28.4	19.3	19.0	18.9	18.8	17.6
Total	806.3	755.4	718.2	692.3	608.6	507.9	471.6	463.5	447.9	405.5

Table A 8.1.2 Summary table of GHG emissions by Gas, including net emissions/removals from LULUCF (Mt CO_2eq) ‐ National Statistics coverage (UK only)

Gas	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
CO_2	605.4	567.2	567.4	566.2	506.1	416.2	381.1	374.0	359.3	321.1
CH_4	134.1	128.0	110.7	89.7	66.8	55.4	54.1	53.6	53.4	51.3
N_2O	49.5	39.8	30.0	26.0	22.9	22.0	22.2	22.0	22.0	20.9
HFCs	14.4	18.6	7.8	9.1	11.8	13.6	13.5	13.1	12.5	11.7
PFCs	1.6	0.6	0.6	0.4	0.3	0.3	0.4	0.1	0.2	0.2
SF_6	1.2	1.2	1.8	1.0	0.7	0.4	0.4	0.5	0.5	0.4
NF_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	806.3	755.4	718.2	692.3	608.6	507.9	471.6	463.5	447.9	405.5

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[36] Land use, land use change and forestry

ANNEX 9: End User Emissions

A 9.1 INTRODUCTION

This Annex explains the concept of an end user emissions (sometimes also referred to a “final user emissions”, summarises the end user calculation methodology with examples, and contains tables of greenhouse gas emissions according to the end user from 1990 to 2020.

The end user sectoral categories used are consistent with those used in the National Communications (NC) to the UNFCCC. The sectoral categories in the NC are derived from the UNFCCC reporting guidelines on national communications[37].

The purpose of the end user calculations is to allocate emissions from fuel and electricity producers to the energy users - this allows the emission estimates for a consumer of energy to include the emissions from the production of the fuel or electricity they use.

The UNFCCC does not require end user data to be included in the UK’s National Inventory Report. These data have been included to provide BEIS with information for their policy support needs.

The tables in this Annex present summary data for UK greenhouse gas emissions for the years 1990-2020, inclusive. These data are updated annually to reflect revisions in the methods used to estimate emissions, and the availability of new information within the inventory. These recalculations are applied retrospectively to earlier years to ensure a consistent time series and this accounts for any differences in data published in previous reports.

Emissions presented in this chapter show emissions from the UK only, consistent with the BEIS UK statistical release.

A 9.2 DEFINITION OF END USERS

The end user[38] calculations allocate emissions from fuel producers to fuel users. The end user calculation therefore allows estimates to be made of emissions for a consumer of fuel, which also include the emissions from producing the fuel the consumer has used.

The emissions included in the end user categories can be illustrated with an example of two end users - the residential sector and road transport:

- Emissions in the **residential** end user category include:
    1. All direct emissions from domestic premises, for example, from burning gas, coal or oil for space heating.

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[37] See page 84 of UNFCCC Guidelines contained in FCCC/CP/1999/7 available at: http://unfccc.int/resource/docs/cop5/07.pdf

[38] An end user is a consumer of fuel for useful energy. A ‘fuel producer’ is someone who extracts, processes or converts fuels for the end use of end users. Clearly there can be some overlap of these categories but here the fuel uses categories of the UK BEIS publication DUKES are used, which enable a distinction to be made.

2. A portion of indirect emissions used by domestic consumers from: power stations generating electricity; emissions from refineries including refining, storage, flaring and extraction; emissions from coal mines (including emissions due to fuel use in the mining industry itself and fugitive emissions of methane from the mines); and emissions from the extraction, storage and distribution of mains gas.

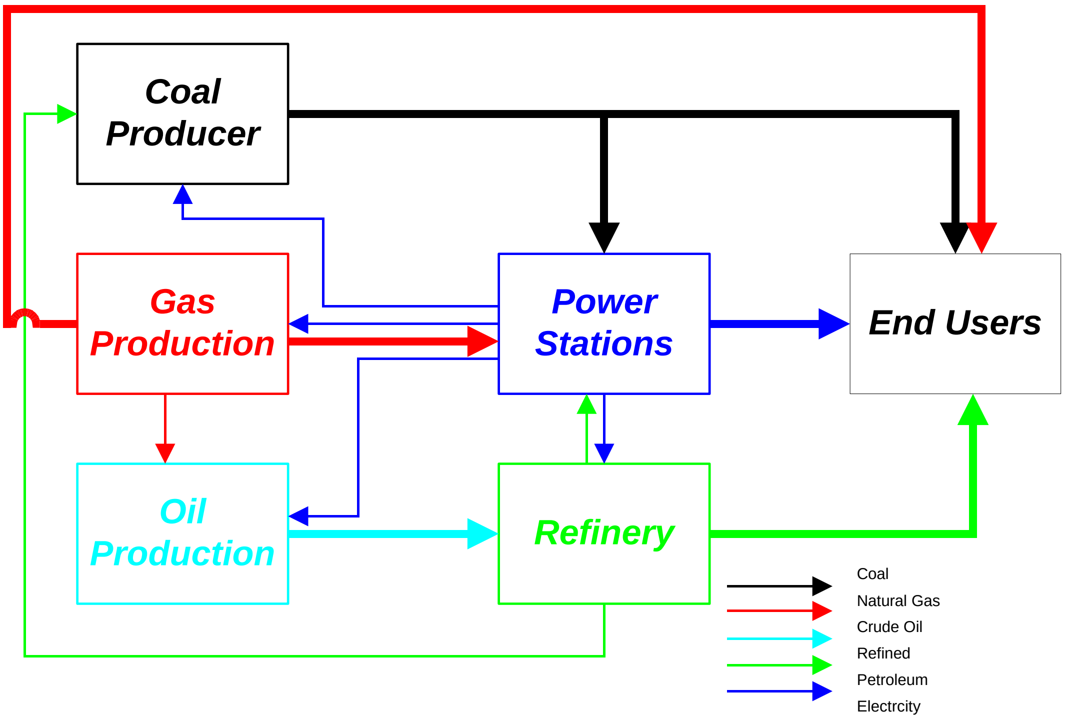
- Emissions in the **road transport** end user category include:
  1. Direct emissions from motor vehicle exhausts.
  2. A portion of indirect emissions from: refineries producing motor fuels, including refining, storage, flaring and extraction of oil; the distribution and supply of motor fuels; and power stations generating the electricity used by electric vehicles.

A 9.3 OVERVIEW OF THE END USER CALCULATIONS

Fuel and electricity producers also require the use of energy which comes from other producers. Therefore, in the process of reallocating emissions to the end user, emissions are allocated from one to the other and then are reallocated to end users. This circularity results in an iterative approach being used to estimate emissions from categories of end users.

Figure A 9.1 shows a simplified view of the energy flows in the UK (the fuels used in the greenhouse gas inventory have hundreds of uses). This figure shows that while end users consuming electricity are responsible for a proportion of the emissions from power stations they are also responsible for emissions from collieries, and some of these emissions in turn come from electricity generated in power stations and from refineries.

Figure A 9.1 Simplified fuel flows for an end user calculation.



The approach for estimating end user emissions is summarised in the three steps below:

1. Emissions are calculated for each sector for each fuel.
2. Emissions from fuel and electricity producers are then distributed to those sectors that use the fuel according to the energy content[39] of the fuel they use (these sectors can include other fuel producers). This distribution is based on inventory fuel consumption data and DUKES electricity consumption data.
3. By this stage in the calculation, emissions from end users will have increased and those from fuel and electricity producers will have decreased. The sum of emissions from fuel producers and power stations in a particular year as a percentage of the total emissions is then calculated. If this percentage, for any year, exceeds a predetermined value (In the model used to determine emissions from end users, the value of this percentage can be adjusted. The tables presented later in this Annex were calculated for a convergence at 0.001%) the process continues at Step 2. If this percentage matches or is less than the predetermined value, the calculation is finished.

Convergence occurs as the fuel flows to the end users are much greater than fuel flows amongst the fuel producers.

While a direct solution could possibly be used it was decided to base the calculation on an iterative approach because:

- This can be implemented in the database structures already in existence for the UK greenhouse gas inventory;
- It can handle a wide range of flows and loops that occur without any of the limits that other approaches may incur; and
- The same code will cover all likely situations and will be driven by tabular data stored in the database.

A 9.4 EXAMPLE END USER CALCULATION

The following example illustrates the methodology used to calculate emissions according to end users. The units in this example are arbitrary.

The example in **Figure A 9.2** has two fuel producers, *power stations* and *collieries*, and three end users, *residential*, *industry* and *commercial*. The following assumptions have been made for simplicity:

- The only fuels used are coal and electricity;
- Coal is the only source of carbon emissions (released from burning coal in power stations to produce electricity and from burning coal in the home for space heating); and
- Commerce uses no coal and so has zero ‘direct’ emissions.

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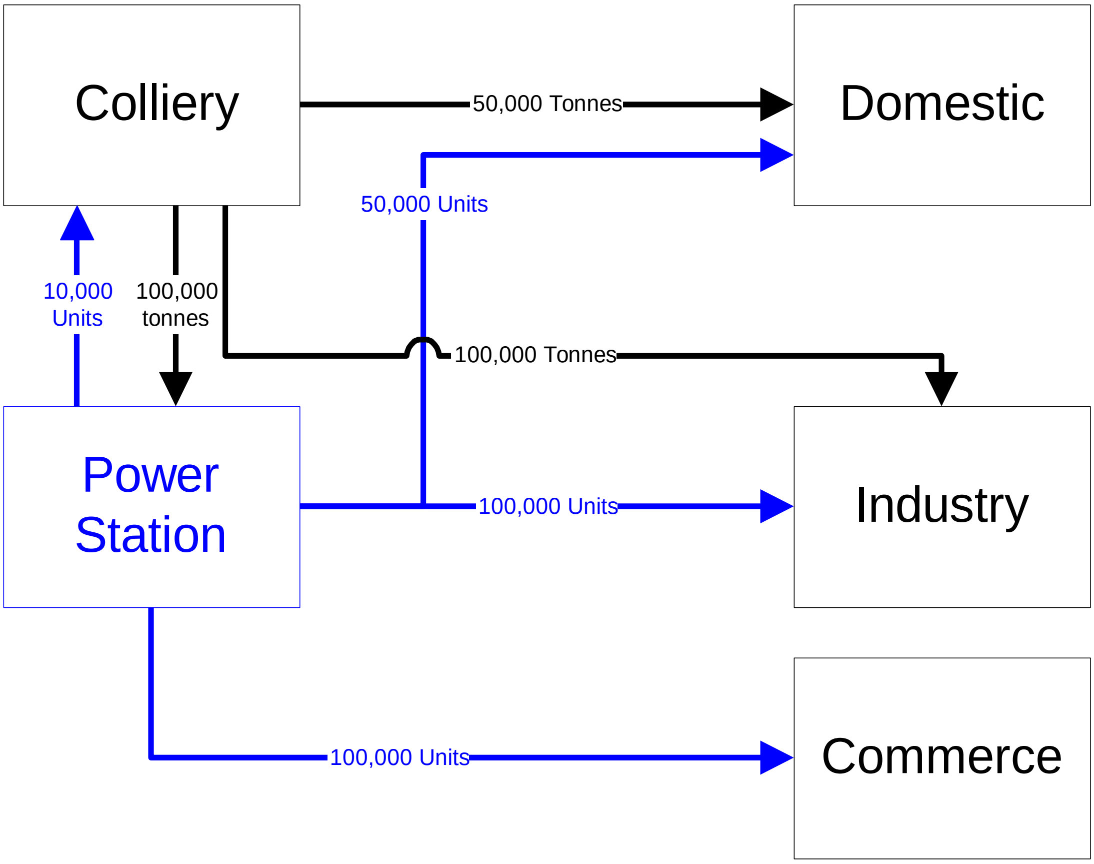
[39] If calorific data for the fuels is not available then the mass of fuel is used instead. This is the case for years prior to 1990.

Figure A 9.2 Fuel use in the example calculation



In **Figure A 9.2**, the tonnes refer to tonnes of coal burnt (black arrows), and the units refer to units of electricity consumed (blue arrows).

In this example the coal extracted by the colliery is burnt in the power station to produce electricity for the end users. Industrial and residential users also directly burn coal. Although the colliery uses electricity produced by the power station, it is not considered to be an end user. The colliery is a 'fuel producer' as it is part of the chain that extracts, processes and converts fuels for the end users.

Table A 9.4.1 summarises the outputs during this example end user calculation.

Table A 9.4.1 Example of the outputs during an end user calculation

			Sector						
			Colliery	Power Station	Residential	Industrial	Commercial	Unallocated emissions as percentage of total emission	Total emission of carbon (tonnes)
Coal use (tonnes)	Mass		100	100,000	50,000	100,000	0		
	Energy content		25,000	25,000,000	12,500,000	25,000,000	0		
Electricity use (arbitrary units)	Energy units		10,000		50,000	100,000	100,000		
Emissions of carbon (tonnes)	Initial		70	70,000	35,000	70,000	0	40.02	175,070
	Emissions after Iteration step	1	2,692	28	48,476	96,951	26,923	1.55	175,070
		2	1	1077	49,020	98,039	26,934	0.62	175,070
		3	41	1	49,227	98,454	27,348	0.02	175,070
		4	0	17	49,235	98,470	27,348	0.01	175,070
		5	1	0	49,238	98,477	27,355	0	175,070
		6	0	0	49,239	98,477	27,355	0	175,070

The initial carbon emissions are 70% of the mass of coal burnt. The emissions from the power stations are distributed to the other sectors by using the factor:

- (Electricity used by that sector)/(total electricity used minus own use by power stations);
- Similarly, for the colliery emissions the following factor is used; and
- (Energy of coal used by that sector)/(total energy of coal consumed used minus own use by collieries).

At the end of iteration step one, the commerce sector has 26,923 tonnes of carbon emissions allocated to it, mainly derived from power stations. Emissions allocated to the residential and industry sectors have also increased over their initial allocations. However, collieries and power stations still have some emissions allocated to them (these come from each other) and so the reallocation process is repeated to reduce these allocations to zero – these two sectors are not end users. The total unallocated (in this example, equal to the total emissions from collieries and power stations) falls in each iteration until the emissions are consistently allocated across the sectors. In this example, six iterations are needed to achieve a consistent allocation across the sectors.

The sum of emissions allocated to the sectors (175,070 tonnes of carbon) remains unchanged from the initial allocation to the allocation in the sixth iteration. This check is an important quality control measure to ensure all emissions are accounted for during the end user calculations.

Figure A 9.3 Comparison of 'direct' and end user emissions of carbon according the sectors considered in the end user example

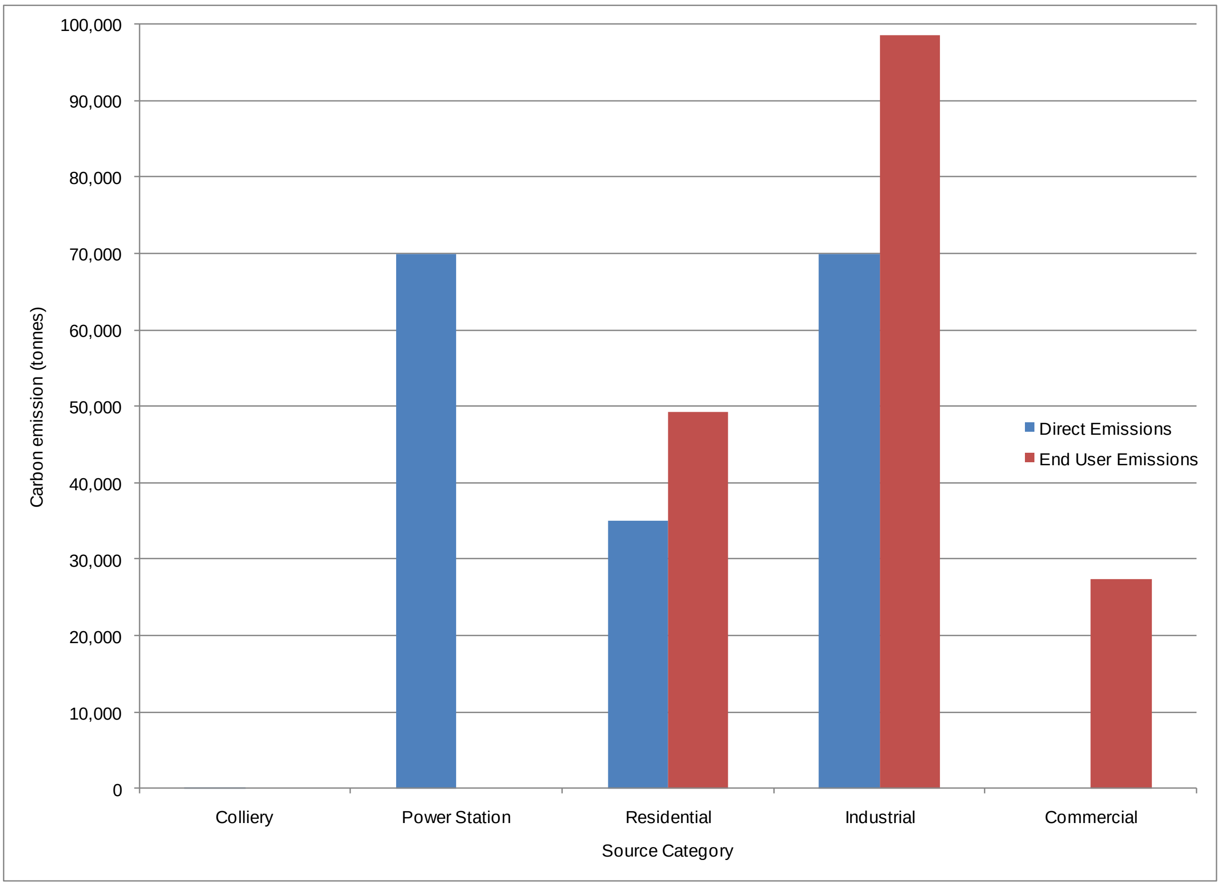


Figure A 9.3 compares the quantities of direct and end user carbon emitted from each sector at the end of the end user calculation. The direct emissions of carbon are from the combustion of coal in the sectors. The direct and end user emissions are from two distinct calculations and must be considered independently – in other words, the direct and end user emissions in each sector must not be summed. The sum of all the direct emissions and the sum of the end user emissions, are identical.

There are relatively large direct emissions of carbon from power stations, residential and industry sectors. The end user emissions from the power stations and the colliery are zero because these two sectors are not end users. The carbon emissions from these two sectors have been reallocated to the residential, industrial and commercial sectors. This reallocation means the end user emissions for the residential and industrial sectors are greater than their 'direct' emissions.

A 9.5 END USER CALCULATION METHODOLOGY FOR THE UK GREENHOUSE GAS INVENTORY

The approach divides fuel user emissions into 8 categories (see column 1 of **Table A 9.5.1**). For each of these groups, source categories are distributed by the total energy consumption of a group of fuels. For example, for the coal group, the emissions of four source categories are distributed to end users according to the energy use of anthracite and coal combined.

Table A 9.5.1 Sources reallocated to end users and the fuels used

End user group	Emission sources to be reallocated to end users	Fuels used for redistribution
1. Coke	Coke production	Coke
	Iron and steel – flaring	Blast furnace gas
2. Coal	Closed Coal Mines	Coal
	Coal storage and transport	Anthracite
	Collieries – combustion	
	Deep-mined coal	
	Open-cast coal	
3. Natural gas	Gas leakage	Natural gas
	Gas production	
	Upstream Gas Production - flaring	
	Upstream Gas Production - fuel combustion	
	Upstream Gas Production - Gas terminal storage	
	Upstream Gas Production - Offshore Well Testing	
	Upstream Gas Production - venting	
	Upstream oil and gas production - combustion at gas separation plant	
	Upstream Gas Production - fugitive emissions	
	Gas Terminal: Other Fugitives	
	Gas Terminal: Gas Flaring	
	Well exploration (unconventional gas): all sources	
	Gas terminal: fuel combustion	

End user group	Emission sources to be reallocated to end users	Fuels used for redistribution
	Gas Terminal: Direct Process	
	Gas Terminal: Venting	
	Onshore natural gas production (conventional)	
	Onshore natural gas gathering	
	Upstream Gas Production: direct process emissions	
4. Electricity	Autogeneration - exported to grid	Electricity
	Nuclear fuel production	
	Power stations	
	Power stations - FGD	

End user group	Emission sources to be reallocated to end users	Fuels used for redistribution
5. Petroleum	Petroleum processes	Aviation spirit
	Refineries - combustion	Aviation turbine fuel
	Upstream Oil Production - flaring	Biodiesel
	Upstream Oil Production - fuel combustion	Bioethanol
	Upstream Oil Production - Offshore Oil Loading	Burning oil
	Upstream Oil Production - Offshore Well Testing	Burning oil (premium)
	Upstream Oil Production - Oil terminal storage	DERV
	Upstream Oil Production - Onshore Oil Loading	Fuel oil
	Upstream Oil Production - venting	Gas oil
	Oil transport fugitives: pipelines (to shore)	Lubricants
	Oil transport fugitives: pipelines (onshore)	LNG
	Oil transport fugitives: road tankers	LPG
	Onshore oil production (conventional)	Naphtha
	Upstream Oil Production: direct process emissions	OPG
	Onshore oil well exploration (conventional)	Petrol
	Upstream Oil Production - fugitive emissions	Petroleum coke
	Oil terminal: fuel combustion	Refinery miscellaneous
	Oil Terminal: Gas Flaring	Vaporising oil
	Oil Terminal: Other Fugitives	
	Oil Terminal: Direct Process	
	Abandoned oil wells (onshore)	
	Onshore oil production: gas flaring	
	Abandoned oil wells (offshore)	
	Oil Terminal: Venting	
6. Solid Smokeless Fuels	Solid Smokeless fuel production	Solid Smokeless Fuels
7. Town gas	Town gas manufacture	Town Gas

End user group	Emission sources to be reallocated to end users	Fuels used for redistribution
8. Charcoal	Charcoal production	Charcoal

Comments on the calculation methodology used to allocate emissions according to the end users are listed below:

- Emissions are allocated to end users on the basis of the proportion of the total energy produced that is used by a given sector. This approach is followed to allow for sectors such as petroleum where different products are made in a refinery;
- Some emissions are allocated to an “exports” category. This is for emissions within the UK from producing fuels, (for example from a refinery or coal mine), which are subsequently exported or sent to bunkers for use outside the UK. Therefore, these emissions are part of the UK inventory even if the use of the fuel produces emissions that cannot be included in the UK inventory because it takes place outside the UK;
- No allowance is made for the emission from the production of fuels or electricity outside the UK that are subsequently imported;
- Some of the output of a refinery is not used as a fuel but used as feedstock or lubricants. This is not currently treated separately and the emissions from their production (which are small) are allocated to users of petroleum fuels. This is partly due to lack of data in the database used to calculate the inventory, and partly due to the lack of a clear, transparent way of separating emissions from the production of fuels and from the production of non-fuel petroleum products; and
- End user emissions are estimated for aviation in four categories: domestic take-off and landing, international take-off and landing, domestic cruise and international cruise. This enables both IPCC and UNECE categories to be estimated from the same end user calculation.

Our exact mapping of end user emissions to IPCC categories is shown in **Table A 9.5.2.** The NAEI source sectors and activity names are also shown, as it is necessary to subdivide some IPCC categories. This classification has been used to generate the end user tables for the greenhouse gases given in this section. As this table is for end users, no fuel producers are included in the table.

Table A 9.5.2 End user category, IPCC sectors, and NAEI source names and activity names used in the emission calculation

National Communication Category	IPCC Sector	Source Name	Activity Name
Agriculture	**1A4ci_Agriculture/Forestry/Fishing:Stationary**	Agriculture - stationary combustion	Burning oil
			Coal
			Fuel oil
			Natural gas
			Straw
	1A4cii_Agriculture/Forestry/Fishing:Off-road	Agriculture - mobile machinery	Gas oil
			Petrol
	2D1_Lubricant_Use	Agricultural engines	Lubricants
	3A1a_Enteric_Fermentation_dairy_cattle	Enteric	Dairy - Dairy Cows
	3A1b_Enteric_Fermentation_non-dairy_cattle	Enteric	Other cattle - Beef females for slaughter
			Other cattle - Bulls for breeding
			Other cattle - Cereal fed bull
			Other cattle - Cows
			Other cattle - Dairy Calves Female
			Other cattle - Dairy In Calf Heifers

National Communication Category	IPCC Sector	Source Name	Activity Name
			Other cattle - Dairy Replacements Female
			Other cattle - Heifers for breeding
			Other cattle - Steers
	3A2_Enteric_Fermentation_sheep	Enteric	Sheep - Ewe
			Sheep - Lamb
			Sheep - Ram
	3A3_Enteric_Fermentation_swine	Enteric	Pig - Boar
			Pig - Fattening Pig < 20 kg
			Pig - Fattening Pig > 80 kg
			Pig - Fattening Pig 20 to 80 kg
			Pig - Gilt
			Pig - Sow
	3A4_Enteric_Fermentation_other:deer	Enteric	Deer
	3A4_Enteric_Fermentation_other:goats	Enteric	Goats
	3A4_Enteric_Fermentation_other:horses	Enteric	Agricultural Horses
			Domestic Horses
			Professional Horses

National Communication Category	IPCC Sector	Source Name	Activity Name
	3B11a_Manure_Management_Methane_dairy_cattle	Digestate	Dairy - Dairy Cows
		Excreta	Dairy - Dairy Cows
		Managed Manure	Dairy - Dairy Cows
	3B11b_Manure_Management_Methane_non-dairy_cattle	Digestate	Other cattle - Beef females for slaughter
			Other cattle - Bulls for breeding
			Other cattle - Cereal fed bull
			Other cattle - Cows
			Other cattle - Dairy Calves Female
			Other cattle - Dairy In Calf Heifers
			Other cattle - Dairy Replacements Female
			Other cattle - Heifers for breeding
			Other cattle - Steers
		Excreta	Other cattle - Beef females for slaughter
			Other cattle - Bulls for breeding

National Communication Category	IPCC Sector	Source Name	Activity Name
			Other cattle - Cereal fed bull
			Other cattle - Cows
			Other cattle - Dairy Calves Female
			Other cattle - Dairy In Calf Heifers
			Other cattle - Dairy Replacements Female
			Other cattle - Heifers for breeding
			Other cattle - Steers
		Managed Manure	Other cattle - Beef females for slaughter
			Other cattle - Bulls for breeding
			Other cattle - Cereal fed bull
			Other cattle - Cows
			Other cattle - Dairy Calves Female
			Other cattle - Dairy In Calf Heifers

National Communication Category	IPCC Sector	Source Name	Activity Name
			Other cattle - Dairy Replacements Female
			Other cattle - Heifers for breeding
			Other cattle - Steers
	3B12_Manure_Management_Methane_sheep	Excreta	Sheep - Ewe
			Sheep - Lamb
			Sheep - Ram
		Managed Manure	Sheep - Ewe
			Sheep - Lamb
			Sheep - Ram
	3B13_Manure_Management_Methane_swine	Digestate	Pig - Boar
			Pig - Fattening Pig < 20 kg
			Pig - Fattening Pig > 80 kg
			Pig - Fattening Pig 20 to 80 kg
			Pig - Gilt
			Pig - Sow
		Excreta	Pig - Boar
			Pig - Fattening Pig < 20 kg

National Communication Category	IPCC Sector	Source Name	Activity Name
			Pig - Fattening Pig > 80 kg
			Pig - Fattening Pig 20 to 80 kg
			Pig - Gilt
			Pig - Sow
		Managed Manure	Pig - Boar
			Pig - Fattening Pig < 20 kg
			Pig - Fattening Pig > 80 kg
			Pig - Fattening Pig 20 to 80 kg
			Pig - Gilt
			Pig - Sow
	3B14_Manure_Management_Methane_other:deer	Excreta	Deer
		Managed Manure	Deer
	3B14_Manure_Management_Methane_other:goats	Excreta	Goats
		Managed Manure	Goats
	3B14_Manure_Management_Methane_other:horses	Excreta	Agricultural Horses
			Domestic Horses
			Professional Horses
		Managed Manure	Agricultural Horses

National Communication Category	IPCC Sector	Source Name	Activity Name
			Domestic Horses
			Professional Horses
	3B14_Manure_Management_Methane_other:poultry	Digestate	Poultry - Breeding Flock
			Poultry - Broilers
			Poultry - Ducks
			Poultry - Geese
			Poultry - Growing Pullets
			Poultry - Laying Hens
			Poultry - Other
			Poultry - Turkeys
		Excreta	Poultry - Breeding Flock
			Poultry - Broilers
			Poultry - Ducks
			Poultry - Geese
			Poultry - Growing Pullets
			Poultry - Laying Hens
			Poultry - Other

National Communication Category	IPCC Sector	Source Name	Activity Name
			Poultry - Turkeys
		Managed Manure	Poultry - Breeding Flock
			Poultry - Broilers
			Poultry - Ducks
			Poultry - Geese
			Poultry - Growing Pullets
			Poultry - Laying Hens
			Poultry - Other
			Poultry - Turkeys
	3B21a_Manure_Management_Non-methane_dairy_cattle	Dairy - Dairy Cows - Direct	Housing
	3B21b_Manure_Management_Non-methane_non-dairy_cattle	Other cattle - Beef females for slaughter - Direct	Housing
		Other cattle - Bulls for breeding - Direct	Housing
		Other cattle - Cereal fed bull - Direct	Housing
		Other cattle - Cows - Direct	Housing
		Other cattle - Dairy Calves Female - Direct	Housing
		Other cattle - Dairy In Calf Heifers - Direct	Housing
		Other cattle - Dairy Replacements Female - Direct	Housing
		Other cattle - Heifers for breeding - Direct	Housing

National Communication Category	IPCC Sector	Source Name	Activity Name
		Other cattle - Steers - Direct	Housing
	3B22_Manure_Management_Non-methane_sheep	Sheep - Ewe - Direct	Storage
		Sheep - Lamb - Direct	Storage
		Sheep - Ram - Direct	Storage
	3B23_Manure_Management_Non-methane_swine	Pig - Boar - Direct	Housing
		Pig - Fattening Pig < 20 kg - Direct	Housing
		Pig - Fattening Pig > 80 kg - Direct	Housing
		Pig - Fattening Pig 20 to 80 kg - Direct	Housing
		Pig - Gilt - Direct	Housing
		Pig - Sow - Direct	Housing
	3B24_Manure_Management_Non-methane_other:Deer	Deer - Direct	Housing
	3B24_Manure_Management_Non-methane_other:Goats	Goats - Direct	Housing
	3B24_Manure_Management_Non-methane_other:horses	Agricultural Horses - Direct	Housing
		Domestic Horses - Direct	Housing
		Professional Horses - Direct	Housing
	3B24_Manure_Management_Non-methane_other:poultry	Poultry - Breeding Flock - Direct	Housing
		Poultry - Broilers - Direct	Housing
		Poultry - Ducks - Direct	Housing
		Poultry - Geese - Direct	Housing
		Poultry - Growing Pullets - Direct	Housing
		Poultry - Laying Hens - Direct	Housing

National Communication Category	IPCC Sector	Source Name	Activity Name
		Poultry - Other - Direct	Housing
		Poultry - Turkeys - Direct	Housing
	3B25_Manure_Management_Indirect_Emissions_dairy_cattle	Dairy - Dairy Cows - Digestate Indirect Deposition	Storage
		Dairy - Dairy Cows - Indirect Deposition	Housing
			Storage
			Yarding
		Dairy - Dairy Cows - Indirect Leach	Storage
	3B25_Manure_Management_Indirect_Emissions_other:deer	Deer - Indirect Deposition	Housing
			Storage
		Deer - Indirect Leach	Storage
	3B25_Manure_Management_Indirect_Emissions_other:goats	Goats - Indirect Deposition	Housing
			Storage
		Goats - Indirect Leach	Storage
	3B25_Manure_Management_Indirect_Emissions_other:horses	Agricultural Horses - Indirect Deposition	Housing
			Storage
		Agricultural Horses - Indirect Leach	Storage
		Domestic Horses - Indirect Deposition	Housing
			Storage
		Domestic Horses - Indirect Leach	Storage
		Professional Horses - Indirect Deposition	Housing

National Communication Category	IPCC Sector	Source Name	Activity Name
			Storage
		Professional Horses - Indirect Leach	Storage
	3B25_Manure_Management_Indirect_Emissions_other:poultry	Poultry - Breeding Flock - Digestate Indirect Deposition	Storage
		Poultry - Breeding Flock - Indirect Deposition	Housing
			Storage
		Poultry - Breeding Flock - Indirect Leach	Storage
		Poultry - Broilers - Digestate Indirect Deposition	Storage
		Poultry - Broilers - Indirect Deposition	Housing
			Storage
		Poultry - Broilers - Indirect Leach	Storage
		Poultry - Ducks - Digestate Indirect Deposition	Storage
		Poultry - Ducks - Indirect Deposition	Housing
			Storage
		Poultry - Ducks - Indirect Leach	Storage
		Poultry - Geese - Digestate Indirect Deposition	Storage
		Poultry - Geese - Indirect Deposition	Housing
			Storage
		Poultry - Geese - Indirect Leach	Storage

National Communication Category	IPCC Sector	Source Name	Activity Name
		Poultry - Growing Pullets - Digestate Indirect Deposition	Storage
		Poultry - Growing Pullets - Indirect Deposition	Housing
			Storage
		Poultry - Growing Pullets - Indirect Leach	Storage
		Poultry - Laying Hens - Digestate Indirect Deposition	Storage
		Poultry - Laying Hens - Indirect Deposition	Housing
			Storage
		Poultry - Laying Hens - Indirect Leach	Storage
		Poultry - Other - Digestate Indirect Deposition	Storage
		Poultry - Other - Indirect Deposition	Housing
			Storage
		Poultry - Other - Indirect Leach	Storage
		Poultry - Turkeys - Digestate Indirect Deposition	Storage
		Poultry - Turkeys - Indirect Deposition	Housing
			Storage
		Poultry - Turkeys - Indirect Leach	Storage
	3B25_Manure_Management_Indirect_Emissions_other_cattle	Other cattle - Beef females for slaughter - Digestate Indirect Deposition	Storage

National Communication Category	IPCC Sector	Source Name	Activity Name
		Other cattle - Beef females for slaughter - Indirect Deposition	Housing
			Storage
			Yarding
		Other cattle - Beef females for slaughter - Indirect Leach	Storage
		Other cattle - Bulls for breeding - Digestate Indirect Deposition	Storage
		Other cattle - Bulls for breeding - Indirect Deposition	Housing
			Storage
			Yarding
		Other cattle - Bulls for breeding - Indirect Leach	Storage
		Other cattle - Cereal fed bull - Digestate Indirect Deposition	Storage
		Other cattle - Cereal fed bull - Indirect Deposition	Housing
			Storage
			Yarding
		Other cattle - Cereal fed bull - Indirect Leach	Storage
		Other cattle - Cows - Digestate Indirect Deposition	Storage
		Other cattle - Cows - Indirect Deposition	Housing

National Communication Category	IPCC Sector	Source Name	Activity Name
			Storage
			Yarding
		Other cattle - Cows - Indirect Leach	Storage
		Other cattle - Dairy Calves Female - Digestate Indirect Deposition	Storage
		Other cattle - Dairy Calves Female - Indirect Deposition	Housing
			Storage
			Yarding
		Other cattle - Dairy Calves Female - Indirect Leach	Storage
		Other cattle - Dairy In Calf Heifers - Digestate Indirect Deposition	Storage
		Other cattle - Dairy In Calf Heifers - Indirect Deposition	Housing
			Storage
			Yarding
		Other cattle - Dairy In Calf Heifers - Indirect Leach	Storage
		Other cattle - Dairy Replacements Female - Digestate Indirect Deposition	Storage
		Other cattle - Dairy Replacements Female - Indirect Deposition	Housing
			Storage

National Communication Category	IPCC Sector	Source Name	Activity Name
			Yarding
		Other cattle - Dairy Replacements Female - Indirect Leach	Storage
		Other cattle - Heifers for breeding - Digestate Indirect Deposition	Storage
		Other cattle - Heifers for breeding - Indirect Deposition	Housing
			Storage
			Yarding
		Other cattle - Heifers for breeding - Indirect Leach	Storage
		Other cattle - Steers - Digestate Indirect Deposition	Storage
		Other cattle - Steers - Indirect Deposition	Housing
			Storage
			Yarding
		Other cattle - Steers - Indirect Leach	Storage
	3B25_Manure_Management_Indirect_Emissions_sheep	Sheep - Ewe - Indirect Deposition	Housing
			Storage
		Sheep - Ewe - Indirect Leach	Storage
		Sheep - Lamb - Indirect Deposition	Housing
			Storage
		Sheep - Lamb - Indirect Leach	Storage

National Communication Category	IPCC Sector	Source Name	Activity Name
		Sheep - Ram - Indirect Deposition	Housing
			Storage
		Sheep - Ram - Indirect Leach	Storage
	3B25_Manure_Management_Indirect_Emissions_swine	Pig - Boar - Digestate Indirect Deposition	Storage
		Pig - Boar - Indirect Deposition	Housing
			Storage
		Pig - Boar - Indirect Leach	Storage
		Pig - Fattening Pig < 20 kg - Digestate Indirect Deposition	Storage
		Pig - Fattening Pig < 20 kg - Indirect Deposition	Housing
			Storage
		Pig - Fattening Pig < 20 kg - Indirect Leach	Storage
		Pig - Fattening Pig > 80 kg - Digestate Indirect Deposition	Storage
		Pig - Fattening Pig > 80 kg - Indirect Deposition	Housing
			Storage
		Pig - Fattening Pig > 80 kg - Indirect Leach	Storage
		Pig - Fattening Pig 20 to 80 kg - Digestate Indirect Deposition	Storage
		Pig - Fattening Pig 20 to 80 kg - Indirect Deposition	Housing

National Communication Category	IPCC Sector	Source Name	Activity Name
			Storage
		Pig - Fattening Pig 20 to 80 kg - Indirect Leach	Storage
		Pig - Gilt - Digestate Indirect Deposition	Storage
		Pig - Gilt - Indirect Deposition	Housing
			Storage
		Pig - Gilt - Indirect Leach	Storage
		Pig - Sow - Digestate Indirect Deposition	Storage
		Pig - Sow - Indirect Deposition	Housing
			Storage
		Pig - Sow - Indirect Leach	Storage
	3D11_Agriculural_Soils_Inorganic_N_Fertilisers	Arable - Direct	Ammonium Nitrate Application
			Ammonium Sulphate and Diammonium Phosphate Application
			Calcium Ammonium Nitrate Application
			Other Nitrogen Including Compounds Application
			Urea Ammonium Nitrate Application

National Communication Category	IPCC Sector	Source Name	Activity Name
			Urea Application
		Grass - Direct	Ammonium Nitrate Application
			Ammonium Sulphate and Diammonium Phosphate Application
			Calcium Ammonium Nitrate Application
			Other Nitrogen Including Compounds Application
			Urea Ammonium Nitrate Application
			Urea Application
	3D12a_Agricultural_Soils_Manure_Applied_to_Soils	Agricultural Horses - Direct	Spreading
		Dairy - Dairy Cows - Direct	Spreading
		Deer - Direct	Spreading
		Domestic Horses - Direct	Spreading
		Goats - Direct	Spreading
		Other cattle - Beef females for slaughter - Direct	Spreading
		Other cattle - Bulls for breeding - Direct	Spreading
		Other cattle - Cereal fed bull - Direct	Spreading

National Communication Category	IPCC Sector	Source Name	Activity Name
		Other cattle - Cows - Direct	Spreading
		Other cattle - Dairy Calves Female - Direct	Spreading
		Other cattle - Dairy In Calf Heifers - Direct	Spreading
		Other cattle - Dairy Replacements Female - Direct	Spreading
		Other cattle - Heifers for breeding - Direct	Spreading
		Other cattle - Steers - Direct	Spreading
		Pig - Boar - Direct	Spreading
		Pig - Fattening Pig < 20 kg - Direct	Spreading
		Pig - Fattening Pig > 80 kg - Direct	Spreading
		Pig - Fattening Pig 20 to 80 kg - Direct	Spreading
		Pig - Gilt - Direct	Spreading
		Pig - Sow - Direct	Spreading
		Poultry - Breeding Flock - Direct	Spreading
		Poultry - Broilers - Direct	Spreading
		Poultry - Ducks - Direct	Spreading
		Poultry - Geese - Direct	Spreading
		Poultry - Growing Pullets - Direct	Spreading
		Poultry - Laying Hens - Direct	Spreading
		Poultry - Other - Direct	Spreading
		Poultry - Turkeys - Direct	Spreading

National Communication Category	IPCC Sector	Source Name	Activity Name
		Professional Horses - Direct	Spreading
		Sheep - Ewe - Direct	Spreading
		Sheep - Lamb - Direct	Spreading
		Sheep - Ram - Direct	Spreading
	3D12b_Agricultural_Soils_Sewage_Sludge_Applied_to_Soils	Sewage Sludge Cake - Direct	Spreading
		Sewage Sludge Liquid - Direct	Spreading
	3D12c_Agricultural_Soils_Other_Organic_Fertilisers_Applied_to_Soils	Beef females for slaughter - Digestate Direct	Spreading
		Boar - Digestate Direct	Spreading
		Broilers - Digestate Direct	Spreading
		Bulls for breeding - Digestate Direct	Spreading
		Cereal fed bull - Digestate Direct	Spreading
		Cows - Digestate Direct	Spreading
		Crop Digestates - Direct	Spreading
		Dairy Calves Female - Digestate Direct	Spreading
		Dairy Cows - Digestate Direct	Spreading
		Dairy In Calf Heifers - Digestate Direct	Spreading
		Dairy Replacements Female - Digestate Direct	Spreading
		Fattening Pig < 20 kg - Digestate Direct	Spreading
		Fattening Pig > 80 kg - Digestate Direct	Spreading
		Fattening Pig 20 to 80 kg - Digestate Direct	Spreading

National Communication Category	IPCC Sector	Source Name	Activity Name
		Food Digestates - Direct	Spreading
		Gilt - Digestate Direct	Spreading
		Heifers for breeding - Digestate Direct	Spreading
		Laying Hens - Digestate Direct	Spreading
		Other organic residue Digestates - Direct	Spreading
		Poultry - Breeding Flock - Digestate Direct	Spreading
		Poultry - Ducks - Digestate Direct	Spreading
		Poultry - Geese - Digestate Direct	Spreading
		Poultry - Growing Pullets - Digestate Direct	Spreading
		Poultry - Other - Digestate Direct	Spreading
		Sow - Digestate Direct	Spreading
		Steers - Digestate Direct	Spreading
		Turkeys - Digestate Direct	Spreading
	3D13_Agricultural_Soils_Manure_Deposited_by_Grazing_Animals	Agricultural Horses - Direct	Grazing
		Dairy - Dairy Cows - Direct	Grazing
		Deer - Direct	Grazing
		Domestic Horses - Direct	Grazing
		Goats - Direct	Grazing
		Other cattle - Beef females for slaughter - Direct	Grazing
		Other cattle - Bulls for breeding - Direct	Grazing

National Communication Category	IPCC Sector	Source Name	Activity Name
		Other cattle - Cereal fed bull - Direct	Grazing
		Other cattle - Cows - Direct	Grazing
		Other cattle - Dairy Calves Female - Direct	Grazing
		Other cattle - Dairy In Calf Heifers - Direct	Grazing
		Other cattle - Dairy Replacements Female - Direct	Grazing
		Other cattle - Heifers for breeding - Direct	Grazing
		Other cattle - Steers - Direct	Grazing
		Pig - Boar - Direct	Grazing
		Pig - Fattening Pig < 20 kg - Direct	Grazing
		Pig - Fattening Pig > 80 kg - Direct	Grazing
		Pig - Fattening Pig 20 to 80 kg - Direct	Grazing
		Pig - Gilt - Direct	Grazing
		Pig - Sow - Direct	Grazing
		Poultry - Breeding Flock - Direct	Grazing
		Poultry - Broilers - Direct	Grazing
		Poultry - Ducks - Direct	Grazing
		Poultry - Geese - Direct	Grazing
		Poultry - Growing Pullets - Direct	Grazing
		Poultry - Laying Hens - Direct	Grazing
		Poultry - Other - Direct	Grazing

National Communication Category	IPCC Sector	Source Name	Activity Name
		Poultry - Turkeys - Direct	Grazing
		Professional Horses - Direct	Grazing
		Sheep - Ewe - Direct	Grazing
		Sheep - Lamb - Direct	Grazing
		Sheep - Ram - Direct	Grazing
	3D14_Agriculural_Soils_Residues	Arable - Direct	Ammonium Nitrate Residue
			Ammonium Sulphate and Diammonium Phosphate Residue
			Calcium Ammonium Nitrate Residue
			No Nitrogen Fertiliser Applied Residue
			Other Nitrogen Including Compounds Residue
			Urea Ammonium Nitrate Residue
			Urea Residue
		Grass - Direct	Ammonium Nitrate Residue
			Ammonium Sulphate and Diammonium Phosphate Residue

National Communication Category	IPCC Sector	Source Name	Activity Name
			Calcium Ammonium Nitrate Residue
			No Nitrogen Fertiliser Applied Residue
			Other Nitrogen Including Compounds Residue
			Urea Ammonium Nitrate Residue
			Urea Residue
	3D15_Agricultural_soils_Mineralization/Immobilization	Cropland management	Mineralisation
	3D16_Agricultural_soils_Cultivation_of_Organic_Soils	Managed Histosols	Land area
	3D21_Agriculural_Soils_Indirect_Deposition	Agricultural Horses - Indirect Deposition	Grazing
			Spreading
		Arable - Indirect Deposition	Ammonium Nitrate Application
			Ammonium Sulphate and Diammonium Phosphate Application
			Calcium Ammonium Nitrate Application
			Other Nitrogen Including Compounds Application

National Communication Category	IPCC Sector	Source Name	Activity Name
			Urea Ammonium Nitrate Application
			Urea Application
		Crop Digestates - Indirect Deposition	Spreading
		Dairy - Dairy Cows - Digestate Indirect Deposition	Spreading
		Dairy - Dairy Cows - Indirect Deposition	Grazing
			Spreading
		Deer - Indirect Deposition	Grazing
			Spreading
		Domestic Horses - Indirect Deposition	Grazing
			Spreading
		Food Digestates - Indirect Deposition	Spreading
		Goats - Indirect Deposition	Grazing
			Spreading
		Grass - Indirect Deposition	Ammonium Nitrate Application
			Ammonium Sulphate and Diammonium Phosphate Application
			Calcium Ammonium Nitrate Application
			Other Nitrogen Including

National Communication Category	IPCC Sector	Source Name	Activity Name
			Compounds Application
			Urea Ammonium Nitrate Application
			Urea Application
		Other cattle - Beef females for slaughter - Digestate Indirect Deposition	Spreading
		Other cattle - Beef females for slaughter - Indirect Deposition	Grazing
			Spreading
		Other cattle - Bulls for breeding - Digestate Indirect Deposition	Spreading
		Other cattle - Bulls for breeding - Indirect Deposition	Grazing
			Spreading
		Other cattle - Cereal fed bull - Digestate Indirect Deposition	Spreading
		Other cattle - Cereal fed bull - Indirect Deposition	Grazing
			Spreading
		Other cattle - Cows - Digestate Indirect Deposition	Spreading
		Other cattle - Cows - Indirect Deposition	Grazing
			Spreading

National Communication Category	IPCC Sector	Source Name	Activity Name
		Other cattle - Dairy Calves Female - Digestate Indirect Deposition	Spreading
		Other cattle - Dairy Calves Female - Indirect Deposition	Grazing
			Spreading
		Other cattle - Dairy In Calf Heifers - Digestate Indirect Deposition	Spreading
		Other cattle - Dairy In Calf Heifers - Indirect Deposition	Grazing
			Spreading
		Other cattle - Dairy Replacements Female - Digestate Indirect Deposition	Spreading
		Other cattle - Dairy Replacements Female - Indirect Deposition	Grazing
			Spreading
		Other cattle - Heifers for breeding - Digestate Indirect Deposition	Spreading
		Other cattle - Heifers for breeding - Indirect Deposition	Grazing
			Spreading
		Other cattle - Steers - Digestate Indirect Deposition	Spreading
		Other cattle - Steers - Indirect Deposition	Grazing
			Spreading

National Communication Category	IPCC Sector	Source Name	Activity Name
		Other organic residue Digestates - Indirect Deposition	Spreading
		Pig - Boar - Digestate Indirect Deposition	Spreading
		Pig - Boar - Indirect Deposition	Grazing
			Spreading
		Pig - Fattening Pig < 20 kg - Digestate Indirect Deposition	Spreading
		Pig - Fattening Pig < 20 kg - Indirect Deposition	Grazing
			Spreading
		Pig - Fattening Pig > 80 kg - Digestate Indirect Deposition	Spreading
		Pig - Fattening Pig > 80 kg - Indirect Deposition	Grazing
			Spreading
		Pig - Fattening Pig 20 to 80 kg - Digestate Indirect Deposition	Spreading
		Pig - Fattening Pig 20 to 80 kg - Indirect Deposition	Grazing
			Spreading
		Pig - Gilt - Digestate Indirect Deposition	Spreading
		Pig - Gilt - Indirect Deposition	Grazing
			Spreading
		Pig - Sow - Digestate Indirect Deposition	Spreading

National Communication Category	IPCC Sector	Source Name	Activity Name
		Pig - Sow - Indirect Deposition	Grazing
			Spreading
		Poultry - Breeding Flock - Digestate Indirect Deposition	Spreading
		Poultry - Breeding Flock - Indirect Deposition	Grazing
			Spreading
		Poultry - Broilers - Digestate Indirect Deposition	Spreading
		Poultry - Broilers - Indirect Deposition	Grazing
			Spreading
		Poultry - Ducks - Digestate Indirect Deposition	Spreading
		Poultry - Ducks - Indirect Deposition	Grazing
			Spreading
		Poultry - Geese - Digestate Indirect Deposition	Spreading
		Poultry - Geese - Indirect Deposition	Grazing
			Spreading
		Poultry - Growing Pullets - Digestate Indirect Deposition	Spreading
		Poultry - Growing Pullets - Indirect Deposition	Grazing
			Spreading

National Communication Category	IPCC Sector	Source Name	Activity Name
		Poultry - Laying Hens - Digestate Indirect Deposition	Spreading
		Poultry - Laying Hens - Indirect Deposition	Grazing
			Spreading
		Poultry - Other - Digestate Indirect Deposition	Spreading
		Poultry - Other - Indirect Deposition	Grazing
			Spreading
		Poultry - Turkeys - Digestate Indirect Deposition	Spreading
		Poultry - Turkeys - Indirect Deposition	Grazing
			Spreading
		Professional Horses - Indirect Deposition	Grazing
			Spreading
		Sewage Sludge Cake - Indirect Deposition	Spreading
		Sewage Sludge Liquid - Indirect Deposition	Spreading
		Sheep - Ewe - Indirect Deposition	Grazing
			Spreading
		Sheep - Lamb - Indirect Deposition	Grazing
			Spreading
		Sheep - Ram - Indirect Deposition	Grazing
			Spreading

National Communication Category	IPCC Sector	Source Name	Activity Name
	3D22_Agriculural_Soils_Indirect_Leaching_and_Run-off	Agricultural Horses - Indirect Leach	Grazing
			Spreading
		Arable - Indirect Leach	Ammonium Nitrate Application
			Ammonium Sulphate and Diammonium Phosphate Application
			Calcium Ammonium Nitrate Application
			Other Nitrogen Including Compounds Application
			Urea Ammonium Nitrate Application
			Urea Application
		Arable - Residue Indirect Leach	Ammonium Nitrate Application
			Ammonium Sulphate and Diammonium Phosphate Application
			Calcium Ammonium Nitrate Application
			No Nitrogen Fertiliser Applied

National Communication Category	IPCC Sector	Source Name	Activity Name
			Other Nitrogen Including Compounds Application
			Urea Ammonium Nitrate Application
			Urea Application
		Crop Digestates - Indirect Leach	Spreading
		Cropland management	Mineralisation - indirect leach
		Dairy - Dairy Cows - Digestate Indirect Leach	Spreading
		Dairy - Dairy Cows - Indirect Leach	Grazing
			Spreading
		Deer - Indirect Leach	Grazing
			Spreading
		Domestic Horses - Indirect Leach	Grazing
			Spreading
		Food Digestates - Indirect Leach	Spreading
		Goats - Indirect Leach	Grazing
			Spreading
		Grass - Indirect Leach	Ammonium Nitrate Application
			Ammonium Sulphate and Diammonium

National Communication Category	IPCC Sector	Source Name	Activity Name
			Phosphate Application
			Calcium Ammonium Nitrate Application
			Other Nitrogen Including Compounds Application
			Urea Ammonium Nitrate Application
			Urea Application
		Grass - Residue Indirect Leach	Ammonium Nitrate Application
			Ammonium Sulphate and Diammonium Phosphate Application
			Calcium Ammonium Nitrate Application
			No Nitrogen Fertiliser Applied
			Other Nitrogen Including Compounds Application
			Urea Ammonium Nitrate Application
			Urea Application

National Communication Category	IPCC Sector	Source Name	Activity Name
		Other cattle - Beef females for slaughter - Digestate Indirect Leach	Spreading
		Other cattle - Beef females for slaughter - Indirect Leach	Grazing
			Spreading
		Other cattle - Bulls for breeding - Digestate Indirect Leach	Spreading
		Other cattle - Bulls for breeding - Indirect Leach	Grazing
			Spreading
		Other cattle - Cereal fed bull - Digestate Indirect Leach	Spreading
		Other cattle - Cereal fed bull - Indirect Leach	Grazing
			Spreading
		Other cattle - Cows - Digestate Indirect Leach	Spreading
		Other cattle - Cows - Indirect Leach	Grazing
			Spreading
		Other cattle - Dairy Calves Female - Digestate Indirect Leach	Spreading
		Other cattle - Dairy Calves Female - Indirect Leach	Grazing
			Spreading
		Other cattle - Dairy In Calf Heifers - Digestate Indirect Leach	Spreading

National Communication Category	IPCC Sector	Source Name	Activity Name
		Other cattle - Dairy In Calf Heifers - Indirect Leach	Grazing
			Spreading
		Other cattle - Dairy Replacements Female - Digestate Indirect Leach	Spreading
		Other cattle - Dairy Replacements Female - Indirect Leach	Grazing
			Spreading
		Other cattle - Heifers for breeding - Digestate Indirect Leach	Spreading
		Other cattle - Heifers for breeding - Indirect Leach	Grazing
			Spreading
		Other cattle - Steers - Digestate Indirect Leach	Spreading
		Other cattle - Steers - Indirect Leach	Grazing
			Spreading
		Other organic residue Digestates - Indirect Leach	Spreading
		Pig - Boar - Digestate Indirect Leach	Spreading
		Pig - Boar - Indirect Leach	Grazing
			Spreading
		Pig - Fattening Pig < 20 kg - Digestate Indirect Leach	Spreading

National Communication Category	IPCC Sector	Source Name	Activity Name
		Pig - Fattening Pig < 20 kg - Indirect Leach	Grazing
			Spreading
		Pig - Fattening Pig > 80 kg - Digestate Indirect Leach	Spreading
		Pig - Fattening Pig > 80 kg - Indirect Leach	Grazing
			Spreading
		Pig - Fattening Pig 20 to 80 kg - Digestate Indirect Leach	Spreading
		Pig - Fattening Pig 20 to 80 kg - Indirect Leach	Grazing
			Spreading
		Pig - Gilt - Digestate Indirect Leach	Spreading
		Pig - Gilt - Indirect Leach	Grazing
			Spreading
		Pig - Sow - Digestate Indirect Leach	Spreading
		Pig - Sow - Indirect Leach	Grazing
			Spreading
		Poultry - Breeding Flock - Digestate Indirect Leach	Spreading
		Poultry - Breeding Flock - Indirect Leach	Grazing
			Spreading
		Poultry - Broilers - Digestate Indirect Leach	Spreading

National Communication Category	IPCC Sector	Source Name	Activity Name
		Poultry - Broilers - Indirect Leach	Grazing
			Spreading
		Poultry - Ducks - Digestate Indirect Leach	Spreading
		Poultry - Ducks - Indirect Leach	Grazing
			Spreading
		Poultry - Geese - Digestate Indirect Leach	Spreading
		Poultry - Geese - Indirect Leach	Grazing
			Spreading
		Poultry - Growing Pullets - Digestate Indirect Leach	Spreading
		Poultry - Growing Pullets - Indirect Leach	Grazing
			Spreading
		Poultry - Laying Hens - Digestate Indirect Leach	Spreading
		Poultry - Laying Hens - Indirect Leach	Grazing
			Spreading
		Poultry - Other - Digestate Indirect Leach	Spreading
		Poultry - Other - Indirect Leach	Grazing
			Spreading
		Poultry - Turkeys - Digestate Indirect Leach	Spreading
		Poultry - Turkeys - Indirect Leach	Grazing
			Spreading

National Communication Category	IPCC Sector	Source Name	Activity Name
		Professional Horses - Indirect Leach	Grazing
			Spreading
		Sewage Sludge Cake - Indirect Leach	Spreading
		Sewage Sludge Liquid - Indirect Leach	Spreading
		Sheep - Ewe - Indirect Leach	Grazing
			Spreading
		Sheep - Lamb - Indirect Leach	Grazing
			Spreading
		Sheep - Ram - Indirect Leach	Grazing
			Spreading
	3F11_Field_burning_wheat	Field burning	Wheat residue
	3F12_Field_burning_barley	Field burning	Barley residue
	3F14_Field_burning_other_cereals	Field burning	Oats residue
	3F5_Field_burning_other_residues	Field burning	Linseed residue
	3G1_Liming - limestone	Liming	Limestone
	3G2_Liming - dolomite	Liming	Dolomite
	3H_Urea application	Fertiliser Application	Urea Application
	non-IPCC	Agriculture - stationary combustion	Electricity
Business	**1A2a_Iron_and_steel**	Iron and steel - combustion plant	Coal
			Coke
			Fuel oil

National Communication Category	IPCC Sector	Source Name	Activity Name
			Gas oil
			LPG
			Natural gas
	1A2b_Non-Ferrous_Metals	Autogeneration - exported to grid	Coal
		Autogenerators	Coal
		Non-Ferrous Metal (combustion)	Coal
			Fuel oil
			Gas oil
			Natural gas
	1A2c_Chemicals	Chemicals (combustion)	Coal
			Fuel oil
			Gas oil
			Natural gas
	1A2d_Pulp_Paper_Print	Pulp, Paper and Print (combustion)	Coal
			Fuel oil
			Gas oil
			Natural gas
	1A2e_food_processing_beverages_and_tobacco	Food & drink, tobacco (combustion)	Coal
			Fuel oil
			Gas oil
			Natural gas

National Communication Category	IPCC Sector	Source Name	Activity Name
	1A2f_Non-metallic_minerals	Cement production - combustion	Coal
			Fuel oil
			Gas oil
			Natural gas
			Petroleum coke
			Scrap tyres
			Waste
			Waste oils
			Waste solvent
		Lime production - non decarbonising	Coal
			Coke
			Natural gas
		Other industrial combustion	Scrap tyres
	1A2gvii_Off-road_vehicles_and_other_machinery	Industrial off-road mobile machinery	DERV
			Gas oil
			Petrol
	1A2gviii_Other_manufacturing_industries_and_construction	Autogeneration - exported to grid	Natural gas
		Autogenerators	Biogas
			Natural gas
		Other industrial combustion	Biomass
			Burning oil

National Communication Category	IPCC Sector	Source Name	Activity Name
			Coal
			Coke
			Coke oven gas
			Colliery methane
			Fuel oil
			Gas oil
			LPG
			Lubricants
			Natural gas
			OPG
			Petroleum coke
			SSF
			Waste solvent
			Wood
	1A4ai_Commercial/Institutional	Heat supply	Landfill gas
		Miscellaneous industrial/commercial combustion	Coal
			Fuel oil
			Gas oil
			MSW
			Natural gas

National Communication Category	IPCC Sector	Source Name	Activity Name
	2B1_Chemical_Industry:Ammonia_production	Ammonia production - combustion	Natural gas
	2B8a_Methanol_production	Methanol production – combustion	Natural gas
	2B8g_Petrochemical_and_carbon_black_production:Other	Chemicals (combustion)	OPG
	2C1b_Pig_iron	Blast furnaces	Blast furnace gas
			Coal
			Coke oven gas
			LPG
			Natural gas
		Iron and steel - combustion plant	Blast furnace gas
			Coke oven gas
	2D1_Lubricant_Use	Industrial engines	Lubricants
	2D3_Other_NEU	Non Energy Use: petroleum coke	Petroleum coke
	2E1_Integrated_circuit_or_semiconductor	Electronics - HFC	Non-fuel combustion
		Electronics - NF_3	Non-fuel combustion
	2F1a_Commercial_refrigeration	All sources	All activities
	2F1b_Domestic_refrigeration	All sources	All activities
	2F1c_Industrial_refrigeration	All sources	All activities
	2F1d_Transport_refrigeration	All sources	All activities
	2F1e_Mobile_air_conditioning	All sources	All activities
	2F1f_Stationary_air_conditioning	All sources	All activities

National Communication Category	IPCC Sector	Source Name	Activity Name
	2F2a_Closed_foam_blowing_agents	Closed foams	Halocarbon bank: HFC-134a
			Halocarbon bank: HFC-152a
			Halocarbon bank: HFC-227ea
			Halocarbon bank: HFC-245fa
			Halocarbon bank: HFC-365mfc
			Halocarbon in products at disposal: HFC-227ea
			Halocarbon in products at disposal: HFC-245fa
			Halocarbon in products at disposal: HFC-365mfc
			Halocarbon used for manufacturing: HFC-134a
			Halocarbon used for manufacturing: HFC-152a
			Halocarbon used for manufacturing: HFC-227ea

National Communication Category	IPCC Sector	Source Name	Activity Name
			Halocarbon used for manufacturing: HFC-245fa
			Halocarbon used for manufacturing: HFC-365mfc
	2F2b_Open_foam_blowing_agents	One Component Foams	Non-fuel combustion
	2F3_Fire_Protection	Firefighting	Halocarbon bank: C4F10
			Halocarbon bank: HFC-227ea
			Halocarbon in products at disposal: C4F10
			Halocarbon in products at disposal: HFC-227ea
			Halocarbon used for manufacturing: C4F10
	2F5_Solvents	Precision cleaning	Halocarbon use: HFC-43-10mee
	2F6b_Other_Applications:Contained-Refrigerant_containers	Transport and distribution of refrigerants	Halocarbon bank: HFC-125
			Halocarbon bank: HFC-134a
			Halocarbon bank: HFC-143a

National Communication Category	IPCC Sector	Source Name	Activity Name
			Halocarbon bank: HFC-32
	2F6b_Other_Applications:Contained-Refrigerant_Processing	F-gas handling	Non-fuel combustion
	2G1_Electrical_equipment	Electrical insulation	Halocarbon bank: SF_6
	2G2_Military_applications	Airborne Warning And Control Systems	Active Aircraft
	2G2_Particle_accelerators	Particle accelerators	Halocarbon use: SF_6
	2G2e_Electronics_and_shoes	Electronics - PFC	Non-fuel combustion
		Electronics - SF_6	Non-fuel combustion
		Sporting goods	Non-fuel combustion
	2G2e_Tracer_gas	Tracer gas	Halocarbon use: SF_6
	2G3a_Medical aplications	N_2O use as an anaesthetic	Population
	5C2.2b_Non-biogenic:Other	Accidental fires - other buildings	Mass burnt
	non-IPCC	Chemicals (combustion)	Electricity
		Food & drink, tobacco (combustion)	Electricity
		Iron and steel - combustion plant	Electricity
		Miscellaneous industrial/commercial combustion	Electricity
		Non-Ferrous Metal (combustion)	Electricity
		Other industrial combustion	Electricity
		Pulp, Paper and Print (combustion)	Electricity
Energy Supply	**1A1ai_Public_Electricity&Heat_Production**	Power stations	Burning oil

National Communication Category	IPCC Sector	Source Name	Activity Name
			Coal
			Fuel oil
			Gas oil
			Natural gas
			Petroleum coke
	1A1b_Petroleum_Refining	Refineries - combustion	Natural gas
	1A1ci_Manufacture_of_solid_fuels	Coke production	Natural gas
		Solid smokeless fuel production	Coke
	1A1cii_Oil_and_gas_extraction	Gas terminal: fuel combustion	Gas oil
		Oil terminal: fuel combustion	Natural gas
		Upstream Gas Production - fuel combustion	Gas oil
		Upstream Oil Production - fuel combustion	Natural gas
	1A1ciii_Other_energy_industries	Collieries - combustion	Natural gas
		Gas production	LPG
		Nuclear fuel production	Natural gas
	1B1b_Solid_Fuel_Transformation	Coke production	Coal
		Solid smokeless fuel production	Coal
			Petroleum coke
	non-IPCC	Collieries - combustion	Electricity
		Gas production	Electricity
		Refineries - combustion	Electricity

National Communication Category	IPCC Sector	Source Name	Activity Name
Exports	**Aviation_Bunkers**	Aircraft - international cruise	Aviation spirit
			Aviation turbine fuel
		Aircraft - international take off and landing	Aviation spirit
			Aviation turbine fuel
		Aircraft between UK and Bermuda - Cruise	Aviation turbine fuel
		Aircraft between UK and Bermuda - TOL	Aviation turbine fuel
		Aircraft between UK and CDs - Cruise	Aviation spirit
			Aviation turbine fuel
		Aircraft between UK and CDs - TOL	Aviation spirit
			Aviation turbine fuel
		Aircraft between UK and Gibraltar - Cruise	Aviation spirit
			Aviation turbine fuel
		Aircraft between UK and Gibraltar - TOL	Aviation spirit
			Aviation turbine fuel
		Aircraft between UK and other OTs (excl Gib. and Bermuda) - Cruise	Aviation turbine fuel
		Aircraft between UK and other OTs (excl Gib. and Bermuda) - TOL	Aviation turbine fuel
		Aircraft engines	Lubricants
	Marine_Bunkers	Shipping - international IPCC definition	Fuel oil
			Gas oil
		Shipping between UK and Bermuda	Fuel oil

National Communication Category	IPCC Sector	Source Name	Activity Name
		Shipping between UK and CDs	Fuel oil
			Gas oil
		Shipping between UK and Gibraltar	Fuel oil
		Shipping between UK and OTs (excl. Gib and Bermuda)	Fuel oil
	non-IPCC	Exports	Aviation turbine fuel
			Burning oil
			Coke
			DERV
			Electricity
			Fuel oil
			Lubricants
			Petrol
			SSF
Public	**1A4ai_Commercial/Institutional**	Heat supply	Sewage gas
		Public sector combustion	Burning oil
			Coal
			Coke
			Fuel oil
			Gas oil
			Natural gas

National Communication Category	IPCC Sector	Source Name	Activity Name
	non-IPCC	Public sector combustion	Electricity
Residential	**1A4bi_Residential_stationary**	Domestic combustion	Anthracite
			Burning oil
			Charcoal
			Coal
			Coke
			Fuel oil
			Gas oil
			LPG
			Natural gas
			Peat
			Petroleum coke
			SSF
			Wood
	1A4bii_Residential:Off-road	House and garden machinery	DERV
			Petrol
	2D2 Non-energy_products_from_fuels_and_solvent_use:Paraffin_wax_use	Non-aerosol products - household products	Petroleum waxes
	2F4a_Metered_dose_inhalers	Metered dose inhalers	Halocarbon bank: HFC-134a
			Halocarbon bank: HFC-227ea

National Communication Category	IPCC Sector	Source Name	Activity Name
	2F4b_Aerosols:Other	Aerosols other than metered dose inhalers	Halocarbon bank: HFC-134a
			Halocarbon bank: HFC-152a
	2G3b_N_2O_from_product_uses:_Other	Recreational use of N_2O	Process emission
	5B1a_composting_municipal_solid_waste	Composting (at household)	Biological waste
	5C2.2b_Non-biogenic:Other	Accidental fires - dwellings	Mass burnt
	5C2.2b_Non-biogenic:Other_Accidental fires (vehicles)	Accidental fires - vehicles	Mass burnt
	non-IPCC	Domestic combustion	Electricity
Transport	**1A3a_Domestic_aviation**	Aircraft - domestic cruise	Aviation spirit
			Aviation turbine fuel
		Aircraft - domestic take off and landing	Aviation spirit
			Aviation turbine fuel
	1A3bi_Cars	Road transport - cars - cold start	DERV
			Petrol
		Road transport - cars - motorway driving	DERV
			Petrol
		Road transport - cars - rural driving	DERV
			Petrol
		Road transport - cars - urban driving	DERV
			Petrol
	1A3bii_Light_duty_trucks	Road transport - LGVs - cold start	DERV

National Communication Category	IPCC Sector	Source Name	Activity Name
			Petrol
		Road transport - LGVs - motorway driving	DERV
			Petrol
		Road transport - LGVs - rural driving	DERV
			Petrol
		Road transport - LGVs - urban driving	DERV
			Petrol
	1A3biii_Heavy_duty_trucks_and_buses	Road transport - buses and coaches - motorway driving	DERV
		Road transport - buses and coaches - rural driving	DERV
		Road transport - buses and coaches - urban driving	DERV
		Road transport - general	Natural gas
		Road transport - HGV articulated - motorway driving	DERV
		Road transport - HGV articulated - rural driving	DERV
		Road transport - HGV articulated - urban driving	DERV
		Road transport - HGV rigid - motorway driving	DERV
		Road transport - HGV rigid - rural driving	DERV
		Road transport - HGV rigid - urban driving	DERV

National Communication Category	IPCC Sector	Source Name	Activity Name
	1A3biv_Motorcycles	Road transport - mopeds (<50cc 2st) - urban driving	Lubricants
			Petrol
		Road transport - motorcycle (>50cc 2st) - urban driving	Petrol
		Road transport - motorcycle (>50cc 4st) - motorway driving	Petrol
		Road transport - motorcycle (>50cc 4st) - rural driving	Petrol
		Road transport - motorcycle (>50cc 4st) - urban driving	Petrol
	1A3bv_Other_road_transport	Road transport - all vehicles biofuels use	Biodiesel
			Bio-MTBE
		Road transport - all vehicles LPG use	LPG
	1A3c_Railways	Rail - coal	Coal
		Railways - freight	Gas oil
		Railways - intercity	Gas oil
		Railways - regional	Gas oil
	1A3d_Domestic_navigation	Inland goods-carrying vessels	Gas oil
		Motorboats / workboats (e.g. canal boats, dredgers, service boats, tourist boats, river boats)	DERV
			Gas oil
			Petrol

National Communication Category	IPCC Sector	Source Name	Activity Name
		Personal watercraft e.g. jet ski	Petrol
		Sailing boats with auxiliary engines	DERV
		Shipping - coastal	Fuel oil
			Gas oil
	1A3eii_Other_Transportation	Aircraft - support vehicles	Gas oil
	1A4ai_Commercial/Institutional	Railways - stationary combustion	Burning oil
			Fuel oil
			Natural gas
	1A4ciii_Fishing	Fishing vessels	Fuel oil
			Gas oil
	1A5b_Other:Mobile	Aircraft - military	Aviation spirit
			Aviation turbine fuel
		Shipping - naval	Gas oil
	2D1_Lubricant_Use	Marine engines	Lubricants
		Road vehicle engines	Lubricants
	2D3_Non-energy_products_from_fuels_and_solvent_use:Other	Road transport - urea	Urea consumption
	non-IPCC	Railways - regional	Electricity
		Road vehicle engines	Electricity
Waste Management	**All sectors**	All sources	All activities
Industrial processes	**1B2d_Other_energy_industries**	Flue Gas Treatment (neutralisation)	Sodium Bicarbonate
	2A1_Cement_Production	Cement - decarbonising	Clinker production

National Communication Category	IPCC Sector	Source Name	Activity Name
	2A2_Lime_Production	Lime production - decarbonising	Limestone
	2A3_Glass_production	Glass - general	Dolomite
			Glass-making additives
			Limestone
			Soda ash
	2A4a_Other_process_uses_of_carbonates:ceramics	Brick manufacture - all types	Bricks
		Brick manufacture - Fletton	Fletton bricks
		Other ceramics	Clays & shales
	2A4b_Other_uses_of_Soda_Ash	Non Energy Use: chemical feedstock	Soda ash
		Other emissive applications of Soda Ash	Soda ash
	2A4d_Other_process_uses_of_carbonates:_Other	Bread baking	Sodium Bicarbonate
		Other emissive applications of Sodium Bicarbonate	Sodium Bicarbonate
		Unknown applications of Sodium Bicarbonate	Sodium Bicarbonate
	2B1_Ammonia_Production	Ammonia production - feedstock use of gas	Natural gas
	2B10_Chemical_Industry:Other	Chemical industry - general	Process emission
	2B2_Nitric_Acid_Production	Nitric acid production	Acid production
	2B3_Adipic_Acid_Production	Adipic acid production	Adipic acid produced
	2B6_Titanium_dioxide_production	Chemical industry - titanium dioxide	Coke
			Petroleum coke

National Communication Category	IPCC Sector	Source Name	Activity Name
	2B7_Soda_Ash_Production	Chemical industry - soda ash	Soda ash produced
	2B8a_Methanol_production	Chemical industry - methanol	Methanol
			Natural gas
	2B8b_Ethylene_Production	Chemical industry - ethylene	Ethylene
	2B8c_Ethylene_Dichloride_and_Vinyl_Chloride_Monomer	Chemical Industry - ethylene dichloride	Ethylene dichloride
	2B8d_Ethylene_Oxide	Chemical industry - ethylene oxide	Ethylene oxide
	2B8e_Acrylonitrile	Chemical industry - acrylonitrile	Acrylonitrile
	2B8f_Carbon_black_production	Chemical industry - carbon black	Carbon black capacity
	2B9a1_Fluorchemical_production:By-product_emissions	Halocarbons production - by-product	Non-fuel combustion
	2B9b3_Fluorchemical_production:Fugitive_emissions	Halocarbons production - fugitive	Non-fuel combustion
	2C1a_Steel	Basic oxygen furnaces	Dolomite
		Electric arc furnaces	Petroleum coke
			Steel production (electric arc)
		Ladle arc furnaces	Steel production (oxygen converters)
	2C1b_Pig_iron	Blast furnaces	Coke
			Fuel oil
	2C1d_Sinter	Sinter production	Coke
			Dolomite
			Limestone

National Communication Category	IPCC Sector	Source Name	Activity Name
	2C3_Aluminium_Production	Primary aluminium production - general	Primary aluminium production
		Primary aluminium production - PFC emissions	Primary aluminium production
	2C4_Magnesium_production	Magnesium cover gas	Non-fuel combustion
	2C6_Zinc_Production	Non-ferrous metal processes	Coke
	2G3b_N_2O_from_product_uses:_Other	Other food - cream consumption	Process emission
	2G4_Other_product_manufacture_and_use	Chemical Industry – other process sources	Process emission
	non-IPCC	Blast furnaces	Electricity
Land use, land use change and forestry	**All sectors**	All sources	All activities

A 9.6 DETAILED EMISSIONS ACCORDING TO END USER CATEGORIES

The end user categories in the data tables in this summary are those used in National Communications. The end user reallocation includes emissions from the UK, this is the coverage used for the UK statistical release, where the end users' data are presented in more detail.

The base year for hydrofluorocarbons, perfluorocarbons, nitrogen trifluoride, and sulphur hexafluoride is 1995. For carbon dioxide, methane and nitrous oxide, the base year is 1990.

Table A 9.6.1 End user emissions from all National Communication categories, $MtCO_2$ equivalent

End user category	Base Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Agriculture	57.4	57.4	56.0	53.4	51.5	48.0	48.1	47.8	48.2	47.5	47.7	46.0
Business	246.2	245.6	215.3	214.2	207.7	181.4	145.8	130.5	125.3	121.2	113.6	103.3
Energy Supply	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exports	7.8	7.8	10.6	10.0	13.0	12.7	9.1	9.0	9.2	8.7	8.5	7.2
Industrial Processes	65.9	63.7	54.1	29.6	21.7	13.7	13.3	11.2	11.6	10.8	11.0	10.0
Land Use, Land Use Change and Forestry	13.1	13.1	10.8	8.2	5.4	3.5	3.1	3.2	3.0	3.6	4.0	3.7
Public	31.1	31.1	28.4	24.3	22.4	19.1	14.5	13.3	12.2	11.9	11.2	10.8
Residential	170.5	170.1	155.3	158.1	162.3	155.8	113.1	105.8	99.2	98.8	93.0	92.4
Transport	152.7	152.7	157.4	159.2	160.9	146.0	141.8	143.7	144.0	142.1	140.1	114.6
Waste Management	64.9	64.9	67.6	61.2	47.5	28.4	19.3	18.6	19.0	18.9	18.8	17.6
Total greenhouse gas emissions	809.4	806.3	755.4	718.2	692.3	608.6	507.9	483.1	471.6	463.5	447.9	405.5

Table A 9.6.2 End user CO_2 emissions from all National Communication categories, $MtCO_2$ equivalent

End user category	Base Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Agriculture	9.9	9.9	9.3	7.9	8.7	7.7	7.3	7.3	7.1	7.1	7.3	6.6
Business	227.8	227.8	200.9	202.1	194.5	166.2	129.6	114.8	109.7	105.9	98.7	89.3
Energy Supply	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

End user category	Base Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Exports	7.1	7.1	9.9	9.5	12.5	12.1	8.6	8.6	8.7	8.2	8.1	6.8
Industrial Processes	21.3	21.3	19.4	18.5	17.1	11.4	12.5	10.5	10.7	10.1	10.3	9.5
Land Use, Land Use Change and Forestry	5.9	5.9	3.7	1.3	-1.4	-3.2	-3.6	-3.4	-3.6	-3.0	-2.7	-3.0
Public	28.8	28.8	26.6	23.3	21.7	18.5	14.1	12.9	11.9	11.6	10.9	10.5
Residential	155.1	155.1	143.6	148.9	154.6	149.0	107.6	100.8	94.5	94.1	88.6	88.3
Transport	148.1	148.1	152.8	155.4	158.1	144.0	139.7	141.6	141.8	139.9	137.9	112.8
Waste Management	1.4	1.4	1.0	0.6	0.5	0.3	0.2	0.3	0.3	0.2	0.2	0.2
Total greenhouse gas emissions	605.4	605.4	567.2	567.4	566.2	506.1	416.2	393.4	381.1	374.0	359.3	321.1

Table A 9.6.3 End user CH_4 emissions from all National Communication categories, $MtCO_2$ equivalent

End user category	Base Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Agriculture	29.3	29.3	28.9	28.2	26.8	25.2	25.6	25.5	25.6	25.1	25.2	24.8
Business	15.4	15.4	11.6	7.4	4.8	3.7	2.7	2.3	2.3	2.2	2.2	2.0
Energy Supply	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exports	0.6	0.6	0.6	0.5	0.4	0.4	0.3	0.3	0.4	0.4	0.3	0.3
Industrial Processes	2.1	2.1	1.7	1.1	0.5	0.4	0.2	0.2	0.2	0.1	0.2	0.2
Land Use, Land Use Change and Forestry	4.7	4.7	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.9	4.9	4.9
Public	2.1	2.1	1.7	0.9	0.7	0.5	0.4	0.3	0.3	0.3	0.3	0.3

End user category	Base Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Residential	14.3	14.3	10.7	6.7	4.9	4.3	3.2	2.8	2.7	2.7	2.6	2.6
Transport	2.9	2.9	2.5	1.8	1.2	0.9	0.8	0.8	0.8	0.9	0.8	0.7
Waste Management	62.6	62.6	65.5	59.4	45.7	26.7	17.4	16.7	17.0	17.0	16.9	15.6
Total greenhouse gas emissions	134.1	134.1	128.0	110.7	89.7	66.8	55.4	53.7	54.1	53.6	53.4	51.3

Table A 9.6.4 End user N_2O emissions from all National Communication categories, $MtCO_2$ equivalent

End user category	Base Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Agriculture	18.1	18.1	17.8	17.3	16.0	15.1	15.2	15.1	15.5	15.3	15.3	14.5
Business	1.5	1.5	1.3	1.2	1.3	1.2	1.2	1.1	1.1	1.1	1.1	1.1
Energy Supply	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exports	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Industrial Processes	23.9	23.9	14.4	5.4	3.1	1.5	0.3	0.3	0.3	0.3	0.3	0.2
Land Use, Land Use Change and Forestry	2.5	2.5	2.4	2.2	2.1	1.9	1.8	1.8	1.8	1.8	1.8	1.8
Public	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Residential	0.7	0.7	0.6	0.5	0.5	0.5	0.4	0.4	0.3	0.4	0.3	0.4
Transport	1.7	1.7	2.1	2.0	1.6	1.2	1.3	1.3	1.3	1.3	1.3	1.2
Waste Management	0.9	0.9	1.0	1.2	1.2	1.4	1.6	1.6	1.7	1.7	1.7	1.7
Total greenhouse gas emissions	49.5	49.5	39.8	30.0	26.0	22.9	22.0	21.7	22.2	22.0	22.0	20.9