Department for Business, Energy & Industrial Strategy

NATIONAL STATISTICS

UK local and regional greenhouse gas emissions estimates for 2005-2020

Technical report

This document has been prepared by Ricardo Energy & Environment on behalf of the Department for Business, Energy & Industrial Strategy (BEIS)

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Any enquiries regarding this publication should be sent to us at:
GreenhouseGas.Statistics@beis.gov.uk

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Executive summary

The local and regional Greenhouse Gas (GHG) emissions estimates for 2005-2020 are produced in order to provide a nationally consistent evidence base for sub-national greenhouse gas emissions. These estimates can be used as an important body of information by local authorities (LAs) and other relevant organisations to help identify high emitting sources of GHGs and energy intensive sectors, monitor changes in GHG emissions over time, and to help design carbon reduction strategies. This is the first year that additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O) are included in this data set, in addition to carbon dioxide (CO_2). It is also the first time that GHG emissions estimates have been published for National Park areas.

This report, prepared by Ricardo Energy & Environment on behalf of the Department for Business, Energy & Industrial Strategy (BEIS), sets out how the local and regional GHG emissions estimates for 2005-2020 were compiled. The full dataset – which is classified as National Statistics – and statistical summary can be found on the gov.uk website[1].

The dataset provides a spatial disaggregation of territorial CO_2, CH_4 and N_2O emissions from the UK Greenhouse Gas Inventory (GHGI), part of the National Atmospheric Emissions Inventory (NAEI), on an end user basis. This means that emissions from the production and processing of fuels, including the production of electricity, are reallocated to users of these fuels to reflect total emissions for each type of fuel consumed. The disaggregation methodology is complex, and different approaches are used to make best use of the quantity and quality of suitable data that are available for each sector.

The activity data used to produce these estimates come from the following main sources:

- BEIS sub-national gas and electricity consumption statistics[2];
- Devolved Administration organisations; Environment Agency (EA), Natural Resources Wales (NRW), Scottish Environment Protection Agency (SEPA), Northern Ireland Department of Agriculture, Environment and Rural Affairs (DAERA)
- Point source emissions from large industrial installations;
- Waste arisings data from the Waste Data Interrogator;

1www.gov.uk/government/collections/uk-local-authority-and-regional-greenhouse-gas-emissions-national-statistics

2 www.gov.uk/government/collections/sub-national-gas-consumption-data and www.gov.uk/government/collections/sub-national-electricity-consumption-data

- High resolution emissions distribution maps developed under the NAEI programme; and,
- Land use, land-use change and forestry (LULUCF) regional data supplied by The UK Centre for Ecology & Hydrology (UKCEH), under the NAEI programme.

National end user emissions data are used to calculate emission factors for each activity. Local authority activity data are then multiplied by the relevant emission factor to generate an estimate of emissions in each LA. This dataset and the GHG inventory are subject to continuous improvement in order to increase confidence in the estimates. Efforts are concentrated each year on topics identified in both inventory and emissions mapping improvement plans with the aims of improving accuracy and reducing uncertainties.

The most significant improvement this year is the addition of 2 new gases to the estimates, methane and nitrous oxide. Both these gases have been estimated for all sectors at a local authority level as explained further in the sector chapters.

1. Introduction

Purpose of the work

The dataset provides a spatial disaggregation of the CO_2, CH_4 and N_2O emissions from the UK Greenhouse Gas Inventory (GHGI), part of the National Atmospheric Emissions Inventory (NAEI), on an end user basis. The GHG emissions are estimated, by sector, for each local authority in the UK. The data help identify the key sources of GHG emissions in each area; allow changes in GHG emissions over time to be monitored and can help mitigation actions to be targeted.

Methodology

This is the technical report for the Local and Regional GHG Emission Estimates for 2005 - 2020 for the UK. It provides a detailed technical description of the methodology.

The dataset is provided in detail in a spreadsheet that accompanies this technical report (https://www.gov.uk/government/statistics/uk-local-authority-and-regional-greenhouse-gas-emissions-national-statistics-2005-to-2020). A summary of results and two further methodology documents also accompany this dataset on the gov.uk website:

- **Infographic.** A one-page document summarising the main headline figures
- **Statistical release.** A short document providing a commentary on trends and patterns shown in the data.
- **Technical report.** This report, which provides a summary of the methodology used to calculate GHG emissions (CO_2, CH_4, N_2O) at local authority (LA) level.
- **Mapping Carbon Emissions and Removals for the Land Use, Land-Use Change and Forestry Sector.** A detailed description of the methods used to compile the Local estimates of Land Use, Land-Use Change and Forestry emissions.
- **Employment based energy consumption in the UK.** A detailed methodological report describing the methods used to estimate the energy use at the UK level by the smaller industrial, commercial, and public sectors and to model the distribution of the energy use across the UK at Local Authority and 1×1 km resolution.

The following chapters explain the technical approaches used to generate estimates of the GHG emissions according to energy use in each sector.

The UK Greenhouse Gas Inventory

The UK Greenhouse Gas inventory (GHGI) is compiled annually by a consortium, led by Ricardo Energy & Environment, on behalf of BEIS as part of the NAEI programme. The GHGI is compiled and reported using international best practice guidance and draws on a variety of National Statistics and sector specific data sources.

The UK GHGI is reported each year to the United Nations Framework Convention on Climate Change (UNFCCC), and is used to assess compliance with the UK's domestic and international emissions reduction targets. A consistent method and common base of activity data is used across the NAEI programme. This provides internally consistent inventories and emissions projections of greenhouse gases and air quality pollutants.

End User basis for reporting emissions

These statistics cover territorial CO_2, CH_4 and N_2O emissions, meaning emissions that occur within the UK's borders. These emissions are reported in a variety of different formats for different organisations and purposes each year with this being the first year that CH_4 and N_2O have been included.

One of these is known as the end user format in which emissions from the production and processing of fuels, and the production of electricity, are reallocated to final consumers of the energy to reflect the total emissions relating to that energy use. This difference in reporting mainly affects emissions related to electricity generation from power stations and fuel processing in refineries. This is in contrast to the 'by source' emission reporting in which emissions are attributed to the sector that emits them directly.

Emissions from sources other than the production and processing of fuels are reported in the same way under both the 'end user' and 'by source' approaches, based on the location of the emission. End user GHG emissions at UK level are reported by BEIS as National Statistics; however, these emissions will be slightly higher than those shown in the local authority breakdown as they include emissions from some excluded sources which are deemed not to belong to any particular LA.

The end user basis for reporting emissions has been chosen for this dataset because it accounts for the emissions from energy use at the local level and does not penalise local areas for emissions from the production of energy which is then 'exported' to and used in other areas. The method used follows, as closely as possible, that used for the end user emissions calculated as part of the GHGI and reported by BEIS at the national level[3].

[3] The estimates presented in this report are not directly comparable with the National and Devolved Administration Greenhouse Gas Inventories. This is because more detailed site-specific data on emissions and fuel consumption data have been used, in order to include more accurate data on

Sectors where emissions occur can be divided into three categories in the NAEI:

- Energy Suppliers (the transformation and supply of energy including electricity);
- Energy Users (such as residential, industrial and road transport); and
- Others (which emit CO_2, CH_4 and N_2O but where the emissions are not related to fuel use, such as agriculture, industrial process emissions, land-use change and waste).

Within the 'Other' category, emissions from waste have been spatially distributed using an approach analogous to the fuel end-user basis, distributing UK total emissions from waste management proportionally to the waste arising in each Local Authority, rather than to the location of waste management facilities. For example, emissions from landfills are distributed based on estimates of biogenic waste arising in each local authority, whilst emissions from sewage plants are distributed based on population.

Table 1 shows the UK total CO_2e by-source emissions in 2020 split into these three types of sectors.

The end user model reallocates emissions from energy supply industries to each energy use sector in the inventory in proportion to the amount of energy they each use. Some energy suppliers use energy from other energy suppliers, for example refineries use electricity. The refineries therefore 'receive' emissions from electricity producers and in turn these emissions are reallocated to the users of the refineries' products. This requires an iterative approach to emissions estimation from the end users which terminates when all fuel producers have no more fuel to reallocate to end users.

Table 2 shows the total emissions in the UK inventory for the end user categories including both reallocated energy supply emissions and the primary emissions at the point of fuel use.

For more information on end user emissions calculations, please see the National Inventory Report (Brown *et al.*, 2022).

emissions from large sources at the local level. The requirements of international inventory compilation (IPCC 2006a) specifies that national datasets of fuel consumption (i.e. the BEIS Digest of UK Energy Statistics, DUKES) must be used. The ETS data for 2005-20 are not fully consistent with DUKES but were used during the compilation process of allocating consumption to particular industrial consuming sectors.

Table 1 UK Total Primary emissions of CO_2, CH_4 and N_2O (kt CO_2e 2020)

Sector	Anthracite & Coal	Coke	SSF and Charcoal	Natural Gas	Oil	Electricity	Non-Fuel	Grand Total
Energy Supply								
Coke production	-	551	-	-	-	-	150	701
Coal production	-	-	-	14	-	-	509	524
Gas Leakage	-	-	-	-	-	-	3,256	3,256
Gas production	-	-	-	4,771	171	-	1,203	6,145
Oil production	-	-	-	7,249	1,575	-	2,960	11,784
Iron and steel - flaring	-	786	-	-	-	-	23	810
Power stations	5,257	-	-	38,694	326	-	6,627	50,905
Refineries - combustion	-	-	-	2,642	8,485	-	-	11,127
Solid smokeless fuel production	125	-	-	-	48	-	4	178
Energy Consumption								
Industry: Iron & Steel	66	9,041	-	851	75	-	752	10,784
Industry: Other Combustion	1,836	-	-	19,169	10,915	-	256	32,175
Industry: Other Processes	1,383	-	-	1,900	5,289	-	7,347	15,919
Commercial	30	-	-	10,671	157	-	724	11,584
Agriculture	-	-	-	194	4,196	-	39,471	43,860
Miscellaneous	-	-	-	-	-	-	17,653	17,653
Rail Transport	37	-	-	2	1,403	-	-	1,443
Domestic	1,457	-	643	54,633	7,989	-	293	65,015
Public	57	-	-	7,293	92	-	-	7,441
Road Transport	-	-	-	58	89,436	-	57	89,551
Inland Waterways	-	-	-	-	854	-	-	854
Land use Change	-	-	-	-	-	-	4,607	4,607
Water Transport: National Navigation	-	-	-	-	4,413	-	-	4,413
Air Transport	-	-	-	-	1,121	-	-	1,121
Military Transport (Air & Water)	-	-	-	-	1,420	-	-	1,420
Exports	-	-	-	-	-	-	-	-
International aviation and shipping	-	-	-	-	-	-	-	-
Total	**10,249**	**10,379**	**16**	**148,142**	**137,965**	**-**	**85,891**	**393,269**

Table 2 UK Total End user emissions of CO_2, CH_4 and N_2O (kt CO_2 2020)

Sector	Anthracite & Coal	Coke	SSF & Charcoal	Natural Gas	Oil	Electricity	Non-Fuel	Grand Total
Energy Supply								
Energy Consumption								
Industry: Iron & Steel	166	10,704	-	909	80	328	752	12,939
Industry: Other Combustion	1,896	-	-	20,487	12,614	14,455	256	49,707
Industry: Other Processes	1,428	-	-	2,031	5,732	-	7,347	16,538
Commercial	31	-	-	11,404	170	11,357	724	23,687
Agriculture	-	-	-	207	4,547	814	39,471	45,039
Miscellaneous	-	-	-	-	-	-	17,653	17,653
Rail Transport	38	-	-	2	1,522	902	-	2,464
Domestic	1,500	-	837	58,384	8,685	21,444	293	91,143
Public	59	-	-	7,793	100	2,834	-	10,785
Road Transport	-	-	-	62	103,450	112	57	103,681
Inland Waterways	-	-	-	-	928	-	-	928
Land use Change	-	-	-	-	-	-	4,607	4,607
Water Transport: National Navigation	-	-	-	-	4,783	-	-	4,783
Air Transport	-	-	-	-	603	-	-	603
Military Transport (Air & Water)	-	-	-	-	1,542	-	-	1,542
Exports	-	-	11	-	4,480	906	-	5,397
International aviation and shipping	-	-	-	-	1,771	-	-	1,771
Total	**5,118**	**10,704**	**848**	**101,280**	**151,008**	**53,151**	**71,159**	**393,269**

Legend and Notes:

Energy Suppliers
Energy Users
Others (CO_2 emissions not related to fuel use)

Sectors: *Excluded from Local GHG estimates in italic*

2. Non-domestic Electricity

Allocating Emissions to Electricity Consumption

Electricity consumption data for 2005-2020 at Local Authority level for England, Wales and Scotland are published on the gov.uk website[4]. More limited data are also available for Northern Ireland (see **Section 2.2**). These datasets have been used to map CO_2, CH_4 and N_2O emissions from electricity generation to the point of consumption.

The emissions associated with electricity consumption have been estimated using an average UK emission factor for the relevant year in units of kilotonnes of carbon dioxide equivalent per gigawatt hour (kt CO_2e per GWh). This average allocates equal shares of coal, gas, oil and renewable powered generation to all of the electricity consumers and is derived from the UK inventory for 2020 (Brown et al., 2022). The factors used are shown in **Table 3**. The end user GHG emission for electricity consumption from the NAEI (as shown in **Table 3**) was distributed across the LAs in proportion to the consumption data for both domestic and non-domestic users. The emissions from electricity are around 97% CO_2 each year.

Annualised electricity consumption data were compiled at meter point using Meter Point Administration Number (MPAN) level data. This data product is compiled by agents of the electricity suppliers, who collate/aggregate electricity consumption levels for each MPAN. The locations of these meters were determined from the Geyser database supplied by ECOES (Electricity Central Online Enquiry Service). Where the address information was not available in the Gemserv database the Royal Mail Postcode Address File (PAF) was used to obtain a full address and postcode and reduce unallocated consumption.

Each meter is allocated a profile class, which enables consumption of domestic customers (profiles 1 and 2) to be identified from the consumption of industrial and commercial customers (profiles 3 to 8). In addition, profile 1 and 2 meters are reallocated to the industrial and commercial sector if annual consumption is greater than 100,000 kWh. Also re-allocated to the industrial and commercial sector are those consuming over 50,000 kWh with address information indicating non-domestic consumption (BEIS 2020b).

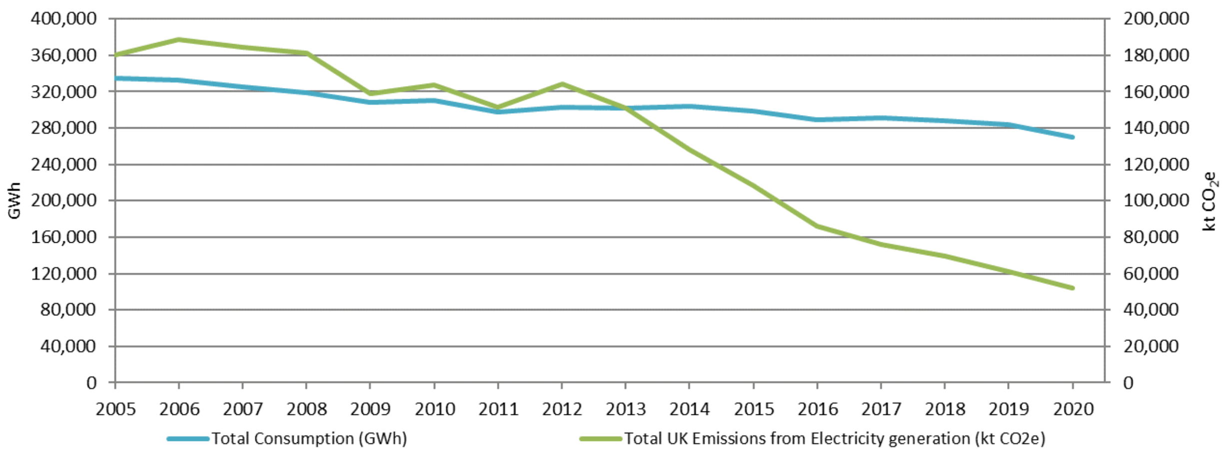
4 https://www.gov.uk/government/collections/sub-national-electricity-consumption-data

Table 3 Electricity CO_2e factors used in this analysis

Year	Total UK Emission for Electricity (kt CO_2e)	Total Consumption (GWh)	Electricity GHG Factor (kt CO_2e per GWh)
2005	180,187	334,561	0.539
2006	188,618	332,495	0.567
2007	184,581	325,464	0.567
2008	181,103	319,082	0.568
2009	158,608	308,113	0.515
2010	163,716	310,332	0.528
2011	151,383	297,984	0.508
2012	164,402	302,649	0.543
2013	150,656	301,661	0.499
2014	127,962	303,711	0.421
2015	108,132	298,155	0.363
2016	86,174	289,530	0.298
2017	75,729	291,036	0.260
2018	69,378	287,764	0.241
2019	61,267	283,386	0.216
2020	52,245	270,061	0.193

Note: includes Northern Ireland electricity consumption and sales direct from high voltage lines

Figure 1 Time-series of electricity consumption and associated emissions in the UK



From 2005 to 2009 there was a continuous decrease in electricity consumption and a similar trend in the associated emissions, with a drop in consumption between 2008 and 2009 likely to be associated with the economic recession. Emissions in 2009 declined due to both the reduction in consumption and due to a reduction in carbon intensity of generated electricity. In 2010, electricity consumption and emissions were slightly higher than in 2009. This was likely to be due to the coldest December on record, and the stabilisation of the economic downturn may also have contributed. In 2011, electricity consumption was lower again due to a warmer winter. After 2011 consumption rose again, but since 2014 it has fallen to below 2011 levels.

The long-term trend from 2005 is a steady decrease in total electricity consumption. This is due in part to a fall in the average electricity consumption per household due to energy efficiency improvements e.g. better insulation and improved appliances, as well an increase in the price of electricity since 2005 (BEIS 2021a). **Figure 1** shows from 2012 onwards the production of emissions reduces at a much quicker rate than the consumption rate of electricity, likely due to switch away from coal in the overall generation mix, toward gas and renewable generation, and some improvements in the efficiency of generating plants.

The average electricity emission factor is dependent on the mix of electricity generation types used that year. Increases in emission factor from 2005-08 are due to an increase in the proportion of electricity produced using coal. During 2010, an increase in coal consumption and a decrease in nuclear power (due to technical problems at some stations) led to a spike in the average emission factor. Supply of gas also increased over this period (DECC, 2011). In 2012, rises in the price of natural gas caused another spike in average electricity emission factor, as UK power generation switched from using natural gas to coal. From 2013 onwards, the price of natural gas relative to coal has reversed and is cheaper than coal (DECC, 2012 and DECC, 2014). Since then, the average electricity emission factor has been rapidly declining.

In 2020, the emission factor was the lowest it had been since 2005, due to the continuing decrease in coal fired generation because of a number of power stations closures, both temporary and permanent, the conversion of a second unit at Drax from coal to biomass, and an increase in the carbon price floor in April 2015. In addition, there are increases in the share of low carbon electricity generation due mostly to consistently increasing renewable capacity over the timeseries, particularly in wind power. Nuclear generation has fallen slightly over the timeseries; however this has been substantially outweighed by the increase in electricity from renewable sources (BEIS, 2022). Overall, the emission factor has declined by 64% between 2005 and 2020.

Electricity consumption in Northern Ireland

Following the creation of a single electricity market in Ireland in late 2007, consumers could choose their electricity supplier, and confidentiality restrictions on the consumption data were reduced. As a result of this, figures for domestic electricity consumption by calendar year from 2008-2011 and non-domestic electricity consumption in 2009-2011 at District Council level in Northern Ireland are available on the gov.uk website[5]. Data for domestic consumption for financial years since 2012/2013 have been available since December 2015, and are now an annual publication. These statistics are produced by BEIS using aggregated meter point data derived from Northern Ireland Electricity's Distribution Use of System (DUoS) Billing system.

The data are based on billed units and relate to final consumption at the point it was derived. Therefore, this dataset excludes autogeneration that does not pass through the public distribution network. In order to develop a consistent time-series from 2005-20 utilising both the calendar and financial year data, the subnational datasets are scaled such that the total is consistent with BEIS calendar year sales data for Northern Ireland. Missing LA-scale data for years 2005-9 is extrapolated such that the total is consistent with calendar year sales data.

Unallocated electricity

Where electricity sales within the datasets have not been successfully allocated to specific LAs, they have been assigned to an additional 'unallocated' category. The BEIS data use to also includes around 3-4 TWh of electricity as direct sales to high voltage lines that could not be allocated to any region or Local Authority due to a lack of accurate address information. Emissions associated with this electricity consumption are included in the final dataset as an unallocated item.

This takes the overall percentage of electricity consumption unallocated to LAs, either because of geo-referencing problems, statistical differences or because it is direct sales, to 4.2% in the industrial and commercial sector and 0.2% in the domestic sector in 2020.

Industrial, commercial, agriculture & public sector split

For the 2005-2020 LA GHG dataset additional detail has been introduced for emissions associated with non-domestic electricity consumption, such that these are now further split between industrial, commercial & public sector. 'Agriculture' is defined as SIC07 subsection 01, 'Industrial' is defined as subsections 02-32, 35-39 & 42, 'Public sector' defined as subsections 84-87, and all other SIC07 subsections are allocated to 'Commercial'.

This split is specific to Local Authority and year for 2010 onwards, with 2010 splits applied for 2005-2009 emissions, and uses the same methodology as has been hitherto used for other fuels, outlined in section 5.1 of this report and in the 'Employment based energy consumption in the UK' report.

5 www.gov.uk/government/collections/sub-national-electricity-consumption-in-northern-ireland#local-authority-data

3. Non-domestic Gas Consumption

Allocating Emissions to Gas Consumption

The gas consumption data published by BEIS provide estimates of gas consumption by the domestic sector and the non-domestic sector for each LA in Great Britain for 2005-2020; these are published on the gov.uk website[6]. These statistics are based on data obtained from Xoserve[7] and groups of independent gas transporters. These data have been mapped to LA areas very accurately, using geographical information from the National Statistics Postcode Directory (NSPD).

The Annual Quantity (AQ) gas consumption data supplied to BEIS from Xoserve, used in the sub-national analysis, is an estimate of annualised consumption between two meter readings at least 6 months apart but ideally close to a year apart. These have historically covered the gas year (1 October to 30 September). For example, 2015 data covers the period from 1 October 2014 to 30 September 2015. However, from 2016 the period covered by gas consumption has changed due to a new data collection method implemented by Xoserve. The gas period for 2017 was mid-June 2017 to mid-June 2018. For 2018 the gas year shifted to mid-May 2018 to mid-May 2019 and has remained mid-May to mid-May for the proceeding years.

Not all AQs are recalculated each year, mainly because gas shippers have not provided any new meter readings. In these cases, the previous year's data is carried forward.

A weather correction factor is applied (except to sites that have automatic meter reading) so that AQ data are adjusted to normal weather conditions. The methodology for this adjustment is detailed in the 'Overview of weather correction of gas industry consumption data' published by DECC in November 2014[8]. In 2022 BEIS published gas consumption data for 2015-2020 that is not weather corrected, however for 2005-15 the data available does not currently enable the weather correction factor to be removed from the annual quantities, or for estimates on a calendar or financial year basis to be produced (DECC, 2012).

For these reasons, the AQ cannot be exactly aligned to gas consumption data in the Digest of UK Energy Statistics (DUKES) (BEIS 2020c), which are based on a calendar year and are not weather corrected, or to the sub-national electricity data

6 https://www.gov.uk/government/collections/sub-national-gas-consumption-data

7 Xoserve was set up in May 2005 after the restructuring of the gas distribution network. Xoserve's role is to deliver transportation transactional services to gas shippers (suppliers) on behalf of the gas transporters.

9 For more information on weather correction, please see the National Grid's Gas Demand Forecasting Methodology note: https://www.nationalgrid.com/sites/default/files/documents/8589937808-Gas%20Demand%20Forecasting%20Methodology.pdf

which are partly calendar year and partly annual from 31st January to 30th January (BEIS 2020a).

BEIS uses the gas industry standard cut-off point of 73,200 kWh to identify small and medium business consumers (BEIS 2020b). This incorrectly allocates many small businesses to the domestic sector and, conversely, a small number of larger domestic consumers to the non-domestic sector. It also means that meters can change sectors from year to year. BEIS estimate that around 2 million small businesses are incorrectly identified as domestic as a result of this cut-off (BEIS 2020b). These domestic and non-domestic definitions are applied for the purposes of the Local and Regional GHG Emissions Estimates 2005-2020.

To ensure non-disclosure agreements are maintained, some suppression of data for the largest gas consumers has taken place. This relates to the industrial and commercial consumption data and comprises approximately 50 power stations and 110 large industrial, commercial, or public sector users. However, the LA areas in which these users are located are known, as is the total gas usage by the large (excluded) users.

Energy use and emissions estimates for the excluded sites have been calculated by Ricardo Energy & Environment using the data from the NAEI point source database, which uses a combination of public domain emissions data and data from the Emissions Trading System (ETS) reports to regulators. This database and the method used to obtain estimates of emissions and fuel use at point sources are described in **Section 4**. These data are included in the Large Industrial Installations sector – Sector C, along with point source emissions from other fuels.

These exclusions from the Xoserve dataset are determined by considering sites consuming over 58,600,000 kWh per year which have any of the following attributes:

- Shared Supply Meter Point (SSMP) – i.e. 2 or more Gas Shippers to the site
- On Shorthaul Tariff Charge (due to close proximity to an input terminal)
- Daily Metered site on Connected System Exit Points (large meter point connected to a pipeline which is owned and operated by Independent Gas Transporters)
- An Interconnector
- Site with Telemetry equipment

Data from the NAEI points source database, based on an Environment Agency database of reported emissions in the ETS, have been used to estimate fuel use from 2005 to 2020. There are however some discrepancies between the DUKES fuel use statistics and those either reported in the ETS or calculated by Ricardo Energy & Environment. These differences mean that the data presented here for Industrial and Commercial emissions of CO_2, CH_4 and N_2O are not fully consistent with the UK GHGI. The differences are described in **Section 4**.

The comparison between the BEIS estimated gas consumption for the excluded sites and gas consumption as estimated by Ricardo Energy & Environment from the

NAEI points source database is shown below in **Table 4**. The difference between these figures is due mainly to two reasons. Firstly, different scopes apply for different reporting requirements; emission reporting in some instances only requires reporting for a particular furnace rather than an entire site, it is not clear whether exclusions from the sub-national dataset are for whole sites or single meters. Secondly, the company names used in the point source database and those supplied by Xoserve are not always consistent and it is therefore not possible to match them all with absolute certainty.

The total of industrial and commercial emissions from end user gas consumption in this LA dataset is consistent with those in the UK national inventory, no emissions are excluded from the dataset total as a result of the differences described above. This means that the difference between the Ricardo Energy & Environment and BEIS estimated gas consumption from large point sources is spread across the BEIS LA gas consumption data, effectively increasing the implied emission factor (IEF) for gas use by a small amount (IEFs shown in **Table 7**).

Industrial, commercial, agriculture & public sector split

For the 2005-2020 LA GHG dataset, additional detail has been introduced for emissions associated with non-domestic gas consumption such that these are now further split between agriculture, industrial, commercial & public sector. ‘Agriculture’ is defined as SIC07 subsection 01, ‘Industrial’ is defined as subsections 02-32, 35-39 & 42, ‘Public sector’ defined as subsections 84-87, and all other SIC07 subsections are allocated to ‘Commercial’.

This split is specific to Local Authority and year for 2010 onwards, with 2010 splits applied for 2005-2009 emissions, and uses the same methodology as has been hitherto used for other fuels, outlined in section 5.1 of this report and in the ‘Employment based energy consumption in the UK’ report.

Table 4 Comparison of BEIS excluded gas consumption and Ricardo Energy & Environment calculated gas consumption at large point sources

Gas consumption excluded from sub-national dataset (GWh)	BEIS estimated excluded gas	Ricardo estimated excluded gas	Difference	Difference as a percentage of total gas consumption
2005	110,327	81,058	29,269	4.2%
2006	88,519	75,831	12,688	1.9%
2007	100,686	77,118	23,568	3.7%
2008	100,460	77,507	22,953	3.6%
2009	99,735	67,959	31,776	5.4%
2010	94,996	65,588	29,408	4.6%
2011	96,224	61,780	34,444	6.4%
2012	102,576	60,580	41,996	7.2%
2013	105,000	55,880	49,119	8.3%
2014	100,623	52,413	48,210	9.5%
2015	97,891	50,296	47,595	9.1%
2016	100,552	47,690	52,862	9.1%
2017	103,058	51,352	51,706	9.8%
2018	104,080	47,327	56,957	10.5%
2019	102,997	48,661	54,810	10.3%
2020	94,503	47,432	47,070	9.1%

Gas consumption in Northern Ireland

Data for Northern Ireland are estimated using information on total Northern Ireland gas consumption from energy providers Airtricity and Firmus energy, and from 2015 onwards BEIS sub-national gas consumption statistics, which provides total consumption, number of meters and average consumption per meter for each District Council area in Northern Ireland (BEIS 2021d).

Comparison of BEIS subnational data with data from gas suppliers shows that the supplier data is consistently lower and may not represent all consumption in Northern Ireland. 2005-14 estimates based on data from gas suppliers have therefore been re-based using 2015 consumption at LA level from the BEIS subnational estimates ensuring a more consistent timeseries and more accurate estimates for consumption in early years.

Calculating GHG Emissions

In order to calculate the total amount of CO_2, CH_4 and N_2O emission represented by the BEIS LA gas consumption (i.e. without the excluded large gas users) it is necessary to remove the GHG emissions associated with these large users from the national total end user emissions. For 2005-15 emissions from gas consumption in Northern Ireland must be removed from total UK emissions as Northern Ireland gas consumption are not weather corrected whilst GB consumption data are. For these years it is therefore more accurate to use a UK-wide average emission factor for gas consumption in NI, and adjust only the weather corrected GB consumption such that the UK total is consistent with GHGI totals based on DUKES. This normalisation approach is continued for 2015-20 data where both GB and NI consumption data are not weather corrected, in order to ensure that there is no artificial timeseries step change caused by differences in normalisation approach across years.

This calculation is shown in **Table 5** where the industrial sectors using gas are listed at the top, with emissions associated with the large gas users and Northern Ireland removed from this total and domestic gas use emissions are added at the bottom. Northern Ireland emissions are calculated by applying the implied emission factor calculated in **Table 6** to gas consumption data reported by energy suppliers.

The Northern Ireland implied emission factor is calculated using the total UK end user emissions from the inventory and the total end user (all sectors other than energy suppliers) gas consumption. The result of the calculation in **Table 5** is a national total gas emission consistent with the BEIS sub-national gas consumption dataset. The resultant implied CO_2e emission factors for the BEIS sub-national gas consumption dataset are shown in **Table 7**. Around 97% of total CO_2e GHG emissions from gas combustion are CO_2.

These data are revised for the entire timeseries each year due to a variety of factors, primarily improvements to the UK GHGI (Brown et al., 2022) and to DUKES commodity balances (BEIS 2021c). All emissions used in these calculations are ‘end user’ emissions and include emissions from the production and transportation of gas. Power stations’ emissions are not included in any of these calculations as they are distributed by electricity consumption.

Table 5 Calculation of CO_2e emission equivalent to BEIS LA gas consumption (kt CO_2e)

GHGI End User Emissions by Sector	Industry and commercial combustion (not including power stations)	Agriculture combustion +	Processes [1] +	Total Local CO_2e Industry and Commercial gas use emission	Large users (not including power stations) excluded from this dataset -	Northern Ireland -	Domestic combustion +	Total emission to distribute using the BEIS sub-national gas data
2005	61,159	455	1,293	62,906	13,676	761	76,812	125,281
2006	57,083	404	998	58,484	12,879	775	73,622	118,453
2007	53,758	399	1,344	55,502	13,417	791	70,540	111,835
2008	55,358	281	1,128	56,767	13,375	934	71,526	113,984
2009	46,278	292	903	47,473	11,576	945	68,784	103,737
2010	48,720	272	1,042	50,033	10,292	1,127	77,322	115,936
2011	44,325	269	674	45,268	9,674	1,112	61,602	96,084
2012	46,192	232	1,067	47,491	9,886	1,203	68,408	104,810
2013	47,702	219	932	48,853	8,705	1,249	68,830	107,729
2014	43,308	215	1,021	44,543	7,775	1,346	56,847	92,269
2015	44,052	196	1,112	45,361	7,509	1,183	59,413	96,081
2016	44,590	199	979	45,768	7,186	1,146	60,153	97,589

GHGI End User Emissions by Sector	Industry and commercial combustion (not including power stations)	Agriculture combustion +	Processes [1] +	Total Local CO_2e Industry and Commercial gas use emission	Large users (not including power stations) excluded from this dataset -	Northern Ireland -	Domestic combustion +	Total emission to distribute using the BEIS sub-national gas data
2017	44,639	201	1,207	46,046	7,824	1,290	57,920	94,853
2018	44,737	202	892	45,831	7,109	1,227	59,727	97,222
2019	44,398	215	1,048	45,661	7,170	1,317	57,653	94,826
2020	41,511	207	1,115	42,834	7,097	1,367	58,384	92,753

(1) Emissions from using natural gas as a feedstock for ammonia production

Table 6: Northern Ireland gas GHG emission factors calculated from UK inventory data

Year	Total UK Emission for Gas	Total Consumption (GWh gross)	NI Gas GHG Factor (kt CO_2e per GWh)
2005	139,718	695,034	0.201
2006	132,106	658,798	0.201
2007	126,042	630,924	0.200
2008	128,294	645,281	0.199
2009	116,258	583,754	0.199
2010	127,355	642,029	0.198
2011	106,870	536,040	0.199
2012	115,899	581,612	0.199
2013	117,683	589,264	0.200
2014	101,391	506,200	0.200
2015	104,773	524,984	0.200
2016	105,921	538,756	0.197
2017	103,966	529,830	0.196
2018	105,581	539,771	0.196
2019	103,349	528,713	0.195
2020	101,280	519,317	0.195

Table 7: Gas GHG emission factors used for Great Britain

Year	Total UK Emission for Gas (to distribute using BEIS gas data)	Total Consumption in BEIS gas data (GWh gross)	GB Gas GHG Factor (kt CO_2e per GWh)
2005	125,281	660,515	0.190
2006	118,453	628,733	0.188
2007	111,835	614,093	0.182
2008	113,984	586,455	0.194
2009	103,737	539,058	0.192
2010	115,936	540,642	0.214
2011	96,084	513,166	0.187
2012	104,810	510,047	0.205
2013	107,729	498,402	0.216
2014	92,269	501,285	0.184
2015	96,081	500,280	0.192
2016	97,589	490,416	0.199
2017	94,853	519,114	0.183
2018	97,262	498,680	0.195
2019	94,842	506,087	0.187
2020	92,753	531,117	0.175

It is important to note that the compilation of the BEIS sub-national gas consumption dataset uses a weather correction factor based on a Met Office model using historic data[9]. This takes account of the warmer weather in more recent years (BEIS 2020b). This is done in order to observe long-term energy consumption trends without being affected by particularly warm or cold years.

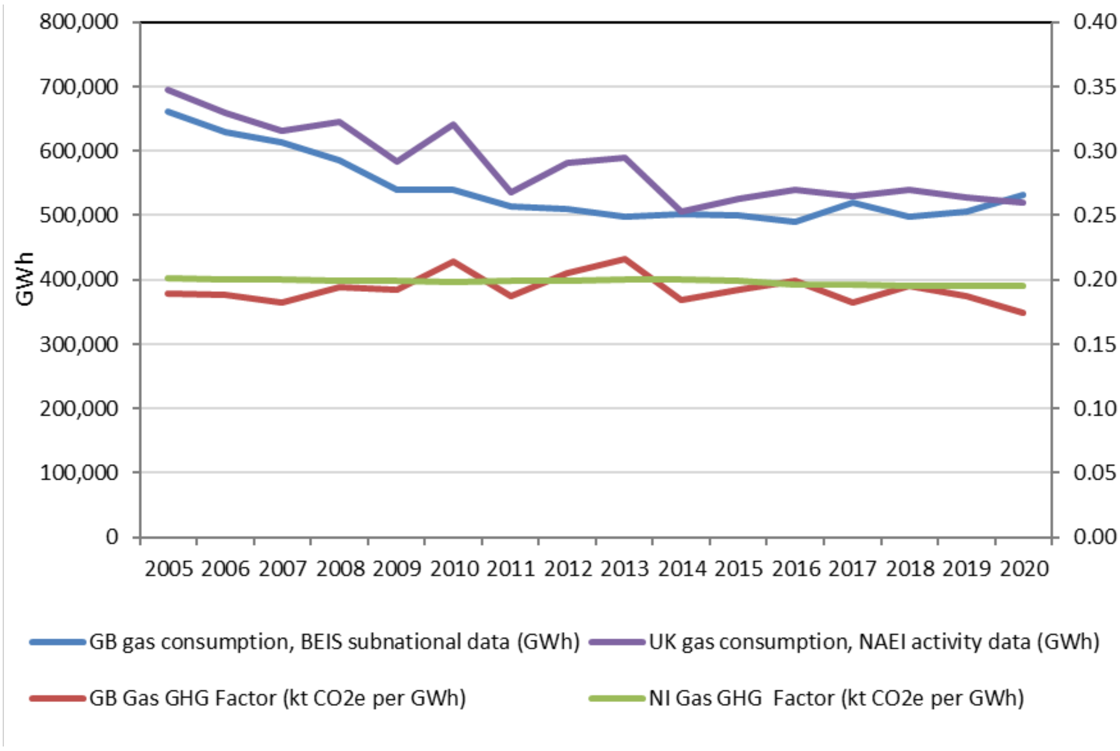
The total UK GHG emissions from gas consumption in the Local GHG dataset are consistent with those from the national inventory which is based on DUKES which is not weather corrected. The national emissions from gas consumption are allocated to LAs based on the BEIS sub-national gas consumption data which are weather corrected. This results in a partial weather correction whereby the impacts of changes in the weather are still evident in the time series for an individual Local Authority, but the magnitude of change is reduced. From 2022 BEIS sub-national gas consumption data was available for 2015-2020 that is not weather corrected, so the full effect of trends in gas consumption arising from changes in weather should be evident in LA level emissions data.

The magnitude of the weather correction is particularly evident for 2010 in **Table 7** above, the implied emission factor is much higher because it was an extremely cold year and more gas was used. Similarly, there is another rise in 2012 and in 2013 the implied emission factor rose further, just above the level seen in 2010, due to the unusually cold weather in the latter months of 2012 and the first half of 2013. In 2014 and 2015, the implied emission factors are lower because they were warm years. In 2015, emissions have increased relative to 2014, whilst consumption has declined, since temperatures in the early months of 2015 were much lower than in 2014 (BEIS 2021a).

The effect of the weather correction can be observed by comparing implied emission factors used for Northern Ireland (not corrected, shown in **Table 6**) and Great Britain (weather corrected, shown in **Table 7**). 2020 emissions from gas consumption have decreased from the previous year and are the lowest seen in the timeseries.

9 For more information on weather correction, please see the National Grid's Gas Demand Forecasting Methodology note: https://www.nationalgrid.com/sites/default/files/documents/8589937808-Gas%20Demand%20Forecasting%20Methodology.pdf

Figure 2 Natural Gas consumption and emission factors, weather-corrected (GB 2005-2014) and not weather-corrected (all of NI and GB 2015-2020)



UK gas consumption is from DUKES which data is reported for a whole year. GB gas data is from Subnational Statistics which report mid-May to mid-May the next year. This can cause descrepancies in the values for GB and UK.

In **Figure 2**, total natural gas consumption decreases by 1.8% for 2020 compared with 2019, as a result of reduced activity across the economy due to COVID-19 restriction (BEIS 2021c).

4. Large Industrial Installations

Data sources and summary of methods

Emissions from large industrial installations are mapped using the NAEI database of point sources. For this LA GHG End User dataset an additional calculation is made in order to account for the GHG emitted during the processing of fuels used in industrial installations. For more information on End User inventories see **Section 1.4**.

The site-specific estimates of emissions have been compiled from a number of detailed data sources that report fuel consumption and/or emissions:

- Information on fuels burnt during 2005-2020 which is held in the Environment Agency (EA), Scottish Environment Protection Agency (SEPA), Natural Resources Wales (NRW), and the Northern Ireland Department of Agriculture, Environment & Rural Affairs (DAERA) databases of installations that are in the ETS.

- Information on emissions of GHG from combustion processes during 2005-2020 which have been reported by operators regulated under IPPC to the EA and NRW for inclusion in the Pollution Inventory (PI), to SEPA for inclusion in the Scottish Pollutant Release Inventory (SPRI) and to the Northern Ireland Environment Agency for inclusion in their Pollution Inventory (PIV). These are hereafter described as the Integrated Pollution Prevention and Control (IPPC) data sets.

Some additional data, supplied by trade associations or individual process operators, have been used to inform the development of the point source fuel use estimates and, in the case of steelworks, these data are used directly in the generation of point source data.

Point source fuel and GHG emissions estimates have been made for the following sectors:

- Power stations, refineries, and coke ovens[10];

- Other plant regulated as combustion processes under Integrated Pollution Control (IPC) and, more recently, IPPC;

- Integrated steelworks;

- Cement clinker manufacture;

- Lime manufacture;

[10]Emissions in the energy supply and fuel production sectors are not included at the point of emissions in the dataset accompanying this report. These emissions have been redistributed to the locations of the relevant fuel consumption. See **Section 1.4**

- Other plant regulated under IPC and IPPC; and,
- Other sites for which ETS annual emissions data are available.

In order to produce a consistent dataset for all sectors and years to be used in this and other emissions mapping work, the following key methods are used for calculating and checking point source emission estimates:

- Direct use of ETS fuel consumption and GHG emission data;
    - Fuel consumption data are checked against inventory classifications and DUKES fuel consumption data. There can be differences in terms of scope of reporting.
- Estimates of emissions from processes outside the scope of ETS, based on IPPC and industry data;
    - Relationships between these installations and those that report the ETS need to be established in order to prevent double counting of emissions and fuel consumption. This also helps to gain information on sources of emissions at installations and the types of fuels used where this is not published.
- Gap filling and modelled estimates where data are not available;
    - In the above sources of data, there are often gaps where sites have not reported emissions for some years. These gaps can be due to installations falling below reporting thresholds for certain years or because of the changing scope of reporting requirements, or simply because of plant closures or replacement. A judgement needs to be made about whether each of these gaps is realistic or if emissions need to be estimated to fill the gap.

More information is given on the above key methods in **Section 4.1.1** below.

As mentioned previously, the data presented in this report are not fully consistent with the UK GHGI (including the Devolved Administration GHGI)[11] because of the use of emissions data reported by operators and also the ETS dataset, both of which are independent of the BEIS National Statistics on fuel use which are used for the UK and Devolved Administration GHGI. However, analyses carried out as part of the GHGI programme of work indicate that the ETS and other operators' data are broadly in line with BEIS energy statistics, and it is estimated that the use of operators' data leads to a difference in estimated carbon emissions of less than 1% of the UK national total.

The advantage of using more detailed, installation-specific, data from operators is that this ensures the use of the best possible information on the fuels used at each industrial and commercial site, even if the total fuel use across the UK is marginally different from that reported in DUKES. Details of where the differences are most significant are given in **Section 4.4**.

[11] Reconciliation tables are published within the full dataset excel file.

The emissions in the NAEI point source database are calculated as 'by source' emissions rather than by end user. Therefore, where appropriate (only for fuel combustion emissions) an end user increment, representing GHG emissions arising from fuel production (e.g. refineries), is also allocated to that end user.

For the purposes of reporting emissions by fuel type a simplified classification of fuel types has been used. This is shown in **Table 8**.

Table 8: Fuel categories for reporting emissions

Fuel Name	Fuel Category
Natural gas	Natural gas
Burning oil	Oils
DERV	Oils
Fuel oil	Oils
Gas oil	Oils
LPG	Oils
Naphtha	Oils
OPG	Oils
Orimulsion	Oils
Petrol	Oils
Lubricants	Oils
Blast furnace gas	Process gases
Coke oven gas	Process gases
Sour gas	Process gases
Anthracite	Solid fuels
Coal	Solid fuels
Coke	Solid fuels
Peat	Solid fuels
Petroleum coke	Solid fuels
SSF	Solid fuels
Landfill gas	Wastes and biofuels
Sewage gas	Wastes and biofuels
Wood	Wastes and biofuels
Municipal solid waste (MSW)	Wastes and biofuels
Scrap tyres	Wastes and biofuels
Waste oils	Wastes and biofuels
Clinical waste	Wastes and biofuels
Waste solvent	Wastes and biofuels

Improvements

The point source data cover the period 2005-2020. There is a programme of continuous improvement and revisions have been made to the point source data for 2005-2019 in a few instances where additional data have become available, or where other changes (such as changes to the methodology of the UK GHGI) have an impact on the point source data. Most point source data, however, will be unchanged from the values used in the previous version of the local and regional estimates of CO_2.

Detailed estimation methods

The derivation of estimates from the above data sources is described in the following sections. There are a number of sectors which are problematic, and a short section outlining these issues then follows.

Fuel use for ETS processes

The EA have provided access to the data that the operators of installations in England have reported for fuel consumption and GHG emissions in 2005-2020 under the ETS. Equivalent data were also received from NRW, (Wales), DAERA (NI), and from SEPA (Scotland).

The type and quantity of fuels burnt by ETS processes are included in the data provided by the regulatory authorities and these fuels have each been assigned to one of the standard fuel types used in the NAEI (e.g. coal, fuel oil, gas oil). Each ETS process has also been allocated to one of the industrial sector classifications used in the NAEI – these are, in turn, based on the classification used in DUKES.

Estimating fuel use for non-ETS processes

A number of combustion processes are not covered by the ETS in the UK, for example small combustion installations would be outside the scope of the scheme. During phase I (2005-2007) and phase II (2008-2012) the scope of ETS was considerably narrower than now, with many sites not required to take part during phase I because of their involvement in other programmes, and driers, furnaces and similar types of installation that use heat in-situ not being covered at all until phase III started in 2013. In these cases, data may be available from other sources including the IPPC data sets.

The IPPC data will also cover many of the combustion processes within the ETS data sets. It is therefore necessary to compare the IPPC data with the ETS data at the level of individual installations, in order to identify additional emissions present in the IPPC data. Care has had to be taken to correctly match up those installations reporting under IPPC that also report in the ETS data sets, in order that the comparison is accurate.

The ETS data provided by the EA includes some information on the relationship between the processes covered by ETS applications and processes reporting to the PI, but in most cases it has been necessary to use expert judgement in order to define the connections between ETS and IPPC installations. This is not always straightforward in that the two data sets quite often have different operator names, site names, or site addresses for installations that appear to refer to the same site, and there are also instances where a single IPPC installation relates to multiple ETS installations, and *vice versa.*

It has taken time to unpick the two sets of data and to understand the relationships between the installations in the ETS data, and those in the IPPC data sets, and this led to revisions to the point source data during the early years of these data being produced. There are likely still some areas of uncertainty in this ‘mapping’ of ETS sites to IPPC sites, but we believe that we now have a good understanding of the relationships for most existing ETS installations. Revision of data due to changes in assumptions in this area should now occur only rarely.

Once the relationship between installations in the two data sets has been established, it is a simple task to compare the reported emissions and to check which installations report additional emissions in the IPPC data, or which only report emissions in the IPPC data. These additional emissions in the IPPC data are added to the point source database. There are also instances where installations report lower emissions in the IPPC data, but these do not need to be considered further and can be ignored.

The additional IPPC data are initially just emissions from an unknown source, and so the next step is to assign those emissions to an emission source category. These additional emissions result from the fact that the scope of reporting is often different in ETS and the IPPC data, and that the scope of IPPC is wider. Most importantly, during phases I and II of the ETS, the UK used the medium definition of combustion installations which covers the production of electricity, heat or steam for the purposes of energy supply.

This meant that, for example, most furnaces used to produce chemicals or melt metals were not covered by ETS in the UK in 2012, although this has now changed with the start of Phase III of the scheme in 2013. The IPPC data for some installations can combine the emissions from combustion processes that are covered by ETS with emissions from processes that are not. For example, a chemical industry site could have steam-raising boilers (covered by both ETS and IPPC data), and product driers (covered only by IPPC). The IPPC data sets can also include carbon from biological fuels such as wood, as well as carbon from non-combustion processes such as chemical syntheses and fermentation.

Finally, there is also the possibility that the additional emissions in the IPPC dataset are due to the use of different assumptions, provisional data or due to errors. Therefore, as well as identifying the relationship between ETS and IPPC installations, it is also necessary to understand the reasons the scope of emissions is different, and particularly whether additional carbon emissions from the IPPC installation is related to non-ETS combustion using fossil fuels, use of biofuels, some non-combustion process, or is anomalous.

This is done using expert judgement, supported by some in-depth research for some of the most significant sites in order to determine the exact scope of both ETS and IPPC installations, although limited access to documentation of the scope of ETS and IPPC permits, and the resource-intensive nature of the investigations needed, mean that our understanding of the relationship between the two data sets is continually developing. This aspect of the points data processing is expected to improve still further in future years, although we believe that fewer revisions will need to be made in the future years compared with previous versions of the data.

Once expert judgements have been made about the nature of the additional emissions in the IPPC data sets, these emissions are assigned to fuels or other GHGI emission source categories where appropriate, or removed from the point source data if considered likely to be either biocarbon or anomalous.

Gap-filling and modelled estimates

All of the data sets have, or seem to have, gaps in reporting; they are not fully complete. In the case of the ETS, the scope of the scheme has changed over time and various installations were able to ‘opt-out’ in Phase I; for example, many cement kilns, brickworks and food & drink industry sites did not need to report. These and other opted-out sites then joined ETS for the start of phase II in 2008, but a voluntary *de minimis* limit was also introduced in that year which allowed operators to exclude individual combustion units that were < 3 MW th from their rated thermal input calculation such that many installations no longer exceeded the 20 MW th limit requiring their inclusion in the scheme.

Many public sector sites such as hospitals and universities ceased reporting to ETS in 2008, presumably as a result of the *de minimis* rule. For ETS phase III, the definition of a combustion installation was changed to the ‘broad’ classification which meant that furnaces and similar devices that use heat directly were included under ETS. As a result, many additional sites started to report to ETS in 2013, including many roadstone coating plants, food production sites, and metal industry sites.

The IPPC data sets do not require reporting of emissions below set ‘reporting thresholds’, so some installations where carbon emissions are close to that threshold value report emissions in some years where the threshold is exceeded, and report no emission value in years when it is not.

If left unchanged, these gaps and data inconsistencies in the ETS and IPPC data sets could lead to unreliable emissions time-series data for individual installations and for local authority areas and so expert judgement is used to assess the time-series and to fill gaps where appropriate, usually by extrapolation of data from other years. We take account of the fact that some apparent gaps in data will be due to plant closures or mothballing of plants, or plants not being in existence in a few cases where there are gaps at the start of the time-series. It is likely that we are not aware of all details of plant commissioning and plant closures, so some revisions might be necessary in this part of the processing in future years.

A final aspect of the point source data is the inclusion of a limited set of data where emissions are modelled rather than based on operators’ data. This is necessary for some processes operated under IPPC which emit relatively small quantities of carbon dioxide and therefore almost invariably do not need to report emissions, for example various small electric arc steelworks, and chemical waste incinerators. It is also done for certain types of process that are not included in the IPPC data sets at all, such as small glassworks. Finally, it is done in instances where IPPC data cannot easily be used, examples in this instance being MSW incinerators where emissions reported in the IPPC data could be dominated by carbon dioxide from waste containing biological carbon, but would also include carbon dioxide from fossil fuels burnt to support the incineration process.

Estimating fuel use for steelworks

The development of estimates for integrated steelworks is dealt with separately here since it presents unique challenges. The estimates utilise a range of data sources:

- DUKES provides detailed fuel use data for the iron and steel sector;
- The PI provides emission estimates for GHG for each integrated works but no fuel data. The estimates are site totals only: no breakdown by process is given;
- ETS data provides fuel use data but does not break it down fully by process type; and,
- SSI and Tata Steel Ltd (the operators of the processes) provide GHG emission estimates by process type but not by fuel type.

None of these sources of data give a fully detailed picture of fuel use and related emissions by process. In addition, the data sources are not completely consistent for all years (in large part because the scope of the data sets is different) and so judgements need to be made about how to combine the various data in order to generate fuel use estimates.

Overall, the data from operators are the most complete set of emissions data across the time series, while the ETS dataset is the most accurate in terms of fuel use. Therefore, the fuel use patterns shown in the ETS data are used to disaggregate the emissions data provided by operators. The operators' data did include emissions from some additional installations such as reheat furnaces during Phase I of ETS and, so the emissions from these furnaces are assigned to fuels based on expert judgement.

Areas of uncertainty in the fuel use estimates

There are a number of issues which introduce uncertainty in the local authority GHG emission estimates and related fuel use estimates. Emission and fuel use estimates for processes included in the IPPC data sets but not in the ETS are based on Ricardo Energy & Environment assumptions about fuels used because IPPC does not require reporting of fuel split. These assumptions are based on an evaluation of data such as:

- Integrated Pollution Control (IPC) authorisation documents which are quite old now but do give an accurate picture of processes in the early to mid-1990s;
- IPPC authorisation documentation which are much more up to date but only available to us for a smaller number of processes;
- recent emissions data for pollutants such as metals and SO_2 that could indicate the use of solid or liquid fuels;

- our general knowledge of a particular process and typical fuels used for that type of process;
- geographical location e.g. processes in very rural areas, Northern Ireland etc. are somewhat less likely to burn gas; and
- any information on processes available from other sources such as DUKES or the internet.

The uncertainty can be broken down into two issues. Firstly, and perhaps most important, is the significant level of uncertainty for a relatively small number of sites over the exact nature of the emission sources. This type of uncertainty is greatest for processes within certain sectors where emissions could result from numerous sources, such as use of biofuels and wastes in combustion processes as well as fossil fuels and non-combustion processes. These sectors would include the chemical, food & drink, and paper industries.

The second issue is uncertainty over the fuels burnt at installations where it is assumed that fuel combustion is taking place. For many sectors of industry, there is a relatively straightforward choice of fuel – natural gas or, less usually, oil (usually fuel oil if large-scale but gas oil might be used on a small-scale or as a backup fuel) or coal. As already stated, reported emissions of SO_2 or metals can indicate coal or fuel oil use, so normally, in the absence of emissions data for these pollutants, our assumption has been that gas is the most likely fuel used. In Northern Ireland and some rural areas, gas use is less likely and fuel oil, for example more likely. For many sites, the expert judgements used to allocate emissions to fuels to introduce uncertainty, but we believe that in most cases the uncertainty is low.

For some sectors, the choice of fuel is more difficult and indeed a range of fuels may be burnt on many sites. Metal industry sites may use coke, and chemical industry sites may burn chemical by-products as well as conventional fossil fuels.

As well as these general areas of uncertainty, some specific issues should be noted:

- Fuel use estimates for cement works prior to 2008 are uncertain because most sites opted out of the ETS. So, while national fuel use data are believed to be very accurate (being supplied by the industry itself), very little information is available at the level of individual sites. CO_2 is emitted both from fuel combustion but also from the calcination of the limestone and dolomite used to make the cement clinker. Prior to 2006, emissions data from the IPPC data sets did not indicate how much CO_2 was ‘thermal’ in nature and how much was ‘chemical’ and so cannot be used to give an accurate estimate of fuel use by site. The system of separate reporting of chemical and thermal CO_2 for each site for 2006-2008 eased this problem, allowing an accurate split of fuel-related and calcination-related emissions for the opted-out sites for 2006 and 2007, but this gave no indication of the actual fuels burnt at each site. Reporting of data in the ETS increased in 2008 to cover all sites due to the end of opt-outs and so in theory these fuel use data could be used to estimate the fuel mix at each plant in earlier years. However, the national data show that there have been some significant changes in fuel use over the last 7 years and this is supported by ETS data for those plants that didn’t opt out. For the early part of the time-series we estimate fuel use on a site-by-site basis, taking into account both the overall national trends in fuel use for 2005-2007, as shown in the industry's data, and the individual site preferences with regard to fuels, as shown in the 2008 ETS data.

- Fuel use estimates for lime works are somewhat less uncertain because these typically burn a single fuel (in most cases gas). However, a handful of sites do burn a varying mixture of solid and liquid fuels and, as for cement works, carbon dioxide is emitted both from fuel combustion but also from the calcination of the limestone used to make the lime. This brings with it similar problems to those associated to cement works. The system of separate reporting of chemical and thermal CO_2 for each site during 2006-2008 eased this problem and the ETS data for 2008 onwards has been used to improve the estimates for solid and liquid fuels. One further problem at some sites is that emissions reported in the PI also include other sources of CO_2, such as gas-fired CHP plant, and driers. However, in these cases, cross-comparison with ETS data for 2008 can give an indication of the proportion of emissions from the lime kilns (using solid fuels) compared with other plant (using gas and liquid fuels).

- Integrated steelworks use fuels in many processes and these uses include fuel transformations and combustion processes. The absence of a single, complete set of data for steelworks, means that fuel use estimates are based on combining data sets which are not fully consistent. Discussions with Tata Steel have helped us to better understand the differences between different data sets.

- Several other processes produce GHG both from the combustion of fuels and from chemical transformations. Examples include primary aluminium production; electric arc steel-making; chemical processes such as production of ammonia, soda ash & titanium dioxide; and glass-making. Emissions data given in the IPPC data sets will include both 'thermal' and 'chemical' GHG for each site, but these are only reported separately in the PI and then only for some sites for the period 2006-2008, with the separate reporting being dropped again in 2009. Use of the IPPC data sets therefore requires assumptions to be made about the split between fuel-related and non-fuel related emissions.

- Several processes reporting in the IPPC data sets may only use process-wastes as fuels, and this may not be taken account of in the fuel use estimates. Generally, unless we have good evidence to the contrary, it is assumed that all reported CO_2 emissions are from fossil fuels but, in the chemical and food industries in particular, it is quite possible that some of the emissions are from process wastes.

The overall impact of these issues cannot be easily quantified, but we believe that good progress towards resolving most of them has been made and that, while further improvements could be made in the future, widespread changes to the time-series of emission estimates are very unlikely.

Comparison of site specific estimates with the GHGI

A comparison between the total GHG estimates by sector for the large fuel consumers (points) and the sector emission totals in the GHGI are summarised in **Table 9**. Note that these are 'by source' emissions i.e. they exclude the reallocation of emissions from fuel production to end users.

Table 9: Comparison of Total GHG Emission Estimates at Point Sources by Sector with GHGI data (kt CO_2e) 2020

Source Name	GHGI	Points	Points total as percentage of GHGI total
Chemicals (combustion)	7,571	6,770	89%
Iron and steel - combustion plant	6,493	6,121	94%
Other industrial combustion	17,151	4,594	27%
Cement - decarbonising	4,448	3,900	88%
Food & drink, tobacco (combustion)	4,187	3,413	82%
Blast furnaces	2,826	2,341	83%
Public sector combustion	7,515	1,929	26%
Cement production - combustion	2,221	1,924	87%
Pulp, Paper and Print (combustion)	1,397	1,679	120%
Sinter production	1,290	1,476	114%
Lime production - decarbonising	1,053	980	93%
Ammonia production - feedstock use of gas	982	974	99%
Ammonia production - combustion	567	601	106%
Lime production - non decarbonising	385	417	108%
Glass - general	369	324	88%
Non-Ferrous Metal (combustion)	668	231	35%
Miscellaneous industrial/commercial combustion	11,734	219	2%
Brick manufacture - all types	338	205	61%
Incineration - chemical waste	163	167	102%
Chemical industry - soda ash	145	142	98%
Basic oxygen furnaces	67	139	209%
Chemical industry - titanium dioxide	152	137	90%
Agriculture - stationary combustion	281	116	41%
Incineration - clinical waste	85	99	117%
Electric arc furnaces	44	65	147%

Table 9 compares the summed emissions for point sources and the national (GHGI) emission for sectors other than energy suppliers and other excluded sectors.

Figures for most source sectors are in good agreement; the point source emissions are all within a few percent of the GHGI figures. In some source sectors, the point source emission is lower than the national emission. This is to be expected since many smaller processes will not be included in the point source data. For example, the point source emissions for **miscellaneous industrial/commercial combustion, other industrial combustion**, **non-ferrous metal (combustion), agriculture – stationary combustion,** and **public sector combustion**, are less than half of GHGI emissions, because many combustion plants in these sectors are too small to be included in the ETS data or IPPC data sets.

Autogenerators are not included in this tables as we are largely unable to distinguish between autogenerators and industrial combustion plants in the ETS and IPPC data. Therefore almost all emissions that would be classified in the GHGI as from autogeneration are instead listed in the point source data as from industrial combustion processes. This means that Table 9 underestimates autogeneration emissions, while overestimating the level of reporting in sectors such as **pulp, paper and print (combustion), electric arc furnaces and basic oxygen furnaces.**

In the case of combustion in the paper industry, the point source data exceed the national total. This demonstrates the impact of the autogeneration issue – because autogeneration within the paper sector cannot be separately identified and split out, the point source emissions in these sectors then exceed the GHGI totals, while the point source data for autogeneration are too low. In the case of the chemical and food sectors, this problem is not so severe, so the points data are below but still close to the national total, and for **other industrial combustion**, the points figure is well below the GHGI figure.

A more realistic comparison of GHGI and points data can be made by combining the figures for autogeneration and the 4 industrial source categories, thus avoiding differences in scope. Taken as a group in this way, the points data for autogenerators and the 4 industrial source categories are 51% of the GHGI total (16,481 ktonnes CO_2e, out of 32,364) which does not seem unreasonable, since in all four sectors one would expect a significant quantity of fuel to be used by small plants not included in the points data.

The figures for **iron and steel (combustion)** are as expected – the sector is dominated by fuel combustion at a small number of very large steelworks, but a small proportion of sector emissions occur at foundries and other small sites. Figures for **non-ferrous metals (combustion)** show a higher proportion of emissions outside the points data and this can be explained by the fact that this sector is less dominated by large plants – the UK has relatively few large non-ferrous metal processes, and most of the sector is small-scale, foundries, galvanisers, alloys production or similar.

In the remaining cases, the differences are due to inconsistencies between the GHGI and the point source emissions, and some commentary on these differences is given below.

The point sources database figure for **basic oxygen furnaces** is much higher than in the GHGI. The points data are based on operator's own estimates, while the GHGI figures are derived using DUKES energy data and a carbon-balance type approach. There are also some differences in the way in which the GHGI emissions are allocated to the different stages of the steelmaking process, compared with the way in which the operators do it, and the different basic methodology, together with the differences in allocation, account for the large difference for basic oxygen furnaces (and also for flaring at steelworks which is not included in **Table 9**).

Similarly, **Electric arc furnace** emissions are higher in the points data. Some of the points data are based on site-specific emission estimates reported by operators, whereas the GHGI data are estimates based on published steel production and an emission factor, and this difference in methodology is probably the main reason for the difference.

The following table shows fuel consumption estimates by fuel type. In each case the data derived here are compared with data taken from the GHGI.

Table 10: Comparison of Estimates of Point Source GHG Emissions by Fuel with GHGI data (emissions in kt CO_2e) 2020

Fuel category	Fuel	GHGI emission estimate	Points emission estimate	Points as % of GHGI estimate
Natural gas	Colliery methane	1	3	271%
	Natural gas	94,771	18,321	19%
Oils	Burning oil	10,966	81	1%
	Fuel oil	556	80	14%
	Gas oil	10,448	233	2%
	LPG	3,160	43	1%
	OPG	2,589	2,397	93%
Process gases	Blast furnace gas	8,888	8,017	90%
	Coke oven gas	354	115	32%
Solid fuels	Coal	4,261	1,760	41%
	Anthracite	606	-	0%
	Coke oven coke	939	862	92%
	Petroleum coke	919	296	32%
	Other Smokeless	627	-	0%
Wastes and biofuels	Scrap tyres	167	158	95%
	Waste	298	320	108%
	Chemical waste	172	167	97%
	Clinical waste	82	99	121%

Table 10 compares the data for fuels used at point sources with the national (GHGI) data, but excludes fuels used by energy suppliers and other excluded sectors. The point source data would be expected to be lower than the GHGI figure because of the absence of smaller combustion processes from the point source data.

This is true for most of the most important fossil fuels – natural gas, burning oil, fuel oil, gas oil, LPG, petroleum coke and coal. Burning oil and LPG are very much lower, as these fuels are almost exclusively used in small equipment, but for emissions from fuels such as OPG, coke and blast furnace gas, which are all expected to be burnt almost exclusively in larger plants, the points figures for these fuels are a significant proportion of the GHGI total.

Natural gas, fuel oil, gas oil and coal, on the other hand, are assumed to be used in plant of all sizes, and so the points data would be expected to cover a lower proportion of emissions. The points data for colliery methane significantly exceed the GHGI figure but emissions are still trivial and the inconsistency probably reflects differences in allocation rather than a real difference in fuel consumption.

In summary, there is very good agreement between the GHG emission and fuel consumption estimates derived from the GHGI and the point source data in many areas, but differences in other areas. Differences are proportionally greater for CH_4 and N_2O due greater uncertainty and variation in emission factors, however highest in absolute terms for CO_2. Overall however these differences are small, and in nearly all cases the difference is to be expected and therefore acceptable because the point source data are not designed to cover all UK sources in a given sector, or because of differences in the scope of the figures in the two data sets. The comparisons indicate some areas where one or other data set could be improved, however these improvements would have a trivial impact on overall agreement.

Year to year consistency within the fuel use estimates

The point source data which are used as the basis of these fuel use estimates have been produced for the period 2005 – 2020 and considerable effort has been expended to ensure as much consistency from year to year as possible. Where data for a particular plant are available for some years but not for others, then a judgement has been made regarding whether to leave the ‘gaps’ or to fill them using the data reported for other years. As a general starting point, it has been assumed that it is more likely that gaps in reporting are due to the operator not being required to report, rather than that the process was not in existence.

Changes to the scope of reporting, particularly in the ETS, as well as changes in the availability of data from one year to another can also affect time series consistency. Most problematic are those instances where for some years only ETS data are available, while for other years, only IPPC data are available. In these cases, it is difficult to judge whether changes in emissions from one year to another are due to actual changes or if they just represent differences in the scope of reporting for ETS and IPPC data sets. As more data has become available and more will be in the future, we are improving our understanding of these processes, and revisions may be required to improve the point source data.

5. Non-domestic 'Other'

The industrial sectors in the NAEI are mapped using a combination of point source estimates of emissions and area source employment-based distributions. For some sectors the NAEI's UK total emissions estimate is entirely accounted for by point source emissions (see **Section 4**). In this instance all of the emissions would be mapped as point sources. In other cases, there are sectors that have no identified point sources, in which case all emissions are mapped as an area source.

Many sectors, however, are comprised of a combination of point source and area source emissions. In this situation point source emissions are mapped explicitly and the remaining residual emission[12] is treated as an 'area source' and distributed across the UK using modelled high resolution (postcode level) emission distributions based on detailed employment and fuel use data. Small industrial combustion is an example of a sector for which the area source distribution is particularly important but there are also some identified point sources.

Area source emissions: High resolution employment based distributions

Emission distribution maps for the small industrial combustion, public services, commercial and agriculture (stationary combustion) sectors were revised in 2020 using updated employment and energy statistics. The method used is described in more detail in the BEIS document **Employment based energy consumption mapping in the UK** on the gov.uk website[13]. The following data sets are used:

- Office of National Statistics Inter-Departmental Business Register (IDBR) which provides data on employment at business unit level by Standard Industrial Classification (SIC) code[14].
- Energy Consumption in the UK (ECUK) data on industrial and service sector fuel usage[15].
- Site-specific fuel consumption as described in **Section 4**. These are compiled from data for regulated processes reported in the EA Pollution Inventory, Scottish SPRI, DoE NI Inventory of Statutory Releases, by the ETS and from other data obtained by the inventory.
- BEIS natural gas consumption by postcode data

[12] Residual emission is the national total minus the point source emission total for the relevant sector

[13] UK local authority and regional greenhouse gas emissions national statistics: 2005 to 2020 https://www.gov.uk/government/statistics/uk-local-authority-and-regional-greenhouse-gas-emissions-national-statistics-2005-to-2020

[14] www.ons.gov.uk/ons/about-ons/products-and-services/idbr/index.html

[15] www.gov.uk/government/statistics/energy-consumption-in-the-uk (Industrial and Services tables)

- Business Register and Employment Survey (BRES) annual employment estimates for the UK split by Region and Broad Industry Group (SIC2007)[16]

The first step was to allocate NAEI point sources to SIC sector and to identify the relevant individual businesses at these locations in the IDBR employment database. This was to allow calculation of the energy for each sector which is already accounted for by point sources and therefore estimate the total residual energy which needs to be distributed using the employment data. This retained the level of detail across emissions subsectors required for the mapping, as the use of total energy by SIC codes would have resulted in a reduction in the quality of the final distribution.

The employment data by SIC codes in the IDBR database were matched with the BEIS energy consumption datasets, to calculate total employment for each sector for which energy consumption data were available. Fuel intensity per employee was calculated for each sector. For commercial and public service sectors the employment data needed to be aggregated to match the level of aggregation of the energy data.

In the case of industrial sectors, a comparable approach was used; where this energy intensity calculation was done at the level of 2 figures SIC codes. Energy consumption data were available for coal, gas oil, fuel oil and natural gas. These were combined to calculate industry specific fuel intensities for coal, oil and gas.

The IDBR employment data at local unit level were aggregated to 2-digit SIC codes at Local Authority resolution using postcodes and grid references provided as part of the database. The employment totals for each sector were then multiplied by the appropriate fuel intensity per employee values to make fuel use distributions across the UK. It has been assumed that fuel intensity for each sector is even across the sector. This is a simplification of reality but necessary because of a lack of more detailed estimates of fuel use.

The resulting fuel distributions have been refined using a subsequent set of modelling steps:

- Sites of employment corresponding to the locations of the highest emissions (as defined by the NAEI point source database) have been removed from the distributions. This is in order to prevent double counting of emissions at these locations (emissions are mapped as point sources);

- Where evidence of areas with natural gas availability, BEIS natural gas consumption by postcode dataset has been used to identify sites with and without gas;

- Based on expert knowledge of fuel use by industry and businesses the distributions of Fuel Oil and Gas Oil have been modified so that consumption is lower per employee in grid squares with Natural Gas availability through the use of a weighting factor;

16 www.ons.gov.uk/ons/rel/bus-register/business-register-employment-survey/index.html

- The distribution of coal has been further limited to outside the locations of Smoke Control Areas.

In order to produce time-series statistics the following ECUK tables were used:

- Industrial final energy consumption at two digit SIC2007 level by fuel type, for the years 2009-2020[17];
- Service sector final energy consumption by sub-sector, for the years 2005-2020

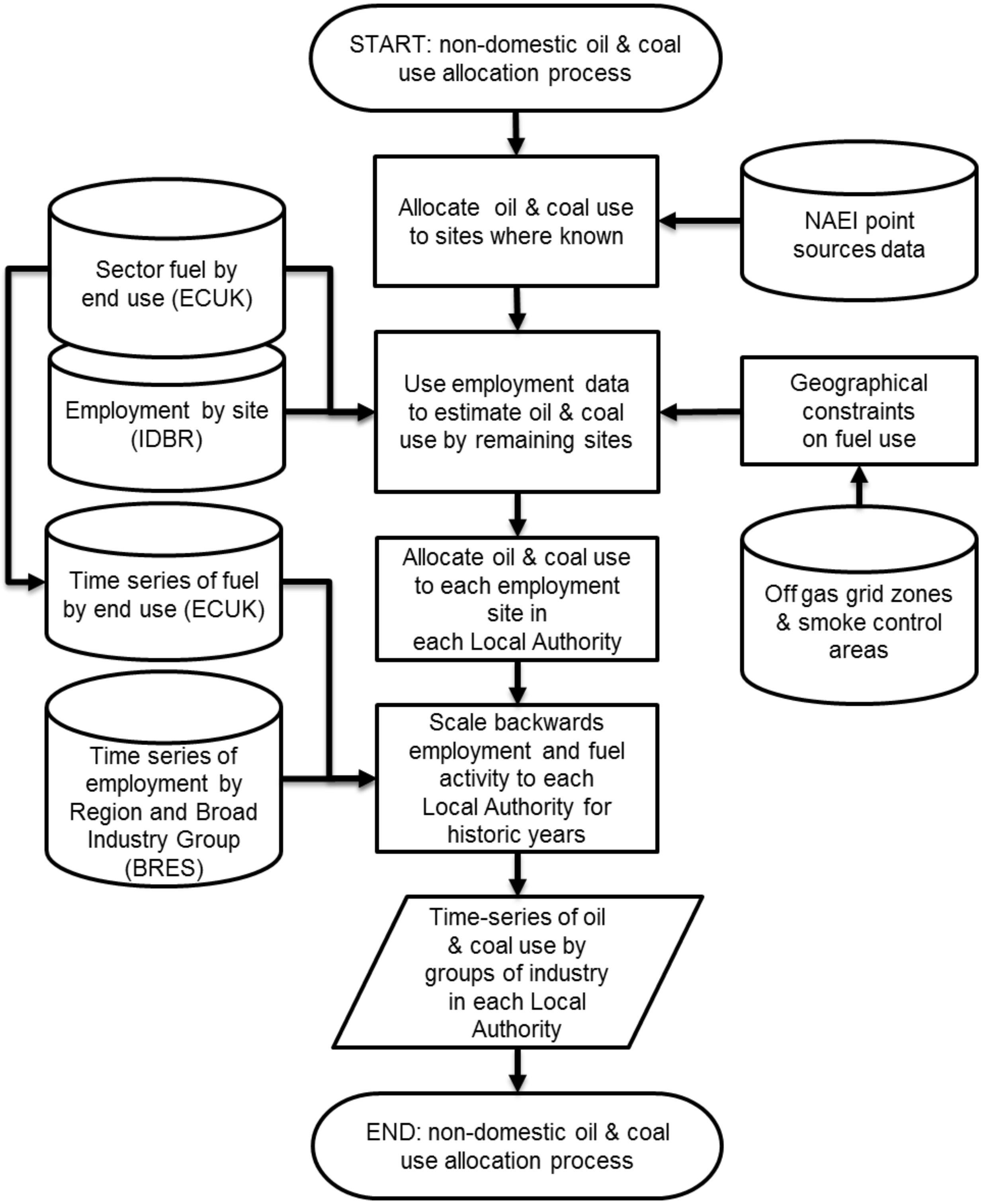
The employment activity was also back-calculated with the use ONS annual employment estimates and applied to each Region and by Broad Industry Group. This was available for the years 2008-2020[18].

Figure 3 shows the process to convert non-domestic fuel usage from individual employment sites into emissions.

[17] Pre-2009 ECUK tables were only available at SIC2003 level

[18] Pre-2008 activity has been estimated from earlier NAEI studies

Figure 3 Non-domestic oil and coal use allocation process



Industrial off-road emissions

For some sectors a simple map of employment has been used instead of fuel use. These are mostly for sectors where process emissions are important but also for estimating the distribution of industrial off-road emissions. These have been mapped using a distribution of employment in heavy industries.

6. Agricultural Emissions

In this submission of the LA GHG emissions the data set has been extended to include CH_4 and N_2O for the first time, as such it now includes emissions from a large number of additional agricultural soils and livestock emission sources. Previously the agriculture category included only CO_2 from fuel combustion, liming and fertiliser application. As such, the expansion of scope of both gases and sources of emissions has led to an increase in the magnitude of emissions from this category in all years.

Soils and Livestock

GHG emissions in the agriculture sector arise primarily from livestock (reported under agriculture livestock), urea application, liming of soils and fertiliser application to soils (reported under agriculture soils). The distributions of CO_2, CH_4 and N_2O emissions from agricultural sources are mapped by the UK Centre for Ecology and Hydrology (UKCEH). Agricultural census/survey data for 2020 were acquired at the holding level from the four UK countries' statistical authorities, i.e. Defra, Scottish Government, Welsh Government and DAERA. These censuses contain data on area by main crop types and livestock types and numbers. Aggregated cattle population data were supplied to and processed by Cranfield University from cattle tracing system (CTS) data. The holding level data for the different countries were aggregated to a common set of emission source categories used by the agricultural emission inventory model to ensure compatibility between the different countries' systems and consistency. Management practices are considered in the LA GHG however these are at a country level rather than holding level. The emission estimates are based on a model jointly developed and first implemented for the 2016 inventory by Rothamsted Research, ADAS, UKCEH and Cranfield University. The 10x10 km estimates from the emissions model have been spatially resolved to produce non-disclosive high-resolution 1x1km emission maps. These data are then mapped onto a LA distribution grid for the LA GHG. (Tsagatakis et al, 2022)

The latest distribution of livestock and agricultural land is scaled by NAEI agricultural emissions to form the timeseries back to 2018.

Agriculture 'Other'

Electricity and gas consumption in the agriculture sector are included in the BEIS local gas and electricity datasets described in **Sections 2 and 3** and therefore are disaggregated using the method described in these sections.

Consumption of solid and liquid fuels has been calculated for each year using the IDBR employment data. The distribution of solid and liquid fuels has been made based on the geographical distribution of gas availability, i.e. with these fuels located in grid squares with no gas available. The method used to calculate the gas availability distribution is explained in the supporting document **Employment based energy consumption mapping in the UK** at gov.uk[19].

Off-road mobile machinery emissions associated with activity in the agriculture sector are distributed using a combination of arable, pasture and forestry land-use data. Each of these land cover classes was weighted according to the off-road machinery activity on each land use. This used data on the number of hours of use of tractors and other machinery on these land-use types.

[19] https://www.gov.uk/government/statistics/uk-local-authority-and-regional-greenhouse-gas-emissions-national-statistics-2005-to-2020

7. Domestic Emissions

Domestic Electricity Consumption

Electricity consumption data for 2005 to 2020 published on the gov.uk website[20] has been used to map GHG emissions from electricity generation to the point of consumption. The emissions associated with electricity consumption have been estimated using an average UK factor for the relevant year in terms of kt GHG per GWh. This average allocates equal shares of coal, gas, oil, nuclear and renewable powered generation to all the electricity consumers and is derived from the UK inventory for 2020. The factors used are described in **Section 2**.

Electricity consumption reported in the sub-national dataset does not match exactly with DUKES. This is partly due to the inclusion of some non-domestic users within this dataset as described in **Section 2.1**. Other reasons for the differences (BEIS 2020b) are that:

- the sub-national consumption data covers Great Britain and DUKES covers the United Kingdom;
- the sub-national consumption data are aggregated from the bottom-up meter point level and the DUKES statistics are produced using a top-down approach;
- DUKES contains a wider sector breakdown than the simple domestic and non-domestic split;
- the sub-national consumption data are not for exactly a calendar year whereas DUKES data are based on a calendar year;
- the sub-national data excludes some Central Volume Allocation (CVA) users – these are very large industrial consumers receiving electricity via the high voltage system;
- some consumption is estimated as opposed to actual metered consumption.

The BEIS dataset outlined above does not currently provide a distribution of electricity consumption in Northern Ireland. However, following the creation of a single electricity market in Ireland in late 2007, consumers were able to choose their electricity supplier and confidentiality restrictions on the data were reduced. Figures for domestic electricity consumption in 2008-2020 at District Council level in Northern Ireland are available on the gov.uk website alongside the Great Britain statistics. These statistics are produced by BEIS using aggregated meter point data derived from Northern Ireland Electricity's Distribution Use of System (DUoS) Billing system.

20 https://www.gov.uk/government/collections/sub-national-electricity-consumption-data

As Northern Ireland electricity consumption data are not available for the whole time series, the distribution of electricity consumption between LAs for 2008 has been used for the years 2005-2008.

Data on total electricity sales as reported by NI suppliers are available in the sub-national electricity and gas summary report (e.g. BEIS 2021a). For all years, there is a statistical difference between the total electricity sales and the published meter point data (BEIS 2021d). Published meter point data provides electricity consumption disaggregated by domestic and non-domestic sources, and it is the year-specific ratio of domestic to non-domestic consumption from this source which is used to split total electricity consumption. The statistical difference between total electricity sales and meter point data is distributed across all local authorities in Northern Ireland, including the unallocated sector, on the basis of the year-specific relative consumption within each.

More information on how CO_2 emissions from electricity consumption are aggregated to LA can be found in **Section 2**.

Domestic Gas Consumption

The gas consumption data published by BEIS provides estimates of gas consumption by the domestic sector and the industrial and commercial sector for each LA in Great Britain for 2005-2020, and for each LA in Northern Ireland for 2015-2020; these are published on the gov.uk website[21,22]. The gas consumption estimates for the domestic sector have been used to calculate CO_2, CH_4 and N_2O emissions for the domestic gas sector using the implied emission factor for Northern Ireland shown in **Table 6** and for Great Britain shown in **Table 7**. More information about how emissions estimates from gas consumption data were produced is provided in **Section 3.**

Gas consumption reported in the sub-national dataset does not match exactly with DUKES for the following reasons (BEIS 2020b):

- the sub-national consumption data covers Great Britain and DUKES covers the United Kingdom;
- the sub-national consumption data are aggregated from the bottom-up meter point level and the DUKES statistics are produced using a top-down approach;
- DUKES contains a wider sector breakdown than the simple domestic and non-domestic split;

21 www.gov.uk/government/collections/sub-national-gas-consumption-data

22 www.gov.uk/government/statistics/sub-national-gas-consumption-statistics-in-northern-ireland

- the sub-national gas data is based on the gas year, the period covering 1 October through to the following 30 September, whereas DUKES in based on the calendar year;
- GB sub-national gas data is weather corrected up to 2015 and then non-weather corrected from 2015 onwards. Whereas DUKES for all years is not weather corrected. Since 2015 therefore this is not a reason for variation between DUKES and subnational consumption.

Domestic 'Other'

Domestic oil and solid fuel use distributions were created by spatially resolving detailed local information on central heating and house type data from the 2011 census with data from the BEIS National Household Model (NHM), which provides average household energy consumption estimates across the 13 regions of England, Wales and Scotland. Regions within England and Wales follow the regional classification scheme[23], with Scottish regions abiding by the Met Office 3-tier regional (Northern, Eastern and Western) classification to represent the spatial shifts in climate[24]. The census data were combined with full-address matched dwelling locations from Ordnance Survey data to give a more accurate distribution of households at LA level.

Solid fuel use was assigned to solid fuel burnt in boilers and non-boiler appliances (such as open fireplaces, closed stoves). It was assumed that solid fuel activity for boilers was used in properties which, according to Census 2011, had Solid Fuel Central Heating. Solid fuel activity for non-boiler appliances was assumed to be used in houses and bungalows with No Central Heating. Supplementary heating from the same technologies was considered more likely to be located in houses and bungalows only. Apartments were excluded for solid fuel use to be consistent with BEIS NHM assumptions on wood use. The number of supplementary heating users for wood was calibrated at regional level by comparing the total wood user count (as derived from all the above assumptions) against the regional count from the Defra Solid Fuels Survey[25].

Following the addition of CH_4 and N_2O to the LA GHG additional categories, Accidental fires – dwellings, recreational use of N_2O and Other food - cream consumption (use of pressurised cream containers) have been added to Domestic 'Other'. Further information on the datasets and methodology used to develop the domestic model can be found in the *UK Emission Mapping Methodology* (Tsagatakis, et al., 2022).

23 https://geoportal.statistics.gov.uk/search?collection=Document&sort=name&tags=all(MAP_EUR)

24 www.metoffice.gov.uk/climate/uk/regional-climates

25 http://sciencesearch.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=20159&FromSearch=Y&Publisher=1&SearchText=burning%20in%20UK%20Homes&SortString=ProjectCode&SortOrder=Asc&Paging=10

8. Road Transport

Road transport fuel use estimates for 2020 at LA level were compiled by Ricardo Energy & Environment for BEIS. The method used is described in this section, with improvements for 2020 summarised at the end of the section.

Emission factors and fuel consumption factors

Fuel consumption factors and emission factors combined with traffic data for 6 major classes of vehicles are used to estimate national fuel consumption and emissions estimates from passenger cars, light goods vehicles (LGVs), rigid and articulated heavy goods vehicles (HGVs), buses/coaches and mopeds/motorcycles. The vehicle classifications are further sub-divided by fuel type (petrol or diesel) and the regulatory emission standard the vehicle or engine had to comply with when manufactured or first registered.

The vehicle Euro emission standards apply to the pollutants nitrogen oxides, particulate matter, carbon monoxide and hydrocarbons but not to CO_2 or fuel consumption. Nevertheless, the Euro standards are a convenient way to represent the stages of improvement in vehicle or engine design that have led to improvements in fuel economy and are related to the age and composition profile of the fleet. For example, the proportion of pre-Euro 1 and Euro 1-4 vehicles in the national car fleet can be associated with the age of the car fleet (year-of-first registration).

Fuel consumption and emission factors are expressed in grams of fuel or emissions per kilometre driven respectively for each detailed vehicle class. The methodology combines traffic activity data (from the Department for Transport's (DfT) national traffic census) with fleet composition data and fuel consumption/emission factors. The vehicle fleet composition data are based on licensing statistics and evidence from Automatic Number Plate Recognition (ANPR) data from DfT; these provide an indication of the vehicle mix by engine size, vehicle size, age, engine and exhaust treatment technology, Euro emission standards, and fuel type as observed on different road types.

Fuel consumption factors are based on a combination of published compilations of factors derived from vehicle emission test data from European sources and factors from industry on the fuel efficiency of cars sold in the UK. In the former case, representative samples of vehicles are tested over a range of drive cycles associated with different average speeds on different road conditions: there are many parameters that affect the amount of fuel a vehicle consumes and average vehicle speed is one of them, so the NAEI uses functions that relate fuel consumption to average speed.

Fuel consumption factors for all vehicle types are derived from the fuel consumption-speed relationships given in the COPERT 5 source. COPERT 5 "*Computer Programme to Calculate Emissions from Road Transport*" is a model and database of vehicle emission factors developed on behalf of the European Environment

Agency and is used widely by other Member States to calculate emissions from road transport. It is a source of factors recommended for national inventory reporting in the EMEP/EEA Emissions Inventory Guidebook (2019).

This included a method for passenger cars which applies a year-dependent ‘real-world’ correction to the average type-approval CO_2 factor weighted by new car sales in the UK from 2005-2020. The new car average type-approval CO_2 factors for cars in different engine size bands were provided by the Society of Motor Manufacturers and Traders (SMMT, 2015). The real-world uplift uses empirically-derived equations in the Guidebook that take account of average engine capacity and vehicle mass.

The fuel consumption maps are calculated from the speed related fuel consumption factors multiplied by vehicle flows. The method for calculating these maps is described in the next section. For GHG, fuel consumption is used as a proxy for the distribution of emissions and activity data sourced at a national level from the NAEI end user inventory.

NAEI petrol and diesel vehicle fuel consumption and emissions are estimated for individual vehicle types from a bottom-up approach using an array of traffic statistics and exhaust emission and fuel consumption factors representing the real-world performance of vehicles. These estimates are reconciled to national energy consumption statistics from DUKES. Further details of the NAEI reconciliation methodology and the effect of this across the timeseries may be found in section 3.4 MS 8 of the UK NIR (Brown et al., 2021).

The emission factors applied for road transport in LA GHG statistics are provided below in **Table 11**. These are derived from NAEI by-source emission factors, calculated from the carbon content of the fuel used, adjusted to an end user basis to account for emissions from the production and processing of fuels. NAEI CO_2 emission factors per unit of fuel for road transport are different for petrol and diesel vehicles, but do not vary according to vehicle type. Whereas CH_4 and N_2O emissions do vary by vehicle as well as fuel type.

Table 11 Emission factors applied for road transport in LA GHG statistics

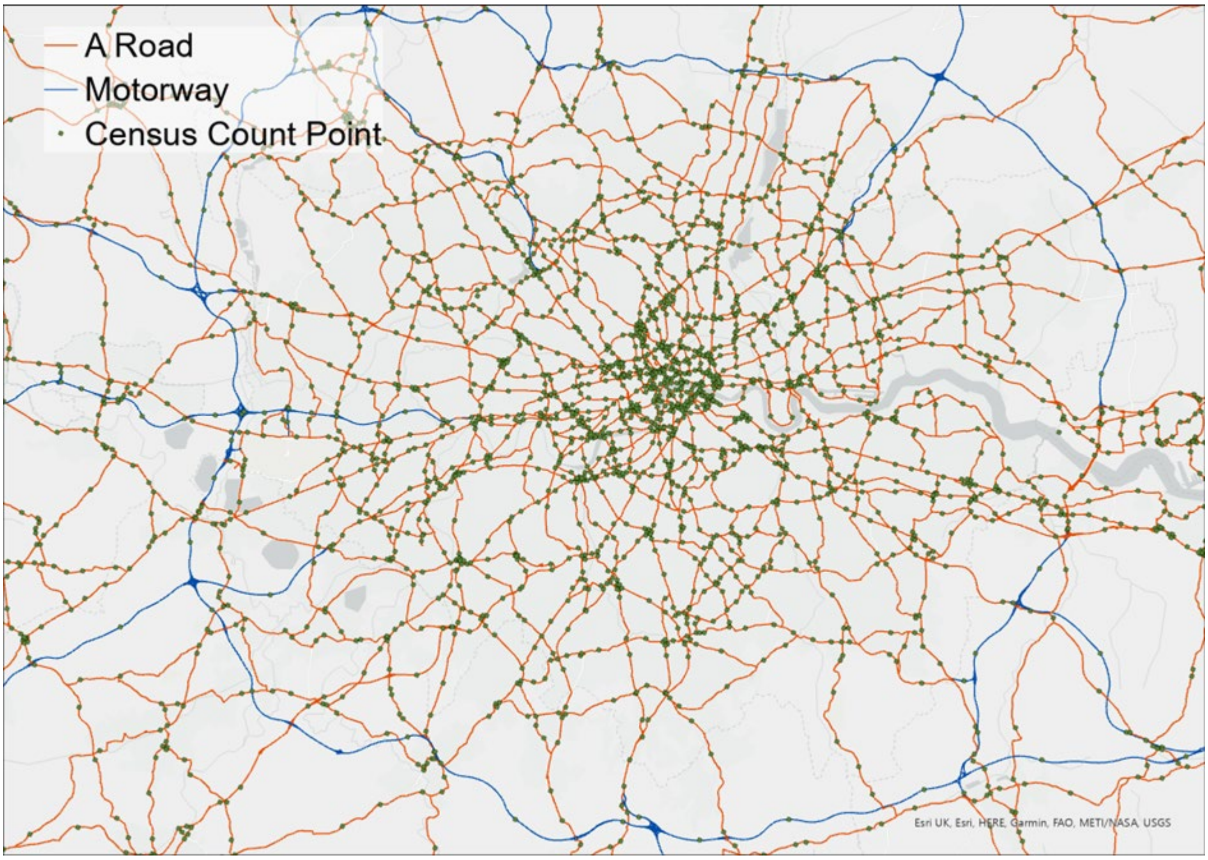
Year	By-source GHG Factor (kt CO_2e per ktoe gross)		End-user GHG Factor (kt CO_2e per ktoe gross)	
	Petrol	DERV	Petrol	DERV
2005	2.831	2.915	3.117	3.198
2006	2.826	2.917	3.089	3.178
2007	2.821	2.924	3.082	3.181
2008	2.814	2.925	3.066	3.173
2009	2.807	2.923	3.067	3.179
2010	2.806	2.927	3.070	3.188
2011	2.804	2.926	3.062	3.182
2012	2.800	2.927	3.035	3.160
2013	2.799	2.930	3.030	3.159
2014	2.798	2.931	3.022	3.153
2015	2.796	2.930	3.024	3.156
2016	2.796	2.931	3.018	3.150
2017	2.798	2.932	3.022	3.153
2018	2.801	2.933	3.023	3.153
2019	2.804	2.939	3.029	3.162
2020	2.804	2.939	3.056	3.189

Road transport mapping methodology

The base map of the UK road network used for calculating hot exhaust road traffic emissions has been developed from two mapping datasets. The Ordnance Survey Open Roads (OSOR) dataset (see **Figure 4**) provides locations of all roads (motorways, A-roads, B-roads and unclassified roads) in Great Britain (GB). For Northern Ireland (NI) a dataset of roads was obtained from Ordnance Survey of Northern Ireland, part of Land & Property Services Northern Ireland.

This year a revised method has been implemented and the population-based area type is not used any more to determine the vehicle speed. The urban status and road type are still taken into consideration, but the speed limit of each road segment is now used to assign the appropriate fuel consumption factor to the relevant roads. Speed limits are available for each major road from Basemap[26]. The speed limit for minor roads is assumed to be 30mph in urban areas and 60mph in rural areas.

Figure 4: Illustration of OSOR road network and DfT count point data for the Greater London area.



Mapping traffic on major roads

Traffic flow data for major roads (A-roads and motorways) are available on a census count point basis for both GB (DfT, 2019) and NI (DfI NI, 2019). The data comprise counts of each type of vehicle as an Annual Average Daily Flow (AADF), aggregated

[26] https://www.basemap.co.uk/speed-limit-data/

up to annual flows by multiplying by 365. These AADF statistics take account of seasonal variation using ‘expansion factors’ applied to single day counts based on data from automatic counts for similar roads and vehicle types.

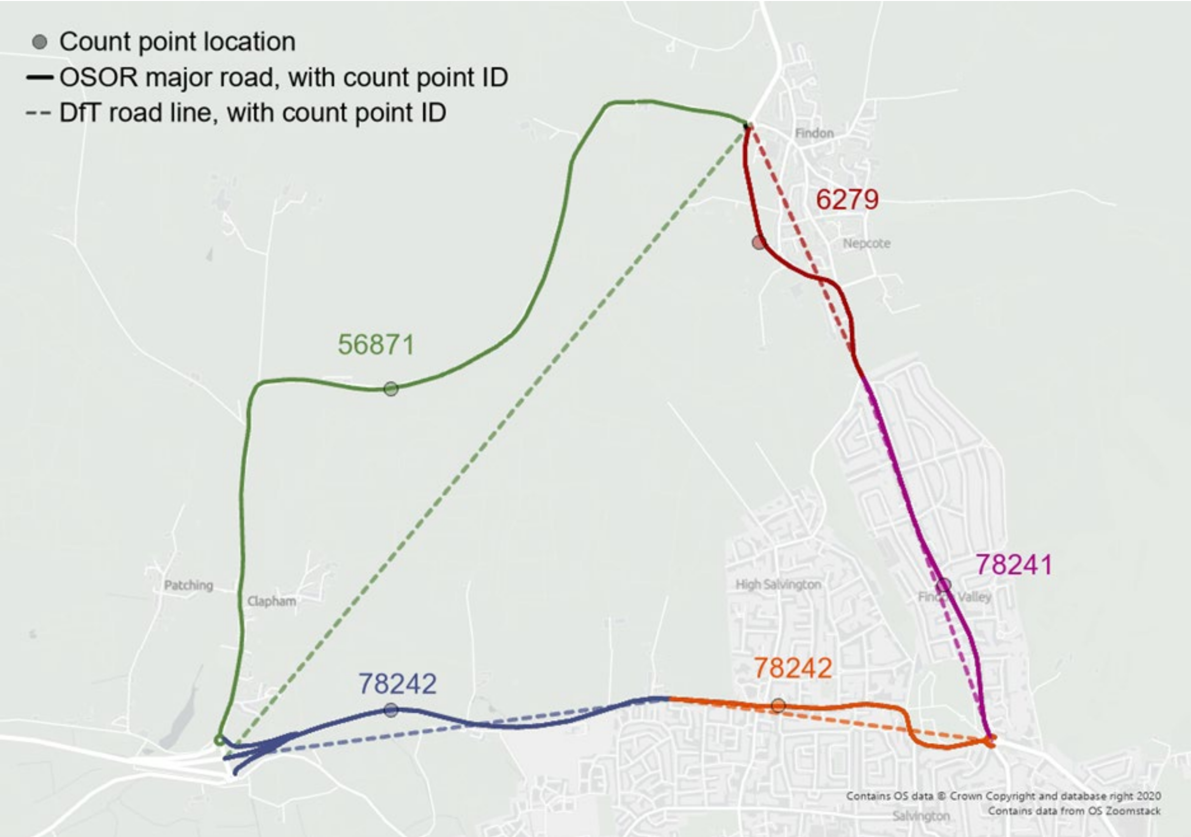
Differences between GB and NI datasets should be noted. Coverage of roads in GB is considerably denser than that for NI. Additionally, in NI, some count points record total vehicles, rather than a split of different vehicle types. An average vehicle split has been applied to these records.

For NI, traffic counts were allocated according to the proximity of the point where the count was made and major roads with the same road number – i.e. each link has the nearest count point with the same road number assigned to it -- using a computer script.

For GB, the OSOR network is more complex than the NI road network, and count point allocation required a different approach. Here, count points were allocated to a section of the major road network according to shared road number and spatial proximity to the stretch of road that each count point covers (**Figure 5**).

This was done by using a highly simplified, straight line, DfT representation of the start and end of each count points’ coverage (‘count point lines’). A series of computer-based processes were used to automatically perform this allocation. Where count point lines overlapped Local Authority boundaries, OSOR roads were split at that boundary and each split assigned to the relevant LA. Automated allocation was followed up with manual checking and verification.

Figure 5: Traffic flows are assigned to the road network (Ordnance Survey Open Roads) by selecting OSOR sections that fall between the start and end points of traffic census count point coverage (DfT road line).



Mapping traffic on minor roads

Traffic flow data are not available on a link-by-link basis for the majority of minor roads. Traffic flows in most minor roads have been modelled based on average regional flows and fleet mix (data from DfT) in a similar way to previous years. Regional average flows by vehicle type have been applied to each type of minor road – B and C roads or unclassified roads. These data were obtained from DfT.

For NI vehicle-specific minor road flows have been calculated from 2014 data (DfI NI, 2019) which provides information on vehicle kilometres travelled for vehicle types and by road types.

County level vehicle kilometre estimates have been obtained from DfT (unpublished) and used to ensure consistency between the NAEI and DfT modelling, to correct at County level the estimates of vehicle kilometres in the NAEI mapping.

Vehicle fleet composition

A development in the 2010 NAEI was the use of DfT's Automatic Number Plate Recognition (ANPR) data to define fleet composition on different road types for the whole of GB while combining devolved administration-country specific vehicle licensing data (DVLA data) to define regional variation (DfT, 2010). The ANPR data continues to be used in two aspects for the 2020 NAEI to define:

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

For other vehicles, it has been assumed that 100% of motorcycles are fuelled by petrol and 100% of heavy goods vehicles and buses run on diesel. More information on the methodology can be found in the UK Informative Inventory Report (Churchill *et al.*, 2022). It is also assumed that the biofuel percentages of the fuel are consistent over all LA but vary year on year.

Fuel consumption calculations

The next step after mapping vehicle movements is to apply the emissions and fuel consumption factors discussed earlier.

The urban or rural classification of a section of OSOR road covered by a count point (here called a 'count point road') was determined through the following logic:

1. Count point roads that have at least two-thirds of their DfT defined length within an urban area: classify as urban.
2. Count point roads that have at least two-thirds of their DfT defined length outside an urban area: classify as rural.

Count point roads not captured by cases 1 or 2 were split at the urban boundary and urban or rural classification of these splits were classed as urban or rural if they were within or outside an urban area. Count point roads intersecting urban areas more than twice were classed based on the majority urban or rural length of the whole road section. Splits of less than 100m were given the urban or rural classification of their counterpart, and splits of less than 15% of the total count point road length were manually inspected for validity.

Vehicle kilometre estimates for each road link are multiplied by fuel consumption (or emission factors) taking into account the speed limit (taken from Basemap) of the road of concern. These calculations were performed for each major road link in the road network resulting in maps of fuel use by fuel type and emissions by pollutant. Each road link is then split into sections according to the LA boundaries which then allow aggregation of fuel consumption estimates for each LA across the UK.

A similar calculation is done for minor roads, using speed limit (30 mph urban areas, 60 mph rural areas) for different types of minor roads and applying the relevant fuel consumption factor for that road type to the vehicle kilometre data modelled as described above. These calculations are undertaken at a resolution of 1×1 km across the UK and the results are aggregated to LA boundaries for the estimates of fuel consumption published by BEIS.

The use of a speed limit approach to estimating emissions for different traffic conditions is a necessary simplification of real-world conditions. At present it is the only appropriate method for national scale modelling. However, work has shown that for modelling vehicle emissions for an inventory covering a road network on a national scale, it is sufficient to calculate emissions from emission factors in g/km related to the speed limit of the vehicle in the drive cycle (Zachariadis and Samaras, 1997). Emission factors for speed limits on the road network are then combined with the national road traffic data.

Continuous improvements for road transport

Methodologies for calculating fuel consumption and emissions are periodically updated as our understanding of the factors that affect them improves. In addition, the input data used to calculate them are updated as DfT revises information, provides more detail in the information gathered and as new information becomes available. Consequently, revisions to the trends in calculated values of road transport fuel consumption and emissions are an inevitable consequence as the science and evidence base improves. The NAEI uses consistent data and approaches to meet the needs of GHGI compilations.

9. Other Transport Emissions

Two other small sources of emissions from road traffic are included in the inventory. These are emissions from combustion of lubricants and from vehicles which run on LPG. The 'Other Transport' sector also includes emissions from inland waterways, coal combustion in the rail sector and aircraft support vehicles.

Railways

It is not possible to separate electricity consumed by the railways from that consumed by other commercial and industrial activities in the BEIS dataset. Therefore, it is not possible to report all rail emissions as a separate sub-sector within the transport sector. Emissions attributable to electricity consumption in the rail sector are included in the commercial and industrial sector, whilst diesel and coal emissions from railways are shown as separate sub-sectors and their methodologies are explained below.

The UK total diesel rail emissions are compiled for three journey types: freight, intercity and regional. The emissions were spatially disaggregated based on a recent Rail Safety and Standards Board (RSSB) project that used 2019 activity data for each line in Great Britain for passenger and freight trains. The emissions along each rail link between Timing Point Locations (TIPLOCs) were assumed to be uniform along the length of the rail link, as no information on either load variation or when engines were on or off is yet available on a national basis. For years other than 2019 emissions along each line have had to be scaled at UK level, as described in the UK Informative Inventory Report (Churchill, et al., 2022), using trends from national statistics on fuel consumption by rail operators.

Rail emissions are distributed across Northern Ireland based on 2019 data from Translink on the number of services run on different routes. These data are for passenger trains only as there is no freight activity in Northern Ireland.

From the above, a set of spatial rail distributions was created which represents better the UK rail activity for the calendar year of 2019. Furthermore, national emissions inventory data have been used to scale this spatial distribution to other reporting years.

Coal based rail emissions have been accounted for by extracting station, line and operating information from the latest version of the 'UK Heritage Railways' website[27]. This information was then verified against two additional independent UK heritage railway guides[28],[29] and dedicated webpage for specific lines. National coal-based rail

[27] www.heritage-railways.com/index.php

[28] www.heritagerailwaysmap.co.uk

[29] The other website used (http://steamrailwaylines.co.uk/) no longer hosts information on this subject

emissions have been proportionally allocated based on the number of days a line operated per year (consistent across all sections of a lines track).

In total, 86 operational heritage lines were identified, and their main station coordinates plotted. Those stations with track lengths >5 miles were mapped with the assistance of route schematics alongside the aerial imagery and OS Open Background map services provided by ESRI (Environmental Systems Research Institute). For the remaining 48 stations activity was assigned to a single 1x1km grid.

Other Road Transport Emissions

Combustion of lubricants and LPG in road vehicles use estimates of total vehicle kilometres calculated from the NAEI maps of traffic flows.

Aircraft support vehicles

The locations of airports and their air support activity were mapped for the 2012 inventory with the use of satellite imagery. The emissions were allocated to the individual airports on the basis of the number of movements of aircraft using data provided by the Civil Aviation Authority.

Inland Waterways

Emissions from inland waterways were first included nationally in the 2010 inventory and were first included in the 2011 LA CO_2 (now the LA GHG) inventory.

Details of the approach used to estimate emissions are given in the GHGI improvement programme report (Walker et al.,2011). A bottom-up approach was used based on estimates of the population and usage of different types of craft and the amounts of different types of fuels consumed. Estimates of both population and usage were made for the baseline year of 2008 for each type of vessel used on canals, rivers and lakes and small commercial, service, and recreational craft operating in estuaries / occasionally going to sea. For this, data were collected from stakeholders, including the British Waterways, DfT, Environment Agency, Maritime and Coastguard Agency (MCGA), and Waterways Ireland.

Sparse data were available to estimate the distribution of emissions from this sector. As a result, total emissions from the inland waterways sector were mapped using datasets of vessel activity for a limited number of Great Britain and Northern Ireland's waterways. Lock passage information for NI were provided by Waterways Ireland (Waterways Ireland, 2012) for the Shannon Erne Waterway and the five Locks on the Lower Bann Navigation as well as a geospatial dataset. Data for GB, including geospatial data, were provided by the British Waterways (British Waterways, 2012). Where data gaps were identified, additional activity data were taken from the 'Members' area of the Association of Inland Navigation Authorities website (AINA, 2012).

The activity data were used in combination with geospatial information to calculate the product of boat activity and distance. This was subsequently combined with the UK's emissions data.

10. Land Use, Land-Use Change and Forestry Emissions

Land Use, Land-Use Change and Forestry (LULUCF) activities are both a source and sink for atmospheric CO_2 and a source of CH_4 and N_2O. Generally, emissions are produced from conversion of land to cropland and settlements, and are removed through forest growth and conversion of cropland to grassland. Currently in the UK, LULUCF activities are a net sink of CO_2 however when including CH_4 and N_2O LULUCF becomes a net source of CO_2e.

Forest Research and the UK Centre for Ecology & Hydrology (UKCEH) in Edinburgh annually prepare estimates of the uptake (removal from atmosphere) of CO_2 by afforestation and net loss or gain of CO_2 from soils (emissions to or removals from the atmosphere) for inclusion in the UK GHGI. In addition to this, estimates of emissions of CH_4 and N_2O to the atmosphere from LULUCF have been made. These emissions are classified as the LULUCF sector for inclusion in the UK GHGI.

The estimates are reported according to IPCC classification of sources and removals. Currently LULUCF is the only sector in which emission sinks, which remove GHGs from the atmosphere, are reported in addition to emission sources. Estimates for 2020 are shown in **Table 13**. Categories are presented in the table in the order of the absolute magnitude of the net emissions or removals. The emissions are also divided into the categories used for reporting these emissions in the national inventory. The emissions to the atmosphere are given as positive values; the removals from the atmosphere are given as negative values.

Changes in net emissions from the LULUCF Sector over time are dominated by the decrease in CO_2 net emissions. While CH_4 emissions are fairly stable over time, they dominate LULUCF overall net emissions by gas in CO_2 equivalents from 2000 onwards (Brown et al. 2021). Estimates in the 2020 inventory for the different GHGs are -2,994 kt CO_2 for carbon dioxide, 4,875 kt CO_2e for methane (or 195 kt CH_4), and 1,778 kt CO_2e for nitrous oxide (or 5.97 kt N_2O) across the UK in 2020). This is due to CH_4 emissions from drained and rewetted organic soils. Emissions of greenhouse gases are produced by undrained modified, rewetted and near natural peatlands (note that CH_4 emissions from near-natural bogs are cancelled out by CO_2 uptake in CO_2-equivalent terms), drainage ditches on peatlands, biomass burning during wildfires or the conversion of Forest Land to Cropland, Grassland or Settlements as per IPCC 2006 classification guidelines. Direct and indirect emissions of N_2O are also produced from nitrogen fertilisation of new forests and soil mineralisation following land-use change. Emissions of non-CO_2 gases from agricultural land (e.g. due to fertilisation) are reported in the agriculture sector of the Greenhouse Gas Inventory.

Full details of the methodology used by UKCEH to estimate emissions and removals by LA for 2020 are provided in a separate document supporting this report: **Mapping Carbon Emissions & Removals for the Land Use, Land-Use Change & Forestry Sector**[30]

Table 12: Emissions of GHG from Land-Use Change and Forestry 2020 (kt CO_2e)

Category	Activity	GHG	2020 UK total kt CO_2e emission (+) or removal (-)
4A	Forest (soil and biomass)	Carbon	-18,686.11
4B	Cropland (mineral soil)	Carbon	+9,013.80
4C	Grassland (mineral soil)	Carbon	-8,635.39
4B	Cropland (drainage of organic soil)	Carbon, CH_4	+5,945.86
4C	Grassland (drainage of organic soil)	Carbon, CH_4, N_2O	+5,820.30
4E	Settlement (mineral soil)	Carbon	+3,275.31
4C	Grassland (undrained organic soil)	Carbon, CH_4, N_2O	+2,415.67
4D	Wetlands (peat extraction)	Carbon, CH_4, N_2O	+2,182.16
4G	Harvested Wood Products	Carbon	-2,128.72
4A	Forest (drainage of organic soil)	Carbon, CH_4, N_2O	+1,347.06
4E	Land converted to Settlement (deforestation to Settlement)	Carbon, CH_4, N_2O	+605.89
4C	Land converted to Grassland (deforestation to Grassland)	Carbon, CH_4, N_2O	+531.16
4B	Land converted to Cropland (soil mineralisation)	N_2O	+396.71
4C	Land converted to Grassland (non-forest biomass)	Carbon	+381.45
4B	Land converted to Cropland (non-forest biomass)	Carbon	-283.10
4E	Land converted to Settlements (soil mineralisation)	N_2O	+278.87
4D	Land converted to Wetland (deforestation to Wetland)	Carbon, CH_4, N_2O	+264.87
4D	Wetlands (rewetted organic soil)	Carbon, CH_4, N_2O	+241.72
4	Indirect N_2O Emissions from Managed Soils	N_2O	+171.75
4A	Forest (wildfires)	Carbon, CH_4, N_2O	+152.33
4C	Grassland (rewetted organic soil)	Carbon, CH_4, N_2O	+145.44

30 https://www.gov.uk/government/statistics/uk-local-authority-and-regional-greenhouse-gas-emissions-national-statistics-2005-to-2020

Category	Activity	GHG	2020 UK total kt CO_2e emission (+) or removal (-)
4A	Land converted to Forest (soil mineralisation)	N_2O	+68.95
4C	Grassland remaining Grassland (grassland management biomass)	Carbon	+54.88
4E	Land converted to Settlements (non-forest biomass)	Carbon	+40.13
4A	Forest (drainage of mineral soil)	N_2O	+33.87
4E	Settlement (drainage of organic soil)	Carbon, CH_4, N_2O	+29.13
4C	Land converted to Grassland (soil mineralisation)	N_2O	+17.51
4B	Cropland remaining Cropland (cropland management soils)	Carbon	-16.63
4D	Wetlands (near-natural organic soil)	Carbon, CH_4	-14.33
4C	Grassland (wildfires)	CH_4, N_2O	+12.24
4B	Cropland remaining Cropland (cropland management biomass)	Carbon	-4.32
4A	Forest (fertilisation)	N_2O	+0.8
4B	Cropland (wildfires)	CH_4, N_2O	+0.05
4B	Land converted to Cropland (deforestation to Cropland)	Carbon, CH_4, N_2O	0
4D	Land converted to Wetlands (grassland to flooded land)	Carbon	0
Total			**+3,659.31**

* Sector 4G (Harvested Wood Products) is not included in the LA estimates because of insufficient data for distributing the emissions and removals

11. Waste Management

Emissions from non-electricity related processes in the waste management sector have been included in the LA GHG data for the first time this year, allocated to Local Authorities based on estimated distributions of where the waste arises rather than where the emissions occurred. Emissions associated with electricity used in the waste industry comes under Industrial and Commercial Electricity. This is also true for emissions from energy from waste plants for which the emissions are associated to the end user of the electricity.

Landfill Emissions

Solid waste disposal is a key category for methane emissions in the UK GHGI (Brown et al, 2022). Methane emissions from landfill arise from the degrading of biodegradable solid waste placed in landfill, and UK level emissions estimates for this are published in the NAEI. In the LA GHG dataset the emissions from landfill have been spatially distributed based on the locations of the producers of waste. Landfill data[31] by LA was obtained for each of the four countries of the UK. The total mass of biological component for each LA was calculated from this data by applying defined percentages of biological component for each waste type[32]. Using the mass of biological component per LA the total methane emitted in each country could be proportioned to the LAs where the waste originated. Some LAs had landfill waste in multiple countries, this is especially noted with waste transfers between Wales and England, so these have to be accounted for.

Due to data availability 2018 waste data was modelled this year and then a time series was extrapolated from this, scaled by total methane emitted from landfill from each devolved administration each year to give data at an LA level for other years 2018-2020. This is with the exception of England where actual LA data is used for 2019 as well. This is a top-down methodology for estimating emissions from LAs so will vary from the carbon factors published by BEIS[33] which can be used in a bottom-up approach to emissions from waste landfilled.

[31] Data obtained from https://data.gov.uk/dataset/d409b2ba-796c-4436-82c7-eb1831a9ef25/2019-waste-data-interrogator, https://www.sepa.org.uk/environment/waste/waste-data/waste-data-reporting/household-waste-data/, https://www.daera-ni.gov.uk/articles/northern-ireland-local-authority-collected-municipal-waste-management-statistics and NRW

[32] The National Inventory Report table 7.1 gives a breakdown of the percentages of biodegradable matter for each category of waste (Brown et al, 2022)

[33] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1049333/conversion-factors-2021-full-set-advanced-users.xlsm

Other Waste Emissions

Total emissions from Waste water treatment, Sewage Sludge decomposition, composting and anaerobic digestion were mapped to LAs using the ONS population grid.

12. National Parks

For each detailed sector the UK-wide activity distributions (such as domestic natural gas) have been geospatially analysed with the National Parks' boundaries to calculate proportions of each National Park to the UK national total.

In most cases, it has been possible to be more geographically accurate in the allocation of emissions to National Parks. In the case of employment-based distribution grids, detailed locations of employment activity have been extracted from the Inter-Departmental Business Register. Full details on the generation of employment-based emissions data can be found in Section 5.

A similar approach was possible for the major[34] road network. The road network was intersected with National Park boundaries allowing the exact length of each road inside and outside of a national park to be calculated. This allowed a detailed estimate of fuel consumption and vehicle kilometres travelled within each park to be calculated. The derived sectoral proportion was then multiplied by the national emission estimates to arrive at an aggregated total of end-user GHG emissions within each National Park.

The methodology used to convert activity distributions to end-user emissions is the same for National Parks as for Local Authorities, and in most cases the same data sources are used to derive activity distributions. The exceptions to this are;

- **Natural gas** and **electricity** distributions for National Parks are derived directly from postcode level consumption data, rather than BEIS published Local Authority scale data.
- **Landfill** emission distributions based on waste arising are scaled down from Local Authority to National Park level using population distributions, i.e. assuming waste arising per capita in each National Park is consistent with that of the Local Authorities in which it falls in each year.

[34] A-roads and Motorways

13. Uncertainty Analysis

As with any inventory, the end user LA GHG emissions estimates are associated with a degree of uncertainty. This section describes how uncertainty has been analysed in this dataset.

Overall uncertainties in the emission estimates for each LA have been assessed by combining three variables. Two of these three variables are sets of uncertainty estimates:

- Uncertainty in national emissions: estimates of the percentage error relating to the national total emissions by sector;
- Uncertainty in the spatial distribution of emissions: an assessment of the degree of correlation between modelled and real-world distributions of fuel consumption, activity and emissions; and
- The proportion that each sector contributes to emissions in each LA.

Overall uncertainties in the 2020 emissions have been estimated using the sum of the squares method for propagating errors through calculations. This method uses the input data on estimates of component uncertainties as described in the following sections.

Uncertainties on LULUCF net emissions are excluded from this analysis since they are very high and would mask other variations in uncertainty. For example, there are over a dozen LAs for which the uncertainty is at least doubled when including LULUCF, of which several are at least tripled, and there's one extreme case where the uncertainty is an order of magnitude higher.

Further information on LULUCF uncertainties may be found in the separate National Inventory Report (Brown et al., 2022) and Mapping Carbon Emissions & Removals for the Land Use, Land-Use Change & Forestry Sector (UKCEH, 2022).

Uncertainty in the national sectoral GHG emissions

Uncertainty estimates for the national total GHG emissions, according to IPCC sector[35], are calculated in the UK's GHGI. This analysis is published in the UK's National Inventory Report, which is updated annually, most recently published for the 2020 inventory (Brown et al., 2022).

The uncertainty analysis in the national inventory is calculated using a Monte Carlo simulation, based on assigning probability distribution functions (PDFs) to each emission factor and piece of activity data. Errors in the UK GHGI are expressed as

[35] The Intergovernmental Panel on Climate Change (IPCC) has devised a reporting nomenclature for greenhouse gases where the gases are reported in six major categories.

half the difference between 2.5 and 97.5 percentiles, equivalent for normal distributions to 1.96*s/E*, where *E* is the central (best) estimate of the emission and *s* is one standard deviation of the mean.

The emission sectors used for the local GHG estimates do not match the sectors reported in the National Inventory Report. Therefore, the percentage error values have been combined, via calculation of a weighted average (weighted by emission in each subsector and by fuel), in order to give national emission percentage error for each of the sectors. These percentage errors are shown in **Table 14**.

Uncertainty in the geographical distributions

The uncertainties in the geographical distributions of emissions for each sector are difficult to quantify. Experts familiar with the mapping methods and emissions by sector have estimated semi-quantitative distribution uncertainties using expert judgement when the local GHG estimates were compiled. With the exception of the BEIS data on gas and electricity, no quantitative estimates of uncertainty for the individual components exist. Therefore, numerical uncertainties have been estimated using 'expert judgment' through a process of 'expert elicitation' as described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006b). **Table 14** provides notes on each sector to help to explain the reasons for the uncertainty scores chosen.

Uncertainty estimates for the domestic and industrial gas and electricity emissions have been obtained from BEIS. They are based on the amount of the consumption that was located correctly based on allocating meter locations to LAs. However it is also necessary to take account of the amount of estimated meter readings used to calculate these consumption data and the cut-off point used to determine whether meters are classed as domestic or non-domestic (see **Sections 2.1** and **3.1**) therefore the higher uncertainty estimates set out in **Table 14** are used.

The mapping of emissions has been divided into point and area sources. In general, mapped point source data are expected to be more accurate than that for area sources since it is predominantly based upon reliable data used for regulatory purposes. As we have seen, area source emissions are mapped using a variety of surrogate data types of varying quality. As part of this process, every attempt is made to utilise the highest quality data (within overall budgetary constraints), however, in some cases the surrogate statistics used may be poorly suited to this task.

Other industrial emissions data (large gas users, wastes and biomass and non-fuel emissions) are considered to have fairly low uncertainty as the geographical location of many of these sources and energy consumption are well reported (see **Section 4**).

The main reasons for uncertainties in the road transport sector are the use of sample/survey data to represent both vehicle movements and emission factors. Average daily flows and average speeds are used on major road links which does not take account of fluctuations in flows and speeds through the day or year.

Regionally average flows and speeds are assumed on minor roads because there is not sufficient data to model this more accurately. However, state of the art national datasets are used in all cases where these are made available and the mapping approach is compliant with the method recommended by international guidance of the EMEP/EEA air pollutant emission inventory guidebook[36].

The estimates of emissions for minor roads also have relatively high uncertainty. There are too few measurements of traffic movements on minor road links to allow detailed modelling to be undertaken therefore regional traffic flows are used.

The next most significant sources of emissions after road transport are agriculture and waste, which are dominated by methane and nitrous oxide. Emissions of these greenhouse gases are more uncertain than those of CO_2 since the chemical mechanism behind the emission process is less strictly defined, and more dependent on abatement and environmental factors.

High uncertainties are assigned to some other sectors which contribute less to total emissions. In particular, the combustion of coal and liquid fuels in small industry, commercial and public service sectors. This is because there is very limited knowledge of the distributions of coal and liquid fuel use. This work does not take into account localised renewable consumption or energy efficiency through the use of combined heat & power and does not attempt to correct or fill gaps in the BEIS electricity use or gas use datasets.

Table 14 also shows the percentage of UK total emissions in each sector. This is presented here to show the relative importance of each sector, but these numbers are not used in the uncertainty analysis. The uncertainty analysis uses actual amounts of emissions in each LA rather than a UK average.

[36] https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

Combining the uncertainty estimates using Sum of Squares Method

The three variables set out at the start of this section have been combined as follows. The percentage emission error in each LA total GHG estimate is calculated using the sum of the squares method using the equation below.

$$Percentage\ Error\ for\ each\ LA = \frac{\sqrt{\sum_{sectors} e^2({i_1}^2 + {i_2}^2)}}{\sum_{sectors} e}$$

Where: e is the local emission in the LA for a given sector;

i_1 is the UK emission uncertainty error for that sector;

i_2 is the mapping emission uncertainty error for that sector.

Table 13: Summary of information used in uncertainty analysis and comments on data quality

Sector	Percentage of 2020 UK emissions excluding LULUCF	National emission error	Geographical Estimated error	Comment on estimated geographical error
Non-domestic Electricity	8.12%	5.2%	3%	97.7% of postcodes have been located correctly. Additional estimate of uncertainty has been made based on 20% of MPAN readings being estimates.
Non-domestic Gas	8.87%	4.5%	3%	BEIS geographical allocation for gas is good. However, the BEIS definition of domestic gas consumers includes some small commercial users. But there is no numerical estimate of this uncertainty
Large Industrial Installations (non-ETS)	0.28%	8.5%	5%	Good location information for point sources but still some emissions modelled
Large Industrial Installations (ETS)	7.62%	1.0%	1%	Estimated % error. Grid references for sites provided by operators. Emissions reported and verified though ETS but some variation in quality of monitoring of emissions.
Non-domestic Other Fuels	4.54%	15.3%	30%	Area emissions modelled using employment and fuel intensity factors. There will be spatial variations in energy intensity that is not taken into account. Good location information for point sources but still some emissions modelled
Agriculture	11.91%	16.5%	30%	Modelled estimates using fuel and employment distributions for stationary combustion; Agricultural census/survey data for 2020 were acquired at the holding level from the four UK countries' statistical authorities. This data is used to distribute livestock, soils & machinery emissions.

Sector	Percentage of 2020 UK emissions excluding LULUCF	National emission error	Geographical Estimated error	Comment on estimated geographical error
Diesel Railways	0.40%	19.5%	20%	Emissions are distributed based on a recent Rail Safety and Standards Board (RSSB) project that mapped 2019 emission estimates for each line in Great Britain for passenger and freight trains, and in NI based on 2019 data from Translink on the number of services run on different routes.
Domestic Electricity (GB)	5.56%	5.2%	3%	98.8% of postcodes have been located correctly. Additional estimate of uncertainty has been made based on 20% of MPAN readings being estimates.
Domestic Electricity (NI)	0.16%	5.2%	8%	Based on 92.4% of postcodes being located correctly.
Domestic Gas	16.05%	4.6%	3%	BEIS geographical allocation for gas is very good. However, the BEIS definition of domestic gas consumers includes some small commercial users. There is a 3% difference between domestic/non-domestic categories between LA GHG and national inventory.
Domestic 'Other Fuels'	3.02%	9.0%	10%	Estimates made using complex modelling of household energy demand compared with known gas usage. Emissions are mapped on population distribution but distribution of garden machinery is not correlated with population density because of smaller garden sizes etc in densely populated areas. Emissions mapped on population distribution which is reasonably well correlated with use of household products
Road Transport (A roads)	10.73%	3.5%	5%	Activity data are good quality annual average traffic count points. Emissions calculated using complex modelling of fleet mix and average speeds on different roads.

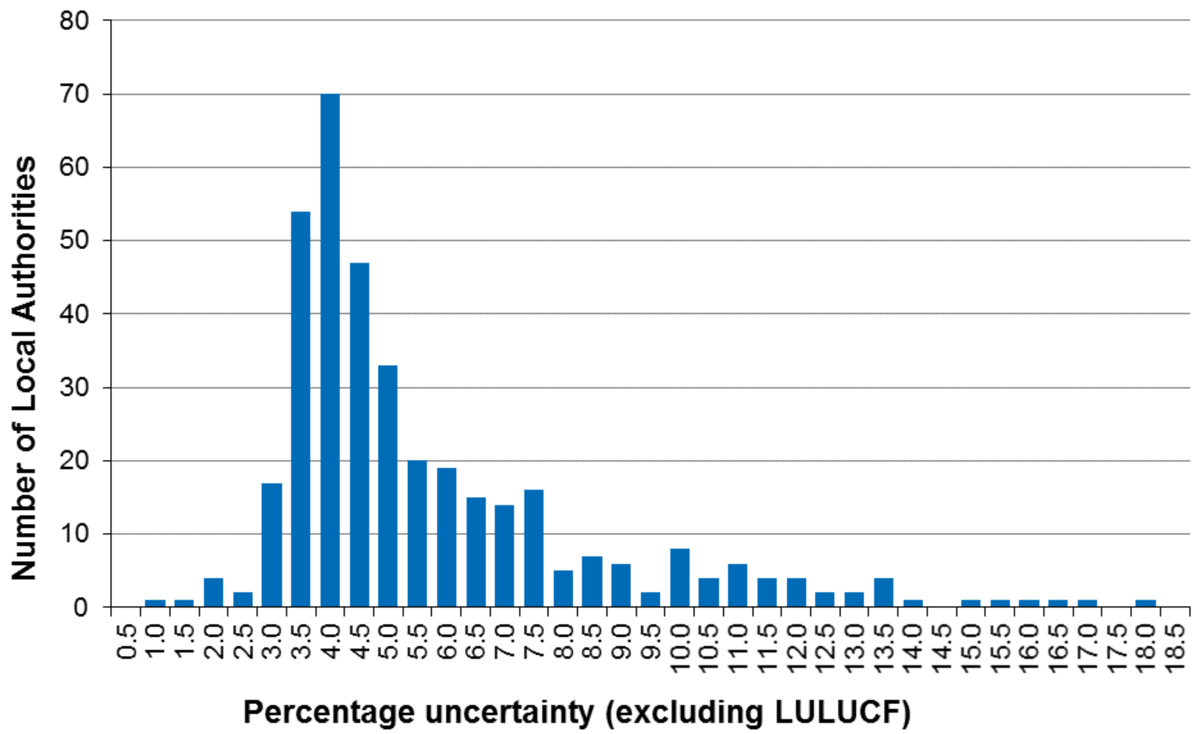
Sector	Percentage of 2020 UK emissions excluding LULUCF	National emission error	Geographical Estimated error	Comment on estimated geographical error
Road Transport (Motorways)	5.55%	3.5%	5%	Activity data are good quality annual average traffic count points. Emissions calculated using complex modelling of fleet mix and average speeds on different roads.
Road Transport (Minor roads)	11.00%	3.5%	20%	Activity data are calculated from regional average traffic flows and vehicle splits. Emissions calculated using complex modelling of fleet mix and average speeds on different roads.
Transport Other	0.57%	25.9%	30%	Locations of LPG use and burning of engine oil are not known and are therefore distributed across all road traffic activity.
Waste Management	4.66%	61.3%	5%	Emissions from landfill distributed using LA data on waste disposed to landfill and NAEI landfill totals for DA.

Results of the uncertainty analysis

Figure 6 shows the uncertainty distribution across the local authorities, which is then mapped into **Figure 7** to show how the errors calculated from the sum of the squares method vary across the UK. The percentage error is 4 or lower for 40% of LAs.

There were no significant revisions to uncertainty factors, however significant changes to overall uncertainties have arisen from the addition of non-CO_2 GHGs. The new waste sector contributes substantially to this increase due to the significance of emissions from landfill and their relatively high uncertainty. The increased significance of the agriculture sector, due to the addition of emissions from soils and livestock, also contributes to an increase in overall uncertainty.

Figure 6: Uncertainty distribution



The limited spread around the mean in **Figure 6** may seem surprising given the size of some of the uncertainties in **Table 14**, particularly for mapping uncertainties. Two factors are relevant:

1. The smallest uncertainties tend to be for the largest emissions.
2. Uncertainties within individual sectors cancel against uncertainties in other sectors within each LA area to a significant extent.

The latter may have important consequences for setting abatement levels by sector within each LA without further analysis at a more local level.

The emissions are dominated by the electricity and gas use in domestic, industrial and commercial sectors for which the UK estimates and the mapping distributions have low percentage errors. Higher overall percentage errors occur particularly where emissions in an LA are dominated by CH_4 & N_2O from agriculture and waste sources.

In percentage terms the smallest estimated spread for any LA is for Neath Port Talbot (±0.88%). This LA has a significant level of emissions from large ETS installations. The largest spread is for the Orkney Islands (±17.8%) because of the relatively high significance of emissions from agricultural livestock.

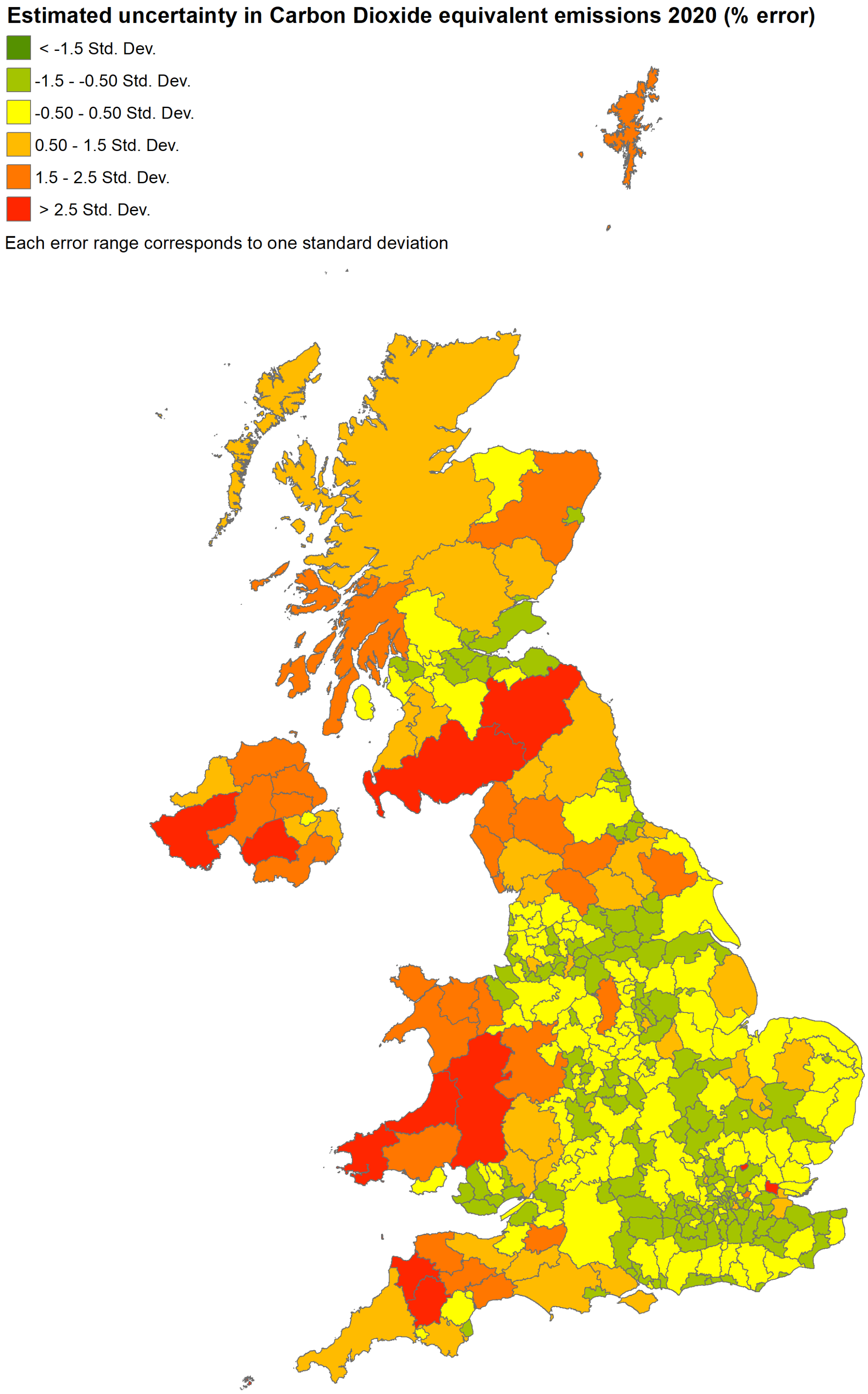
The median uncertainty across all Local Authorities, and in each of the Devolved Administrations, is presented in the table below.

Table 14: Median uncertainty for all UK Local Authorities and in each Devolved Administration

	Median uncertainty	
	Excluding LULUCF	Including LULUCF
England	±4.3%	±4.4%
Scotland	±4.7%	±4.9%
Wales	±5.3%	±5.4%
Northern Ireland	±10.6%	±10.3%
UK	±4.4%	±4.6%

By comparison the National GHG Inventory uncertainty on total UK GHG emissions for 2020 was ±2.5%. In the Devolved Administration GHG Inventory, for England, Scotland, Wales and Northern Ireland, the uncertainty estimates for GHGs were ±3%, ±6%, ±4% and ±6% respectively. In both cases these inventories include LULUCF in the estimates of uncertainty. Emissions & removals from LULUCF tend to be concentrated in a small number of LAs, so the impact of LULUCF uncertainty does not noticeably impact on the figures

Figure 7: Estimated uncertainty in the GHG emissions 2020 (not including LULUCF emissions)



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References

AINA. (2012, April 12). Association of Inland Navigation Authorities. Retrieved from http://www.aina.org.uk/members

British Waterways. (2012, February). Ben Mansbridge, Glenn Millar. Personal communication.

Brown P, Cardenas L, Choudrie S, Del Vento S, Karagianni E, MacCarthy J, Mullen P, Passant N, Richmond B, Thistlethwaite G, Thomson A, Wakeling D. (2022) 'UK Greenhouse Gas Inventory, 1990 to 2020: annual report for submission under the Framework Convention on Climate Change.' 978-0-9933975-8-5. https://naei.beis.gov.uk/reports/reports?report_id=1072

BEIS (2016) Energy Trends March 2016 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/524695/energy_trends_march_2016.pdf

BEIS (2017) Energy Trends March 2017 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/612492/energy_trends_march_2017.pdf

BEIS (2022) Energy Trends March 2022 https://www.gov.uk/government/statistics/electricity-section-5-energy-trends

BEIS (2021a) Sub-national electricity and gas consumption summary report 2020 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/946968/sub-national-electricity-and-gas-consumption-summary-report-2019.pdf

BEIS (2020b) Sub-national consumption statistics. Methodology and guidance booklet https://www.gov.uk/government/publications/regional-energy-data-guidance-note

BEIS (2021c) Digest of United Kingdom Energy Statistics (DUKES) 2021 https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2021

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/736148/DUKES_2018.pdf

BEIS (2021d) Northern Ireland sub-national electricity consumption 2009 to 2020 https://www.gov.uk/government/statistics/sub-national-electricity-consumption-statistics-in-northern-ireland

Churchill S, Richmond B, MacCarthy J, Broomfield M, Brown P, Del Vento S, Galatioto F, Gorji S, Karagianni E, Misra A, Murrells T, Passant N, Pearson B, Richardson J, Stewart R, Thistlethwaite G, Travasso N, Tsagatakis I, Wakeling D, Walker C, Wiltshire J, Wong J, Yardley R (Ricardo Energy & Environment) Hobson M, Gibbs M, Dore C. (Aether) Misselbrook T. (Rothamsted Research) DRAGOSITS U, Tomlinson S. (UKCEH) (2022) UK Informative Inventory Report (1990 to 2020). https://uk-air.defra.gov.uk/library/reports?report_id=1071

DECC (2011) Energy Trends March 2011

DECC (2012) Energy Trends December 2012 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65906/7343-energy-trends-december-2012.pdf

DECC (2014) Energy Trends March 2014 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/295362/et_march_2014.pdf

DfT (2010), personal communication with Mike Dark, Vehicle Licensing Statistics, Department for Transport

DfT (2019). Annual Average Daily Traffic Flows. Retrieved from Transport Statistics Department: http://www.dft.gov.uk/traffic-counts

DfI NI (2019) Traffic and travel information (incorporating annual traffic census and variations in traffic flow): https://www.infrastructure-ni.gov.uk/publications/traffic-and-travel-information-incorporating-annual-traffic-census-and-variations

EMEP (2019), EMEP/EEA air pollution emission inventory guidebook 2019 https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

IPCC (2006a) 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2 Energy, https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html

IPCC (2006b) 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3 Uncertainties, www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_volume1/v1_3_ch3_uncertainties.pdf

Network Rail (2012) SRS Provisional Data provided by Network Rail's Geospatial Network Team in December 2012

SMMT (2015). Personal communication with Tim Bruin, Society of Motor Manufacturers and Traders, September 2015

Translink (2012) Data provided by David Stewart at Translink in October 2012

Tsagatakis, I., Richardson, J., Evangelides, C., Pizzolato, M., Pearson, B., Passant, N., Pommier M. & Otto, A (2022) UK Spatial Emissions Methodology: A report of the National Atmospheric Emission Inventory 2019 https://naei.beis.gov.uk/reports/reports?report_id=1024

UKCEH (2022), Mapping Carbon Emissions & Removals for the Land Use, Land-Use Change & Forestry Sector. Hannah Clilverd, Gwen Buys, Rachel Nickerson, Amanda Thomson, Heath Malcolm, Paul Henshall & Robert Matthews. UKCEH, Edinburgh.

Walker, H., Conolly, C., Norris, J., & Murrells, T. (2011). Greenhouse Gas Emissions from Inland Waterways and Recreational Craft in the UK. AEAT/ENV/R/3175, Task 25 of the 2010 DA / UK GHG Inventory Improvement Programme. http://uk-air.defra.gov.uk/reports/cat07/1106231031_ip_task_25_inland_waterways_issue_1.pdf

Waterways Ireland. (2012, February). Orla Foster, Brian Mullan. Personal communication.

Zachariadis, Th. & Samaras, Z. (1997), Int. J. of Vehicle Design, 18, 312

This publication is available from: https://www.gov.uk/government/statistics/uk-local-authority-and-regional-greenhouse-gas-emissions-national-statistics-2005-to-2020