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Local and Regional Carbon Dioxide Emissions Estimates for 2005–2013 for the UK

Technical Report

Report for Department of Energy and Climate Change

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Executive summary

The local and regional carbon dioxide (CO_2) emissions estimates for 2005-2013 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 CO_2 and energy intensive sectors, monitor changes in CO_2 emissions over time and to help design carbon reduction strategies.

This report, prepared by Ricardo-AEA on behalf of the Department of Energy and Climate Change (DECC), sets out how the local and regional CO_2 emissions estimates for 2005-2013 were compiled. The full dataset – which is classified as National Statistics – and statistical summary can be found on the gov.uk website[1].

The dataset provides a spatial disaggregation of CO_2 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:

- DECC sub-national gas and electricity consumption statistics[2];
- 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).

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 improvements made this year are:

- Updated distribution grids for domestic and non-domestic solid and liquid fuel consumption using off-grid postcodes data (see section 9); and
- Estimation of emissions from drainage of organic soils on grassland are reported for the first time, and emissions drainage of organic soils on cropland have been updated (CEH, 2015).

[1] https://www.gov.uk/government/statistics/local-authority-emissions-estimates
[2] https://www.gov.uk/government/collections/sub-national-gas-consumption-data
[2] https://www.gov.uk/government/collections/sub-national-electricity-consumption-data

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1 Introduction

1.1 Purpose of the work

The dataset provides a spatial disaggregation of the CO_2 emissions from the UK Greenhouse Gas Inventory (GHGI), part of the National Atmospheric Emissions Inventory (NAEI), on an end user basis. The CO_2 emissions are estimated, by sector, for each local authority in the UK. The data help identify the key sources of CO_2 emissions in each area; allow changes in CO_2 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 CO_2 Emissions Estimates for 2005 - 2013 for the UK. It provides a detailed technical description of the methodology.

The dataset is provided in detail in a spreadsheet that accompanies this report (Full_dataset.xls). A summary of results and three further methodology documents also accompany this dataset on the gov.uk website[3]:

- **Statistical summary.** This document provides a commentary on trends and patterns shown in the data.
- **Methodology summary.** This report provides a summary to the methodology used to calculate carbon dioxide emissions (CO_2) at local authority (LA) level.
- **Employment based energy consumption mapping in the UK.** The method statement gives a detailed description of the improvement work to update the modelling of small industrial, commercial and public admin emissions for the 2013 inventory.
- **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.

The following chapters explain the technical approaches used to generate estimates of CO_2 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-AEA, on behalf of DECC 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 (EUMM) 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.

[3] https://www.gov.uk/government/statistics/local-authority-emissions-estimates

1.4 End User basis for reporting emissions

CO_2 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 DECC as National Statistics; however these emissions will be slightly higher than those shown in the local authority breakdown as they include emissions from Crown Dependencies and some other 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 DECC at the national level[4].

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 CO_2 but where the emissions are not related to fuel use, such as industrial process emissions, and land use change).

Table 1 on the next page shows the UK total CO_2 primary emissions in 2013 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 (Webb *et al*, 2014).

[4] The estimates presented in this report are not directly comparable with the National and Devolved Administration Greenhouse Gas Inventories for CO_2. 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 DECC Digest of UK Energy Statistics, DUKES) must be used. The EU ETS data for 2005-13 are not fully consistent with DUKES but were used during the compilation process of allocating consumption to particular industrial consuming sectors.

Table 1 UK Total Primary emissions of CO_2 (kt CO_2 2013)

Sector	Anthracite & Coal	Coke	Solid Smokeless Fuel	Natural Gas	Oil	Electricity	Non Fuel	Total
Energy Supply								
Coke production	-	753	-	-	-	-	506	1,259
Collieries - combustion	7	-	-	11	-	-	137	155
Gas Leakage	-	-	-	-	-	-	7	7
Gas production	-	-	-	4,289	910	-	509	5,707
Oil Production	-	-	-	6,509	1,781	-	3,274	11,563
Iron and steel - flaring	-	2,115	-	-	-	-	54	2,169
Power stations	112,125	-	-	33,173	832	-	2,574	148,703
Refineries - combustion	-	-	-	2,062	12,614	-	-	14,676
Solid smokeless fuel production	80	-	-	-	42	-	-	121
Energy Consumption								
Industry: Iron & Steel	139	14,658	-	1,124	90	-	1,489	17,499
Industry: Other Combustion	5,576	29	-	19,674	9,982	-	609	35,870
Industry: Other Processes	1,349	-	-	1,663	5,483	-	6,818	15,313
Commercial	29	-	-	14,441	212	-	54	14,737
Agriculture	-	-	-	202	3,709	-	247	4,158
Miscellaneous	-	-	-	-	-	-	250	250
Rail Transport	33	-	-	2	1,926	-	-	1,960
Domestic	1,849	18	881	63,514	7,952	-	60	74,273
Public	363	-	-	8,989	137	-	-	9,489
Road Transport	-	-	-	-	106,463	-	186	106,649
Inland Waterways	-	-	-	-	941	-	-	941
Land Use Change	-	-	-	-	-	-	-5,216	-5,216
Water Transport: National Navigation	-	-	-	-	1,268	-	9	1,278
Air Transport	-	-	-	-	2,078	-	-	2,078
Military Transport (Air & Water)	-	-	-	-	2,285	-	-	2,285
Exports	-	-	-	-	-	-	-	-
International aviation and shipping	-	-	-	-	-	-	-	-
Total	121,548	17,573	881	155,655	158,704	-	11,568	465,929

Table 2 UK Total End user emissions of CO_2 (kt CO_2 2013)

Sector	Anthracite & Coal	Coke	Solid Smokeless Fuel	Natural Gas	Oil	Electricity	Non Fuel	Total
Energy Supply								
Energy Consumption								
Industry: Iron & Steel	154	18,081	-	1,174	97	1,451	1,489	22,446
Industry: Other Combustion	5,596	34	-	20,557	11,652	42,061	609	80,510
Industry: Other Processes	1,354	-	-	1,738	6,008	-	6,818	15,919
Commercial	30	-	-	15,090	234	37,239	54	52,647
Agriculture	-	-	-	211	4,093	1,884	247	6,436
Miscellaneous	-	-	-	-	-	-	250	250
Rail Transport	33	-	-	2	2,126	1,982	-	4,143
Domestic	1,855	21	1,019	66,366	8,812	54,802	60	132,937
Public	364	-	-	9,393	151	7,801	-	17,709
Road Transport	-	-	-	-	117,860	16	186	118,062
Inland Waterways	-	-	-	-	1,041	-	-	1,041
Land Use Change	-	-	-	-	-	-	-5,216	-5,216
Water Transport: National Navigation	-	-	-	-	1,399	-	9	1,408
Air Transport	-	-	-	-	1,793	-	-	1,793
Military Transport (Air & Water)	-	-	-	-	2,528	-	-	2,528
Exports	-	50	14	-	7,477	1,509	-	9,050
International aviation and shipping	-	-	-	-	4,266	-	-	4,266
Total	9,386	18,186	1,033	114,532	169,538	148,746	4,507	465,929

Legend and Notes:

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

Sectors: *Excluded from Local CO_2 estimates in italics;*

2 Industrial and Commercial Electricity

2.1 Allocating Emissions to Electricity Consumption

Electricity consumption data for 2005-2013 at Local Authority level for England, Wales and Scotland are published on the gov.uk website[5]. More limited data are also available for Northern Ireland (see **Section 2.2**). These datasets have been used to map CO_2 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 CO_2 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 2013 (Webb *et al*, 2014). The factors used are shown in **Table 3**.

Annualised electricity consumption data was 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 Gemserve database supplied by ECOES (Electricity Central Online Enquiry Service). Where the address information was not available in the Gemserve 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. (DECC 2014b).

The end user CO_2 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.

Table 3 Electricity CO_2 factors used in this analysis

Year	Total UK Emission for Electricity	Total Consumption GWh	Electricity CO_2 Factor (kt CO_2 per GWh)
2005	174,552	334,561	0.522
2006	183,463	332,495	0.552
2007	179,865	325,464	0.553
2008	176,583	319,082	0.553
2009	154,285	308,414	0.500
2010	158,680	310,601	0.511
2011	146,879	298,537	0.492
2012	160,098	303,017	0.528
2013	147,237	301,406	0.489

Note: includes Northern Ireland electricity consumption

From 2005 to 2009 there was a continuous decrease in electricity consumption and a similar trend in the associated emissions, with a large drop between 2008 and 2009 likely to be associated with the economic recession. 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. Following

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

unusually low electricity consumption in 2011 due to a warmer winter, consumption in 2012 and 2013 returned to follow approximately the long-term downward trend (DECC 2014b).

The average electricity emission factor is heavily reliant on the mix of electricity generation types used that year. For example, in the early years of this time series, an increase was observed due to an increase in the proportion of electricity produced using coal, but a record low in coal use in 2009 resulted in a reduction in this average emission factor. During 2010, an increase in coal consumption and a decrease in nuclear power (due to technical problems at some stations) led to an increase in the average emission and supply from gas also increased during this period (DECC, 2011). This emissions factor rose significantly in 2012 as a result of fuel-switching in UK power generation from natural gas to coal, due to rises in the price of natural gas, however this was reversed in 2013, with the emission factor falling back just below the level of 2011.

2.2 Electricity consumption in Northern Ireland

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 consumption data were reduced. As a result of this, figures for domestic electricity consumption in 2008-2011 and non-domestic electricity consumption in 2009-2011 at District Council level in Northern Ireland are available on the gov.uk website[6]. Statistics for 2012 and 2013 are due to be published in September 2015 and will therefore be reflected in the 2016 release of the LA CO_2 emissions statistics, covering 2005-2014. Emissions of CO_2 from industrial and commercial electricity consumption in Northern Ireland are allocated using these sub-national NI non-domestic electricity statistics. These statistics are produced by DECC 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. These data therefore exclude autogeneration that does not pass through the public distribution network.

As these data are only available currently for 2008-11, emissions are distributed for all earlier years in proportion to the electricity consumption in 2008 or 2009 and for 2012 & 2013 in proportion to 2011.

Data on total electricity sales as reported by NI suppliers are available in the sub-national electricity and gas consumption summary report (DECC, 2014b). The total electricity consumption in Northern Ireland for 2013 was 7,834 GWh, and the split between domestic and non-domestic sectors has been produced using the 2011 distribution. For all years, there is some statistical difference between the total electricity sales and the published meter point data, this remains unallocated.

2.3 Unallocated electricity

Where electricity sales within the DECC dataset have not been successfully allocated to specific LAs, they have been assigned to an additional 'unallocated' category. The DECC data also includes 3,879 GWh in 2013 of electricity as direct sales to high voltage lines that cannot be allocated to any region or LA due to the lack of information. Emissions associated with this electricity consumption are included in the final dataset as an unallocated item. The statistical difference between total electricity sales provided by DECC for Northern Ireland and the published meter point data is also included in the unallocated category.

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

This takes the overall percentage of electricity consumption unallocated to LAs, either because of geo-referencing problems, statistical differences or because it is direct sales, to 4.7% in the industrial and commercial sector and 0.5% in the domestic sector.

3 Industrial and Commercial Gas Consumption

3.1 Allocating Emissions to Gas Consumption

The gas consumption data published by DECC provide estimates of gas consumption by the domestic sector and the industrial and commercial sector for each LA in Great Britain for 2005-2013; these are published on the gov.uk website[7]. These statistics are based on data obtained from xoserve[8] 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 Quantities (AQ) gas consumption data supplied to DECC 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, 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. A weather correction factor is applied (except to sites that have automatic meter reading) so that AQ data are adjusted to normal weather conditions. Unfortunately, the data available to 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, 2012a). The methodology for this adjustment is detailed in the 'Overview of weather correction of gas industry consumption data' published by DECC in November 2014[9].

For these reasons, the AQ cannot be exactly aligned to gas consumption data in the Digest of UK Energy Statistics (DUKES) (DECC, 2014d), 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 (DECC, 2014b).

DECC 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.

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-AEA 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 Scheme reports to regulators. This database and the method used to obtain estimates of emissions and fuel use at point sources is described in **Section 4**. These data are included in the Large Industrial Installations sector – Sector C, along with point source emissions from other fuels.

Data from the Environment Agency database of reported emissions in the EU Emissions Trading System (EU ETS) has been used to estimate fuel use from 2005 to 2013. There are however some discrepancies between the DUKES fuel use statistics and those either

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/statistics/overview-of-weather-correction-of-gas-industry-consumption-data

reported in the EU ETS or calculated by Ricardo-AEA. These differences mean that the data presented here for Industrial and Commercial emissions of CO_2 are not fully consistent with the UK GHGI. The differences are described in **Section 4**.

The comparison between the DECC estimated gas consumption for the excluded sites and gas consumption as estimated by Ricardo-AEA 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 Local Authority 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-AEA and DECC estimated gas consumption from large point sources is spread across the DECC Local Authority 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 DECC excluded gas consumption and Ricardo-AEA calculated gas consumption at large point sources

Gas consumption excluded from sub-national dataset (GWh)	2005	2006	2007	2008	2009	2010	2011	2012	2013
DECC estimated excluded gas	110,327	88,519	100,686	100,460	91,235	98,904	94,494	91,506	93,292
Ricardo-AEA estimated excluded gas	72,377	75,636	78,260	78,352	71,767	71,779	67,516	65,842	60,813
Difference	37,950	12,883	22,426	22,108	19,468	27,125	26,978	25,664	32,478
Difference as a percentage of total gas consumption	5%	2%	4%	3%	3%	4%	5%	4%	5%

3.2 Gas consumption in Northern Ireland

Data for Northern Ireland has been added to the DECC dataset using information on total Northern Ireland gas consumption from energy providers Airtricity and Firmus energy.

3.3 Calculating CO_2 Emissions

In order to calculate the total amount of CO_2 emission represented by the DECC LA gas consumption (i.e. without the excluded large gas users) it is necessary to remove the CO_2 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 DECC sub-national gas consumption dataset. The resultant implied CO_2 emission factors for the DECC sub-national gas consumption dataset are shown in

Table 7.

All emissions used in these calculations are ‘end user’ emissions and include emissions from the production and transportation of gas. Power stations’ emissions are not included in any of these calculations as they are distributed by electricity consumption.

Table 5 Calculation of CO_2 emission equivalent to DECC LA gas consumption (kt CO_2)

GHGI End User Emissions by Sector		2005	2006	2007	2008	2009	2010	2011	2012	2013
Industry and commercial combustion (not including power stations)		58,904	54,889	51,923	54,222	44,693	47,926	45,794	45,090	47,055
Agriculture combustion	+	439	390	385	272	283	311	260	223	211
Processes (1)	+	1,260	942	1,289	1,062	801	1,010	672	990	899
Total Local CO_2 Industry and Commercial gas use emission	=	60,603	56,221	53,597	55,555	45,776	49,247	46,726	46,304	48,166
Large users (not including power stations) excluded from this dataset	-	11,506	10,843	11,271	11,403	10,046	9,694	8,963	9,000	8,193
Northern Ireland	-	604	611	623	750	758	911	904	985	1,031
Domestic combustion	+	74,150	71,002	68,066	69,103	66,304	74,798	56,443	66,259	66,366
Total emission to distribute using the DECC sub-national gas data	=	122,644	115,770	109,768	112,505	101,276	113,439	93,302	102,578	105,308

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

Table 6 Northern Ireland gas CO_2 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	134,753	694,003	0.194
2006	127,223	657,478	0.194
2007	121,662	630,736	0.193
2008	124,659	648,624	0.192
2009	112,080	582,349	0.192
2010	124,044	646,115	0.192
2011	103,170	536,298	0.192
2012	112,563	586,241	0.192
2013	114,532	594,532	0.193

Table 7 Gas CO_2 emission factors used for Great Britain

Year	Total UK Emission for Gas (to distribute using DECC gas data) (kt CO_2)	Total Consumption in DECC gas data (GWh)	Gas CO_2 Factor (kt CO_2 per GWh)
2005	122,644	660,515	0.186
2006	115,770	628,733	0.184
2007	109,768	614,093	0.179
2008	112,505	586,455	0.192
2009	101,276	539,058	0.188
2010	113,439	540,642	0.210
2011	93,302	513,166	0.182
2012	102,578	510,047	0.201
2013	105,308	498,402	0.211

It is important to note that the compilation of the DECC sub-national gas consumption dataset uses a 17 year average weather correction, which takes account of the warmer weather in more recent years (DECC, 2014c). This is done in order to observe long-term energy consumption trends without being affected by particularly warm or cold years. The total UK CO_2 emissions from gas consumption in the Local CO_2 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 DECC 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 seen in 2010, due to the unusually cold weather in the latter months of 2012 and the first half of 2013. The DECC subnational gas consumption dataset is weather corrected. 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**).

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 End User dataset an additional calculation is made in order to account for the CO_2 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 2005-2013 which is held in the Environment Agency (EA), Scottish Environment Protection Agency (SEPA), and the Department of the Environment in Northern Ireland (DoE (NI)) databases of installations that are in the EU Emissions Trading System (ETS).
- Information on emissions of CO_2 from combustion processes during 2005-2013 which have been reported by operators regulated under IPPC to the EA for inclusion in the Pollution Inventory (PI), to SEPA for inclusion in the Scottish Pollutant Release Inventory (SPRI) and to DoE (NI) for inclusion in their Inventory of Sources and Releases (ISR). 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 CO_2 emissions estimates have been made for the following sectors:

- Power stations, refineries, coke ovens[10]
- 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 CO_2 emission data

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

  - 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. 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 Greenhouse Gas Inventory (including the Devolved Administration GHGI)[11] because of the use of emissions data reported by operators and also the EU ETS dataset, both of which are independent of the DECC 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 DECC 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 CO_2 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

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

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
Petroleum coke	Solid fuels
SSF	Solid fuels
Landfill gas	Wastes and biofuels
Sewage gas	Wastes and biofuels
Wood	Wastes and biofuels
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 2005-2013. There is a programme of continuous improvement and revisions have been made to the point source data for 2005-2012 in a few instances where additional data have become available, or where other changes (such as changes to the methodology of the UK GHGI) have an impact on the point source data. Most point source data, however, will be unchanged from the values used in the previous version of the local and regional estimates of CO_2.

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 data for installations in England and Wales which reported fuel consumption and CO_2 emissions in 2005-2013 under the EU ETS. Equivalent data were also received from DoE (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 large number of combustion processes are not currently covered by the EU ETS in the UK, for example many driers and furnaces are currently outside the scope of the scheme. In these cases, data may be available from other sources including the Integrated Pollution Prevention and Control (IPPC) data sets (the PI in England and Wales, the SPRI in Scotland and the ISR in Northern Ireland). The IPPC data will also cover many of the combustion processes within the EU ETS data sets. So it is 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 probably 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 CO_2 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;
- Tata Steel Ltd (the operator of the processes) provides CO_2 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 Tata Steel is 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 Tata Steel. The Tata Steel 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 CO_2 emission estimates and related fuel use estimates:

- Emission and fuel use estimates for processes which report to the PI/SPRI/ISR (under IPPC regulations) but not to EU ETS are based on Ricardo-AEA assumptions about fuels used because IPPC does not require reporting of fuel split. These assumptions are based on an evaluation of data such as:
  - Integrated Pollution Control (IPC) authorisation documents which are quite old now but do give an accurate picture of processes in the early to mid-1990s;
  - IPPC authorisation documentation which are much more up to date but only available to us for a smaller number of processes;
  - recent emissions data for pollutants such as metals and SO_2 that could indicate the use of solid or liquid fuels;

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

The uncertainty can be broken down into two issues. Firstly, and perhaps most serious, 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 SO_2 or metals can indicate coal or fuel oil use, so normally, in the absence of emissions data for these pollutants, our assumption has been that gas is the most likely fuel used. In Northern Ireland and some rural areas, gas use is less likely and fuel oil, for example more likely. For many sites, the expert judgements used to allocate emissions to fuels to introduce uncertainty but we believe that in most cases the uncertainty is low.

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

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

- Fuel use estimates for cement works prior to 2008 are uncertain because most sites opted out of the 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. CO_2 is emitted both from fuel combustion but also from the calcination of the limestone and dolomite used to make the cement clinker. Prior to 2006, emissions data from the PI/SPRI/ISR did not indicate how much CO_2 was ‘thermal’ in nature and how much was ‘chemical’ and so cannot be used to give an accurate estimate of fuel use by site. The system of separate reporting of chemical and thermal CO_2 for each site for 2006-2008 eased this problem, allowing an accurate split of fuel-related and calcination-related emissions for the opted-out sites for 2006 and 2007,but this gave no indication of the actual fuels burnt at each site. Reporting of data in the 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 CO_2 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 CO_2, 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 CO_2 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 PI/SPRI/ISR will include both ‘thermal’ and ‘chemical’ CO_2 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 PI/SPRI/ISR data therefore requires assumptions to be made about the split between fuel-related and non-fuel related emissions.
- A number of processes reporting in the PI/SPRI/ISR 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 CO_2 emissions are from fossil fuels but, in the chemical and food industries in particular, it is quite possible that some of the emissions are from process wastes.

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

4.4 Comparison of site specific estimates with the GHGI

A comparison between the total CO_2 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 CO_2 Emission Estimates at Point Sources by Sector with GHGI data (kilotonnes CO_2) 2013

Source Name	GHGI	Points	Points total as percentage of GHGI total
Agriculture - stationary combustion	249	103	41%
Ammonia production - combustion	523	523	100%
Ammonia production - feedstock use of gas	860	706	82%
Autogenerators	2,658	1	0%
Basic oxygen furnaces	102	1,055	1033%
Blast furnaces	3,961	3,900	98%
Brick manufacture - all types	276	290	105%
Cement - decarbonising	4,029	4,029	100%
Cement production - combustion	1,937	1,938	100%
Chemical industry - soda ash	285	285	100%
Chemical industry - titanium dioxide	123	115	93%
Chemicals (combustion)	8,150	9,533	117%
Electric arc furnaces	28	66	234%
Food & drink, tobacco (combustion)	4,497	3,600	80%
Glass - general	389	391	101%
Incineration - chemical waste	171	171	100%
Incineration - clinical waste	80	79	99%
Iron and steel - combustion plant	10,709	10,086	94%
Iron and steel - flaring	2,169	1,393	64%
Lime production - decarbonising	1,239	1,216	98%
Lime production - non decarbonising	388	346	89%
Miscellaneous industrial/commercial combustion	14,737	190	1%
Non-Ferrous Metal (combustion)	493	263	53%
Other industrial combustion	17,968	4,892	27%
Primary aluminium production - general	68	66	97%
Public sector combustion	9,489	1,911	20%
Pulp, Paper and Print (combustion)	1,970	2,082	106%
Railways - stationary combustion	4	4	99%
Sinter production	2,690	2,671	99%

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, blast furnaces, sinter production, railways - stationary combustion, glass - general, cement production - combustion, ammonia production - combustion, lime production - decarbonising, incineration - clinical waste,**

incineration - chemical waste and **chemical industry - soda ash** 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, PI, SPRI or ISR.

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), food, drink and tobacco (combustion), pulp, paper and print (combustion),** and **other industrial combustion**.

In the case of the chemical and paper industries, the point source data actually exceed the national total.. This demonstrates the impact of the autogeneration issue – because autogeneration within the chemical and paper sectors 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 food and drink sector, 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 are 57% of the GHGI total (20,108 ktonnes CO_2, out of 35,244) 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.

Point source figures for **ammonia production – feedstock use of gas** only include emissions from the ammonia production sites, whereas the GHGI figures also include CO_2 which is recovered and sold for use in carbonated drinks (and therefore emitted elsewhere).

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 CO_2 Emissions by Fuel with GHGI data (emissions in kilotonnes CO_2) 2013

Fuel category	Fuel	GHGI	Points	% points
Natural gas	Colliery methane	3	34	967%
	Natural gas	111,373	20,391	18%
Oils	Burning oil	10,435	107	1%
	Fuel oil	869	380	44%
	Gas oil	10,721	226	2%
	LPG	2,252	29	1%
	OPG	3,623	2,893	80%
Process gases	Blast furnace gas	8,002	5,742	72%
	Coke oven gas	747	1,017	136%
Solid fuels	Coal	8,675	2,295	26%
	Petroleum coke	1,687	398	24%
	Other Smokeless	881	0	0%
Wastes and bio fuels	Scrap tyres	193	193	100%
	Waste oils	0	99	N/A

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, OPG, blast furnace gas, 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, coke oven gas, blast furnace gas and petroleum coke, 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. For all waste-derived fuels on the other hand, points figures are equal or higher than those in the GHGI, and in these cases it is likely that the GHGI underestimates the use of those fuels.

In summary, there is very good agreement between in the CO_2 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 (e.g. for waste-derived fuels), 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 – 2013 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 PI/SPRI/ISR 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 PI/SPRI/ISR. 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 emission[12] is treated as an 'area source' and distributed across the UK using modelled high resolution (1 km^2) 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 updated for the 2013 inventory. The method used is described in the document **Employment based energy consumption mapping in the UK** (Tsagatakis, 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) code[13].
- Energy Consumption in the UK (ECUK) data on industrial and service sector fuel usage[14].
- 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 dataset[15]
- Business Register and Employment Survey (BRES) annual employment estimates for the UK split by Region and Broad Industry Group (SIC2007)[16]

The first step was to allocate NAEI point sources to SIC sector and to identify the relevant individual businesses at these locations in the IDBR employment database. This was 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.

[12] Residual emission is the national total minus the point source emission total for the relevant sector
[13] http://www.ons.gov.uk/ons/about-ons/products-and-services/idbr/index.html
[14] https://www.gov.uk/government/statistics/energy-consumption-in-the-uk (Industrial and Services tables)
[15] www.xoserve.com/wp-content/uploads/Off-Gas-Postcodes.xlsx
[16] http://www.ons.gov.uk/ons/rel/bus-register/business-register-employment-survey/index.html

The employment data by SIC codes in the IDBR database were matched with the DECC 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.

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 where used:

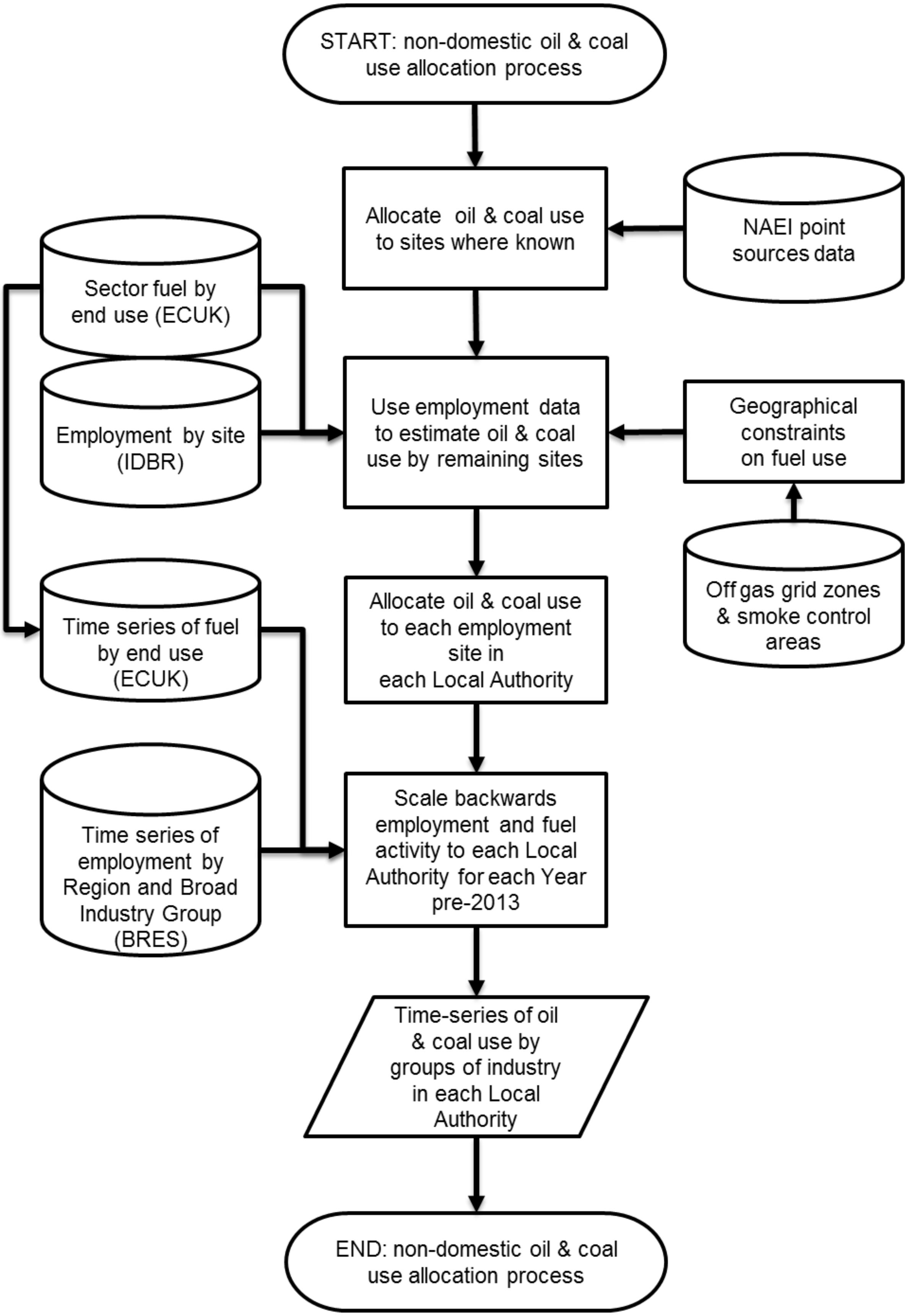
- Industrial final energy consumption at two digit SIC2007 level by fuel type, for the years 2013-2009[17]
- Service sector final energy consumption by sub-sector, for the years 2013-2005

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 2013-2008[18].

Error! Reference source not found. Figure 1 shows the process to convert industrial & commercial fuel usage from individual employment sites into emissions.

[17] Pre-2009 ECUK tables were only available at SIC2003 level
[18] Pre-2008 activity has been estimated from earlier NAEI studies

Figure 1 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 DECC 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 CO_2 emissions from urea application and liming of soils. Previously emissions from liming have 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 both these sources are distributed using data on land use provided by CEH.

7 Domestic Electricity Consumption

Electricity consumption data for 2005 to 2013 published on the gov.uk website[19] has been used to map CO_2 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 CO_2 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 2013. 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 are that the consumption data are not for exactly a calendar year and some consumption is estimated as opposed to actual metered consumption (DECC 2014c).

The DECC 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 2008-2011 at District Council level in Northern Ireland are available on the gov.uk website alongside the Great Britain statistics. These statistics are produced by DECC 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 2011 has been used for 2011 onwards.

Data on total electricity sales as reported by NI suppliers are available in the sub-national electricity and gas summary report (DECC, 2014b). The total electricity consumption in Northern Ireland for 2011 was 7,935 GWh, and the split between domestic and non-domestic sectors has been produced using the 2011 distribution. For all years, there is some statistical difference between the total electricity sales provided in personal communication by DECC and the published meter point data, this remains unallocated.

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

[19] https://www.gov.uk/government/collections/sub-national-electricity-consumption-data

8 Domestic Gas Consumption

The gas consumption data published by DECC provides estimates of gas consumption by the domestic sector and the industrial and commercial sector for each LA in Great Britain for 2005-2013; these are published on the gov.uk website[20]. The gas consumption estimates for the domestic sector have been used to calculate CO_2 emissions for the domestic gas sector using the implied emission factor for Northern Ireland shown in

[20] https://www.gov.uk/government/collections/sub-national-gas-consumption-data

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.**

9 Domestic 'Other Fuels'

Domestic 'other fuel' use distributions are created by spatially resolving detailed local information on central heating and house type data from the 2011 census (output areas of approximately 124 households[21]) with data from DECC's 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 Government Office Region (GOR) classification scheme[22], with Scottish regions abiding by the Met Offices 3-tier regional (Northern, Eastern and Western) classification so as to represent the spatial shifts in climate[23].

The following data series were used in the domestic model:

1. 2011 Census returns on dwelling type and central heating fuel types
    a) Office for National Statistics (ONS) – cross-tabulated records [24]
    - *Census table 'CT0213' provided 2011 estimates classifying all occupied households by type of central heating by dwelling type at the Lower Super Output Area (LSOA) level in England and Wales on census day (27th March 2011). A household's accommodation is classified as having a categorised form of central heating if it is present in some or all rooms (whether used or not).*

    b) National Records of Scotland (NRS)
    - *Information for central heating (only) on the day of census (27th March 2011) at the OA level were collected from table 'QS415SC' of the Scottish census 2011 Release 3C[25].*
    - Information for dwelling type (only) on the day of census (27th March 2011) at the OA level were collected from table '*KS401SC*' of the Scottish census 2011 Release 2C.

    c) Northern Ireland Statistics and Research Agency (NISRA) - cross-tabulated records
    - Census table '*CT0084NI*' provided 2011 estimates classifying all occupied households by type of central heating by dwelling type at the Small Area (SA) level in Northern Ireland on census day (27th March 2011).[26]

2. DECC National Household Model (NHM)[27] regional energy consumption estimates per household by house type by fuel type
    - *2010 regional energy consumption estimates per 400 dwellings of a detailed build form (subsets of census dwelling type) and in the presence of central heating were created by DECC on 31st March 2014 from the NHM scenario "GHG_Emissions_Data_Request" version 3. Coal and oil have been calibrated to DUKES; gas and electricity have been calibrated to metered readings.*

3. Time-series statistics
    a. DECC Sub-national gas connections data by area for England, Scotland & Wales[28]
    b. Natural Gas Suppliers gas connections data for Northern Ireland
    c. DCLG Housebuilding statistics: permanent dwellings started and completed[29]

[21] www.ons.gov.uk/ons/guide-method/geography/products/census/report--changes-to-output-areas-and-super-output-areas-in-england-and-wales--2001-to-2011.pdf
[22] http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/maps/index.html
[23] http://www.metoffice.gov.uk/climate/uk/ws/
[24] www.ons.gov.uk/ons/guide-method/census/2011/census-data/2011-census-data-catalogue/commissioned-tables/index.html
[25] http://www.scotlandscensus.gov.uk/ods-web/data-warehouse.html
[26] http://www.ninis2.nisra.gov.uk/public/Theme.aspx
[27] http://www.cse.org.uk/projects/view/1233
[28] https://www.gov.uk/government/collections/sub-national-gas-consumption-data#lsoa-msoa-data
[29] https://www.gov.uk/government/statistical-data-sets/live-tables-on-house-building

A summary of how these datasets were utilised in the model is given in **Table 11**.

Table 11 Description of methods using the above data series

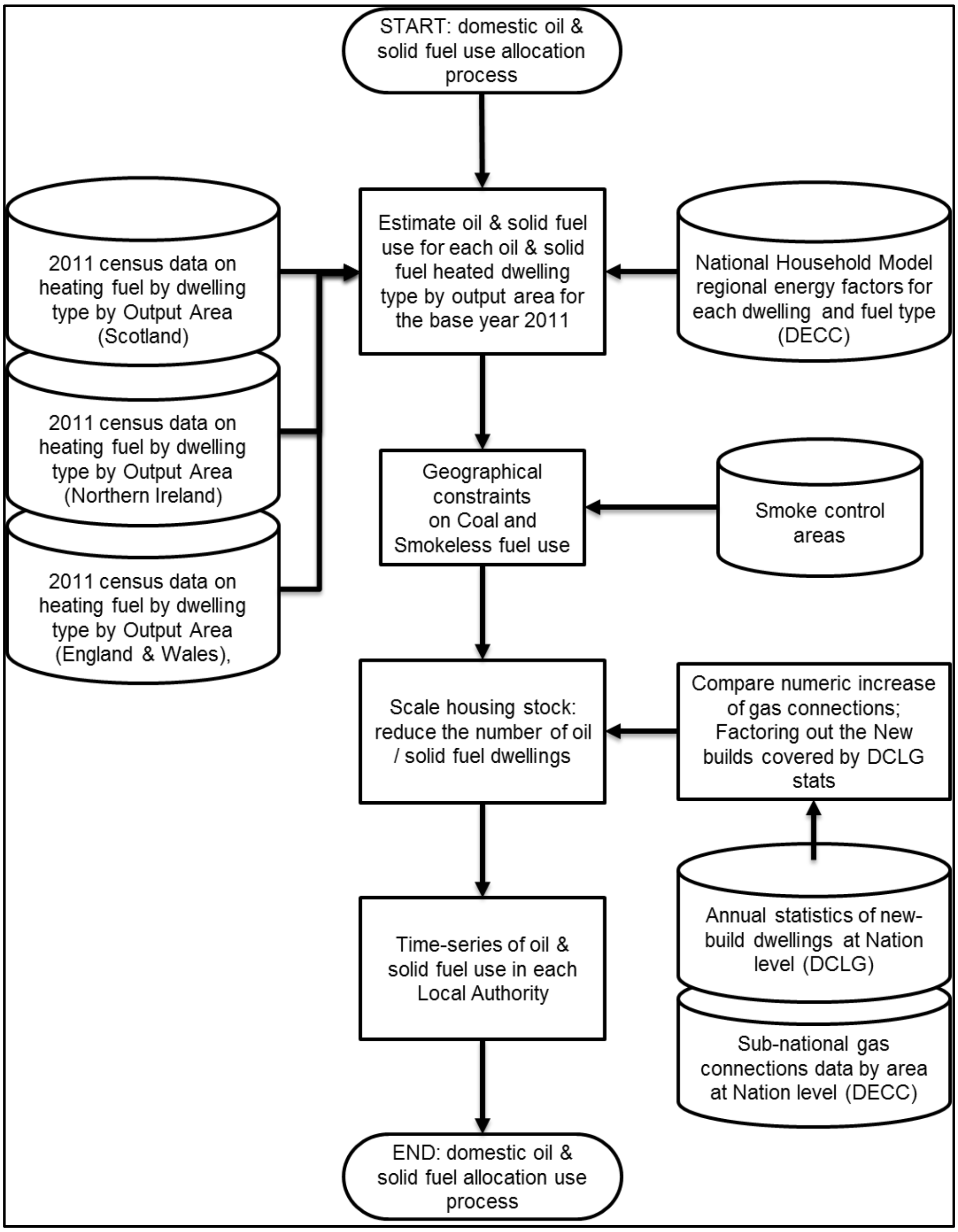
Task and data series used	Application
1	2011 census returns on household types were used to calculate Output Area (OA) counts of dwelling type by fuel characteristics. For England & Wales, ONS cross-tabulated census data provided a breakdown of dwelling type (detached, semi-detached, terraced, flat/other) by central heating characteristics (gas, electricity, oil, solid, and multiple) at the LLSOA. LLSOA fuel splits for a given dwelling type were then applied to OA dwelling type counts, based on geographic nesting. Limitations in the NRS data meant that for Scotland a 2011 OA split of central heating was evenly allocated across counts from the 2011 OA level house type classification. NISRA data across Northern Ireland provided a complete breakdown of dwelling type by central heating characteristics at the SA level. As such, no additional data processing was required.
2	DECC NHM regional energy statistics by dwelling type and heating type (sampled per 400 dwellings) were used to generate spatial distribution databases for domestic gas, oil and solid fuel consumption across England/Wales and Scotland (13 regions: Eastern Scotland, East Midlands, East of England, London, North East, Northern Scotland, North West, South East, South West, Wales, Western Scotland, West Midlands, Yorkshire and Humber). Households characterised as having a central heating system operating with multiple fuel types were assumed to have an even split of the gas, electricity, oil and solid fuel central heating returns occurring in matching house types of that OA. Energy statistics for 'Western Scotland' were deemed most appropriate (building forms and climate) to represent the domestic energy factors within Northern Ireland.
3	The numeric annual increase of gas connections at Country level has been compared against the Census 2011 housing stock number to estimate the percentage change of dwelling which have switched fuels over the years. This was done after factoring out the new builds covered by DCLG stats. This percentage change was then used to scale the base year 2011 housing stock count backward and forward, and therefore produce domestic fuel activity time-series since 2005.

Furthermore, it has been assumed that:

- Coal is burnt exclusively outside Smoke Control Areas;
- Smokeless solid fuels (SSF, coke, anthracite) are burnt exclusively within smoke control areas;
- Wood consumption is assumed to have the same distribution as coal.

Figure 2 presents a high level summary of the data model for the UK which was built to manipulate and analyse the large quantities of data used in this study.

Figure 2 Domestic oil and coal use allocation process



The updates and improvements that have been adopted in the 2013 inventory study, have an impact on the CO_2 data compared to the 2012 inventory release. Key changes have occurred in Scotland through the application of fuel splits to counts of dwelling type from the 2011, rather than 2001 census. Over this period Scottish housing stock has increased by 12.8% to 2,473,881. A few changes may also be observed in the composition of Scottish housing stock between censuses:

- 2001: 20.4% Detached, 23.5% Semi-Detached, 20.2% Terraced, 35.9% Other
- 2011: 22.1% Detached, 22.4% Semi-Detached, 18.5% Terraced, 36.9% Other

10 Road Transport

Road transport fuel use estimates for 2013 at LA level were compiled by Ricardo-AEA for DECC. The method used is described in this section, with improvements for 2013 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 CO_2 or fuel consumption. Nevertheless, the Euro standards are a convenient way to represent the stages of improvement in vehicle or engine design that have led to improvements in fuel economy and are related to the age and composition profile of the fleet. For example, the proportion of pre-Euro 1 and Euro 1-4 vehicles in the national car fleet can be associated with the age of the car fleet (year-of-first registration).

Fuel consumption and emission factors are expressed in grams of fuel or emissions per kilometre driven respectively for each detailed vehicle class and are taken from the following data sources.

- Vehicle emission test data provided by the Transport Research Laboratory (TRL) on behalf of the Department for Transport (DfT), over different drive cycles from measurements on a limited sample of vehicles;
- NO_X emission factors for all vehicle types (except motorcycles) and emission degradation methodology for light duty vehicles based on COPERT 4 (v8.1)[30];
- Car manufacturers' data on CO_2 emissions and surveys with freight haulage companies on fuel efficiency of HGVs;
- Figures from DfT on the Bus Service Operators Grant system (BSOG), an audited subsidy, directly linked to the fuel consumed on local bus services. From this, the costs and hence quantity of fuel used for local bus services are calculated.

However, the amount of fuel that a vehicle consumes in travelling a certain distance depends on many parameters including; the driving cycle, how much stopping and starting a vehicle does, how aggressively the vehicle is driven, the load applied to the vehicle's engine (due to its laden weight or road incline), how well maintained it is, tyre inflation and use of air conditioning etc. It is impossible to evaluate all of these parameters for every vehicle on the road and as a result averages are used for what are in fact quite variable rates of fuel consumption for different groups of vehicle types.

The fuel consumption factors used in the NAEI calculations are polynomial functions expressing the relationship between fuel consumption rate and average vehicle speed for each class of vehicle. These are based on measurements of fuel consumption and emission rates for samples of in-service vehicles taken off the road and tested under controlled

[30] COPERT 4 is a software tool used world-wide to calculate air pollutant and greenhouse gas emissions from road transport. The development of COPERT is coordinated by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre for Air Pollution and Climate Change Mitigation.

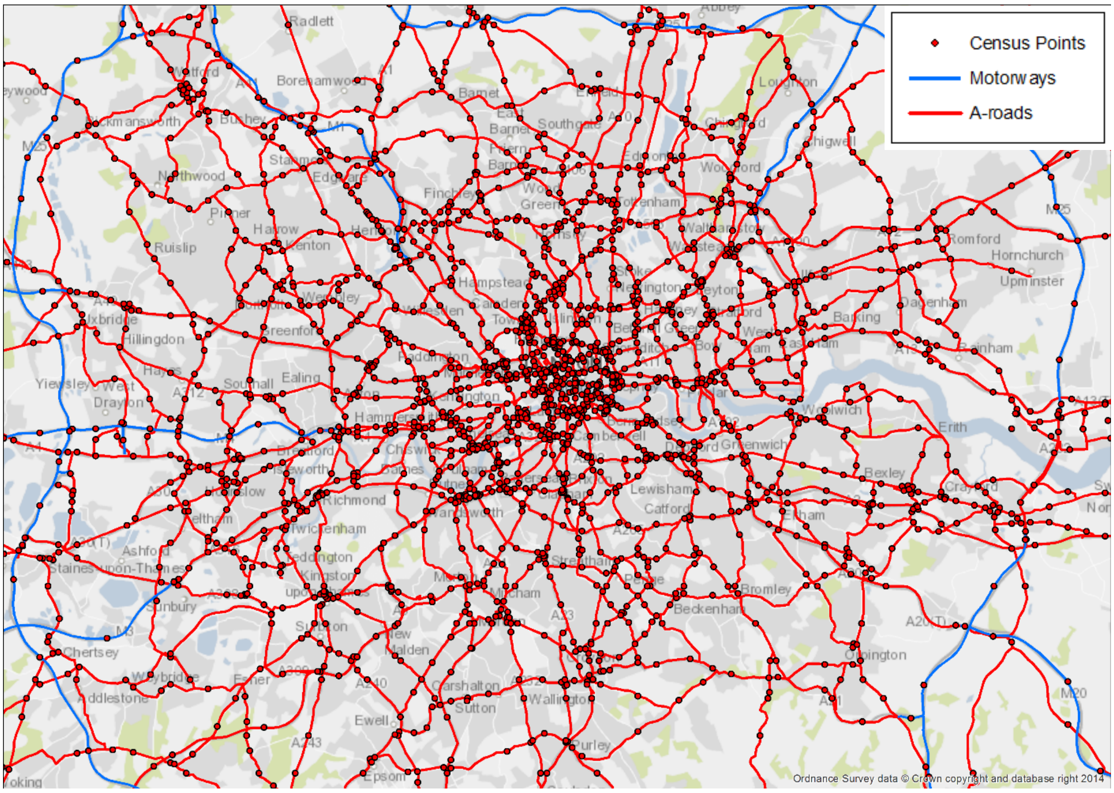
laboratory conditions over a range of different operational drive cycles. The factors used by the NAEI come from a combination of the TRL-maintained database and the COPERT 4 (v8.1) database – both include factors measured over different test cycles that simulate real world conditions (Webb *et al*, 2014). Using average speed of a vehicle is itself a crude, but so far the only kind of indicator, to the way a vehicle operates. There could be many different cycles, all with the same average speed, that have different levels of acceleration and deceleration built into them and for each of these, the fuel consumption rate will be very different.

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 CO_2, 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 dataset (see **Figure 3**). 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 3 Illustration of the detail in the road network and count point database



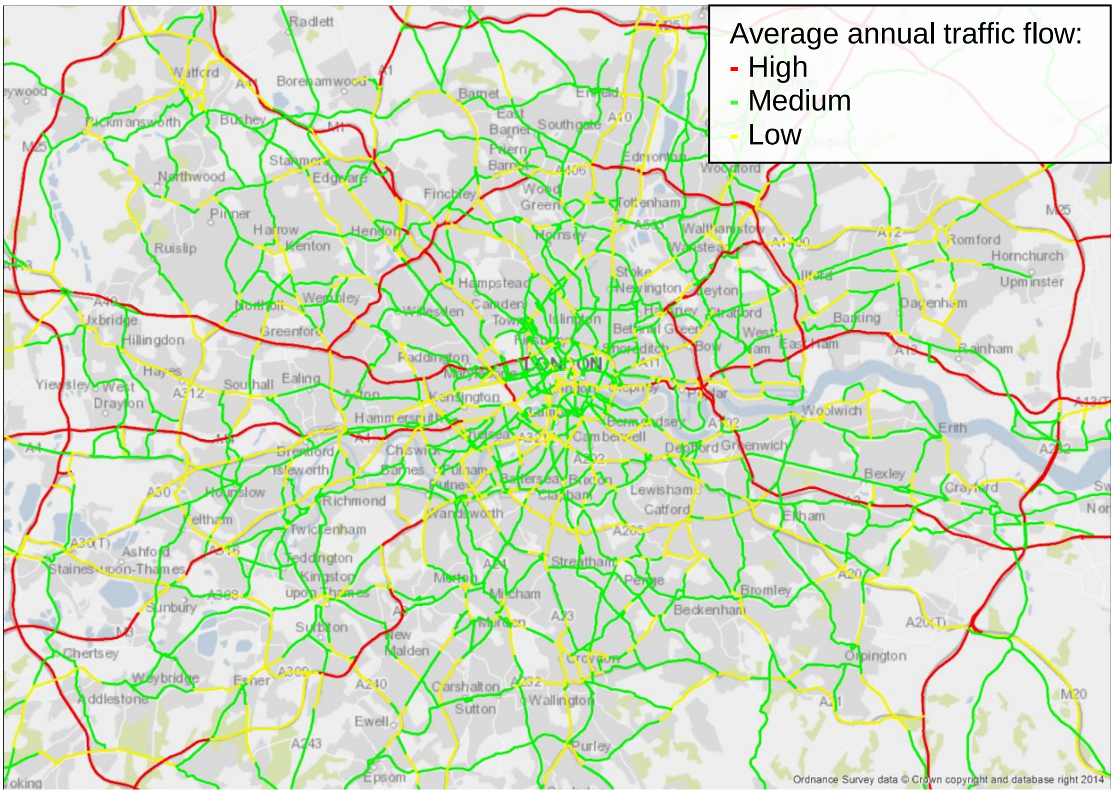
10.2.1 Mapping traffic on major roads

Traffic flow data for major roads (A roads and motorways) are available on a census count point basis for both GB (DfT, 2014) and NI (Roads Service, 2014). 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 4**).

Figure 4 Flows are assigned to the road links using a GIS script



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 data in the 2013 Traffic and Travel Information report (Roads Service, 2014) which provides average flows for all vehicle types by minor roads and also average vehicle splits by the same 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 2013 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 (Misra *et al*, 2015).

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 12** 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 12 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 km^2 across the UK and the results are aggregated to LA boundaries for the estimates of fuel consumption published by DECC.

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.

Improvements introduced for the 2013 inventory include the incorporation of taxi traffic flows in London with the use of data from TfL and an update to the Northern Ireland Road Network GIS layer. The inclusion of the taxi data provides an improvement to the distribution of fuel use throughout Local Authorities in London. The updated GIS layer for Northern Ireland represents more accurately today's real geography and as such distributes fuel use in Northern Ireland with higher precision. The impact of these changes is minor for all LAs, not representing more than a few percent of the LA total.

11 Railways

It is not possible to separate electricity consumed by the railways from that consumed by other commercial and industrial activities in the DECC 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 CO_2 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' website[31]. This information was then verified against two additional independent UK heritage railway guides[32],[33] 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.

[31] http://www.heritage-railways.com/index.php
[32] http://www.heritagerailwaysmap.co.uk/
[33] 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 2007 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' website[34]. This information was then verified against two additional independent UK heritage railway guides[35,36] 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[37]. 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 Local Authority CO_2 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

[34] http://www.heritage-railways.com/index.php
[35] http://www.heritagerailwaysmap.co.uk/
[36] http://www.steamrailwaylines.co.uk/index.htm
[37] http://www.esriuk.com/products/data/online/free-services

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.

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 CO_2. 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 CO_2 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 2013 are shown in **Table 13**. Categories are presented in the table in the order of the absolute magnitude of the net emissions or removals. The emissions are also divided into the categories used for reporting these emissions in the national inventory. The emissions to the atmosphere are given as positive values; the removals from the atmosphere are given as negative values.

For some Local Authorities, a large change in emissions/removals for the LULUCF sector has been observed between years in the Local CO_2 dataset. The largest of these time series changes is associated with land converted to and/or remaining grassland which increases in magnitude as an emissions sink across the time series by an average of around 3% per year.

The most significant impacts on the time-series for total net emissions are associated with the removal of carbon by forest land (4A), and with the emission of carbon from cropland soil (4B). These effects are counteractive since 4A decreases in magnitude as a sink across the time series by an average of 1% per year, and 4B decreases in magnitude as a source by 2% per year. Soil carbon fluxes due to conversion take many decades to reach equilibrium and the trends observed in 4A are a consequence of a falloff in the sequestration potential of forest land planted many years ago.

Large changes in carbon stock in forest living biomass for some local authorities 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.

Full details of the methodology used by CEH to estimate emissions and removals by LA for 2013 are provided in a separate document supporting this report: **Mapping Carbon Emissions & Removals for the Land Use, Land Use Change & Forestry Sector**[38]

[38] https://www.gov.uk/government/publications/local-authority-carbon-dioxide-emissions-methodology-notes

Table 13 Emissions of CO_2 from Land Use Change and Forestry 2013 (kt CO_2)

Category*	Activity	2013 UK total $ktCO_2$ emission (+) or removal (-)
4A	Land converted to and land remaining Forest Land (not including emissions from wildfires)	-17,317.48
4B	Land converted to and remaining Cropland (change in soil carbon not including losses from drainage of organic soils)	10,682.83
4C	Land converted to and remaining Grassland (change in soil carbon not including losses from drainage of organic soils)	-9,805.29
4E	Land converted to and remaining Settlement (change in soil carbon)	5,850.13
4C1	Grassland remaining Grassland (drainage of organic soils)	3,535.95
4B1	Cropland remaining Cropland (drainage of organic soils)	1,701.88
4G*	Harvested Wood Products	-1,120.63
4C2	Forest Land converted to Grassland (deforestation to grass – not including soil changes)	635.58
4B1	Cropland remaining Cropland (cropland management practices)	-407.04
4D1	Wetlands remaining Wetlands (peat extraction)	300.48
4C2	Non-Forest land converted to Grassland (change in non-forest living biomass)	-236.54
4B2	Non-Forest land converted to Cropland (change in non-forest living biomass)	135.45
4A1	Forest Wildfires	58.67
4E2	Non-Forest land converted to Settlements (change in non-forest living biomass)	-53.13
4E2	Forest Land converted to Settlement (deforestation to settlement – not including soil changes)	48.77
4B2	Forest Land converted to Cropland (deforestation to crop – not including soil changes)	2.46
	Total	-5,987.91

* 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 CO_2 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;
- The proportion that each sector contributes to emissions in each LA.

Overall uncertainties in the 2013 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.

14.1 Uncertainty in the national sectoral GHG emissions

Uncertainty estimates for the national total GHG emissions, according to IPCC sector[39], are calculated in the UK's greenhouse gas inventory. This analysis is published in the UK's National Inventory Report, which is updated annually, most recently published for the 2013 inventory (Webb *et al.*, 2014).

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 CO_2 estimates do not match the sectors reported in the National Inventory Report. Therefore the percentage error values have been combined, via calculation of a weighted average (weighted by emission in each subsector and by fuel), in order to give national emission percentage error for each of the sectors. These percentage errors are shown in **Table 14**.

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 CO_2 estimates were compiled. With the exception of the DECC 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

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

Inventories (IPCC, 2006b). **Table 14** provides notes on each sector to help to explain the reasons for the uncertainty scores chosen.

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

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

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

The main reasons for uncertainties in the road transport sector are the use of sample/survey data to represent both vehicle movements and emission factors. Average daily flows and average speeds are used on major road links which does not take account of fluctuations in flows and speeds through the day or year. Regionally average flows and speeds are assumed on minor roads because there is not sufficient data to model this more accurately. However, state of the art national datasets are used in all cases where these are made available and the mapping approach is compliant with the method recommended by international guidance of the EMEP/EEA air pollutant emission inventory guidebook[40].

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 DECC electricity use or gas use datasets.

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

[40] http://www.eea.europa.eu/publications/emep-eea-guidebook-2013

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 CO_2 estimate is calculated using the sum of the squares method using the equation below.

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

where: e is the local emission in the LA for a given sector;
i_1 is the UK emission uncertainty error for that sector;
i_2 is the mapping emission uncertainty error for that sector.

Table 14 Summary of information used in uncertainty analysis and comments on data quality

Sector	Percentage of 2013 UK emissions excluding LULUCF	National emission error	Geographical Estimated error	Comment on estimated geographical error
A. Industry and Commercial Electricity	20.39%	2.6%	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	8.70%	4.4%	3 %	DECC geographical allocation for gas is good. However the DECC definition of domestic gas consumers includes some small commercial users. But there is no numerical estimate of this uncertainty
C. Large Industrial Installations	0.37%	10.5%	5 %	Good location information for point sources but still some emissions modelled
C. Large Industrial Installations - EU ETS	8.97%	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	3.85%	17.6%	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	1.08%	5.3%	30 %	Modelled estimates using fuel and employment distributions for stationary combustion; land use data used to distribute liming and machinery emissions.
F. Diesel Railways	0.47%	20.8%	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

Sector	Percentage of 2013 UK emissions excluding LULUCF	National emission error	Geographical Estimated error	Comment on estimated geographical error
G. Domestic Electricity (GB)	11.92%	2.6%	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)	0.29%	2.6%	7.6%	Based on 92.4% of postcodes being located correctly.
H. Domestic Gas	14.87%	4.7%	3 %	DECC geographical allocation for gas is very good. However the DECC 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'	2.61%	13.8%	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)	11.53%	2.3%	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)	6.12%	2.3%	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)	8.37%	2.3%	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	0.46%	22.8%	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.

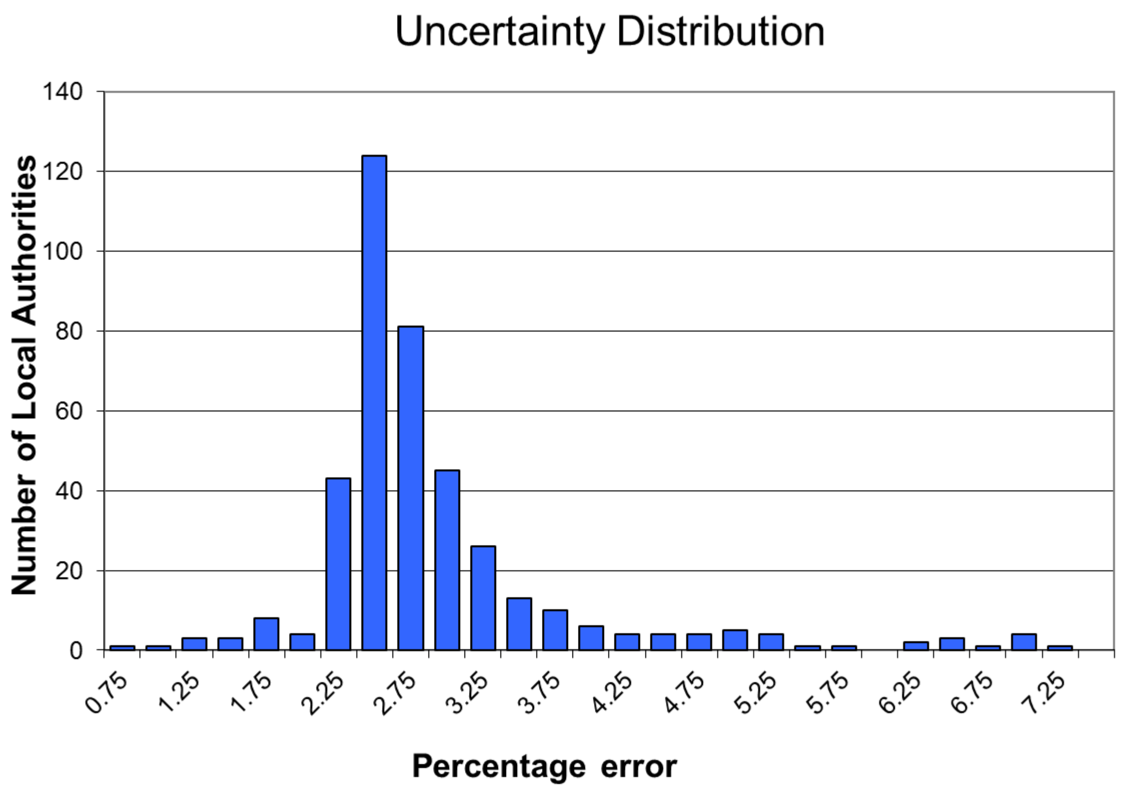
14.4 Results of the uncertainty analysis

Figure 5 shows how the errors calculated from the sum of the squares method vary across the UK. The percentage error is 3 or lower for 77% of LAs. This is 11% lower than in the assessment for 2012 carried out in 2014, due to revisions following a peer review of the national uncertainty model. The major revisions associated with this review were;

- Uncertainty parameters ascribed to activity data, emission factors or emissions in the following sectors were updated: energy (selection of subcategories), industry (selection of subcategories), agriculture (all subcategories) and waste (categories relating to waste combustion). Several sources of data were used: DECC DUKES publication, EU ETS detailed returns, and expert elicitation.
- Methodological changes were made to the error propagation method to optimise the use of the emission factor uncertainty data where categories are aggregated. In our uncertainty analysis, we used an aggregated emission factor uncertainty for each fuel type. The aggregated emission factor was selected as the most representative value from the component sectors. We have improved on this by calculating the aggregate emission factor uncertainties as:

$$U_f = \sqrt{\frac{\sum_i U_{fi}^2 E_i^2}{\sum_i E_i^2}}$$

where U_f are the emission factor uncertainties and E is the emissions from the component sectors, i.



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

1. The smallest uncertainties tend to be for the largest emissions.

2. Uncertainties within individual sectors cancel against uncertainties in other sectors within each LA area to a significant extent.

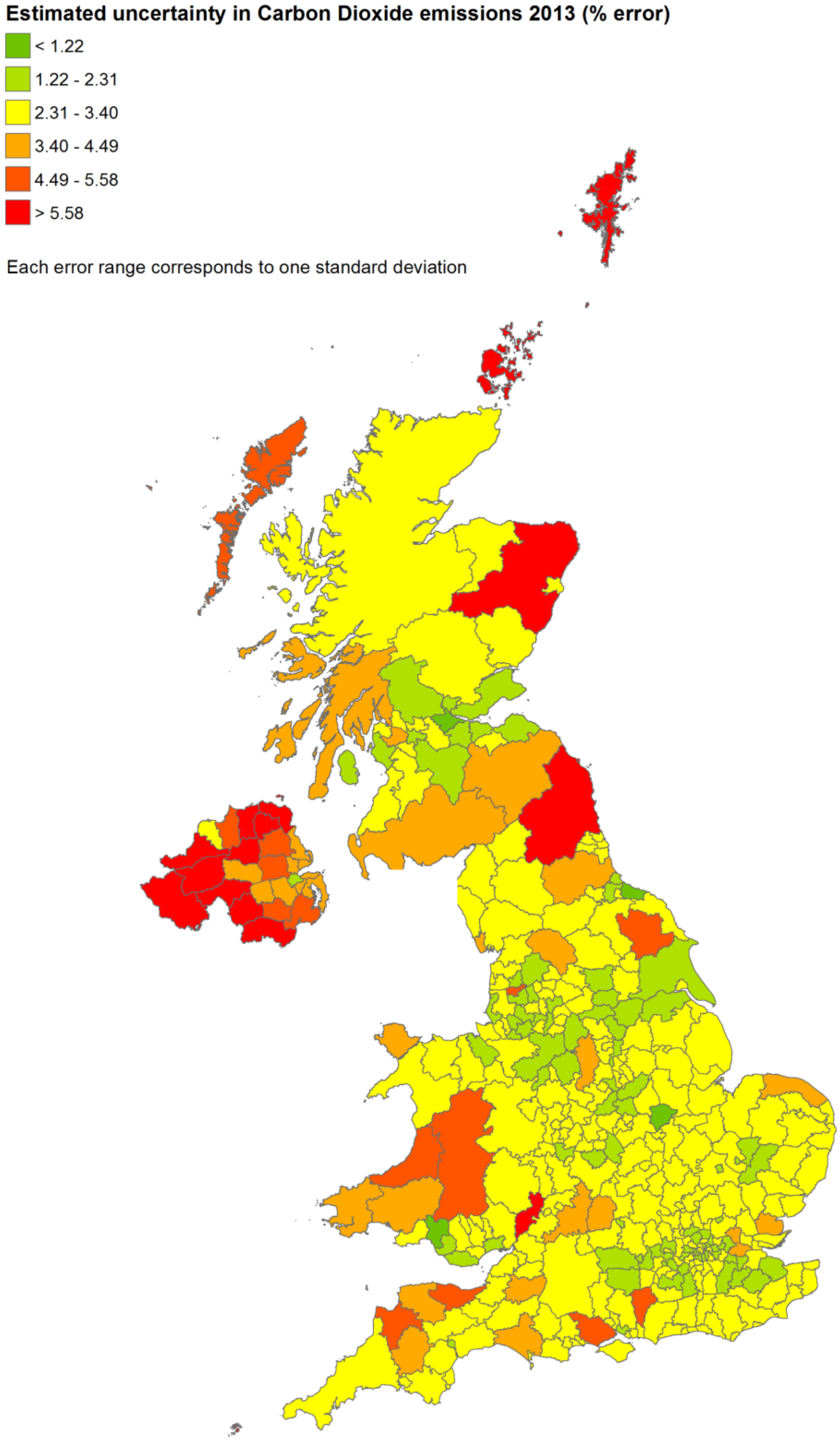
The latter may have important consequences for setting abatement levels by sector within each LA without further analysis at a more local level.

The emissions are dominated by the electricity and gas use in domestic, industrial and commercial sectors for which the UK estimates and the mapping distributions have low percentage errors. Higher overall percentage errors occur 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 Redcar and Cleveland in England (± 0.7%). This LA has a significant level of emissions from a number of EU ETS installations. The largest spread is for Magherafelt in Northern Ireland (± 9.7%) because of the lack of gas supply, little industry and high dependence on oil and solid fuels.

Comparing this with the National and Devolved Administration GHG Inventories, the uncertainty introduced on the national carbon dioxide emissions for 2013 was 2%. For Scotland, Wales, Northern Ireland and England; the comparable uncertainty estimates were 17%, 4%, 8% and 2% respectively.

Figure 5 Estimated uncertainty in the CO_2 emissions 2013 (not including LULUCF emissions)



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