




National Atmospheric Emissions Inventory

Local and Regional Carbon Dioxide Emissions Estimates for 2005–2016 for the UK

Technical Report

Prepared by Ricardo Energy & Environment for BEIS

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Executive summary

The local and regional carbon dioxide (CO₂) emissions estimates for 2005-2016 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 CO₂ and energy intensive sectors, monitor changes in CO₂ emissions over time and to help design carbon reduction strategies.

This report, prepared by Ricardo Energy & Environment on behalf of the Department for Business, Energy and Industrial Strategy (BEIS), sets out how the local and regional CO₂ emissions estimates for 2005-2016 were compiled. The full dataset – which is classified as National Statistics – and statistical summary can be found on the gov.uk website¹.

The dataset provides a spatial disaggregation of CO₂ 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 four main sources:

- BEIS sub-national gas and electricity consumption statistics²;
- Point source emissions from large industrial installations;
- High resolution emissions distribution maps developed under the NAEI programme; and,
- Land use, land use change and forestry (LULUCF) regional data supplied by the Centre of Ecology and Hydrology (CEH), 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 as a whole 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 made this year is to estimates of emissions from forest land, due to the use of new planting statistics and the altering of the age assumptions for some areas of woodland, and improvements to the LULUCF modelling approach for other vegetation.

¹ <https://www.gov.uk/government/collections/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics>

² <https://www.gov.uk/government/collections/sub-national-gas-consumption-data>

² <https://www.gov.uk/government/collections/sub-national-electricity-consumption-data>

Table of contents

1	Introduction	1
1.1	Purpose of the work	1
1.2	Methodology	1
1.3	The UK Greenhouse Gas Inventory	1
1.4	End User basis for reporting emissions	1
2	Industrial and Commercial Electricity	4
2.1	Allocating Emissions to Electricity Consumption.....	4
2.2	Electricity consumption in Northern Ireland.....	5
2.3	Unallocated electricity	6
3	Industrial and Commercial Gas Consumption	7
3.1	Allocating Emissions to Gas Consumption	7
3.2	Gas consumption in Northern Ireland	8
3.3	Calculating CO ₂ Emissions	8
4	Large Industrial Installations	3
4.1	Data sources and summary of methods	3
4.1.1	Improvements.....	5
4.2	Detailed estimation methods	5
4.2.1	Fuel use for EU ETS processes.....	5
4.2.2	Estimating fuel use for non-EU ETS processes	5
4.2.3	Gap-filling and modelled estimates	6
4.2.4	Estimating fuel use for steelworks.....	7
4.3	Areas of uncertainty in the fuel use estimates	7
4.4	Comparison of site specific estimates with the GHGI	9
4.5	Year to year consistency within the fuel use estimates.....	12
5	Industrial and Commercial ‘Other Fuels’	14
5.1	Area source emissions: High resolution employment based distributions	14
5.2	Industrial off-road emissions	16
6	Agricultural Emissions	17
7	Domestic Electricity Consumption	18
8	Domestic Gas Consumption	19
9	Domestic ‘Other Fuels’	20
10	Road Transport	21
10.1	Emission factors and fuel consumption factors.....	21
10.2	Road transport mapping methodology	22
10.2.1	Mapping traffic on major roads.....	22
10.2.2	Mapping traffic on minor roads.....	23
10.2.3	Vehicle fleet composition.....	23
10.2.4	Fuel consumption calculations	24
10.3	Continuous improvements for road transport.....	24
11	Railways	26
12	Other Transport Emissions	27
12.1	Other Road Transport Emissions	27
12.2	Aircraft support vehicles	27
12.3	Coal combustion in railways.....	27
12.4	Inland Waterways.....	27
13	Land Use, Land Use Change and Forestry Emissions	28
14	Uncertainty Analysis	30
14.1	Uncertainty in the national sectoral GHG emissions.....	30
14.2	Uncertainty in the geographical distributions	30

14.3 Combining the uncertainty estimates using Sum of Squares Method 31
14.4 Results of the uncertainty analysis..... 33
15 References 36

1 Introduction

1.1 Purpose of the work

The dataset provides a spatial disaggregation of the CO₂ emissions from the UK Greenhouse Gas Inventory (GHGI), part of the National Atmospheric Emissions Inventory (NAEI), on an end user basis. The CO₂ emissions are estimated, by sector, for each local authority in the UK. The data helps identify the key sources of CO₂ emissions in each area; allows changes in CO₂ emissions over time to be monitored and can help mitigation actions to be targeted.

1.2 Methodology

This is the technical report for the Local and Regional CO₂ Emissions Estimates for 2005 - 2016 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. A summary of results and three further methodology documents also accompany this report and dataset on the gov.uk website³:

- **Statistical release.** A short document providing a commentary on trends and patterns shown in the data.
- **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 1x1km resolution.

The following chapters explain the technical approaches used to generate estimates of CO₂ emissions according to energy use in each sector.

1.3 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 the European Monitoring Mechanism Regulation (MMR) 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.

1.4 End User basis for reporting emissions

CO₂ emissions are reported in a variety of different formats for different organisations and purposes each year. One of these is known as the end users format in which emissions from the production and processing of fuels (including the production of electricity) are reallocated to consumers of these fuels to reflect the total emissions relating to that fuel 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. End user GHG emissions at UK level are reported by BEIS as National Statistics;

³ <https://www.gov.uk/government/collections/uk-local-authority-and-regional-carbon-dioxide-emissions-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 a particular LA.

The end user basis for reporting emissions has been chosen for this dataset because it fully 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 level⁴.

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

- Energy Producers (the production and processing of fuels including electricity);
- Energy Users (such as residential, industrial and road transport); and
- Others (which emit CO₂ but where the emissions are not related to fuel use, such as industrial process emissions, and land use change).

⁴ The estimates presented in this report are not directly comparable with the National and Devolved Administration Greenhouse Gas Inventories for CO₂. 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 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 EU ETS data for 2005-16 are not fully consistent with DUKES but were used during the compilation process of allocating consumption to particular industrial consuming sectors.

Table 1 shows the UK total CO₂ primary emissions in 2016 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 used by each. Some fuel producers use fuel from other fuel producers, 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*, 2018).

Table 1 UK Total Primary emissions of CO₂ (kt CO₂ 2016)

Sector	Anthracite & Coal	Coke	Solid Smokeless Fuel	Natural Gas	Oil	Electricity	Non Fuel	Total
Energy Supply								
Coke production	-	638	-	-	-	-	147	785
Collieries - combustion	-	-	-	11	-	-	101	112
Gas Leakage	-	-	-	-	-	-	6	6
Gas production	-	-	-	3,936	963	-	593	5,491
Oil Production	-	-	-	6,887	1,726	-	3,516	12,129
Iron and steel - flaring	-	920	-	-	-	-	29	949
Power stations	27,079	-	-	51,233	703	-	3,464	82,479
Refineries - combustion	-	-	-	2,326	11,268	-	-	13,594
Solid smokeless fuel production	225	-	-	-	96	-	-	320
Energy Consumption								
Industry: Iron & Steel	91	9,556	-	891	61	-	914	11,512
Industry: Other Combustion	2,636	-	-	20,231	10,409	-	477	33,754
Industry: Other Processes	1,608	-	-	1,709	6,091	-	7,052	16,460
Commercial	28	-	-	11,283	336	-	308	11,955
Agriculture	-	-	-	174	4,059	-	366	4,599
Miscellaneous	-	-	-	-	-	-	283	283
Rail Transport	36	-	-	3	1,959	-	-	1,998
Domestic	1,557	-	682	57,297	7,445	-	26	67,007
Public	357	-	-	7,635	159	-	-	8,150
Road Transport	-	-	-	-	112,744	-	283	113,027
Inland Waterways	-	-	-	-	836	-	-	836
Land Use Change	-	-	-	-	-	-	-15,099	-15,099
Water Transport: National Navigation	-	-	-	-	5,005	-	3	5,008
Air Transport	-	-	-	-	1,972	-	-	1,972
Military Transport (Air & Water)	-	-	-	-	1,547	-	-	1,547
Exports	-	-	-	-	-	-	-	-
International aviation and shipping	-	-	-	-	-	-	-	-
Total	33,615	11,114	682	163,615	167,378	-	2,469	378,874

Table 2 UK Total End user emissions of CO₂ (kt CO₂ 2016)

Sector	Anthracite & Coal	Coke	Solid Smokeless Fuel	Natural Gas	Oil	Electricity	Non Fuel	Total
Energy Supply								
Energy Consumption								
Industry: Iron & Steel	112	11,318	-	925	65	663	914	13,997
Industry: Other Combustion	2,651	-	-	21,019	12,145	23,251	477	59,544
Industry: Other Processes	1,617	-	-	1,775	6,673	-	7,052	17,117
Commercial	28	-	-	11,722	367	20,779	308	33,205
Agriculture	-	-	-	181	4,455	1,291	366	6,292
Miscellaneous	-	-	-	-	-	-	283	283
Rail Transport	36	-	-	3	2,151	1,325	-	3,514
Domestic	1,565	-	999	59,530	8,198	31,113	26	101,431
Public	359	-	-	7,932	174	4,514	-	12,979
Road Transport	-	-	-	-	124,098	38	283	124,419
Inland Waterways	-	-	-	-	920	-	-	920
Land Use Change	-	-	-	-	-	-	-15,099	-15,099
Water Transport: National Navigation	-	-	-	-	5,491	-	3	5,494
Air Transport	-	-	-	-	1,604	-	-	1,604
Military Transport (Air & Water)	-	-	-	-	1,702	-	-	1,702
Exports	-	-	30	-	6,592	628	-	7,250
International aviation and shipping	-	-	-	-	4,222	-	-	4,222
Total	6,368	11,318	1,029	103,087	178,857	83,602	-5,387	378,874

Legend and Notes:

Energy producers	Energy Users	Others (CO ₂ emissions not related to fuel use)
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Sectors: Excluded from Local CO₂ estimates in italics;

2 Industrial and Commercial Electricity

2.1 Allocating Emissions to Electricity Consumption

Electricity consumption data for 2005-2016 at Local Authority level for England, Wales and Scotland are published on the gov.uk website⁵. More limited data are also available for Northern Ireland (see **Section 2.2**). These datasets have been used to map CO₂ 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 terms of kt CO₂ 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 2016 (Brown *et al*, 2018). The factors used are shown in **Table 3**. The end user CO₂ 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 industrial and commercial users.

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 Gemserv 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.

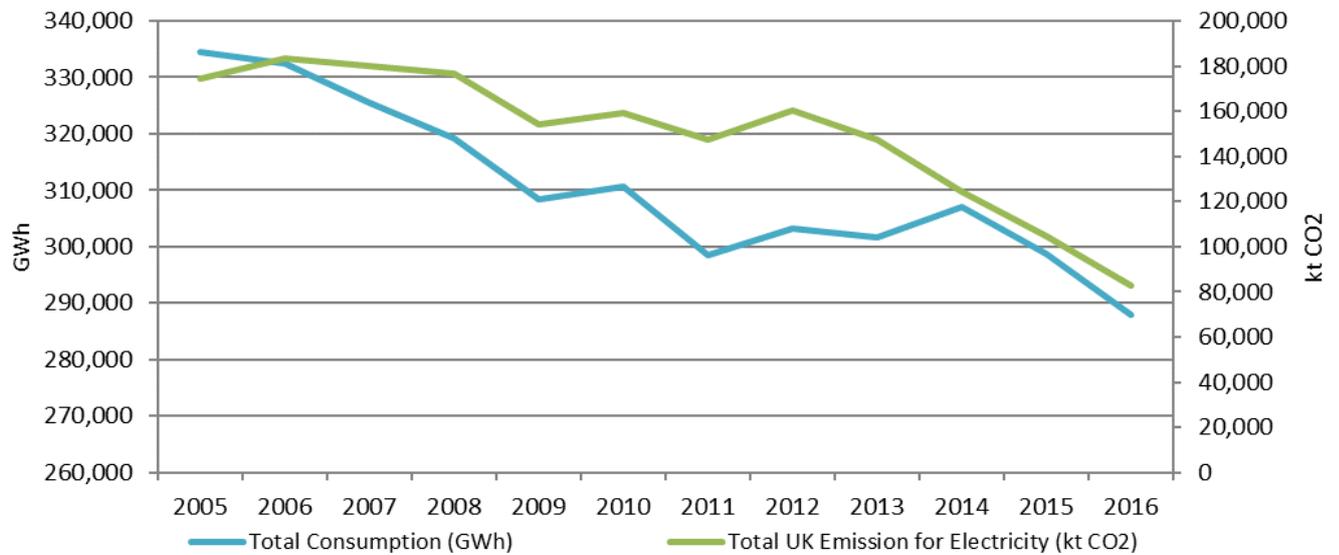
Each meter is allocated a profile class, which enables consumption of domestic customers (profiles 1 and 2) to be identified from the consumption of industrial and commercial customers (profiles 3 to 8). In addition, profile 1 and 2 meters are reallocated to the industrial and commercial sector if annual 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, 2017c).

Table 3 Electricity CO₂ factors used in this analysis

Year	Total UK Emission for Electricity	Total Consumption GWh	Electricity CO ₂ Factor (kt CO ₂ per GWh)
2005	174,583	334,561	0.522
2006	183,427	332,495	0.552
2007	179,884	325,464	0.553
2008	176,587	319,082	0.553
2009	154,288	308,414	0.500
2010	159,390	310,601	0.513
2011	147,171	298,537	0.493
2012	160,274	303,210	0.529
2013	147,272	301,689	0.488
2014	124,483	307,011	0.405
2015	104,772	298,824	0.351
2016	82,973	287,998	0.288

Note: includes Northern Ireland electricity consumption

⁵ <https://www.gov.uk/government/collections/sub-national-electricity-consumption-data>

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 large drop in consumption between 2008 and 2009 likely to be associated with the economic recession. Emissions in 2009 decline 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 longer trend from 2005 is a significant decrease (BEIS, 2017b).

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 2016, the emission factor was the lowest it had been since 2005, since coal fired generation was much lower 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 to increasing renewable capacity and rise in nuclear generation due to a fall in outages in the fourth quarter of 2014 (BEIS, 2017a). Overall, the emission factor has declined by 45% between 2005 and 2016.

2.2 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 website⁶. 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

⁶ <https://www.gov.uk/government/collections/sub-national-electricity-consumption-in-northern-ireland#local-authority-data>

public distribution network. In order to develop a consistent time-series from 2005-15 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 and 2016 are similarly extrapolated such that the total is consistent with calendar year sales data.

In addition, total electricity sales, as reported by NI suppliers, are available in annual sub-national electricity and gas consumption reports (e.g. BEIS, 2017b). For all years, there is a statistical difference between total electricity sales and the sum of published meter point data (e.g. BEIS, 2017e) because of incomplete records at the detailed scale. Therefore, some additional consumption needs to be distributed to Local Authorities, including the unallocated sector, on the basis of the year-specific relative consumption within each to account for this. This additional consumption is split between domestic and non-domestic use on the basis of the year-specific ratio that may be derived from the published meter consumption dataset. For 2016, data on total electricity sales have been estimated through extrapolation from 2015 due to concerns over time-series consistency from the sub-national publication. In 2016, the total electricity consumption in Northern Ireland is therefore estimated to be 7,605 GWh.

2.3 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 also includes 3,373 GWh in 2016 of electricity as direct sales to high voltage lines that cannot 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 3.45% in the industrial and commercial sector and 0.23% in the domestic sector in 2016.

3 Industrial and Commercial Gas Consumption

3.1 Allocating Emissions to Gas Consumption

The gas consumption data published by BEIS provide estimates of gas consumption by the domestic sector and the industrial and commercial sector for each LA in Great Britain for 2005-2016; these are published on the gov.uk website⁷. These statistics are based on data obtained from Xoserve⁸ 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 covers the gas year – the period covering 1 October through to the following 30 September. The AQ data is an estimate of annualised consumption between two meter readings at least 6 months apart but ideally close to a year apart, with the closing reading taken within the period 1 October to 30 September. However, 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 2014⁹. Unfortunately, the data available to BEIS (formerly DECC) via Xoserve and the independent gas transporters 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, 2017d), which are based on a calendar year and are not weather corrected, or to the sub-national electricity data which are partly calendar year and partly annual from 31st January to 30th January (BEIS, 2017b).

BEIS uses the gas industry standard cut-off point of 73,200 kWh to identify small and medium business consumers. 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, 2017c). The official statistics remain in use for the purposes of the Local and Regional CO₂ Emissions Estimates 2005-2016.

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 40 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 EU Emissions Trading System (EU 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

⁷ <https://www.gov.uk/government/collections/sub-national-gas-consumption-data>

⁸ 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 <https://www.gov.uk/government/publications/overview-of-weather-correction-of-gas-industry-consumption-data>

Data from the Environment Agency database of reported emissions in the EU ETS have been used to estimate fuel use from 2005 to 2016. There are however some discrepancies between the DUKES fuel use statistics and those either reported in the EU ETS or calculated by Ricardo Energy & Environment. These differences mean that the data presented here for Industrial and Commercial emissions of CO₂ 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 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**).

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)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
BEIS estimated excluded gas	110,327	88,519	100,686	100,460	106,335	109,244	104,734	102,576	105,000	100,623	99,200	97,997
Ricardo Energy & Environment estimated excluded gas	78,781	80,955	81,759	81,078	70,900	69,129	66,170	63,913	58,088	57,175	54,581	50,425
Difference	31,546	7,564	18,927	19,382	35,435	40,115	38,564	38,663	46,912	43,449	44,618	47,572
Difference as a percentage of total gas consumption	5%	1%	3%	3%	6%	6%	7%	7%	8%	9%	9%	9%

3.2 Gas consumption in Northern Ireland

Data for Northern Ireland have been added to the BEIS dataset using information on total Northern Ireland gas consumption from energy providers Airtricity and Firmus energy. The recent expansion of the gas network of Vayu is not captured within this dataset due to a lack of data, but is understood to currently only constitute a very minor share of the Northern Ireland gas network.

3.3 Calculating CO₂ Emissions

In order to calculate the total amount of CO₂ emission represented by the BEIS LA gas consumption (i.e. without the excluded large gas users) it is necessary to remove the CO₂ emissions associated with these large users from the national total end user emissions. For this calculation, emissions from gas consumption in Northern Ireland are also removed from total UK emissions as Northern Ireland gas consumption are not weather corrected and it is therefore more accurate to use a UK-wide average emission factor for this part of the gas consumption.

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 CO₂ emission factors for the BEIS sub-national gas consumption dataset are shown in **Table 7**.

These data are revised for the entire timeseries each year due to a variety of factors, primarily improvements to the UK GHG Inventory (Brown *et al.*, 2018) and to DUKES commodity balances (BEIS, 2017d).

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 CO₂ emission equivalent to BEIS LA gas consumption (kt CO₂)

GHGI End User Emissions by Sector		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Industry and commercial combustion (not including power stations)		59,008	55,034	51,916	53,602	44,803	47,183	42,739	44,587	46,069	41,745	42,286	42,476
Agriculture combustion	+	438	389	385	272	282	263	260	223	211	207	190	181
Processes ⁽¹⁾	+	1,259	942	1,289	1,062	801	1,011	672	991	902	985	1,077	901
Total Local CO₂ Industry and Commercial gas use emission		60,706	56,365	53,591	54,936	45,886	48,456	43,670	45,801	47,182	42,938	43,553	43,558
Large users (not including power stations) excluded from this dataset	-	12,540	11,930	12,386	12,380	10,402	9,829	9,160	9,086	8,241	7,746	7,519	6,912
Northern Ireland	-	603	610	623	751	757	911	904	986	1,032	1,115	956	538
Domestic combustion	+	74,045	70,886	68,028	69,142	66,410	74,818	59,374	65,918	66,404	54,749	57,428	59,530
Total emission to distribute using the BEIS sub-national gas data		121,608	114,712	108,610	110,947	101,138	112,534	92,980	101,647	104,313	88,826	92,506	95,637

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

Table 6: Northern Ireland gas CO₂ emission factors calculated from UK inventory data

Year	Total UK Emission for Gas (kt CO ₂)	Total Consumption (GWh)	Gas CO ₂ Factor (kt CO ₂ per GWh)
2005	134,750	694,975	0.194
2006	127,251	658,699	0.193
2007	121,619	630,855	0.193
2008	124,078	645,241	0.192
2009	112,297	583,724	0.192
2010	123,274	641,929	0.192
2011	103,044	536,007	0.192
2012	111,719	581,640	0.192
2013	113,586	589,290	0.193
2014	97,687	506,186	0.193
2015	100,980	523,272	0.193
2016	103,087	539,217	0.191

Table 7: Gas CO₂ emission factors used for Great Britain

Year	Total UK Emission for Gas (to distribute using BEIS gas data) (kt CO ₂)	Total Consumption in BEIS gas data (GWh)	Gas CO ₂ Factor (kt CO ₂ per GWh)
2005	121,608	660,515	0.184
2006	114,712	628,733	0.182
2007	108,610	614,093	0.177
2008	110,947	586,455	0.189
2009	101,138	539,058	0.188
2010	112,534	540,642	0.208
2011	92,980	513,166	0.181
2012	101,647	510,047	0.199
2013	104,313	498,402	0.209
2014	88,826	495,025	0.179
2015	92,506	490,528	0.189
2016	95,637	494,775	0.193

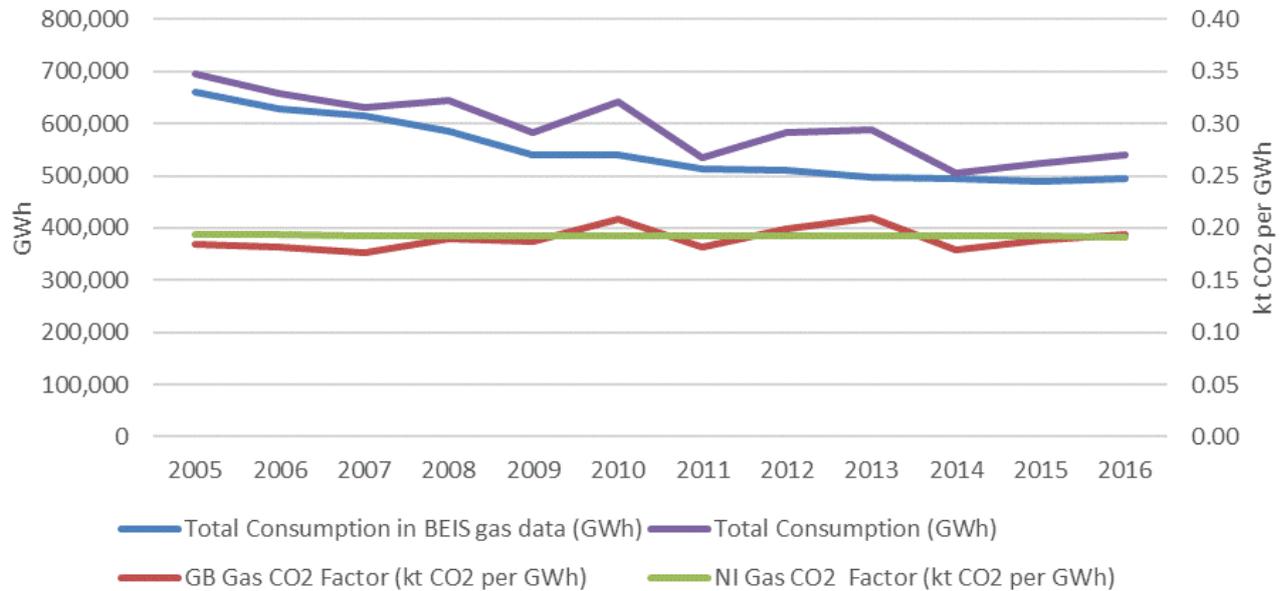
It is important to note that the compilation of the BEIS sub-national gas consumption dataset uses a weather correction factor based on a Met Office model using historic data¹⁰. This takes account of the warmer weather in more recent years (BEIS, 2017c). This is done in order to observe long-term energy consumption trends without being affected by particularly warm or cold years. The total UK CO₂ emissions from gas consumption in the Local CO₂ 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.

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

¹⁰ For more information on weather correction, please see the National Grid's Gas Demand Forecasting Methodology note: <http://www.nationalgrid.com/NR/ronlyres/71CFD0F6-3607-474B-9F37-0952404976FB/52071/GasDemandForecastingMethodologyFeb12.pdf>.

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, 2017b). 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**).

Figure 2 Natural Gas consumption and emission factors, weather-corrected and non-weather-corrected



4 Large Industrial Installations

4.1 Data sources and summary of methods

Emissions from large industrial installations are mapped using the NAEI database of point sources. For this Local Authority CO₂ End User dataset an additional calculation is made in order to account for the CO₂ 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 2005-2016 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 EU ETS.
- Information on emissions of CO₂ from combustion processes during 2005-2016 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 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 CO₂ emissions estimates have been made for the following sectors:

- Power stations, refineries, coke ovens¹¹;
- Other plant regulated as combustion processes under Integrated Pollution Control (IPC) and, more recently, Integrated Pollution Prevention and Control (IPPC);
- Integrated steelworks;
- Cement clinker manufacture;
- Lime manufacture;
- Other plant regulated under IPC and IPPC; and,
- Other sites for which EU 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 EU ETS fuel consumption and CO₂ 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 EU ETS need to be established in order to prevent double counting of emissions and fuel consumption.

¹¹Emissions 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**

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 that report emissions in some years, do not do so in others. 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)¹² because of the use of emissions data reported by operators and also the EU 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 EU 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**.

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 CO₂ 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

¹² Reconciliation tables are published within the full dataset excel file.

Fuel Name	Fuel Category
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

4.1.1 Improvements

The point source data cover the period 2005-2016. There is a programme of continuous improvement and revisions have been made to the point source data for 2005-2015 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 CO₂.

4.2 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.

4.2.1 Fuel use for EU ETS processes

The EA have provided access to the data that the operators of installations in England have reported for fuel consumption and CO₂ emissions in 2005-2016 under the EU ETS. Equivalent data were also received from NRW, (Wales), DAERA (NI), and from SEPA (Scotland).

The type and quantity of fuels burnt by EU 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 EU 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.

4.2.2 Estimating fuel use for non-EU ETS processes

A number of combustion processes are not covered by the EU 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 EU 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 EU ETS data sets. It is therefore necessary to compare the IPPC data with the EU 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 EU ETS data sets, in order that the comparison is accurate. The EU ETS data provided by the EA includes some information on the relationship between the processes covered by EU 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 EU 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 EU 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 EU 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 EU ETS sites to IPPC sites, but we believe that we now have a good understanding of the relationships for most existing EU

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 EU ETS and the IPPC data, and that the scope of IPPC is wider. Most importantly, during phases I and II of the EU ETS, the UK used the medium definition of combustion installations which covers the production of electricity, heat or steam for the purposes of energy production. This meant that, for example, most furnaces used to produce chemicals or melt metals were not covered by EU 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 EU ETS with emissions from processes that are not, for example a chemical industry site could have steam-raising boilers (covered by both EU 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 EU ETS and IPPC installations, it is also necessary to have an understanding of 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 EU ETS and IPPC installations, although limited access to documentation of the scope of EU 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.

4.2.3 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 EU 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 EU 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 EU ETS in 2008, presumably as a result of the *de minimis* rule. For EU 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 EU ETS. As a result, a large number of additional sites started to report to EU 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 EU 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 actually 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.

4.2.4 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 CO₂ for each integrated works but no fuel data. The estimates are site totals only: no breakdown by process is given;
- EU 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 CO₂ emission estimates by process type but not by fuel type.

Unfortunately, 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 EU ETS dataset is the most accurate in terms of fuel use. Therefore, the fuel use patterns shown in the EU 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 EU ETS and, so the emissions from these furnaces are assigned to fuels based on expert judgement.

4.3 Areas of uncertainty in the fuel use estimates

There are a number of issues which produce uncertainty in the local authority CO₂ emission estimates and related fuel use estimates:

- Emission and fuel use estimates for processes included in the IPPC data sets but not in the EU 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 SO₂ 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 obviously 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 SO₂ 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 EU 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. CO₂ 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 CO₂ 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 CO₂ 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 EU 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 EU ETS data for those plants 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 EU 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 CO₂ for each site during 2006-2008 eased this problem and the EU 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 CO₂, such as gas-fired CHP plant, and driers. However, in these cases, cross-comparison with EU 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.
- A number of other processes produce CO₂ 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' CO₂ 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.
- A number of processes reporting in the IPPC data sets only may 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 CO₂ 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.

4.4 Comparison of site specific estimates with the GHGI

A comparison between the total CO₂ 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 CO₂ Emission Estimates at Point Sources by Sector with GHGI data (kilotonnes CO₂) 2016

Source Name	GHGI	Points	Points total as percentage of GHGI total
Autogenerators	1,984	2	0%
Blast furnaces	2,995	2,642	88%
Iron and steel - combustion plant	7,029	6,502	92%
Non-Ferrous Metal (combustion)	469	286	61%
Chemicals (combustion)	7,763	8,086	104%
Pulp, Paper and Print (combustion)	2,130	1,732	81%
Food & drink, tobacco (combustion)	4,292	3,308	77%
Lime production - non decarbonising	335	336	100%
Cement production - combustion	2,260	2,255	100%
Other industrial combustion	17,071	4,232	25%
Railways - stationary combustion	2.54	2.60	102%
Public sector combustion	8,150	1,873	23%
Miscellaneous industrial/commercial combustion	11,646	210	2%
Agriculture - stationary combustion	229	106	46%
Cement - decarbonising	4,553	4,539	100%
Lime production - decarbonising	1,021	1,005	98%
Glass - general	361	365	101%
Brick manufacture - all types	317	308	97%
Ammonia production - combustion	575	529	92%
Ammonia production - feedstock use of gas	868	780	90%
Chemical industry - titanium dioxide	169	169	100%
Chemical industry - soda ash	144	144	100%
Electric arc furnaces	25	42	166%
Basic oxygen furnaces	90	372	413%
Sinter production	1,366	1,425	104%
Primary aluminium production - general	73	68	93%
Incineration - clinical waste	83	82	100%
Incineration - chemical waste	200	359	180%

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 many source sectors are in good agreement – the point source emissions for **cement – decarbonising, lime production - non decarbonising, glass – general, cement production – combustion, lime production – decarbonising, incineration - clinical waste** and **chemical industry - titanium dioxide** are all within a few percent of the GHGI figures.

In many other cases, the point source emission is lower than the national emission and 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**, and **public sector combustion**, are only a small fraction of GHGI emissions, because many combustion plants in these sectors are too small to be included in the EU ETS data or IPPC data sets.

The figures for **autogenerators** reflect the fact that we are largely unable to distinguish between autogenerators and industrial combustion plants in the EU ETS and IPPC data. Therefore, there are almost no point source data for autogenerators, and 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 the percentage given in

Table 9 for autogenerators underestimates the coverage of autogeneration emissions, while overestimating the level of reporting in sectors such as **chemicals (combustion)**.

In the case of combustion in the chemical industry, the point source data actually exceed the national total. This demonstrates the impact of the autogeneration issue – because autogeneration within the chemical 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 paper and food sectors, this problem is not so severe, so the points data are below but still fairly 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 52% of the GHGI total (17,360 ktonnes CO₂, out of 33,240) 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 CO₂ Emissions by Fuel with GHGI data (emissions in kilotonnes CO₂) 2016

Fuel category	Fuel	GHGI	Points	% points
Natural gas	Colliery methane	2	4	171%
	Natural gas	100,786	18,424	18%
Oils	Burning oil	9,929	83	1%
	Fuel oil	1,247	282	23%
	Gas oil	11,653	270	2%
	LPG	3,272	73	2%
	OPG	2,762	2,830	102%
Process gases	Blast furnace gas	9,515	8,730	92%
	Coke oven gas	402	54	13%
Solid fuels	Coal	5,725	1,994	35%
	Anthracite	605	0	0%
	Coke oven coke	962	928	97%
	Petroleum coke	643	364	57%
	Other Smokeless	682	0	0%
Wastes and bio fuels	Scrap tyres	185	187	101%
	Waste oils	0.73	0.73	100%

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 CO₂ emission and fuel consumption estimates derived from the GHGI and the point source data in many areas, but differences in other areas. Often, those 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.

4.5 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 – 2016 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 EU 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 EU 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 EU 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 Industrial and Commercial ‘Other Fuels’

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 emission¹³ is treated as an ‘area source’ and distributed across the UK using modelled high resolution (1 km²) 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.

5.1 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 this year using updated employment and energy statistics. The method used is described in more detail in the document **Employment based energy consumption mapping in the UK** (Tzagatakis, 2015) on the gov.uk website. 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) code¹⁴.
- Energy Consumption in the UK (ECUK) data on industrial and service sector fuel usage¹⁵.
- 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 EU-ETS and from other data obtained by the inventory.
- Xoserve’s Off-Gas Postcode dataset¹⁶
- Business Register and Employment Survey (BRES) annual employment estimates for the UK split by Region and Broad Industry Group (SIC2007)¹⁷

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 in order to be able to calculate 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 in order 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.

¹³ Residual emission is the national total minus the point source emission total for the relevant sector

¹⁴ <http://www.ons.gov.uk/ons/about-ons/products-and-services/idbr/index.html>

¹⁵ <https://www.gov.uk/government/statistics/energy-consumption-in-the-uk> (Industrial and Services tables)

¹⁶ www.xoserve.com/wp-content/uploads/Off-Gas-Postcodes.xlsx

¹⁷ <http://www.ons.gov.uk/ons/rel/bus-register/business-register-employment-survey/index.html>

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, Xoserve's Off-Gas Postcode dataset has been used to identify sites with no 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;
- 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 2009-2016¹⁸;
- Service sector final energy consumption by sub-sector, for the years 2005-2016

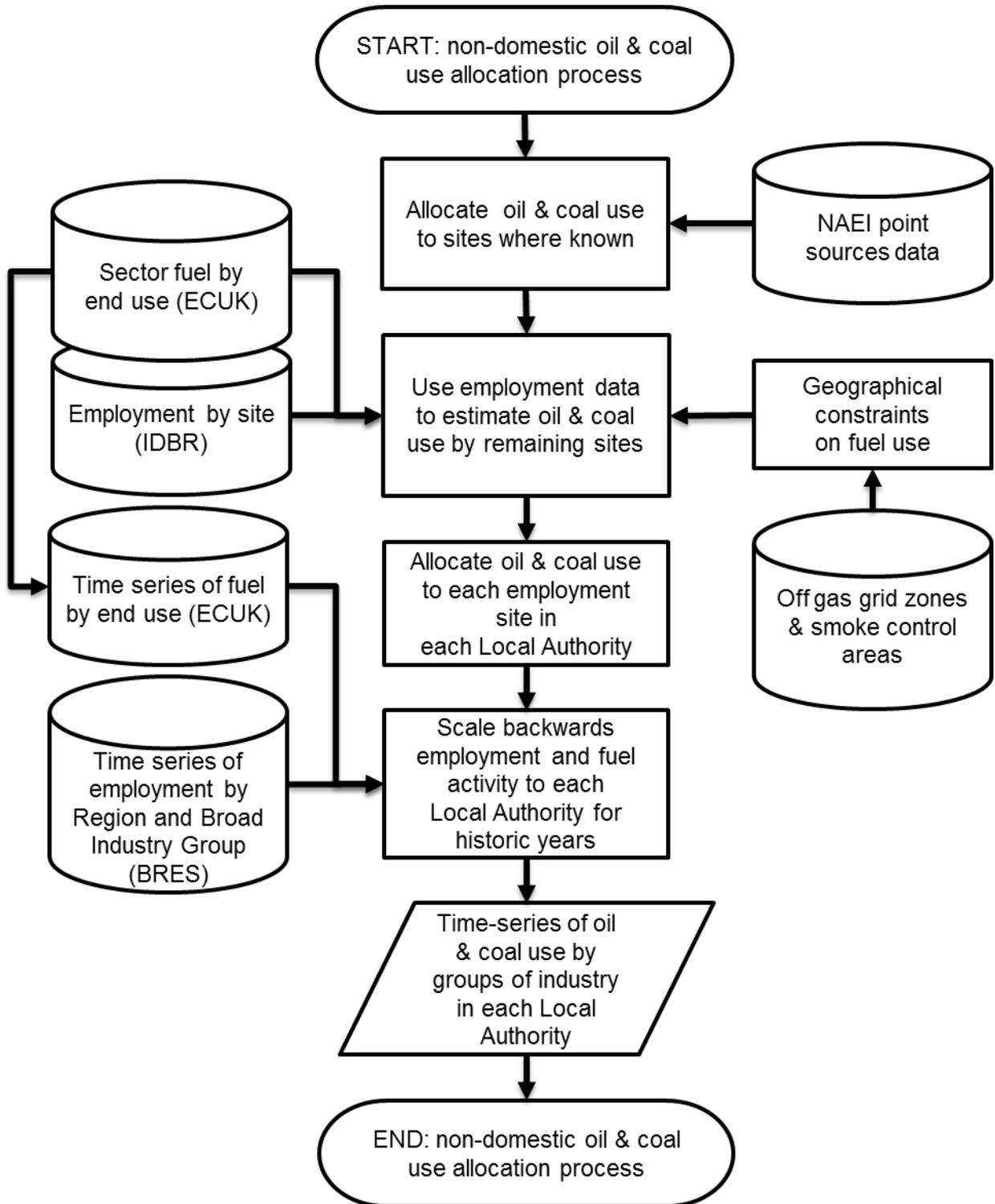
The employment activity was also back-calculated with the use BRES annual employment estimates and applied to each Region and by Broad Industry Group. This was available for the years 2008-2016¹⁹.

Figure 3 shows the process to convert industrial & commercial fuel usage from individual employment sites into emissions.

¹⁸ Pre-2009 ECUK tables were only available at SIC2003 level

¹⁹ Pre-2008 activity has been estimated from earlier NAEI studies

Figure 3 Non-domestic oil and coal use allocation process



5.2 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

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 the consumption of these fuels related to the agriculture sector cannot be disaggregated.

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** (Tsagatakis, 2015).

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.

The agriculture non-fuel sector includes CO₂ emissions from urea application and liming of soils. Prior to the 2017 release of LA CO₂ dataset, emissions from liming had been included in the LULUCF (Land Use, Land Use Change and Forestry) sector, but having been reallocated in the 2006 IPCC guidelines for GHG inventory compilation, are now included in the Agriculture sector. Emissions from urea application and liming are distributed using data on land use provided by CEH and Rothamsted Research respectively.

7 Domestic Electricity Consumption

Electricity consumption data for 2005 to 2016 published on the gov.uk website²⁰ has been used to map CO₂ 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 CO₂ 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 2016. 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, 2017c) 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 2008-2015 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.

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 and the distribution for 2015 has been used for 2016.

Data on total electricity sales as reported by NI suppliers are available in the sub-national electricity and gas summary report (e.g. DECC, 2017b). However, in 2016, an extrapolated value was used in preference to the report due to concerns over time-series consistency. The total electricity consumption in Northern Ireland for 2015 was 7,610 GWh. For all years, there is a statistical difference between the total electricity sales and the published meter point data (BEIS, 2017e). 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 CO₂ emissions from electricity consumption are aggregated to LA can be found in **Section 2**.

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

8 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 2005-2016; these are published on the gov.uk website²¹. The gas consumption estimates for the domestic sector have been used to calculate CO₂ 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, 2017c):

- 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 gas data is based on the gas year whereas DUKES is based on the calendar year;
- the sub-national gas data is weather corrected, whereas DUKES is not weather corrected.

²¹ <https://www.gov.uk/government/collections/sub-national-gas-consumption-data>

9 Domestic ‘Other Fuels’

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 scheme²², with Scottish regions abiding by the Met Office 3-tier regional (Northern, Eastern and Western) classification so as to represent the spatial shifts in climate²³. 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 BEIS Residential wood survey²⁴.

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., 2017).

²² <http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/maps/index.html>

²³ <http://www.metoffice.gov.uk/climate/uk/regional-climates>

²⁴ <https://www.gov.uk/government/publications/summary-results-of-the-domestic-wood-use-survey> (Table 1.1)

10 Road Transport

Road transport fuel use estimates for 2016 at LA level were compiled by Ricardo Energy & Environment for BEIS. The method used is described in this section, with improvements for 2016 summarised at the end of the section.

10.1 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 CO₂ 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 DfT's 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 uses and average vehicle speed is one of them, so the NAEI uses functions that relate fuel consumption to average speed.

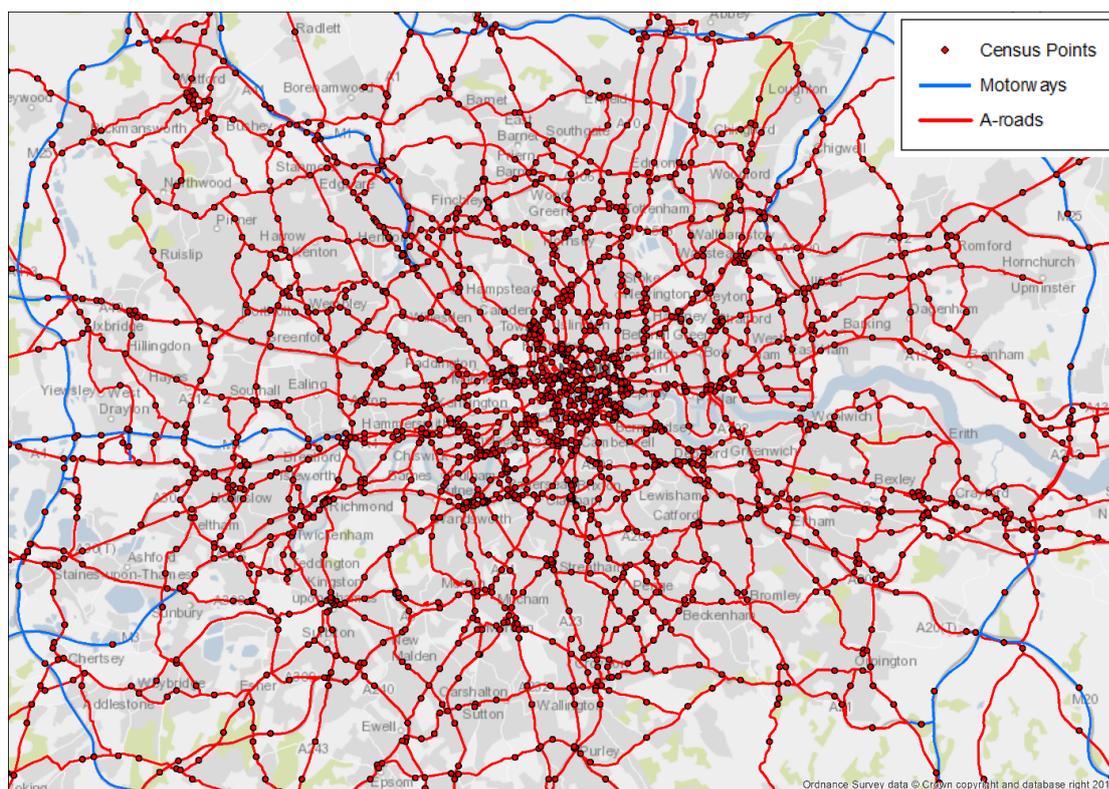
In previous versions of the inventory, these functions were developed by Transport Research Laboratory (TRL) on behalf of DfT in 2009. However, the source of fuel consumption factors changed this year and factors for all vehicle types are now derived from the fuel consumption-speed relationships given 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 (2016). This included a method for passenger cars which applies a year-dependent 'real-world' correction to the average type-approval CO₂ factor weighted by new car sales in the UK from 2005-2016. The new car average type-approval CO₂ factors for cars in different engine size bands were provided by the Society of Motor Manufacturers and Traders (SMMT, 2017). The real-world uplift uses empirically-derived equations in the Guidebook that take account of average engine capacity and vehicle mass. Previous versions of the inventory calibrated speed-fuel consumption curves for HGVs and buses with independent data from DfT on the fuel efficiencies of these vehicles in the UK obtained from surveys of haulage companies and bus operators' fuel returns. However, DfT have recently found the data to be less complete than was previously considered and therefore less suitable for use in the inventory.

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 CO₂, fuel consumption is used as a proxy for the distribution of emissions.

10.2 Road transport mapping methodology

The base map of the UK road network used for calculating the hot exhaust road traffic emissions is derived from the Ordnance Survey Meridian 2 dataset (see **Figure 4**). This provides locations of all roads (motorways, A roads, B roads and Unclassified roads) in Great Britain. In addition, a dataset of roads in Northern Ireland was obtained from the Land & Property Services which is responsible for all of the Ordnance Survey of Northern Ireland.

Figure 4: Illustration of the detail in the road network and count point database



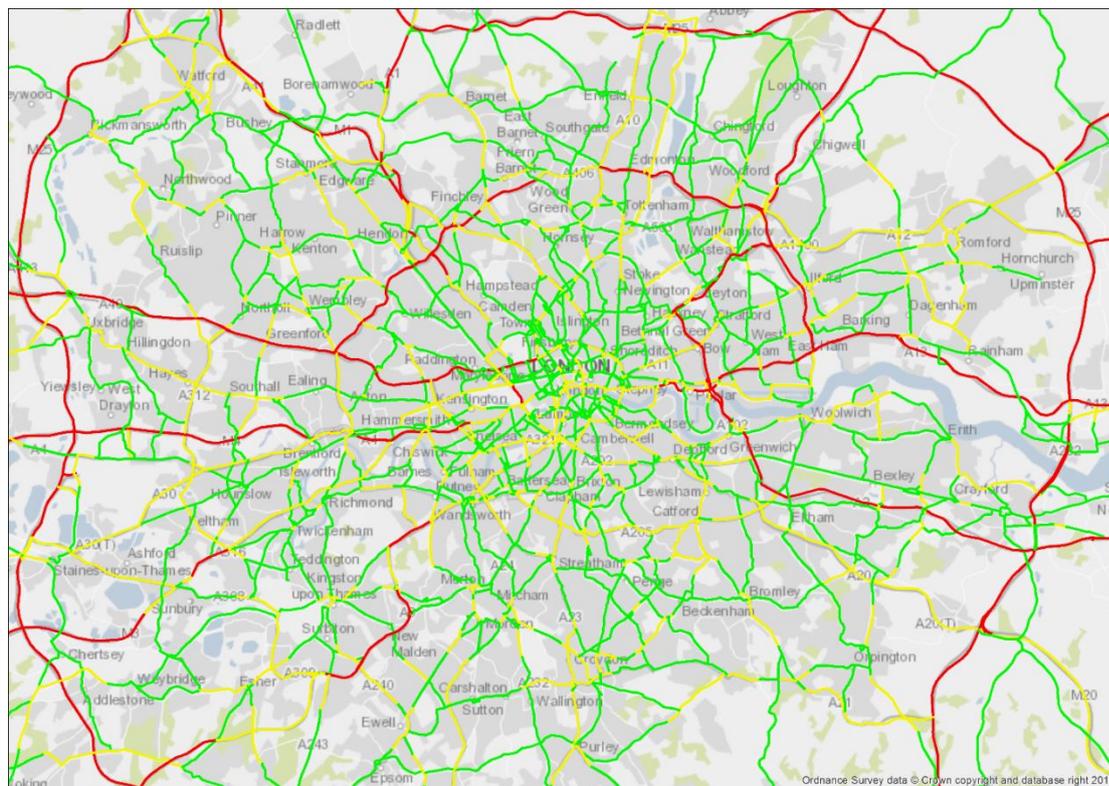
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10.2.1 Mapping traffic on major roads

Traffic flow data for major roads (A roads and motorways) are available on a census count point basis for both GB (DfT, 2017) and NI (DRDNI, 2017). The coverage of roads in GB is considerably denser than that for Northern Ireland. The traffic flow data includes counts of each type of vehicle as an annual average daily flow. These have been aggregated up to annual flows by multiplying by 365. The Annual Average Daily Flow statistics take account of seasonal variation through the use of 'expansion factors' applied to the single day counts based on data from automatic counts for similar roads and vehicle types. Some Northern Ireland count points only record total vehicles, rather than a split of different vehicle types. An average vehicle split has therefore been applied to these.

Each traffic count point has been allocated to a section of the major road network according to the road name and its proximity to the road by using a GIS script – i.e. each link has the nearest count point with the same road name assigned to it (**Figure 5**).

Figure 5: Flows are assigned to the road links using a GIS script



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10.2.2 Mapping traffic on minor roads

Traffic flow data are not available on a link by link basis for the majority of minor roads. But where these data are available they have been used to enhance the accuracy of the mapping. Minor road count points have been allocated to minor roads in a similar way to that described for major roads, but also using census point local parameters (LA, Area type, distance). Traffic flows in the majority of 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 Northern Ireland vehicle-specific minor road flows have been calculated from 2014 data (DfI NI, 2016) which provides information on vehicle kilometres travelled for vehicle types and by road types.

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

10.2.3 Vehicle fleet composition

A development in the 2010 NAEI was the use of DfT's Automatic Number Plate Recognition (ANPR) data to define the fleet composition on different road types for the whole of GB while combining DA-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 2016 NAEI to define:

- Petrol and diesel 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 revised methodology can be found in the UK Informative Inventory Report (Wakeling *et al*, 2018).

10.2.4 Fuel consumption calculations

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

Each major road link has been assigned an area type using the DfT definitions of urban area types shown in **Table 11** below. Vehicle speeds have then been assigned to different road types (built up and non-built up A roads and motorways) within each area type.

Table 11: Department for Transport Urban Area Type Classification

Area Type ID	Description	Population
1	Central London	N/A
2	Inner London	N/A
3	Outer London	N/A
4	Inner Conurbations	N/A
5	Outer Conurbations	N/A
6	Urban Big	> 250,000
7	Urban Large	>100,000
8	Urban Medium	> 25,000
9	Urban Small	> 10,000
10	Rural	N/A

Vehicle kilometre estimates for each road link are multiplied by fuel consumption (or emission factors) taking into account the average speed on 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 average speeds 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 km² across the UK and the results are aggregated to LA boundaries for the estimates of fuel consumption published by BEIS.

The use of an average speed 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 average speed of the vehicle in the drive cycle (Zachariadis and Samaras, 1997). Emission factors for average speeds on the road network are then combined with the national road traffic data.

10.3 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.

Although no major improvements were carried out in the 2016 cycle, a review of traffic counts on specific roads was undertaken to ensure that the most appropriate count points were used. As in previous years,

updates were made to the road network to ensure new roads and count points are fully incorporated. Updates to the road network made use of the latest OS Open Roads GIS dataset (this replaces OS Meridian 2 which has been discontinued).

11 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. Instead emissions attributable to electricity consumption in the rail sector are included in the commercial and industrial sector, and only diesel emissions are shown as a separate sub-sector.

Emissions from railways in the national inventory also include emissions from combustion of coal which have been included in DUKES. These emissions make up 2% of all railway emissions in the Local CO₂ data. The method used is described in the 'Transport – Other' section as this is where the emissions are reported.

The UK total diesel rail emissions are compiled for three journey types: freight, intercity and regional. The rail mapping methodology has been updated for the 2011 emission maps. The emissions have been spatially disaggregated using data from the Department for Transport's Rail Emissions Model (REM). This provides emission estimates for each strategic route in Great Britain for passenger and freight trains. The emissions along each rail link are assumed to be uniform along the length of the rail link, as no information on load variations is yet available. The most recent year in REM is 2009/10 and therefore the 2011 emissions for each strategic route have had to be scaled using emission totals for 2011. These were then distributed across Great Britain with the use of GIS data provided by Network Rail, containing the Strategic Routes Sections (SRS) as those have been defined in 2012 (Network Rail, 2012).

Rail emissions are distributed across Northern Ireland using data from Translink (Translink, 2012) on amounts of fuel used on different sections of track aggregated to LA. These data are for passenger trains only as there is no freight activity in Northern Ireland.

Coal based rail emissions have been accounted for by extracting station, line and operating information from the latest version of the 'UK Heritage Railways' website²⁵. This information was then verified against two additional independent UK heritage railway guides^{26, 27} and dedicated webpages for specific lines. National coal based rail 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.

²⁵ <http://www.heritage-railways.com/index.php>

²⁶ <http://www.heritagerailwaysmap.co.uk/>

²⁷ <http://www.steamrailwaylines.co.uk/index.htm>

12 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.

12.1 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.

12.2 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.

12.3 Coal combustion in railways

Coal based rail emissions have been accounted for by extracting station, line and operating information from the latest version of the 'UK Heritage Railways' website²⁸. This information was then verified against two additional independent UK heritage railway guides²⁹ and dedicated webpages for specific lines. National coal based rail emissions were 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 OpenData basemap services provided by ESRI UK. For the remaining stations, activity was assigned to a single 1km grid.

12.4 Inland Waterways

Emissions from inland waterways were first included nationally in the 2010 inventory and were first included in the 2011 LA CO₂ 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 vehicle 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.

²⁸ <http://www.heritage-railways.com/index.php>

²⁹ <http://www.heritagerrailwaysmap.co.uk/>

13 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 CO₂. Generally, emissions are produced from soils and liming of soils and are removed through forest growth. Currently in the UK, LULUCF activities are a net sink resulting in the removal of emissions from the atmosphere.

The Centre for Ecology and Hydrology (CEH) in Edinburgh annually prepares estimates of the uptake (removal from atmosphere) of CO₂ by afforestation and net loss or gain of carbon dioxide from soils (emissions to or removals from the atmosphere) for inclusion in the UK GHG Inventory. These emissions are classified as the LULUCF sector for inclusion in the UK GHG Inventory.

The estimates are reported according to IPCC classification of sources and removals. Estimates for 2016 are shown in **Table 12**. 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.

For some Local Authorities, a large change in emissions/removals for the LULUCF sector has been observed between years in the Local CO₂ dataset. Overall net removals across the UK (excluding Harvested Wood Products, which is not mapped) have increased in magnitude by 39% since 2005. The most significant impacts on the time-series for total net emissions are associated with the emission of carbon from cropland soil (4B) and the carbon sink grassland soil (4C). 48% of the total trend is accounted for by land converted to and/or remaining cropland, which decreases in magnitude as a source by around 1.6% per year as soil carbon fluxes due to conversion take many decades to reach equilibrium. Land converted to and/or remaining grassland increases in magnitude as an emissions sink across the time series by an average of around 1.1% per year, accounting for 28% of the total trend in net emissions.

Large changes in carbon stock in forest living biomass for some local authorities, particularly in Scotland, are due to forest management. The forest carbon model assumes standard forest management practice where plantations are harvested and replanted once they reach a certain age. Many conifer plantations in Scotland were planted in the mid-20th century and are now starting to come to maturity and being harvested. This loses a large stock of living biomass in the mature trees which is replaced with a much smaller stock in the young tree.

The most significant recalculations have been made to estimates of emissions from sector 4A, which have been revised due to;

- changes in estimated areas of forest, arising from the use of new planting statistics and the altering of the age assumptions for some areas of woodland,
- improvements to the modelling approach including addition of non-tree vegetation, in-year turnover of fine roots and incorporation of transfer of organic matter to the soil carbon pool, and
- correction of an error in the use of spatial location data for broadleaf forests during disaggregation to LA scale.

Full details of the methodology used by CEH to estimate emissions and removals by LA for 2016 are provided in a separate document supporting this report: **Mapping Carbon Emissions & Removals for the Land Use, Land Use Change & Forestry Sector**³⁰

³⁰ <https://www.gov.uk/government/statistics/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics-2005-2016>

Table 12: Emissions of CO₂ from Land Use Change and Forestry 2016 (kt CO₂)

Category*	Activity	2016 UK total ktCO ₂ emission (+) or removal (-)
4A	Land converted to Forest land and land remaining Forest Land (not including emissions from wildfires)	-24,017.16
4B	Land converted to Cropland and land remaining Cropland (change in soil carbon not including losses from drainage of organic soils)	+10,260.62
4C	Land converted to Grassland and land remaining Grassland (change in soil carbon not including losses from drainage of organic soils)	-10,000.61
4E	Land converted to Settlement and land remaining Settlement (change in soil carbon)	+6,055.14
4B1.2	Cropland remaining Cropland (drainage of organic soils)	+1,701.88
4G*	Harvested Wood Products	-844.66
4C2.2	Forest Land converted to Grassland (deforestation to grassland – not including soil changes)	+658.93
4B1.3	Cropland remaining Cropland (cropland soil management practices)	-644.95
4E2.2	Forest Land converted to Settlement (deforestation to settlement – not including soil changes)	+391.78
4D1	Wetlands remaining Wetlands (peat extraction)	+319.71
4C2.1	Non-Forest land converted to Grassland (change in non-forest living biomass)	-234.39
4C1.2	Grassland remaining Grassland (drainage of organic soils)	+176.80
4B2.1	Non-Forest land converted to Cropland (change in non-forest living biomass)	+132.13
4C1.3	Grassland remaining Grassland (grassland biomass management practices)	+54.87
4E2.1	Non-Forest land converted to Settlements (change in non-forest living biomass)	-53.24
4B1.4	Cropland remaining Cropland (cropland biomass management practices)	+12.45
4A1	Forest Wildfires	+5.10
4B2.2	Forest Land converted to Cropland (deforestation to crop – not including soil changes)	
	Total	-16,025.59

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

14 Uncertainty Analysis

As with any inventory, the end user LA CO₂ 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 2016 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. Further information on LULUCF uncertainties may be found in the separate National Inventory Report (Brown *et al.*, 2018) and Mapping Carbon Emissions & Removals for the Land Use, Land Use Change & Forestry Sector (CEH, 2018).

14.1 Uncertainty in the national sectoral GHG emissions

Uncertainty estimates for the national total GHG emissions, according to IPCC sector³¹, 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 2016 inventory (Brown *et al.*, 2018).

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 GHG inventory are expressed as half the difference between 2.5 and 97.5 percentiles, equivalent for normal distributions to $1.96s/E$, 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 CO₂ 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 13**.

14.2 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 CO₂ 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). **Error! Reference source not found. Table 13** 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

³¹ The Intergovernmental Panel on Climate Change (IPCC) has devised a reporting nomenclature for greenhouse gases where the gases are reported in six major categories.

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 13** 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 guidebook³².

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.

High uncertainties are assigned to some sectors. 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 13 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.

14.3 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 CO₂ estimate is calculated using the sum of the squares method using the equation below.

³² <http://www.eea.europa.eu/publications/emep-eea-guidebook-2013>

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

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 2016 UK emissions excluding LULUCF	National emission error	Geographical Estimated error	Comment on estimated geographical error
A. Industry and Commercial Electricity	13.87%	3.3%	3%	97.7% of postcodes have been located correctly. Additional estimate of uncertainty has been made based on 20% of MPAN readings being estimates.
B. Industry and Commercial Gas	9.68%	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
C. Large Industrial Installations (non-EU ETS)	0.48%	7.2%	5%	Good location information for point sources but still some emissions modelled
C. Large Industrial Installations (EU ETS)	7.77%	1.0%	1%	Grid references for sites provided by operators. Emissions reported and verified though ETS but some variation in quality of monitoring of emissions.
D. Industrial and Commercial Other Fuels	4.75%	14.3%	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
E. Agriculture	1.44%	36.4%	30%	Modelled estimates using fuel and employment distributions for stationary combustion; land use data used to distribute liming and machinery emissions.
F. Diesel Railways	0.58%	18.6%	20%	Modelled estimates using known rail link locations. Emissions along each rail link are assumed to be uniform along the length of the rail link
G. Domestic Electricity (GB)	8.24%	3.3%	3%	98.8% of postcodes have been located correctly. Additional estimate of uncertainty has been made based on 20% of MPAN readings being estimates.
G. Domestic Electricity (NI)	0.23%	3.3%	8%	Based on 92.4% of postcodes being located correctly.

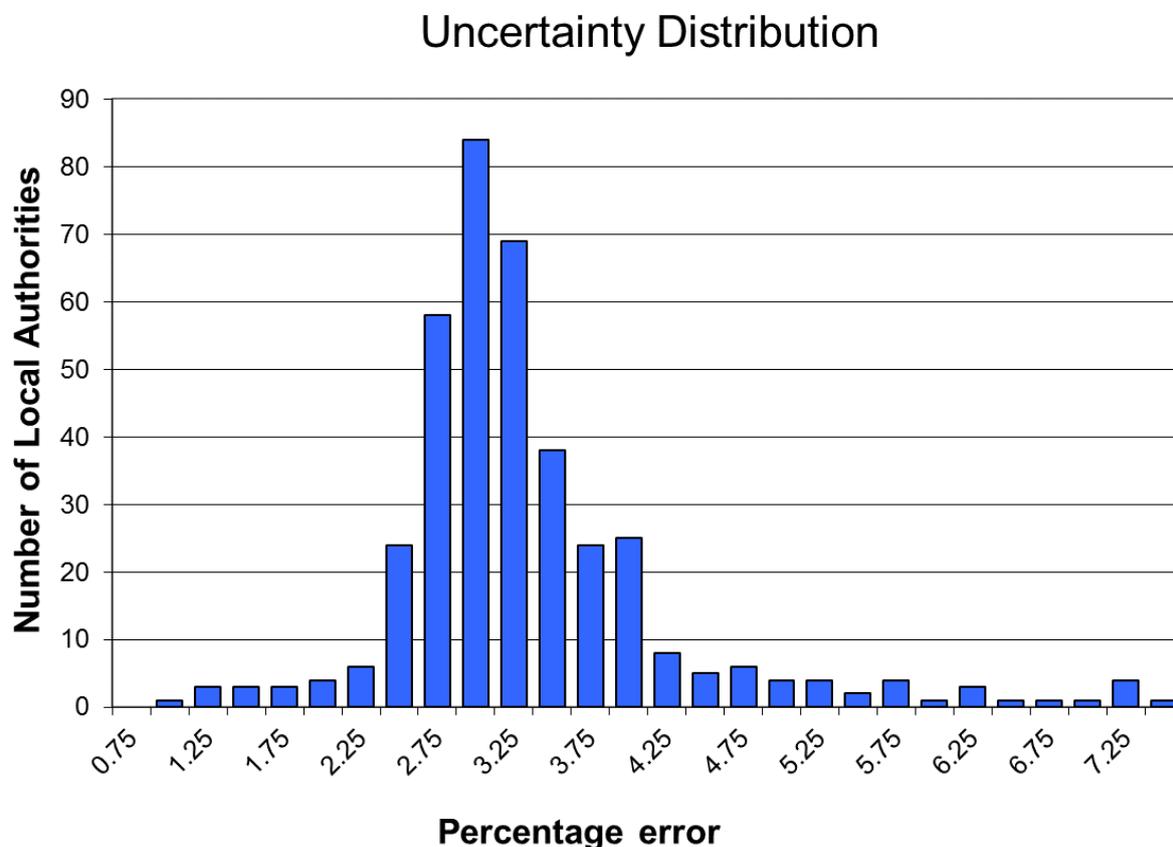
Sector	Percentage of 2016 UK emissions excluding LULUCF	National emission error	Geographical Estimated error	Comment on estimated geographical error
H. Domestic Gas	16.21%	4.6%	3%	BEIS geographical allocation for gas is very good. However, the BEIS definition of domestic gas consumers includes some small commercial users. There is a 3% difference between domestic/non-domestic categories in LACO ₂ and national inventory.
I. Domestic 'Other Fuels'	2.90%	8.6%	10%	Estimates made using complex modelling of household energy demand compared with known gas usage. New distributions of domestic fuel use has been achieved by combining very detailed spatially resolved data on central heating and house type data from the 2011 census. This provides a much better indication of where different fuels are burnt, but still uncertain because of average regional fuel consumption data.
J. Road Transport (A roads)	14.63%	3.3%	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.
K. Road Transport (Motorways)	7.55%	3.3%	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.
L. Road Transport (Minor roads)	11.17%	3.3%	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.
M. Transport Other	0.55%	27.5%	30%	Locations of LPG use and burning of engine oil are not known and are therefore distributed across all road traffic activity. Aircraft support vehicle emissions based on aircraft movements out of airports. Sparse data available for distribution of emissions for inland waterways. Coal combustion from railways has been modelled using information on heritage railways, but the uncertainty remains high.

14.4 Results of the uncertainty analysis

Figure 7 shows how the errors calculated from the sum of the squares method vary across the UK. The percentage error is 3 or lower for 48% of LAs. This proportion is reduced from the assessment for 2015 carried out in 2017, and has fallen substantially over time since as emissions from the more certain sources reduce the overall uncertainty levels increase.

There were no significant revisions to uncertainty factors. Most changes to overall uncertainty have resulted from revisions to the relative contribution of sources to the emission uncertainty.

Figure 6: Uncertainty distribution



The limited spread around the mean may seem surprising given the size of some of the uncertainties in **Table 13**, 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 where the dominance of gas supply is lower so there are more emissions from solid and liquid fuels in the domestic and business/industry sectors.

In percentage terms the smallest estimated spread for any LA is for Neath Port Talbot in Wales ($\pm 0.95\%$). This LA has a significant level of emissions from large EU ETS installations. The largest spread is for Orkney Islands in Scotland ($\pm 10.5\%$) because of the lack of gas supply, little industry and high dependence on oil and solid fuels.

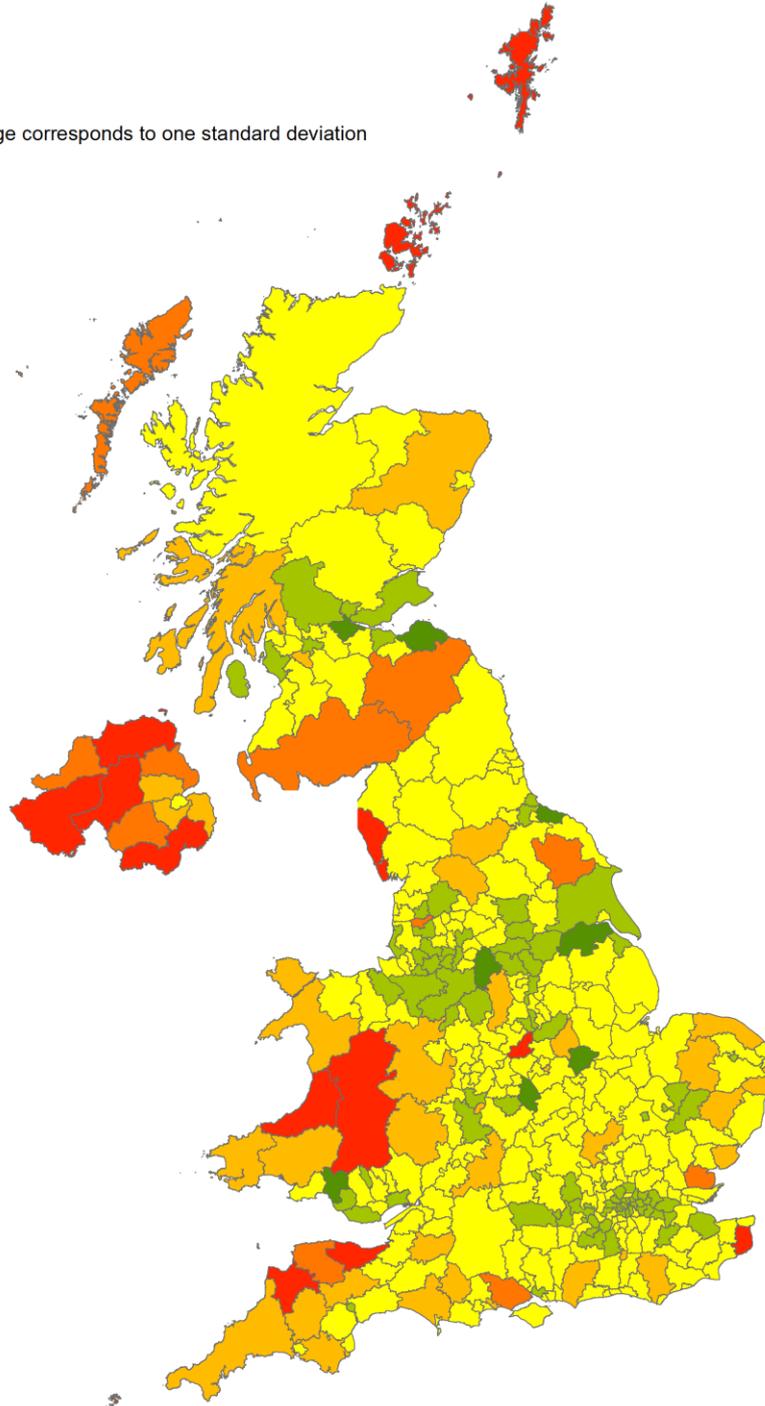
By comparison the National GHG Inventory uncertainty on total UK carbon dioxide emissions for 2016 was $\pm 3\%$. In the Devolved Administration GHG Inventory, for England, Scotland, Wales and Northern Ireland, the comparable uncertainty estimates were $\pm 2\%$, $\pm 20\%$, $\pm 3\%$ and $\pm 8\%$ respectively.

Figure 7: Estimated uncertainty in the CO₂ emissions 2016 (not including LULUCF emissions)

Estimated uncertainty in Carbon Dioxide emissions 2016 (% error)



Each error range corresponds to one standard deviation



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