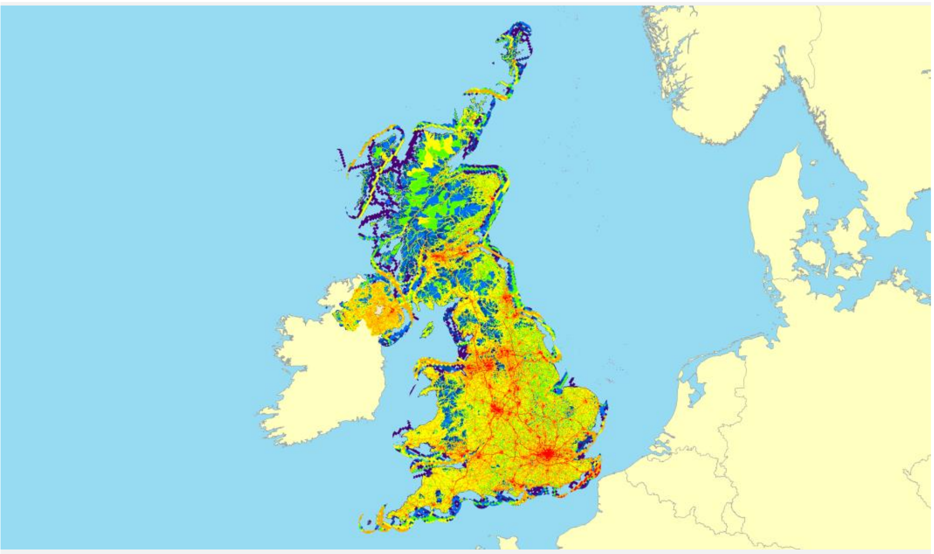
UK Emission Mapping Methodology 2011

A report of the National Atmospheric Emissions Inventory



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List of Abbreviations

CLRTAP	Convention on Long-range Transboundary Air Pollution
DECC	Department of Energy and Climate Change
DUKES	Digest of UK Energy Statistics
Defra	Department for Environment, Food and Rural Affairs
EMEP	European Monitoring and Evaluation Programme
ETS	Emissions Trading Scheme
GHG	Greenhouse Gases
GIS	Geographic Information Systems
INSPIRE	Infrastructure for Spatial Information in Europe
NAEI	National Atmospheric Emissions Inventory
NFR	Nomenclature for Reporting
SEPA	Scottish Environmental Protection Agency
SNAP	Selected Nomenclature for reporting of Air Pollutants
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change

Executive summary

This report describes the methods used to map emissions from each sector in the National Atmospheric Emissions Inventory (NAEI). The maps provide modelled and reported estimates of emissions compiled at a 1x1 km resolution. One set of maps is produced each year for the most recent inventory year. The mapped emissions data are made freely available on the NAEI web site at http://naei.defra.gov.uk/data/mapping.

The geographical distribution of emissions across the UK is built up from a number of map distributions for each sector. For large industrial and commercial sources, emissions are compiled from a variety of official UK regulatory sources. For diffuse emission sources in the UK, distribution maps are generated using appropriate surrogate statistics for each sector. The method used for each source sector varies according to the data available.

The emission maps are used for a variety of Government policy support work at the national scale. In particular, the maps are used as input into a programme of air pollution modelling studies. They are also used to compile and report the UK gridded emissions to the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP). Local area statistics are also compiled from the maps and related data. For example, carbon dioxide emissions and fuel use at the Local Authority level have been produced for Defra and DECC since 2003 using data from the NAEI mapping work. As of March 2008, these datasets were designated as National Statistics. Furthermore, the emission maps can be used by the public to find out the emissions at the point of interest.

Uncertainty analyses have been undertaken to consider the quality of the emission maps for some of the major air quality pollutants and greenhouse gases. Quality ratings have been calculated for point source emissions, area source emissions and the overall emission distribution for each pollutant. The pollutants with the highest quality ratings have a large proportion of their emissions from point sources, whereas pollutants with a greater proportion of their emissions from area sources have lower quality ratings.

The distribution of emissions presented in the NAEI maps has been verified for key pollutants which are used in UK scale air quality modelling. The results for NO_X show good agreement between the spatial pattern of emissions from area sources and background ambient air concentrations recorded at automatic air quality monitoring sites.

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1 Introduction

The UK National Atmospheric Emission Inventory (NAEI) and Greenhouse Gas Inventory (GHGI) are compiled by Ricardo-AEA on behalf of The Department for Environment Food and Rural Affairs (Defra), the Department for Energy and Climate Change (DECC), the Welsh Assembly Government, the Scottish Government and the Department of the Environment for Northern Ireland. This report describes the methodology used to compile spatially disaggregated emissions maps at a 1x1 km grid resolution under the NAEI system.

The NAEI is the reference standard for air emissions in the UK and provides annual estimates of emissions to atmosphere for a wide range of important pollutants including air quality pollutants, greenhouse gases, regional pollutants contributing to acid deposition and photochemical pollution, persistent organic pollutants and other toxic pollutants such as heavy metals. A spatially disaggregated inventory is produced each year.

A great variety of reports describing the methods used for calculating national total emission estimates under the NAEI and other outputs of the inventory system get published every year and can be found on the NAEI website at http://naei.defra.gov.uk/reports/.

1.1 Emission mapping scope and purpose

Emission maps are routinely produced within the NAEI for the 27 pollutants[1], listed below:

1,3-butadiene	Nitrous oxide
Benzene	Methane
Carbon monoxide	Arsenic
Carbon dioxide	Cadmium
Particulate matter (PM_{10}, $PM_{2.5}$, PM_1 & $PM_{0.1}$)	Chromium
Nitrogen oxides (NO_x)	Copper
Non Methane Volatile Organic Compounds	Lead
Sulphur dioxide	Mercury
Ammonia	Nickel
Benzo[a]pyrene	Selenium
Dioxins	Vanadium
Hydrogen chloride	Zinc

[1] 23 pollutants plus 4 species of particulate matter

The maps provide modelled estimates of the distribution of emissions at a 1x1 km resolution and are aggregated to UNECE sectors using the Selected Nomenclature for reporting of Air Pollutants (SNAP) sectors reporting format as shown in Table 1.1 below. Data for large point sources are reported separately.

Table 1.1: UNECE Emissions Sectors Classification

UNECE Sector Code	Description
1	Combustion in energy production and transfer
2	Combustion in commercial, institutions, residential and agricultural sectors
3	Combustion in industry
4	Production processes
5	Extraction / Distribution of fossil fuels
6	Solvent use
7	Road transport
8	Other transport and machinery
9	Waste Treatment and disposal
10	Agricultural, forests and land use change
11	Other sources and sinks

The mapped emissions are made freely available in a neutral file format[2] on the NAEI web site at http://naei.defra.gov.uk/data/map-uk-das. These maps are also available through an online interactive GIS tool at http://naei.defra.gov.uk/data/gis-mapping.

They provide a valuable resource for those interested in local air quality:

- The maps are frequently used as a starting point for many local emission inventories, which may then be used to assess current and future air quality;

- Emission estimates for point sources and emissions arising from the surrounding area are used in modelling studies as part of Environmental Impact Assessments by developers and their consultants.

The emission maps are used for a variety of Government policy support work at the national scale. In particular, spatially disaggregated emissions estimates (1x1 km) and road link-specific emissions information from the NAEI are used annually to underpin Defra's Modelled air quality data[3]. These models are incorporated into the UK's national air quality compliance assessments that are reported to the Commission under European Directives.

They are also used to compile and report the UK emissions to the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP). More specifically, the UK emissions are aggregated to nomenclature for reporting (NFR) codes for Gridding and LPS (GNFR sectors[4]) at 50x50 km EMEP Grid spatial resolution and lately at 0.1°x0.1° long-lat in a geographic coordinate system (WGS84). These datasets are available through the WedDab emission database[5].

[2] ASCII grid format
[3] http://uk-air.defra.gov.uk/data/modelling-data
[4] http://www.ceip.at/fileadmin/inhalte/emep/doc/AnnexIII_Aggregation_gridded_data_300909.doc
[5] http://www.ceip.at/webdab-emission-database/

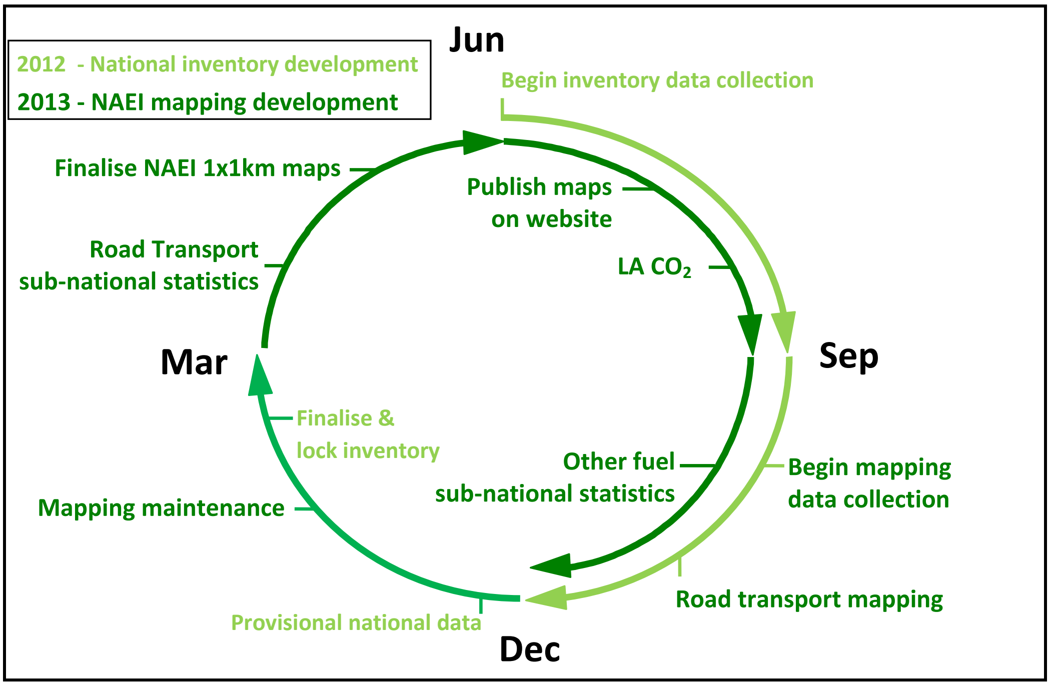
Local area statistics are also compiled from the maps and related data e.g. the Local Authority level data on carbon dioxide emissions (Webb N. , 2013b) and fuel use[6] which have been produced for Defra and DECC (formerly BERR) since 2003. As of March 2008, these datasets were classified as National Statistics.

1.2 Annual cycle of map compilation

The NAEI is compiled on an annual basis. Each year the full inventory time-series is recalculated to take account of improved data inputs and any advances in methodology. Updating the full time-series is an important process as it ensures that the entire dataset is calculates using the most current methodology. National totals and temporal trends are reported to the European Commission (under systems supporting the National Emission Ceiling Directive and the European Union Monitoring Mechanism), UN/ECE, UNFCCC and other international fora.

Historically, emissions maps are routinely compiled for the latest year in the NAEI time-series. Hence, there is no consistent time-series in spatially disaggregated emissions maps. However, for the first time in 2006, a time-series relative to a 2005 base year was calculated for end-user emission maps for CO_2 and sub-national energy consumption estimates. These maps and datasets were developed in order to support national policy on energy consumption and carbon emissions on behalf of DECC. There is a commitment in future years to back-calculate the emissions maps for end-user CO_2 and fuel use to take into account improvements in mapping methodology and to ensure that a comparable time-series starting in 2005 is always maintained.

Figure 1.1: The 2011 NAEI mapping Cycle



The maps are compiled after the inventory is finalised in March each year. This annual cycle of activity is represented schematically in Figure 1.1.

[6] https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/sub-national-consumption-of-other-fuels

2 National Inventory Compilation

The NAEI compiles emissions for a number of individual emission sectors to produce a detailed and accurate estimate of emissions across the UK. For each sector a national total emission estimate is produced from a combination of reported emissions and estimates based on modelling.

The NAEI obtains most of its data on fuel consumption from the Digest of UK Energy Statistics (DUKES). National totals based on these data are further refined for some sectors taking into account other more detailed data from the regulators of industrial processes: the Environment Agency, the Scottish Environmental Protection Agency (SEPA) and the Department of the Environment Northern Ireland (DOENI). Data from the returns under the Emissions Trading System (ETS) are also used.

Emission estimates are calculated by applying an emission factor to an appropriate activity statistic:

$$Emission = Factor \times Activity$$

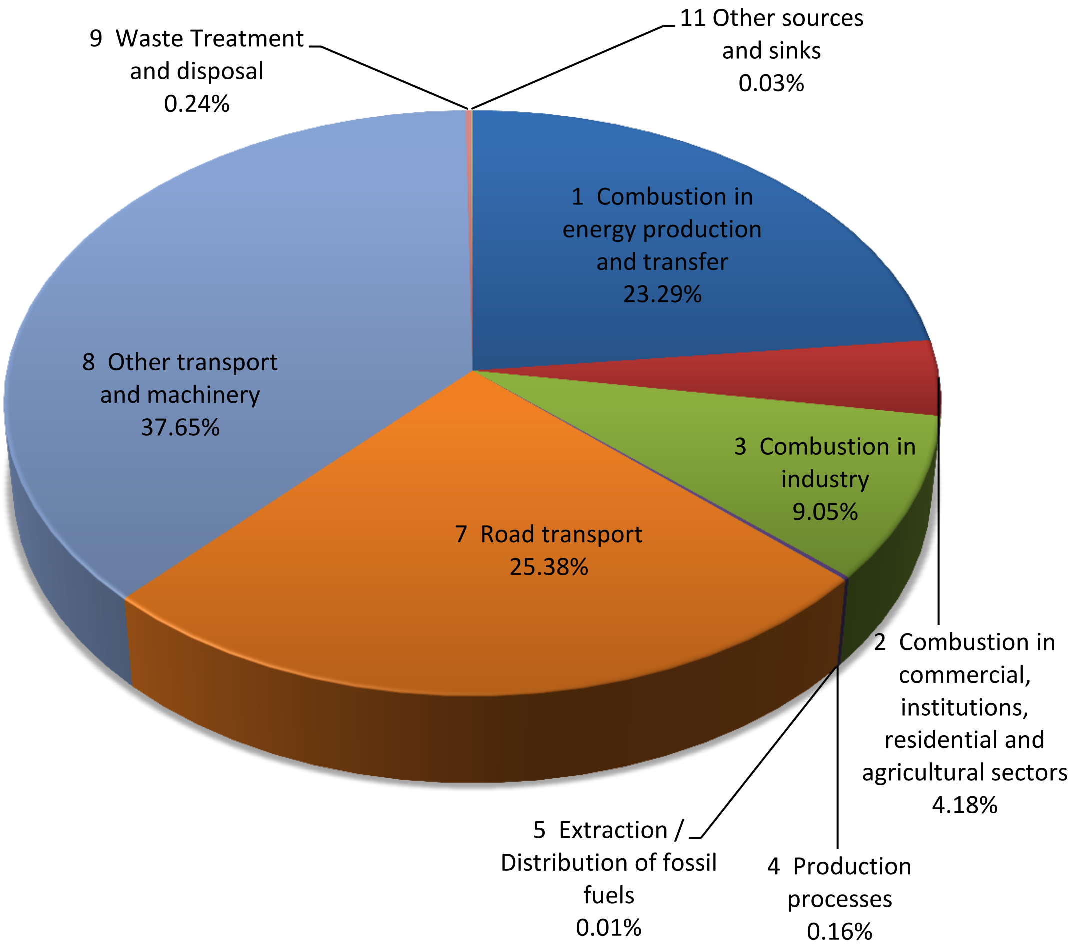
Emission factors are generally derived from measurements made on a number of sources representative of a particular emission sector, the concentrations of elements in fuels burnt, or stoichiometric or empirical relationships between emissions and specific activities. Examples of emission factors include the amount of NO_x emitted from a car per kilometre it travels and the amount of SO_2 emitted from a power station per tonne of coal burned.

Activity statistics are obtained from Government statistical sources, such as DUKES (DECC, 2012), Transport Statistics Great Britain (DfT, 2012a), and from organisations such as trade associations and research institutes e.g. the UK Petroleum Industries Association (UKPIA) provides data on the sulphur content of fuels, and the Institute of Grassland and Environmental Research (IGER) which provides data on livestock numbers and fertiliser usage.

A detailed breakdown of the NAEI source sectors for NO_X in 2011 is shown in Appendix 1, and a summary aggregated to the SNAP sectors is shown in Figure 2.1. Emission estimates of NO_x are in fact compiled in considerably more detail. The NO_x inventory will be used throughout this report as an aide to illustrate the mapping methods used.

The relative contribution of emissions from different sectors varies by pollutant. The Emissions of Air Quality Pollutants document (Defra, 2013) provides details of emissions by sector at a national level.

Figure 2.1: UK NO_X Emissions in 2011 by UNECE Source Sector



3 Methods for calculating emission distributions

The spatial characterisation of emissions across the UK is built up from the component distributions for each NAEI emission sector. These individual sectoral distributions are developed using a variety of statistics appropriate to each sector. For large industrial 'point' sources, emissions are compiled from detailed official sources prepared by the Environment Agency, SEPA, DOENI and Local Authorities. These enable both the geographic location and the magnitude of the emissions to be well characterised. For other sources that are distributed more widely across the UK (known as 'area' sources) and for which less detailed information on the location and magnitude of emissions is available, a map of the distribution of emissions is generated using appropriate surrogate statistics at a sector level. The method used for each source sector varies according to the data available. Table 3.1 presents the types of mapping distributions used for each of the UNECE sectors within the NAEI. The mapping methods used to develop these distributions are explained in the following sections.

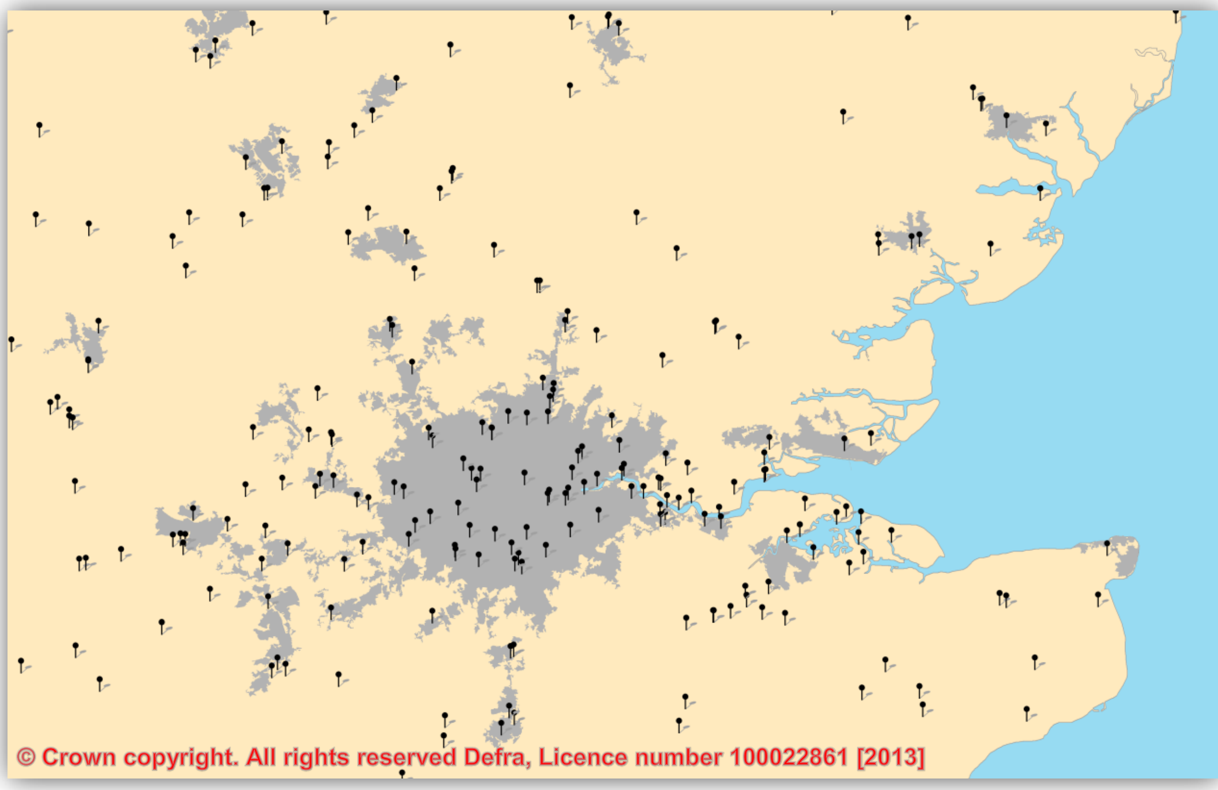
Table 3.1: Methods used to map emissions in each of the 11 UNECE source sectors

Method	UNECE source sectors										
	1	2	3	4	5	6	7	8	9	10	11
Agriculture								✓		✓	
Airports								✓			
Domestic		✓			✓						
IDBR agriculture		✓									
IDBR commercial & public		✓									
IDBR employment	✓	✓	✓	✓		✓		✓	✓		
IDBR industry			✓								
Landfill									✓		
Land-use						✓			✓	✓	✓
Offshore	✓				✓				✓		
Other				✓	✓			✓			✓
Points Sources	✓	✓	✓	✓	✓	✓			✓		
Population				✓	✓	✓		✓			✓
Rail								✓			
Road transport				✓			✓				
Shipping				✓				✓			

3.1 Large industrial and commercial sources

The NAEI receives detailed data on individual large sources in the industrial and commercial sector, also called ‘point sources’. A point source is an emission source at a known location, which has grid references, and therefore, it can be mapped directly (Figure 3.1). Emissions from large point sources across the UK may be either collectively responsible for the full national total emission for that sector (such as coal-fired power stations where the sector is made up of large operational facilities for which emission reporting is mandatory) or in part (such as combustion in industry, for which only the large sites within the sector are required to report emissions). In the latter case, the residual emission (i.e. the proportional of the national total emission not accounted for by individual installations) is mapped as an area source.

Figure 3.1: Illustration of a sample of industrial and commercial point sources in the London area



Emissions for the point sources are compiled using a number of different data sources and techniques. For convenience, the point source data can be divided into four groups:

1. Point sources, largely regulated under the Integrated Pollution Control (IPC) or Integrated Pollution Prevention and Control (IPPC) regulatory regimes, for which emissions data are available to the NAEI from the Environment Agency’s Pollution Inventory (PI), from the Scottish Environment Protection Agency’s Scottish Pollutant Release Inventory (SPRI), from the Inventory of Sources and Releases (ISR) produced by the Department of the Environment (Northern Ireland) or direct from process operators or trade associations;
2. Point sources registered with and trading emission credits under the EU-Emissions Trading Scheme (EU ETS);
3. Point sources, regulated under Local Authority Pollution Control/Air Pollution Control (LAPC/APC) in England and Wales, and in Scotland respectively, for which emissions

data are estimated by Ricardo-AEA on the basis of site-specific data collected from regulators;

4. Point sources where emissions are modelled by distributing national emission estimates over the known sources on the basis of capacity or some other 'surrogate' statistic.

For emissions grouped into (1) above, the most important source of information is the PI which includes emissions data for most pollutants covered by the NAEI. The PI covers processes regulated by the Environment Agency in England and Wales under IPC and IPPC. It does not include any data on processes regulated under LAPC or IPPC by local authorities in England and Wales. Reporting of emissions started in 1991 and is conducted annually. The quality and quantity of reported data has increased in recent years and the level of reporting is very high from the late 1990s onwards. From 1998 onwards, emission reporting is only required where emissions exceed a ‘reporting threshold’, e.g. for carbon monoxide the reporting threshold in 2003 was 100 tonnes and this means that some smaller point sources do not have to report emissions.

The SPRI was first compiled for 2002 and from 2004 onwards it was compiled annually. As with the PI, process operators do not need to report emissions which are below reporting thresholds.

The ISR contains annual data from 1999 onwards and also relies on a reporting threshold to eliminate the need for smaller sources to report emissions.

Additional data on NO_X and SO_2 emissions from processes subject to the Large Combustion Plant (LCP) Directive are available for Northern Ireland and Scotland for 1990 onwards. The LCP data also include data for processes in England and Wales although in many cases these data are also available from the PI.

Some process operators and trade associations also provide emissions data direct to Ricardo-AEA. Notable examples include:

- Corus UK Ltd, who provide data for integrated steelworks broken down into emissions from sinter plant, blast furnaces, basic oxygen furnaces, electric arc furnaces, flaring/losses, stockpiles and combustion plant. PI emissions data for the steelworks do not give this breakdown;
- United Kingdom Petroleum Industry Association (UKPIA) supply emissions data for process sources of VOC and combustion processes at crude oil refineries;
- Oil & Gas UK provide emissions data for offshore oil and gas exploration and production installations as well as various onshore installations linked to the production of oil and gas. These data are taken from the Environmental Emissions Monitoring System (EEMS) database which is compiled for Oil & Gas UK and DECC.

The use of carbon dioxide emissions data from the EU ETS requires careful cross-checking with the PI/SPRI/ISR data, and data from trade associations and process operators. This need arises because there is considerable duplication of emissions in these various sources and it is vital that where emissions data are included from the EU ETS dataset, the same emissions records are not also included from other sources. The cross-checking requires a thorough understanding of how the various processes permitted under IPC/IPPC and reported in the PI/SPRI/ISR correspondingly relate to processes that are permitted under EU ETS. Identifying the same process in each of the data sets is not always straightforward since operator names, site names and even site addresses and postcodes can differ. Over the past few years, the NAEI’s understanding of these relationships has improved greatly and this has led to some revision of data from one version of the maps to the next.

A further complication is that even where a given installation is present in both the EU ETS and other data sets, the exact scope of the emissions data may not be the same. For example, emissions data in the PI will include carbon dioxide from bio fuels, whereas the EU ETS data will not. The PI will also include emissions from driers, furnaces and other plant where fuels are burnt to provide heat which is used within the combustion device. In many cases, the EU ETS data set will exclude the emissions from these types of plant. As a result, there is a need to understand how the scope of each IPC/IPPC permit compares with the scope of each EU ETS permit. This is a major task which would require significant resources to do fully. As an interim proportionate measure, resources have been focussed on understanding the relative scope of permits for those installations which report very different carbon emissions in different data sets. Good progress has been made in understanding key differences; even so, fully understanding these is a work in progress requiring further resourcing going forward. One sector that is particularly complex is that of the terminals receiving crude oil and gas from the North Sea. For these facilities we have emissions data from the EU ETS, the PI & SPRI, and also from the EEMS database, compiled for UK Oil & Gas & DECC. These three data sets often contain very different emissions data for the same installation, and it is not always possible to identify a clear reason for this. Carbon dioxide point source emissions data for complex sources such as these are subject to a high degree of uncertainty and are liable to be revised if new information becomes available.

The EU ETS data gives detailed information on the types of fuels burnt at each site. This is used to split emissions data for pollutants other than carbon dioxide that are available from the PI, SPRI & ISR. The procedure involves generating a fuel consumption profile for each facility and year. Subsequently, a series of default emission factors is used to calculate a theoretical emission of each pollutant and fuel type. These theoretical emissions are then used to calculate an emissions profile for each facility, indicating the likely distribution of emissions between the different fuels burnt at that site. Finally, the emissions profile is combined with the emission data reported in the PI/SPRI/ISR to give fuel-specific emission estimates.

Point source data for some processes regulated under LAPC/APC are based on information obtained on a periodic basis from regulators. This is an important information stream for processes using solvents which are significant sources of VOC emissions but are not included in the PI.

It should be noted, however, that even given the comprehensive information compiled in the above registers and datasets, point source data are not available for all processes. For sources below the reporting thresholds described above, or processes regulated by local authorities, the NAEI may not collect any emissions data from the regulator. Furthermore, some point sources are not regulated. In these cases, point source data are generated using national emission factors and a ‘surrogate’ activity statistic. Examples of this approach are given below:

- Estimates of plant capacity, including estimates made by Ricardo-AEA can be used to allocate the national emission estimate. This approach is, for example, used for bread bakeries where Ricardo-AEA have estimated the capacity of each of about 70 large mechanised bakeries;
- Emission estimates for one pollutant can be used to disaggregate the national emission estimate of another pollutant. For example, emissions of PM_{10} from certain coating processes have been estimated by allocating the national total to sites based on their share of the national VOC emission;
- Assuming that plants which do not report emissions have similar rates of emission as plants within the same sector which do report emissions. In cases where point source data are available for the sector from the PI, emissions data may be missing for a small proportion of sites, generally either because the process is small and emissions are below reporting thresholds or because the site closed that year and did not therefore submit a report. In these cases, emissions are calculated by assuming that these sites will emit at the same rate as other sites for which emissions data are available;
- Emissions can be distributed using surrogate data other than capacity. For example, in the case of Scotch malt whisky distilleries, emissions of VOC from distilling are

distributed using capacity, except in cases where this is not known where the number of stills is used as a measure of the scale of operations and therefore emissions;
- Assuming that all plants in a given sector have equal emissions. In a few cases where there are relatively few plants in a sector but no activity data can be derived, emissions are assumed to be equal at all of the sites.

With the possible exception of using plant capacity, many of the approaches listed above will yield emission estimates which are subject to higher uncertainties than uncertainties associated with mapped emissions from point sources. However, most of the emission estimates generated using these methods are, individually, relatively small and the generation of point source data by these means is judged better than mapping the emissions as area sources. This would mean mapping using surrogate data, such as sectoral employment data or population, which are likely to be poorly correlated to emissions.

The Local and Regional CO_2 technical report (Webb N. , 2013b) describe in more detail the methodology used to calculate the emissions at point sources.

3.2 Other industrial, commercial and public sector consumers

As indicated above, the emissions at large point sources represent a substantial proportion of the total industrial and commercial fuel consumption. Subtracting the site-specific emissions from the NAEI sector total calculates a residual emission[7], which is treated as an ‘area source’. This residual emission is allocated to the UK grid using distribution maps for each sector derived from employment statistics. Each distribution map provides the percentage of the UK’s residual sector fuel consumption estimate to be allocated to each 1x1 km.

Emission distribution maps for the small industrial combustion, public services, commercial and agriculture (stationary combustion) sectors were updated for the 2010 inventory. The method used is described in the document *Employment based energy consumption mapping in the UK* (Tsagatakis, 2012). 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;
- Energy consumption in the UK data based on industrial and service sector fuel usage[8];
- Site-specific fuel consumption as described in **Section 3.1**. 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;
- Display Energy Certificates in England and Wales for public sector buildings / offices larger than 1000 m^2.

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 done 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

[7] Residual emission = national total – point source emission total
[8] https://www.gov.uk/government/publications/energy-consumption-in-the-uk

using the employment data. Table 3.2 describes the calculations done in the services sectors for oil use.

Table 3.2: Calculation of service sector oil consumption in 2009 (thousand tonnes of oil equivalent)

Sectors	Sub-sectors	Final UK energy consumption (ECUK Tables)	Total fuel from site-specific datasets (e.g. Points sources)	Total residual energy for modelling
Agriculture - stationary combustion	Agriculture	284.75	0.26	**284.49**
Miscellaneous industrial / commercial combustion	Communication and Transport	4.11	2.64	**1.46**
Miscellaneous industrial / commercial combustion	Commercial Offices	98.41	4.81	**93.60**
Miscellaneous industrial / commercial combustion	Hotel and Catering	56.97	0.01	**56.96**
Miscellaneous industrial / commercial combustion	Other	53.02	0.04	**52.99**
Miscellaneous industrial / commercial combustion	Retail	54.86	0.00	**54.86**
Miscellaneous industrial / commercial combustion	Sport and Leisure	5.30	0.22	**5.09**
Miscellaneous industrial / commercial combustion	Warehouses	314.25	0.01	**314.24**
Public sector combustion	Education	210.95	2.22	**208.73**
Public sector combustion	Government	113.66	15.59	**98.08**
Public sector combustion	Health	45.70	16.77	**28.92**

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. This is considered to be a major improvement for the new version set of maps compared to previous similar modelling.

The employment data by SIC codes in the IDBR database were matched with the DECC energy consumption datasets (energy consumption UK table 5.6) 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 (see Table 3.3). Energy consumption data were available for coal, manufactured fuel (SSF), LPG, gas oil, fuel oil and natural gas. These were aggregated to calculate industry specific fuel intensities for coal, oil and gas.

Table 3.3: Industrial sub-sectors by SIC codes

SIC(2003) codes	Description
14	Other mining and quarrying
15	Manufacture of food products and beverages
16	Manufacture of tobacco products
17	Manufacture of textiles
18	Manufacture of wearing apparel; Dressing and dying of fur
19	Manufacture of leather and leather products
20	Manufacture of wood and wood products
21	Manufacture of pulp, paper and paper products
22	Publishing, printing and reproduction of recorded media
24	Manufacture of chemicals, chemical products and man-made fibres
25	Manufacture of rubber and plastic products
26	Manufacture of other non-metallic mineral products
27	Manufacture of basic metals
28	Manufacture of fabricated metal products (except machinery and equipment)
29	Manufacture of machinery and equipment
30	Manufacture of office machinery and computers
31	Manufacture of electrical machinery and apparatus
32	Manufacture of radio, television and communication equipment and apparatus
33	Manufacture of medical, precision and optical instruments, watches and clocks
34	Manufacture of motor vehicles, trailers and semi-trailers
35	Manufacture of other transport equipment
36	Manufacture of furniture
37	Recycling
41	Collection, purification and distribution of water
45	Construction

The IDBR employment data at local unit level were aggregated to 2 figure SIC codes at 1x1 km resolution using 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 (as explained above) 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 prevents double counting of emissions at these locations (emissions are mapped as point sources);
- High-resolution gas consumption data at Middle Layer Super Output Area (MSOA) has been used to adjust the distribution of gas predicted by the employment and energy intensity data. An adjustment has also been applied in Northern Ireland based on local authority level gas consumption data;

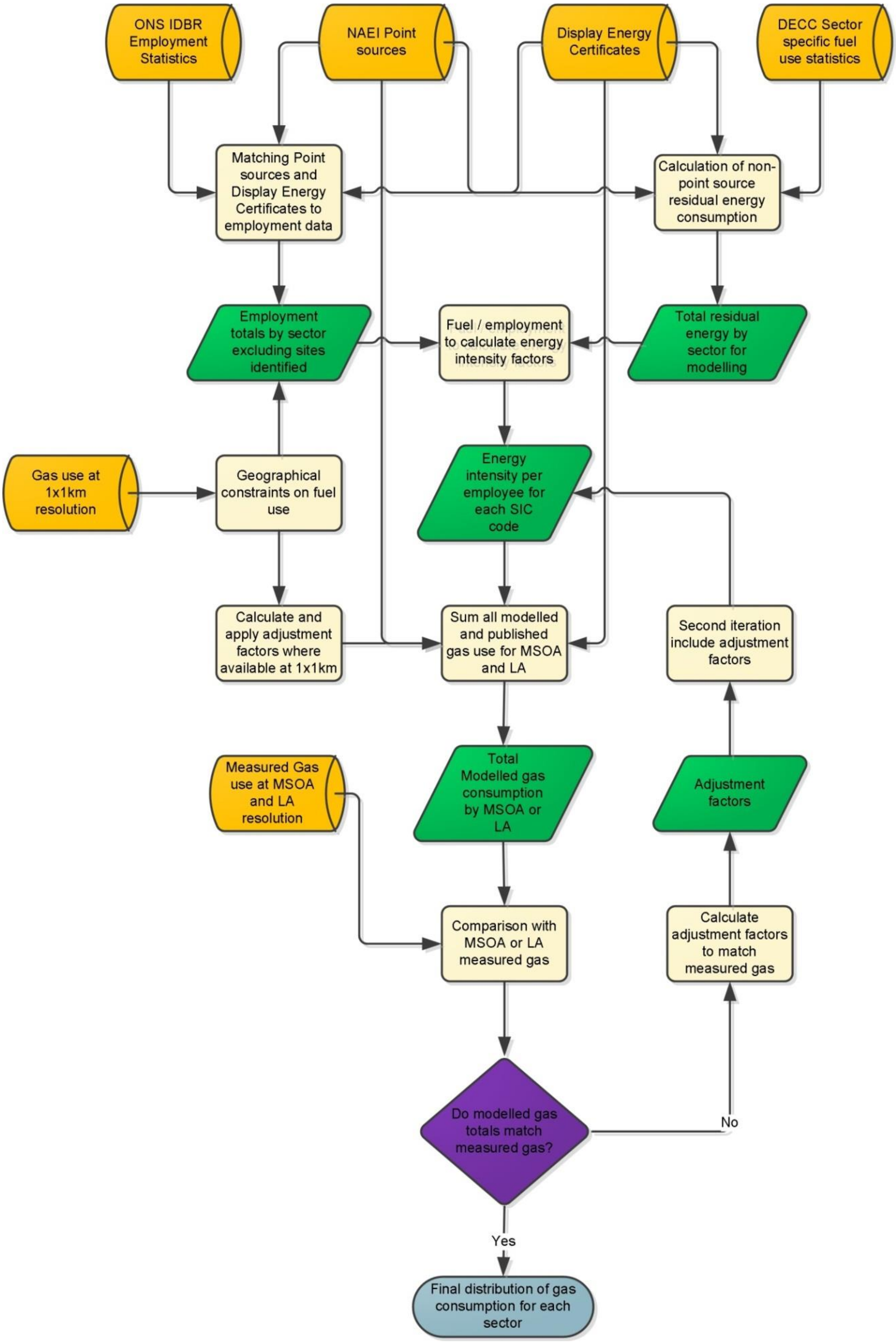
- Based on expert knowledge of fuel use by industry and businesses the distributions of fuel oil and gas oil have been modified so that consumption is lower per employee in grid squares with Natural Gas availability through the use of a weighting factor;
- The distribution of coal has been further limited to outside the locations of Smoke Control Areas;
- There have been no maps generated of Smokeless Solid Fuel consumption as part of this work. According to the DECC dataset (Energy Consumption in the UK Table 4.6[9]) there is only one sector using manufactured fuel (manufacture of coke oven products).

Figure 3.2 summarises graphically the data flows and processes for the modelling undertaken for gas consumption.

Further information on these processes, including data flows of other fuel types, can be found in documentation provided in the report *Employment based energy consumption mapping in the UK* (Tsagatakis, 2012).

[9] https://www.gov.uk/government/publications/energy-consumption-in-the-uk

Figure 3.2: Gas consumption modelling data and process flow



3.3 Road transport

Hot exhaust emissions and the related fuel consumption estimates are calculated within the NAEI using fuel consumption and emission factors for each vehicle type. These in turn are calculated on the basis of the composition of the vehicle fleet (age profile and fuel mix). The resulting fuel consumption and emission factors are applied to detailed spatially resolved traffic movements. The vehicle fleet age profiles, Euro standard and fuel mix for each of the Devolved Administrations are derived using Regional Vehicle Licensing Statistics (DVLA) and the DfT's Automatic Number Plate Recognition (ANPR) database. As the fleet mix varies by location, different emission factors are applied to different road types in the Devolved Administrations.

3.3.1 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 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[10] 4 (v8.1);
- 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.

[10] 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.

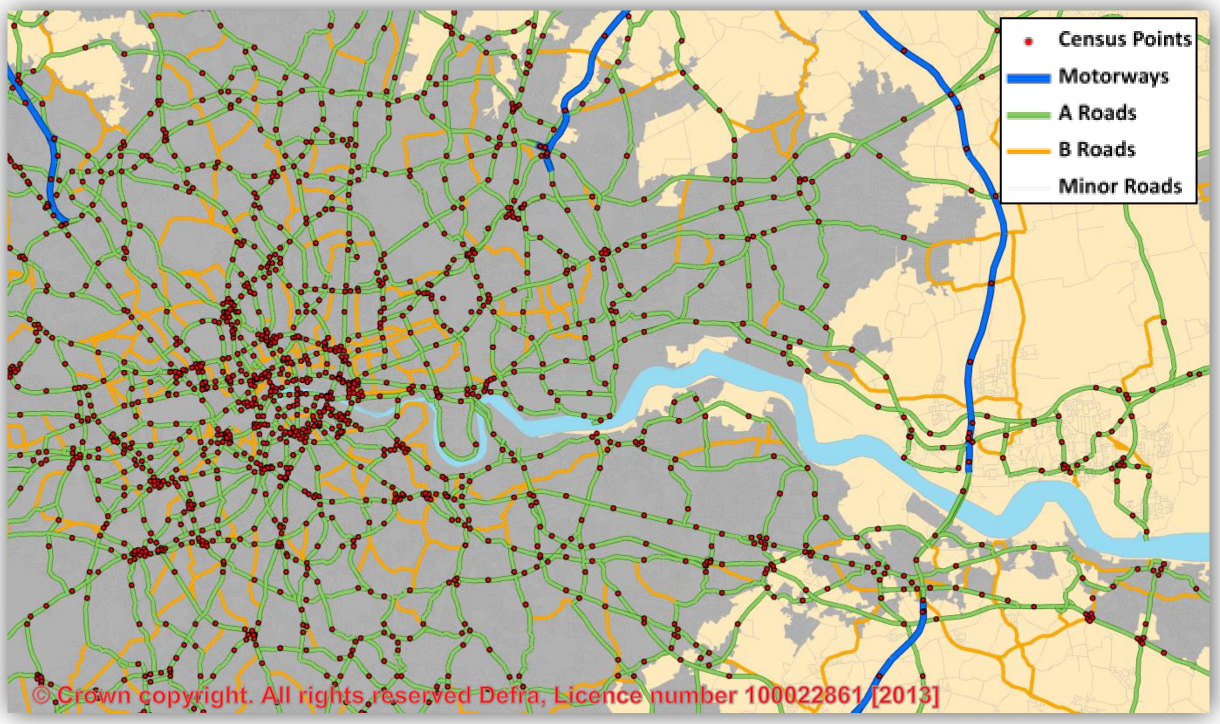
The fuel consumption factors used in the NAEI calculations are polynomial functions expressing the relationship between fuel consumption rate and average vehicle speed for each class of vehicle. These are based on measurements of fuel consumption and emission rates for samples of in-service vehicles taken off the road and tested under controlled 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 N, 2013). 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 emission maps are calculated from the speed related emission factors multiplied by vehicle flows. The method for calculating these maps is described in the next section.

3.3.2 Road transport mapping methodology

The base map of the UK road network used for calculating the hot exhaust road traffic emissions is derived from the Ordnance Survey Meridian 2 dataset. This provides locations of all roads (motorways, A-roads, B-roads and minor 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 Ordnance Survey of Northern Ireland. The traffic flow data is available on a census count point basis for GB (DfT, 2012). Provisional data for Northern Ireland and only a small number of count points were available for 2011 when the road transport mapping process was undertaken; therefore 2010 data (Roads Service, 2012) were used and scaled to 2011 where traffic was not available for this year. Figure 3.3 shows part of the dataset described above.

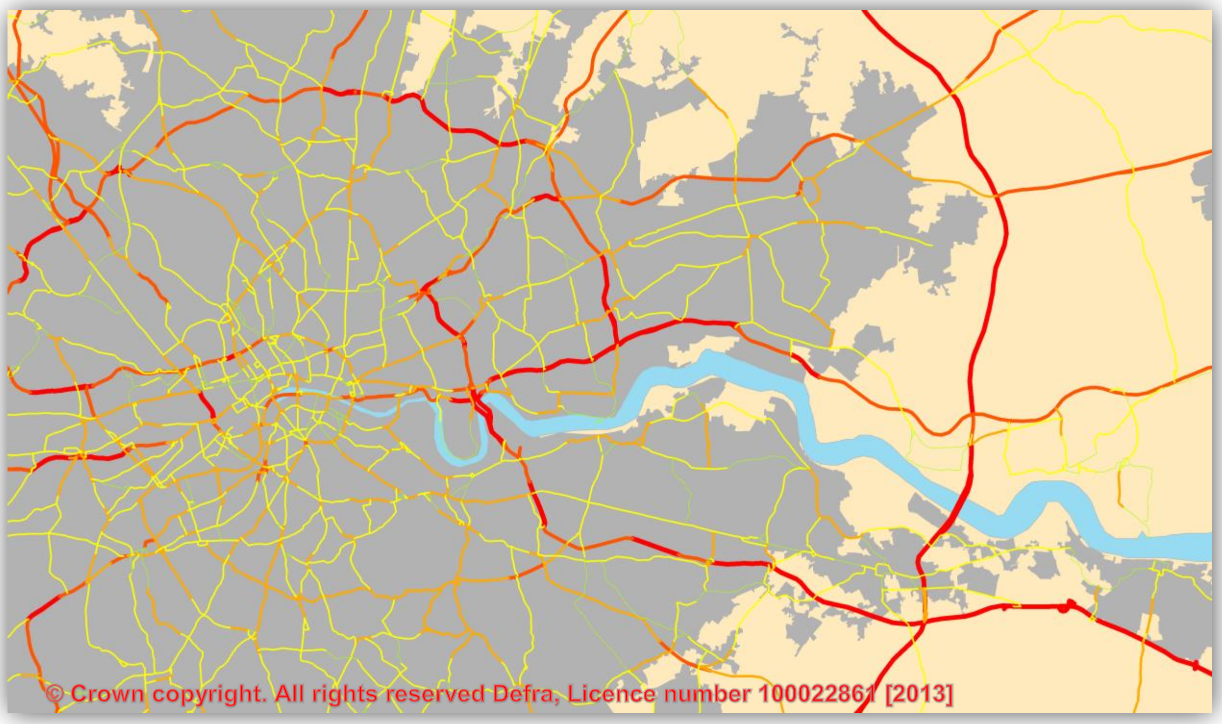
Figure 3.3: A map to illustrate the detail in the road network and count point database



The traffic flow data on major roads include counts of each type of vehicle as an annual average daily flow. These are aggregated up to annual flows by multiplying by 365. The Annual Average Daily Flow (AADF) 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 is therefore applied to these.

Each traffic count point is 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 3.4).

Figure 3.4: Flows are assigned to the road links using a GIS script



The distribution maps on minor roads are not updated each year. However, the mapping methodology and the traffic data have been updated this year, in order to reflect the changes on the road network and implement updated minor roads traffic counts after the release of updated minor roads statistics from DfT (February 2012).

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 Department for Transport. For Northern Ireland vehicle-specific minor road flows have been calculated from data in the 2010 Traffic and Travel Information report 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 has been used to correct at County level the estimates of vehicle kilometres in the NAEI mapping.

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 3.4 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.

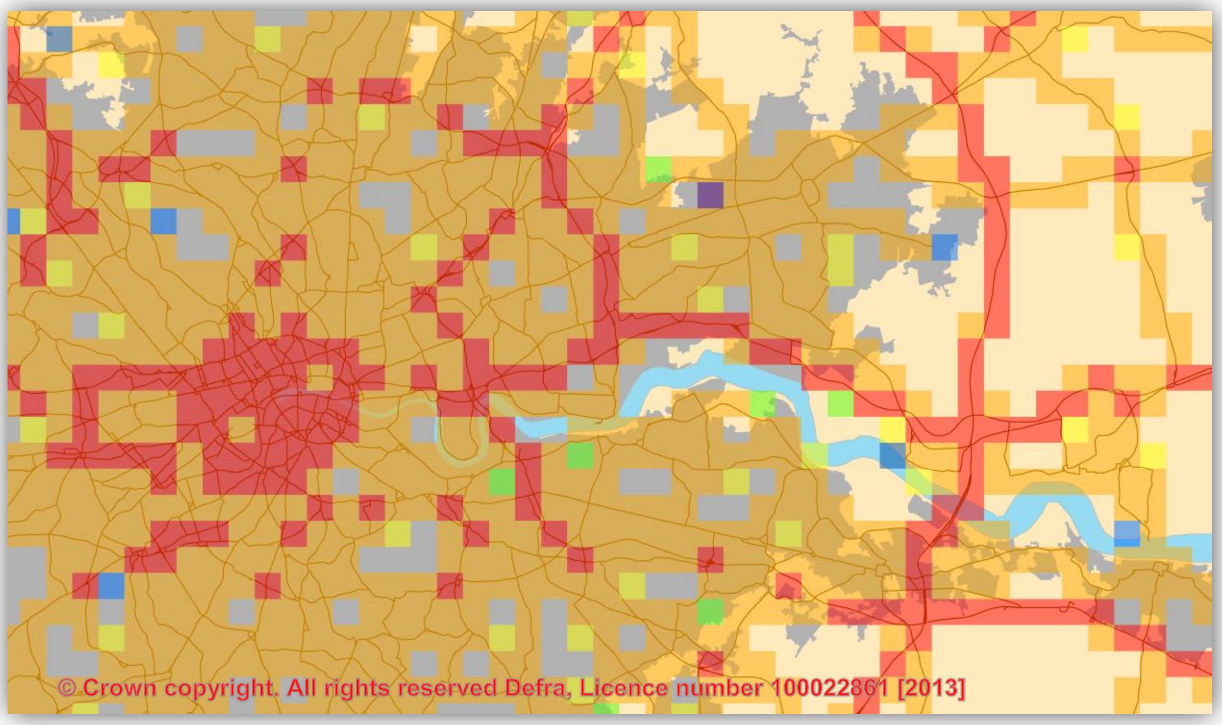
Table 3.4: Department for transport urban area type classification

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

VKM estimates by vehicle type 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 of 1 km grid squares which enable the mapping of emissions and energy estimates across the UK (Figure 3.5).

A similar calculation is performed for minor roads estimates using average speeds for different types of minor roads and applying the relevant fuel consumption factor for that road type to the VKM data modelled as described above. Calculations for minor roads are undertaken at a resolution of 1x1 km across the UK.

Figure 3.5: NO_X road transport emissions aggregated to 1x1 km resolution



3.3.3 Other Road transport emissions

Cold start emissions are produced by vehicles before the engine has reached normal operating temperature. Estimates of the distance travelled by vehicles whilst operating under cold start conditions are available in the NAEI for cars by average trip length and trip type. Cold start conditions in Northern Ireland are assumed to have similar characteristics to those in Great Britain. These data enable estimates of the associated emissions to be determined at the UK level.

The trip types used in these calculations are classified as 'home to work', 'home to other locations' and 'work based' trips. 'Home to work' related emissions are distributed across the UK using detailed population census data on whether people use their car as their method of transport to work. Emissions for trips from home to other locations are mapped using data on car ownership. Work based cold start emissions are mapped on a distribution of all employment across the UK. These have been reconciled with the outputs from DfT's TEMPRO model (DfT, 2009). The ratio of Northern Ireland to UK cold-start emissions, for each pollutant, is calculated from the NAEI road transport model. These emissions estimates are based on the COPERT III model for cold-starts (Ntziachristos & Samaras, 2000).

Evaporative emissions of benzene and NMVOC from petrol vehicles have been distributed using a map of petrol fuel use on all roads derived using the method described in section 3.3.2 above.

PM_{10} and $PM_{2.5}$ emissions from brake and tyre wear and road abrasion are distributed using a 1x1 km resolution map of estimated total vehicle kilometres on major and minor roads.

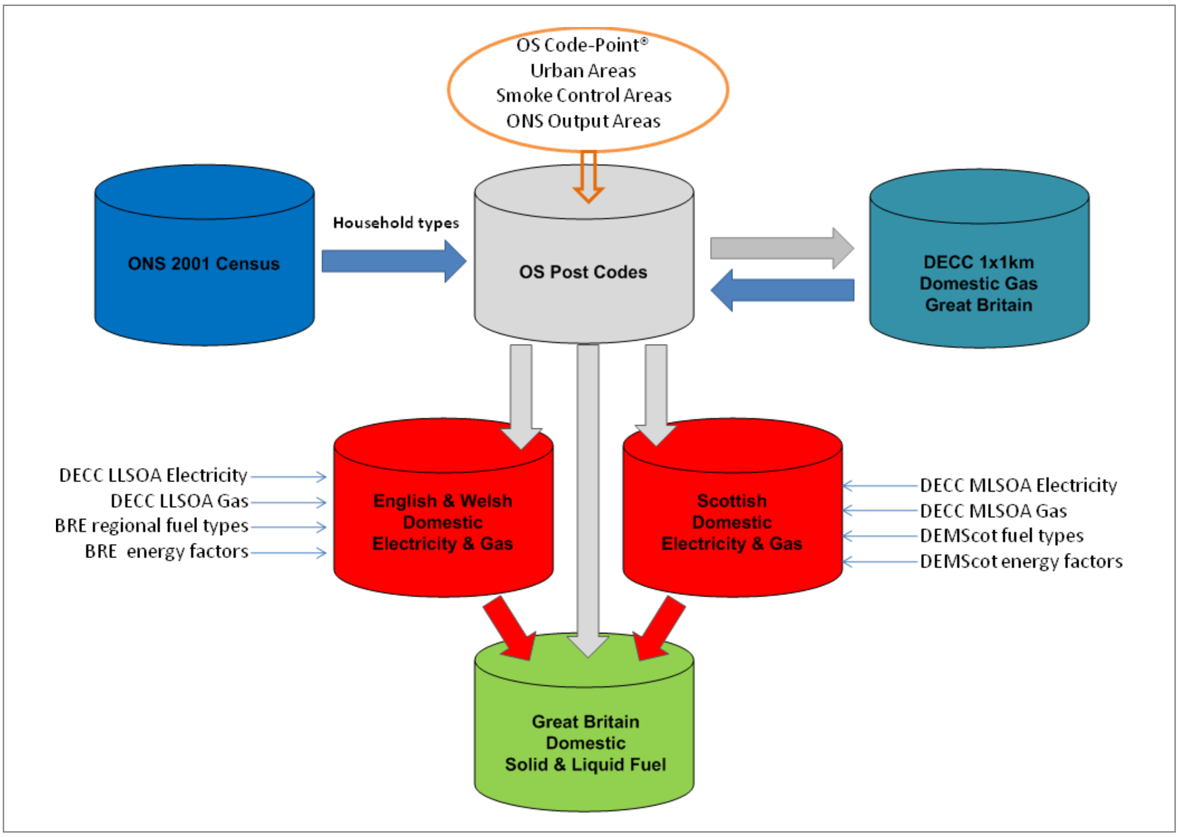
There are two other small sources of emissions from road traffic included in the inventory. These are combustion of waste lubricants and emissions from LPG vehicles. Both of these sources are distributed using estimates of total vehicle kilometres calculated from the NAEI maps of traffic flows.

3.4 Domestic

High resolution distributions of domestic solid and liquid fuel use in Great Britain have been updated for the energy estimates and were used to generate the emissions estimates presented in this report. In the 2008 and 2009 inventories, two mapping methods were implemented; one method was applied to England, Scotland and Wales (Great Britain) and the other method to Northern Ireland. This approach was necessary owing to varying levels of data quality and availability in Northern Ireland compared to the rest of GB where higher resolution datasets were more readily available.

A summary of the methodology is provided below. Figure 3.6 presents a high level summary of the data model for GB which was built to manipulate and analyse the large quantities of data used in this study.

Figure 3.6: NAEI domestic data processing model



The following data series were used in the domestic model:

1. Ordnance Survey Code-Point data[11];
2. Office for National Statistics 2001 Census returns on Household types;
3. DECC sub-national energy consumption statistics:
    a. electricity[12] and gas[13] at Lower Level Super Output Area (LLSOA) 2008 for England and Wales
    b. electricity and gas at Middle Level Super Output Area (MLSOA) 2008 for Scotland
    c. 1x1km gas consumers & consumption for Great Britain;
4. DEMScot: Domestic Energy Model data for Scotland (Scottish Government, 2010);
5. Data from BRE on total energy use by dwelling and fuel type and regional data on the numbers of households using different fuels (BRE, 2006).

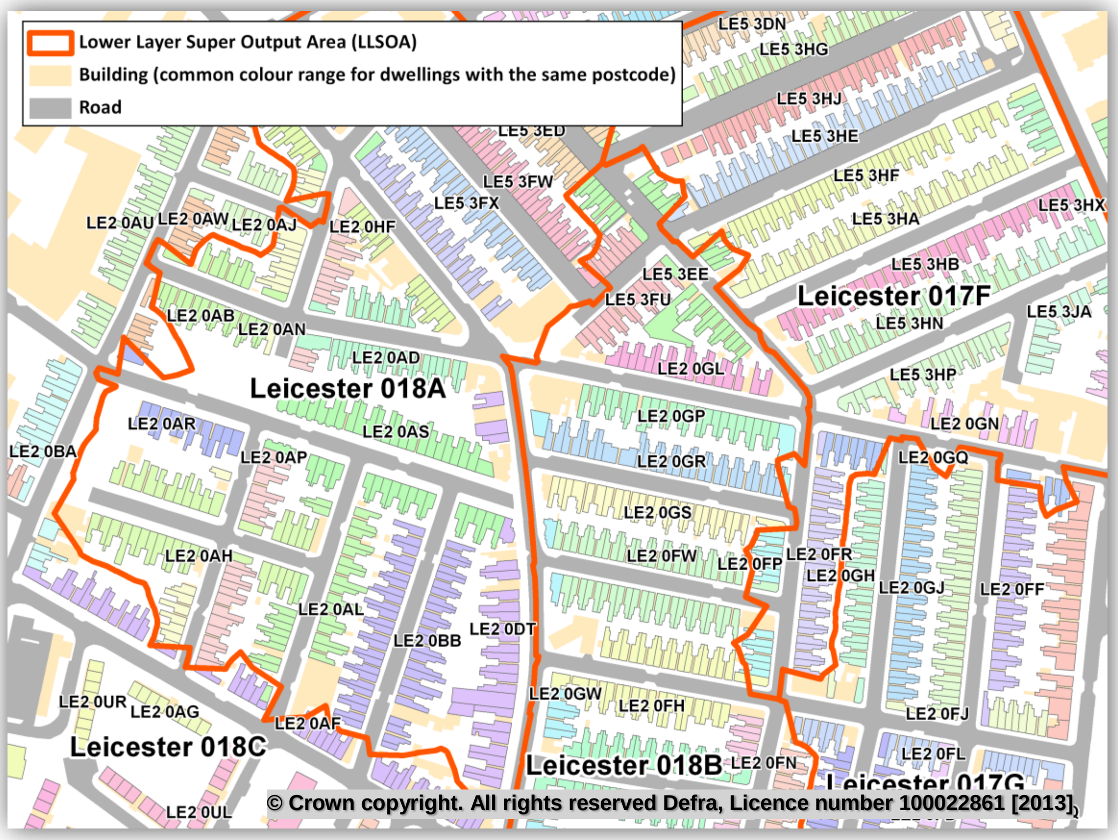
[11] November 2009 release
[12] https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/sub-national-electricity-consumption-data
[13] https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/sub-national-gas-consumption-data

A summary of how these datasets were utilised in the model is given in Table 3.5.

Table 3.5: Description of methods using the above data series

Task and data series used	Application
1	OS Code Point geographies were used to generate a spatial resolved database at full postcode level. Post codes were also assigned urban area, Smoke Control Area and ONS Output Areas attributes (see Figure 3.7).
2	ONS 2001 census returns on household types were used to calculate percentages of house types within each Output Area.
3 a, b & c	Sub national energy statistics were used to generate domestic electricity and gas spatial distribution databases for England / Wales and Scotland respectively. Comparing the total number of dwellings within output areas, with consumers using gas and economy 7heating, a residual fuel component was estimated.
4 & 5	BRE and DEMScot domestic energy model assumptions used in combination with the postcode database to generate the domestic solid and liquid fuels distribution across Great Britain.

Figure 3.7: Sample of the combination of datasets used



Further information was also provided by BRE on total energy use by dwelling and fuel type and regional data on the numbers of households using different fuels (BRE, 2006). The BRE data provided estimates of the gas use per household for various categories of house type (e.g. detached, semi-detached etc.).

It has been assumed that:

- Coal is burnt exclusively outside Smoke Control Areas;
- Oil is burnt outside large urban areas (of greater than 100,000 population) but inside the smaller cities in grid squares where there is residual demand;
- Smokeless solid fuels (SSF, coke, anthracite) are burnt exclusively within smoke control areas;
- Wood consumption is assumed to have the same distribution as coal.

Within Northern Ireland, a comparable approach is used using datasets specific to Northern Ireland and the particular domestic fuel use characteristics of this part of the UK. Datasets used to characterise the emissions from Northern Ireland domestic fuel consumption include:

1. Ordnance Survey Code-Point data;
2. Ordnance Survey Address Point data;
3. Interim update on Northern Ireland House Condition Survey (HCS) 2009;
4. Northern Ireland House Condition Survey (HCS) data 2001;
5. Northern Ireland Housing Executive (NIHE) 2009 survey of tenanted properties;
6. Gas connections information for domestic properties provided by Phoenix Gas;
7. Gas connections information for domestic properties provided by Firmus Gas;
8. Data from BRE on total energy use by dwelling and fuel type and regional data on the numbers of households using different fuel.

From these datasets an updated bottom-up approach to the characterisation of domestic fuel emissions was prepared using local data. Table 3.6 below describes briefly how the datasets above have been used to compile the mapped emission estimates for Northern Ireland.

Table 3.6: Description of methods using the above data series for Northern Ireland

Task & data series used	Application
1, 2 & 3	An up-to-date geographic distribution of housing and house type was prepared using Ordnance Survey Code Point, Address Point data and information from the 2001 Census (ONS, as for GB) at an output area level and scaled to 2009 using information from the 2009 HCS. Geographical distribution of Smoke Control Areas, derived from GIS data provided by DoE Northern Ireland is used to allocate housing to Smoke Control Areas.
3 & 4	Fuels used in the private housing stock is derived from the 2001 detailed HCS and is scaled to 2009 using information from the 2009 HCS
5	Fuels used in social housing stock is taken from the 2009 NIHE
6 & 7	Distribution of Households connected to gas is derived from Phoenix Gas and Firmus Gas 2009
8	BRE domestic energy model assumptions are used in combination with the postcode database to generate the domestic solid and liquid fuels distribution across Northern Ireland.

3.5 Agriculture

Emissions of PM_{10} and $PM_{2.5}$ from agricultural livestock and poultry sources are distributed using agricultural census data. Detailed, farm level data within England was obtained from Defra for this purpose (Defra, 2002) and was used to generate 1 km^2 resolution datasets for different livestock types and poultry. For Scotland, Wales and Northern Ireland agricultural census data were only available for larger spatial units – Parishes in Scotland (Scottish Executive, 2002), Districts in Northern Ireland (NISRA, 2002) and Small Areas in Wales (Welsh Assembly , 2002). Therefore land use data were used to generate a distribution of emissions within these spatial units. The distribution of grazing land was used to distribute cattle and sheep livestock. All non-urban land was used to distribute pigs and poultry numbers. The resulting distributions for England, Scotland Wales and Northern Ireland were combined and weighted according to the relevant regional statistics on the number of livestock or poultry in these regions.

The distributions of ammonia, methane and N_2O emissions from agricultural sources were mapped at a 5 km^2 resolution by the Centre for Ecology and Hydrology (CEH). This work is undertaken as a subcontract of the NAEI. Data from the Agricultural Census for England, Scotland, Wales and Northern Ireland were combined with emission factors for livestock, fertiliser use and CEH Land Cover Map 2000 data within the AENEID model to calculate emissions maps. Ammonia, methane and N_2O emissions from other non-industrial sectors are also calculated by CEH as part of the same subcontract (Dragosits & Sutton, 2013a), (Dragosits & Sutton, 2013b).

Incineration of animal carcases is mapped partly as a point source but mainly across all UK arable land because the location of this source is very uncertain.

Land Cover Map 2000 data from CEH is used to map a variety of other agricultural emissions. These are distributed evenly across the arable land cover map for the UK:

- Emissions of VOCs from agrochemical use;
- CO_2, emissions from agricultural soils;
- Dioxin and Benzo[a]pyrene emissions from agricultural waste burning.

Agriculture stationary combustion has also been mapped using the IDBR employment data and the UK agriculture energy consumption by fuel (ECUK Table 5.1c)[14]. The distribution of solid and liquid fuels was made based on the location of smoke control areas and the geographical distribution of gas availability. The method used is explained in summary in **section 3.2 3.1** or detailed in the supporting document *Employment based energy consumption mapping in the UK* (Tsagatakis, 2012).

Agricultural off-road data 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, sourced by Ricardo-AEA for improving the UK inventory in this sector.

3.6 Rail

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.

[14] https://www.gov.uk/government/collections/energy-consumption-in-the-uk

3.7 Shipping

The NAEI estimates emissions for:

- Coastal shipping;
- Naval shipping;
- International marine.

The method is based upon data developed by Amec (formerly Entec) under contract to Defra for calculating fuel consumption and emissions from shipping activities around UK waters using a bottom-up procedure based on detailed shipping movement data for different vessel types, fuels and journeys (Entec, 2010)[15].

Amec developed a detailed gridded ship emissions inventory for UK waters using recent information on ship movements, vessel engine characteristics and emission factors to quantify atmospheric emissions from shipping sources. The methodology developed was based on guidance from the EMEP/CORINAIR Atmospheric Emission Inventory Guidebook (2006) and relies on the following information, which largely dictates the emissions from a vessel:

- Installed engine power
- Type of fuel consumed
- Vessel speed and the distance travelled (or the time spent travelling at sea)
- Time spent in port
- Installed emission abatement technologies

Fuel consumption estimates for the year 2007 were calculated at a 5 km^2 grid resolution (based on the EMEP grid) for an emissions domain extending 200 miles from the UK coastline.

The revised MARPOL[16] Annex VI Regulations came into force in July 2010. A new method has been used to estimate coastal and international marine emissions for the 2011 NAEI maps. This revision took into account up to date estimates of the impacts of MARPOL on PM and SO_2 emissions from ships operating within an Emission Control Area.

In order to estimate 2011 fuel estimates, growth factors having applied to the 2007 fuel consumption in each grid square. The same growth factors have been applied to domestic and international shipping and for all types of movements.

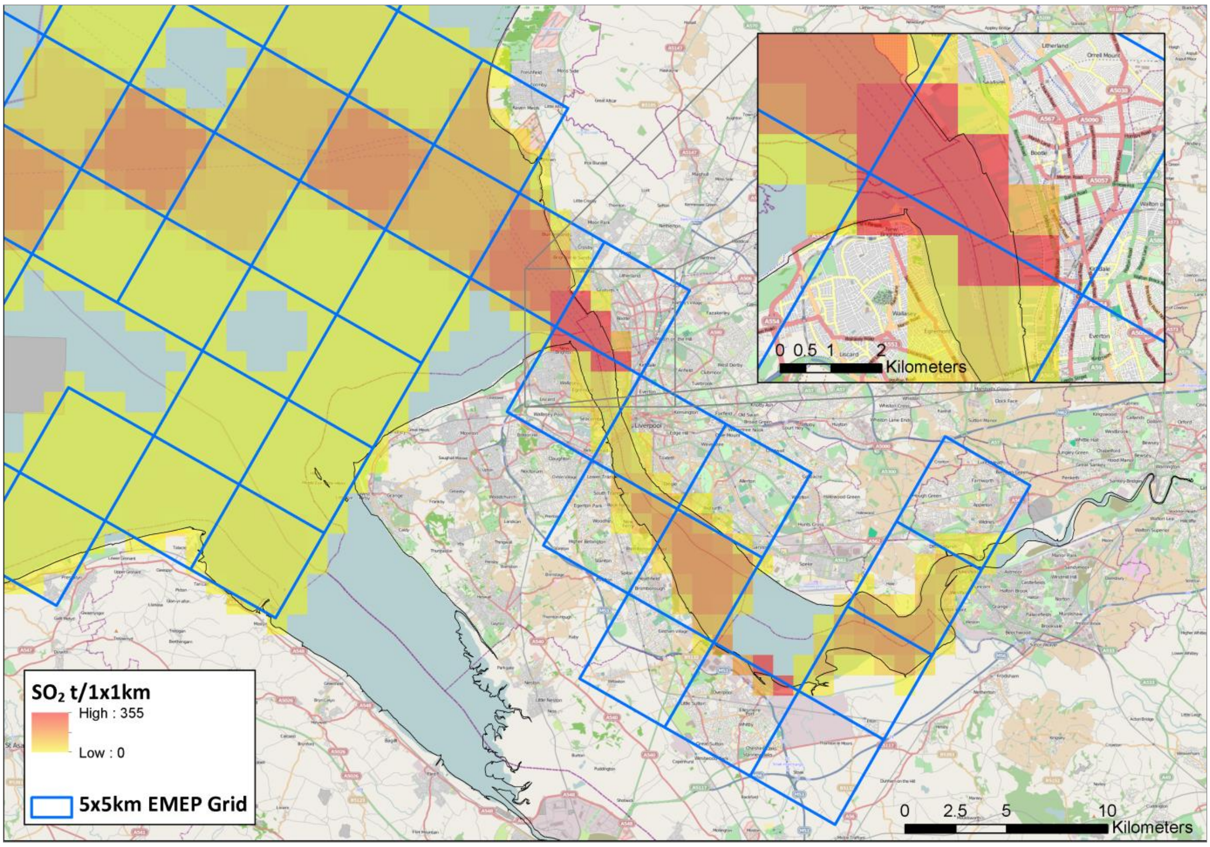
Different emissions factors for key pollutants have been used for grids within SECA and non-SECA and for the different movement types, in order to take into account MARPOL and the SCMFD.

The emission estimates in 5x5 km EMEP grid squares were re-mapped to a 1x1 km grid based on the OSGB grid system. This was achieved by intersecting these two datasets. The misalignment between these two different gridded datasets led to the use of an area weighted technique and to the distribution of the total emissions of each 5 km EMEP grid square to the respective 1 km UK square. Criteria such as the area covered by sea - using the UK's administrative boundaries as provided by OS - were taken under consideration. Figure 3.8 below illustrates the two separate types of data that were combined.

A detailed split of emissions by domestic and international shipping and by all types of movements (at "sea", "manoeuvring" and at berth activities) and by fuel types is currently available: fuel oil (RO) and gas oil (MGO and MDO).

[15] For additional information see MacCarthy et al., 2011 http://uk-air.defra.gov.uk/reports/cat07/1103150849_UK_2011_CLRTAP_IIR.pdf.
[16] The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes.

Figure 3.8: SO_2 emissions at 1x1 km UK grids, overlaid by 5x5 km EMEP grids



3.8 Inland waterways

Emissions from inland waterways were first included nationally in the 2010 inventory. Emissions from vessels used on inland waterways were previously not reported in the UK inventory because there are no national fuel consumption statistics on the amount of fuel used by this sector in DUKES. However as all fuel consumed by all sources in the UK was captured by the inventory, emissions from inland waterways were effectively captured, but were previously misallocated to other sectors using the same types of fuels.

Emissions from the inland waterways class are calculated according to four categories and sub-categories:

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

Details of the approach used to estimate emissions are given in the GHGI improvement programme report (Walker, Conolly, Norris, & Murrells, 2011). A bottom-up approach was used based on estimates of the population and usage of different types of craft and the amounts of different types of fuels consumed. Estimates of both population and usage were made for the baseline year of 2008 for each type of vessel used on canals, rivers and lakes and small commercial, service and recreational craft operating in estuaries or 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.

3.9 Aircraft

The NAEI estimates national total emissions from aircraft operating on the ground and in the air over the UK, up to an altitude of 1000 m (equating to the take off and landing). Emissions estimates are calculated from the number of movements of aircraft by type at UK airports (data provided by the Civil Aviation Authority) and from estimates of fuel consumption for component phases of the take and landing cycle. Emissions from aircraft at cruise are also included in the NAEI although these emissions are not mapped.

For the 2007 emission maps, the locations of airports and their ground level footprints were revised and mapped with the use of satellite imagery. Take-off and landing emissions were allocated to the individual airports on the basis of the modelled emissions at each airport using the CAA data outlined above. In addition, at larger airports emissions from aircraft on the ground (e.g. whilst taxiing or on hold etc.) have been separated from emissions whilst in the air (e.g. climb and approach phases below 1000 m). The former has been mapped evenly over the airport apron and runway, the latter over a 4 km strip adjacent to the end of the airport runways representing emissions from aircraft at climb or descent below 1000 m. For smaller airports all emissions are mapped evenly over the airport footprint.

The maps for aircraft emissions provide a useful split of emissions occurring on the ground and in the air for the air pollution modelling community.

3.10 Industrial off-road

Industrial off-road emissions have historically been disaggregated on the basis of employment in heavy industry. In earlier studies, modelling artefacts have resulted in emission estimates being disproportionately allocated to city centres because of the location of the headquarters of many companies associated with heavy industry and therefore employees in such areas. We reviewed the employment dataset for this study to identify and remove those instances where high industrial employment in urban areas did not correlate well with expected heavy industry activity.

3.11 Accidental fires and small scale west burning

The distribution of accidental fires across the UK is particularly uncertain. Distribution maps have been made using the Land Cover Map 2007 supplied by CEH. The land cover type has been matched to the type of accidental fire as shown in Table 3.7. Classes were added together on an equal basis to make aggregated land cover maps for each NAEI sector.

The ‘Accidental fires - dwellings’ and ‘Accidental fires - other buildings’ sectors have been mapped using the Census 2011 population.

Table 3.7: Land cover data used to distribute emissions from fires

NAEI Source sector	Land Cover classes
Accidental fires - forests	Broad leaved/mixed woodland Coniferous woodland
Accidental fires - straw	Arable cereals Arable horticulture Arable non-rotational
Accidental fires - vegetation	Setaside grass Natural grass Calcareous grass Acid grass Bracken Bogs (deep peat) Dense dwarf shrub heath Open dwarf shrub heath
Accidental fires - vehicles	Suburban
Small scale waste burning	Suburban
Bonfires	Suburban

3.12 Landfill sites

Emissions from landfill sites feature in the NAEI in two different source sectors. The first is landfill gas combustion which is used for electricity generation and/or heating. These emissions are mapped as point sources. The second sector comprises emissions from the landfill sites themselves. Emissions are estimated for 1,3-butadiene, benzene, dioxins, ammonia and VOC. This sector is mapped as an area source.

The level of and quality of information available for the NAEI 2009 mapping exercise on the location and scale of landfill activity varied across the UK. Information on the geographical extent of landfill sites in England and Wales was available from the Environment Agency in GIS format. Within Scotland and Northern Ireland the geographic location of the landfill sites was available from SEPA and DOENI but not the spatial extent. SEPA figures however, also provided estimates of infill received by each landfill in 2008. Using this information, estimates of the MSW waste arisings received by each landfill were made and used as a proxy for the emission rates for landfills in the UK. Distributions were calculated using:

- Regional MSW waste arising by Devolved Administration;
- Actual infill rates for landfills in Scotland for 2008;
- Area of landfill as a proxy for infill rate for sites in England, Wales and Northern Ireland (information on the area of landfill was absent for Northern Ireland, hence all operations were assumed to be of similar size).

Ammonia and methane emissions from landfills have been mapped at 5 km^2 resolution by CEH as part of a subcontract to the NAEI to map all non-industrial ammonia emissions (Dragosits & Sutton, 2013b). This uses a combination of landfill site locations where available and population distributions to fill gaps where the landfill site locations are not available.

3.13 Offshore

Emissions from offshore installations are provided by United Kingdom Offshore Operators Association (UKOOA). These include:

- Use of gas oil;
- Use of fuel oil;
- Use of natural gases;
- Flaring;
- Venting of gases;
- Loading of crude oils into tankers;
- Fugitive emissions from valves, flanges etc.;
- Direct process emissions.

These estimates are aggregated for the UK totals. For the UK emission maps, the reported emissions by installation are split into emissions from fixed platforms and mobile units such as diving support vessels and drill rigs. Although these mobile units may be used in a static position for periods of time, their locations in any given year are not known so they are treated as shipping. Emissions from these mobile units are relatively small compared with those from the fixed platforms. The exact location of the fixed platforms is also not known, however each platform can be assigned to an offshore oil or gas field, or group of fields. The position of wells is known (DECC Oil & Gas, 2011), and so the location of the well that led to the discovery of each field is then used as the location of all fixed platforms associated with that field. It is unlikely that the position of these initial discovery wells will exactly coincide with the position of the platforms intended to exploit those discoveries, but it is assumed that they will be in that vicinity and, in the absence of better information, this is the best compromise that can currently be achieved. In some cases, this will inevitably lead to platforms being mapped some distance away from their actual position. This is more evident in large fields with multiple platforms that clearly cannot all be located at the same place; e.g. the Brent & Forties fields have multiple platforms that are located some kilometres apart but are mapped at the same location. Other platforms are used to exploit multiple small fields and so are likely positioned between those fields. For the moment though, they are mapped by allocating to a single field and therefore located using the discovery well for that field.

3.14 Other sectors

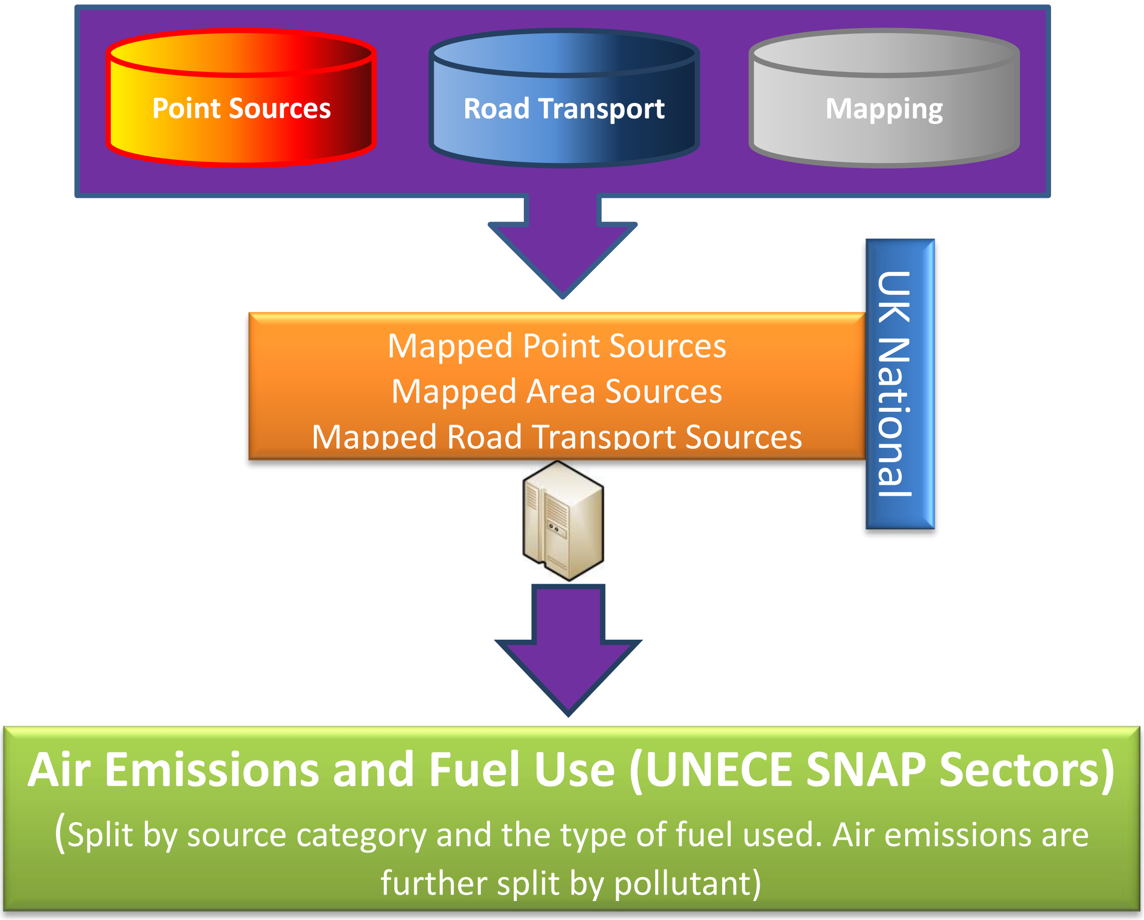
Emissions of PM_{10} from mines and quarries are distributed using data from the British Geological Survey on the locations of mines and quarries in the UK. This data set includes the location of the site and a brief description of products and commodities. There are no data on actual production amounts for each mine or quarry. Regional production statistics for the various commodities are therefore distributed across the sites in each region on an equal weight basis. Only open cast mining and quarrying activities are included. The production statistics are aggregated to 1 km^2 grid and PM_{10} emissions distributed on this basis.

4 Emission maps and data products

4.1 Compilation of maps

The 1x1 km resolution maps are compiled within a GIS environment. Maps for each sector are generated by summing the spatially distributed proportions of the NAEI national total (see Figure 4.1).

Figure 4.1: GIS based methodology



Area and road transport source emissions are aggregated for the 11 UNECE source sectors, and point source emissions aggregated to a 1x1 km grid are added to the area source emissions to calculate a UK total emission map such as those shown in Figure 4.2, Figure 4.3, Figure 4.4 below.

A full set of maps are available at:

http://naei.defra.gov.uk/data/map-uk-das

and through an online interactive GIS tool at:

http://naei.defra.gov.uk/data/gis-mapping.

Figure 4.2: UK total PM_{10} emissions in 2011

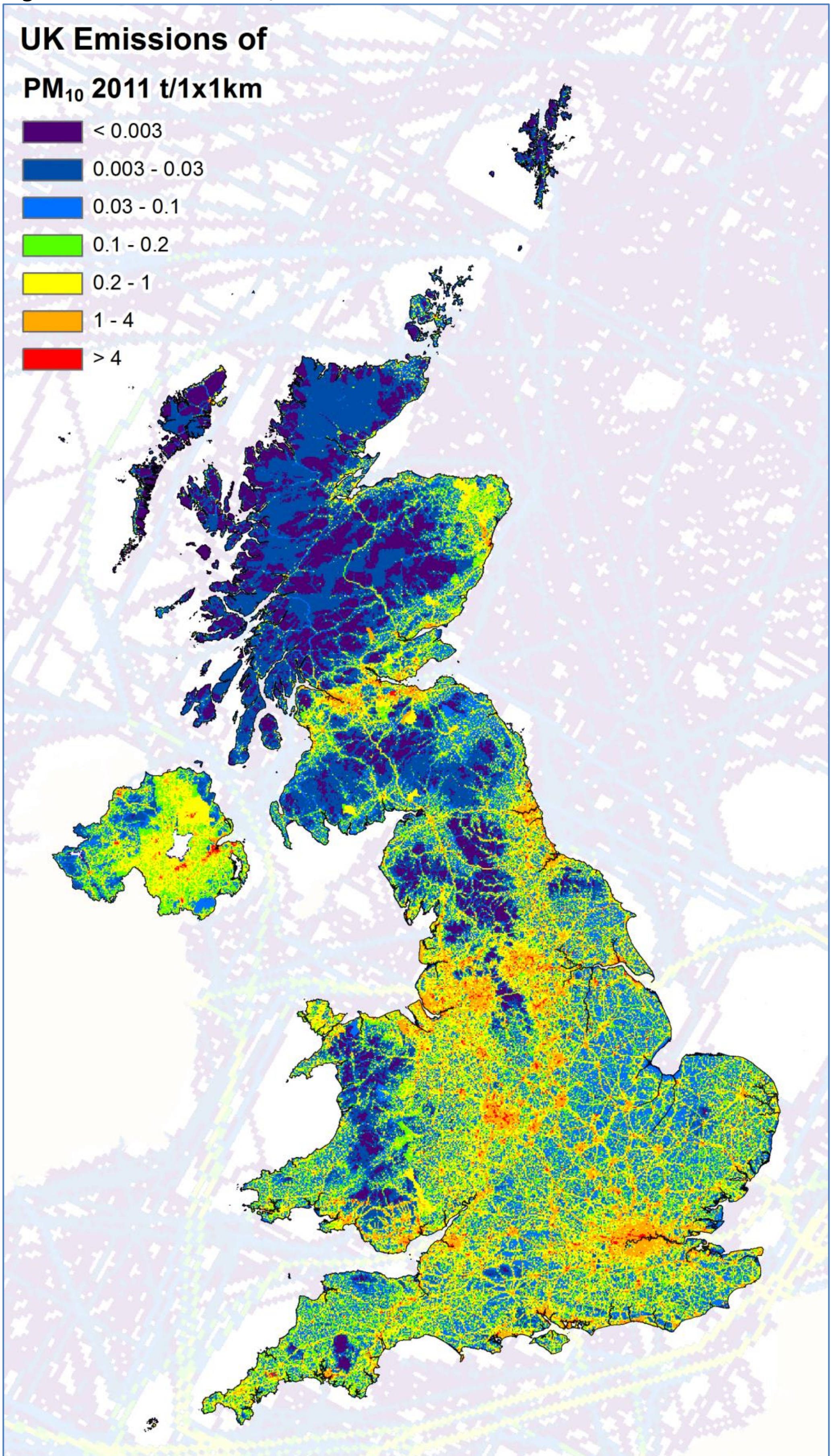


Figure 4.3: UK total SO_2 emissions in 2011

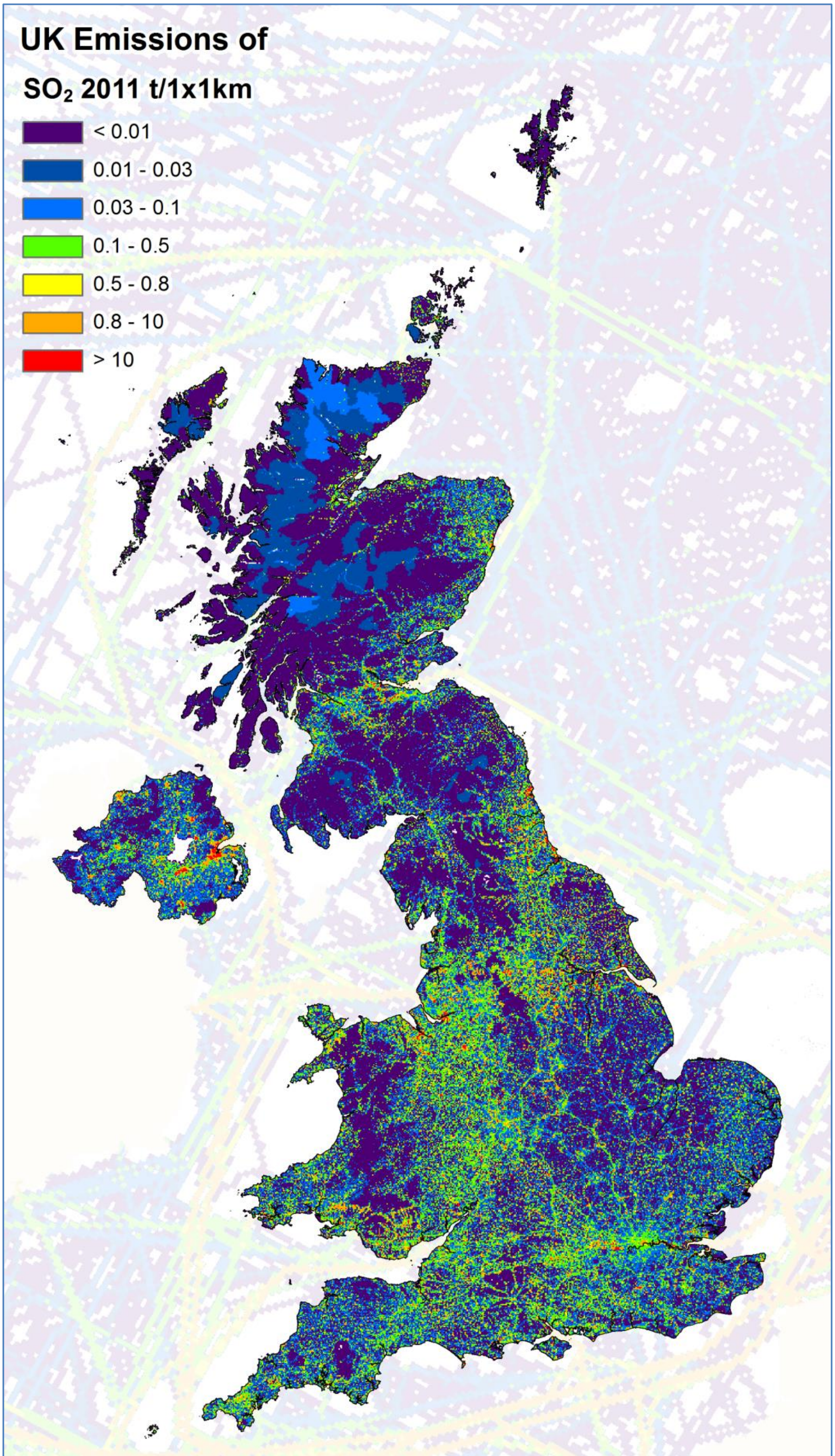
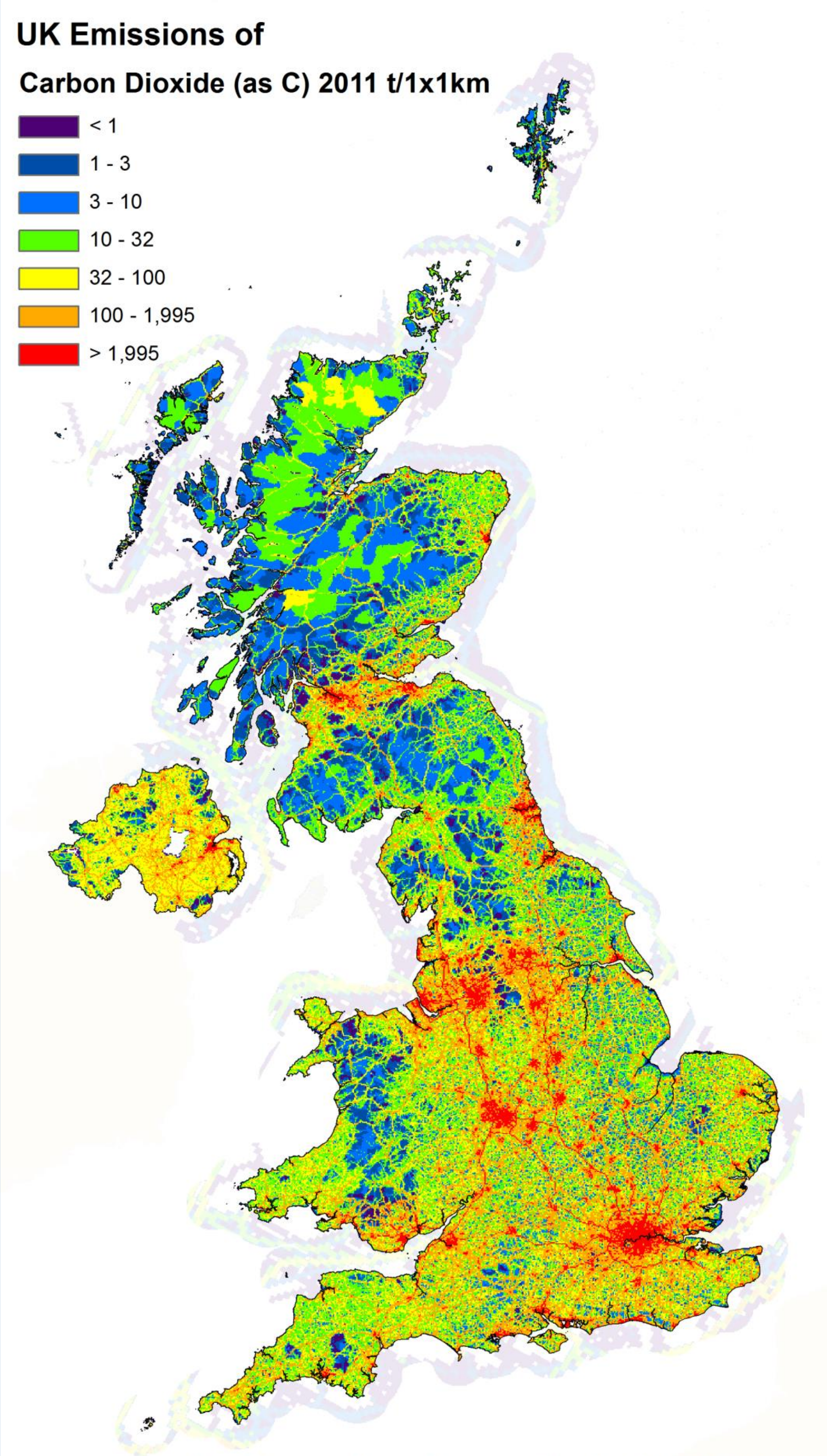


Figure 4.4: UK total CO_2 emissions in 2011



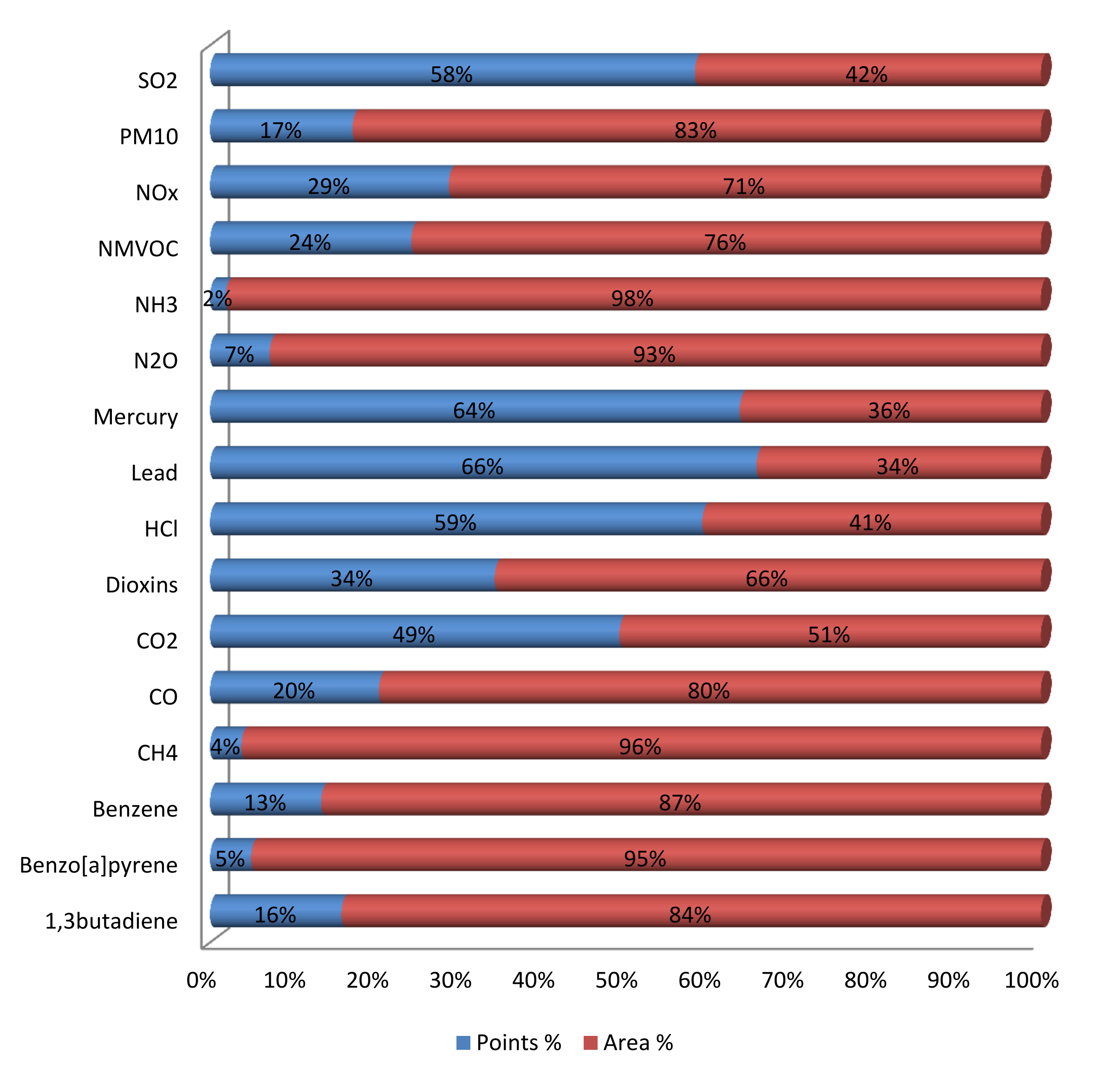
5 Quality of mapping verification

5.1 Estimating quality and uncertainty

As noted in previous sections, 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 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.

One simple, semi-quantitative way of assessing the overall quality of the emission maps by pollutant is to compare the proportion of the national total emission which is mapped as point or area sources. Figure 5.1 shows these proportions for selected pollutants in 2011.

Figure 5.1: Contribution of point sources to mapped emission totals (2011)



Taking the proportion of point sources as a measure of quality, Figure 5.1 suggests that maps for lead, mercury, sulphur dioxide, hydrogen chloride and carbon dioxide are likely to be of higher quality than those for ammonia, methane and benzo[a]pyrene for example. However, this assessment does not differentiate between point source data which are derived from good site-specific emissions data and those which are based on simple modelling, nor does it differentiate between area sources which are mapped using reliable appropriate surrogate statistics and those which use less optimal datasets.

A more sophisticated approach to assessing uncertainty in the maps is to use 'data quality ratings' ranging from 1 (highest quality) to 5 (lowest quality) for the mapping of emissions of each pollutant and source. An overall 'confidence rating' can then be calculated for each pollutant map as follows:

$$\textbf{Emission}_A \textbf{ x Rating}_A \textbf{ + Emission}_B \textbf{ x Rating}_B \textbf{ etc. / Emission}_{Total}$$

Where: $Emission_A$, $Emission_B$ etc. are the emissions of the pollutants from each of the sources in the inventory

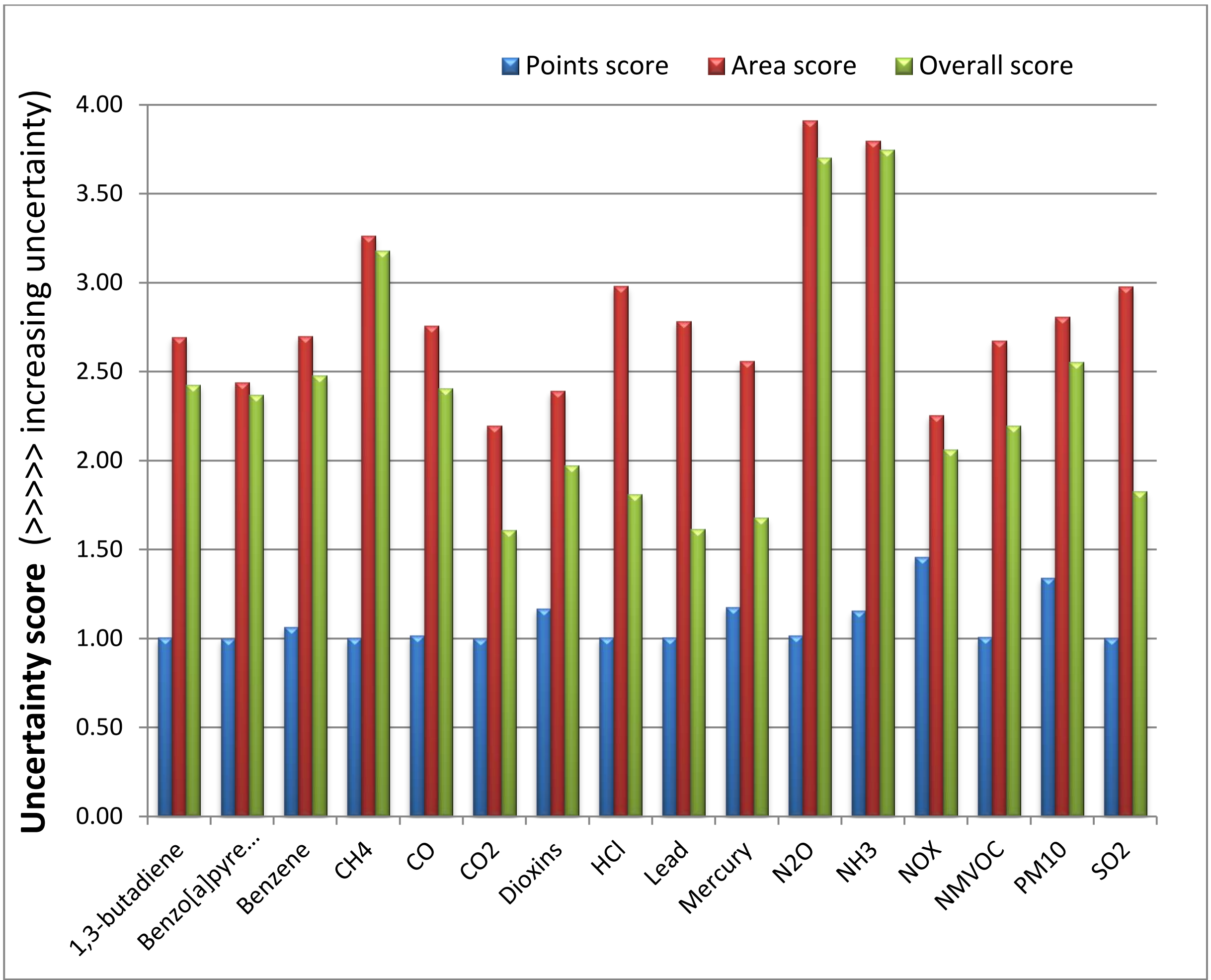
$Rating_A$, $Rating_B$ etc. are the data quality ratings applied to the mapping of emissions from each of the sources in the inventory

Some general rules have been applied when defining data quality ratings for mapping procedures. Point source data from industry and regulators are given a rating of 1 because the locations of emissions are 'known' precisely. Modelled point source data are given a quality rating of 2 to reflect the fact that, although all point sources are known, there is uncertainty regarding the distribution of emissions over these sources. Quality ratings for area/line sources are allocated following an assessment of:

- The quality of the spatially resolved data used to make the grid;
- The reliability of the grid as a measure of emissions from a source.

A rating is defined for each of the above parameters and the mean is used as the overall data quality rating for the source sector. For example, a grid based on 2011 census population data has been allocated a rating of 2 since it is based on very accurate census data which is generalised across the 1x1 km grid. The use of such a grid to map emissions from decorative paint use is considered appropriate and has been assigned a rating of 1. The area source data for decorative paints therefore has an overall quality rating of 1.5. On the other hand, while a grid based on suburban land cover is also good quality and assigned a rating of 2, its use to map emissions from small scale waste burning (bonfires) is considered much less reliable and is given a rating of 4. Area source data for these emissions has an overall quality rating of 3. Figure 5.2 shows the resulting confidence ratings for the NAEI pollutant maps.

Figure 5.2: Confidence ratings for mapping elements of the 2011 NAEI maps



These data quality ratings show a broadly similar pattern to those observed in the assessment of proportions emitted by point and area source (Figure 5.1). Although there are some differences, many of the area source emissions have contributions from sectors that are difficult to map accurately, such as military aircraft. The maps for N_2O show the highest overall uncertainty score because a large proportion of the emissions (about 80%) are from agriculture sector and even though all the data is collected and originally produced outputs of the data in 1x1km, due to non-disclosure constraints, the data have been aggregated at 5x5km resolution. As a result, by evenly distributing the 5x5km maps in 1x1km maps, there is a loss in data quality.

5.2 Verification

Maps of spatially disaggregated atmospheric emissions are a key input to air quality assessments. It is good practice to verify emissions maps particularly if they are to be reliably used to model potential exceedances of air quality objectives and European limit values. Within this context, it is helpful to draw a distinction between emission inventory validation and verification. Validation is the process of checking that emissions have been estimated using the appropriate protocols, while verification involves comparison with independently derived data such as ambient monitoring data and model outputs to provide a 'reality check' on the emissions estimates.

The annual mean background concentration of air pollutants can be considered to be made up of three parts:

- A rural field comprising contributions from relatively distant major point and area sources such as power stations, large conurbations and transboundary sources. Measurements from monitoring sites well away from local sources, for example from rural stations within the UK's Automatic Urban and Rural Network[17] (AURN), provide good indications of the spatial variation of concentrations arising from distant sources;
- Contributions from local point sources; where for example concentrations are modelled using dispersion models parameterised using data from individual industrial sites;
- Contributions from more local diffuse sources (area and line sources).

The NAEI area source maps are routinely used in air quality models to characterise the local contribution to ambient concentrations of air pollutants. National scale air quality modelling activities use emissions from the NAEI area source maps to model ambient concentrations across the whole UK (Brookes, et al., 2013). As part of this work a dispersion kernel modelling approach is applied to the area source emission maps within an area of 33 km x 33 km square surrounding each receptor location, in order to calculate the uncalibrated contribution from area sources to the ambient concentration at a central receptor. Ambient measurements from monitoring sites are then used to calibrate this area source model. The strength of the relationship between measured concentrations and the model results provides an indication of the quality of the emission distribution as it compares actual concentrations measured with predicted concentrations from the mapped emissions.

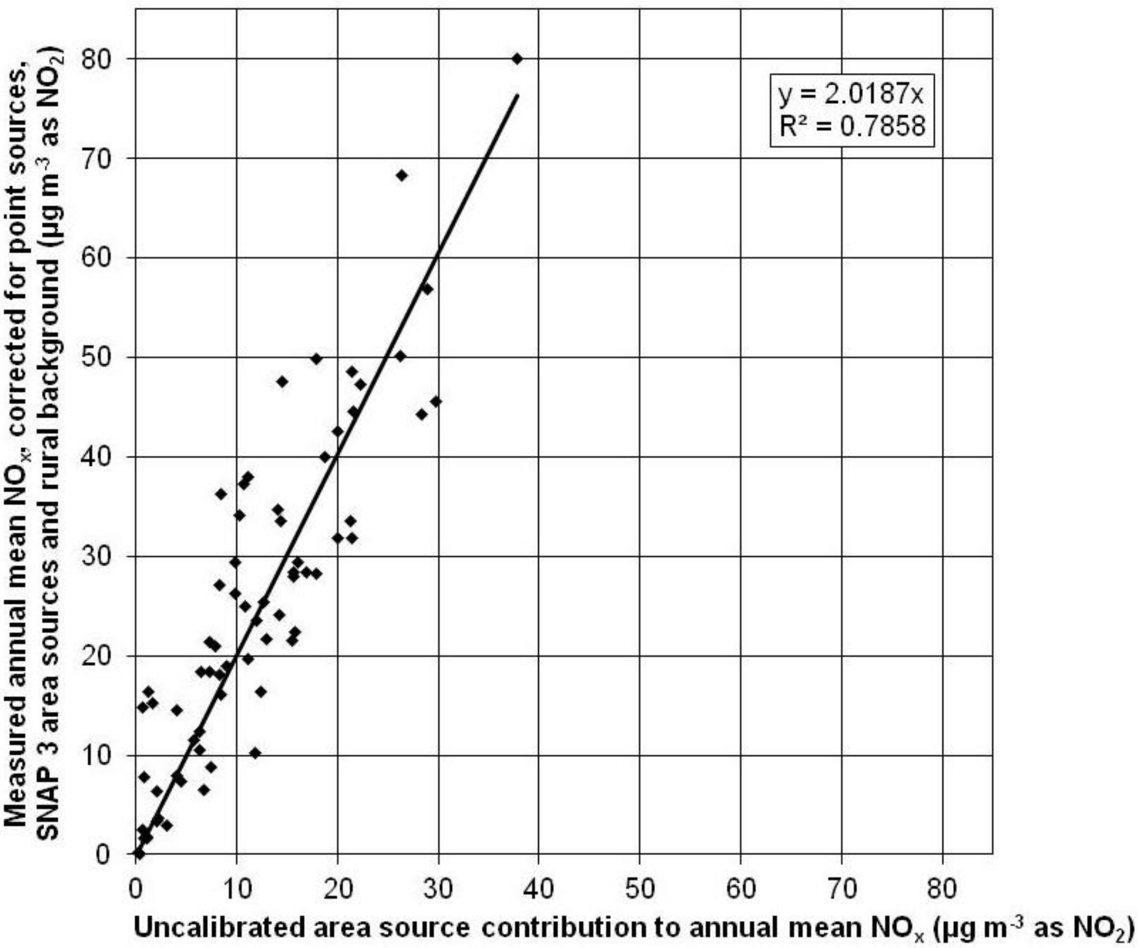
Figure 5.3 shows calibration data for the area source NO_x model and identifies the relationship between area source emissions and measured annual mean NO_x concentrations at AURN monitoring stations. The modelled local emission contribution to overall annual mean NO_x concentration (X axis) is compared with the measured NO_x after removing the rural and point source contributions at each site (Y axis). Some of these values are marginally below zero, indicating that the NO_x concentration for these sites is almost entirely associated with point sources and any rural background. Different dispersion kernels have been used to characterise the dispersion of pollutants in large conurbations, smaller urban areas and rural areas. The graph shows little scatter about the line of best fit but poor agreement between the scale of ambient concentrations estimated from measurements and modelled using the emission inventory in combination with the dispersion model. The degree of scatter about the line of best fit suggests that the spatial distribution of area source emissions remains well characterised by the emission inventory.

Recent work has demonstrated that the ambient concentrations of NO_x and NO_2 have decreased less than suggested by current UK emission factors (Carslaw, et al., 2011). Following this work, the decision was taken to revise the NAEI road transport NO_x emission factors for all vehicle types (except motorcycles) and to update the emission degradation methodology for light duty vehicles based on COPERT 4 (v8.1). In the NAEI 2011 inventory there have been further updates. These updates include PM_{10} and hydrocarbon (HC) emission factors based on COPERT 4 v9.0.

The verification of the spatial distribution of other pollutants can also be carried out using similar methods to those described above. Inventory verification for pollutants such as PM_{10} is, however, more problematic due to the diverse nature of PM_{10} and the range of sources of primary particles, secondary and mechanically generated coarse particles.

[17] http://uk-air.defra.gov.uk/interactive-map

Figure 5.3: Calibration of area source NO_x model ($\mu g\ m^{-3}$, as NO_2) for 2012



The 4th Daughter Directive (AQDD4), 2004/107/EC, sets target values to be achieved for arsenic (As), cadmium (Cd), nickel (Ni), and polycyclic aromatic hydrocarbons with benzo(a)pyrene (B(a)P) as an indicator species, and the Council Directive on ambient air quality and cleaner air for Europe (2008/50/EC), the 'Air Quality Directive' (AQD)

The number of monitoring sites required for compliance is defined within the air quality directives and is significantly reduced if other means of assessment, in addition to fixed monitoring sites, are also available for inclusion in the annual air quality assessment. Air quality modelling has therefore been carried out to supplement the information available from the UK national air quality monitoring networks

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Appendix 1 – Detailed source sector breakdown of UK emissions of NO_X in 2011

UNECE Source Sector	NAEI Detailed Source Sector	NO_X emission (tonnes)
1 Combustion in energy production and transfer	Coke production	4,919
	Collieries - combustion	181
	Gas production	1,950
	Incineration - MSW	5,046
	Landfill gas combustion	16,439
	Power stations	209,470
	Refineries - combustion	22,248
	Sewage gas combustion	3,094
	Upstream Gas Production - fuel combustion	9,466
	Upstream oil and gas production - combustion at gas separation plant	2,263
	Upstream Oil Production - fuel combustion	35,734
1 Combustion in energy production and transfer total		**310,810**
2 Combustion in commercial, institutions, residential and agricultural sectors	Agriculture - stationary combustion	1,172
	Domestic combustion	34,791
	Incineration - MSW	145
	Miscellaneous industrial/commercial combustion	9,703
	Public sector combustion	9,944
	Railways - stationary combustion	4
2 Combustion in commercial, institutions, residential and agricultural sectors total		**55,758**
3 Combustion in industry	Ammonia production - combustion	968
	Autogenerators	16,853
	Blast furnaces	249
	Cement - non-decarbonising	11,626
	Chemicals (combustion)	17,262

	Food & drink, tobacco (combustion)	11,637
	Iron and steel - combustion plant	7,365
	Lime production - non decarbonising	5,906
	Non-Ferrous Metal (combustion)	1,378
	Other industrial combustion	34,576
	Pulp, Paper and Print (combustion)	7,213
	Sinter production	5,762
3 Combustion in industry total		**120,795**
4 Production processes	Basic oxygen furnaces	85
	Chemical industry - nitric acid use	603
	Electric arc furnaces	486
	Iron and steel - flaring	502
	Nitric acid production	128
	Primary aluminium production - anode baking	146
	Primary aluminium production - general	230
	Solid smokeless fuel production	6
4 Production processes total		**2,187**
5 Extraction / Distribution of fossil fuels	Upstream Gas Production - process emissions	4
	Upstream Gas Production - venting	1
	Upstream Oil Production - Offshore Well Testing	64
	Upstream Oil Production - process emissions	59
5 Extraction / Distribution of fossil fuels total		**128**
6 Solvents and other products		**0**
7 Road transport	Road transport – diesel cars - cold start	5,144
	Road transport – petrol cars - cold start	7,411
	Road transport – diesel LGVs - cold start	2,059
	Road transport – petrol LGVs - cold start	163
	Road transport - major roads	229,465
	Road transport - minor roads	94,461
7 Road transport total		**338,704**

8 Other transport and machinery	Agriculture - mobile machinery	26,654
	Aircraft - military	5,254
	Aircraft - domestic take off and landing	1,502
	Aircraft - international take off and landing	9,894
	Aircraft - support vehicles	3,259
	Aircraft between UK and CDs - TOL	118
	Aircraft between UK and Gibraltar - TOL	13
	Aircraft between UK and other OTs (excl Gib.) - TOL	35
	Fishing vessels	1,853
	House and garden machinery	853
	Industrial off-road mobile machinery	57,532
	Inland goods-carrying vessels	79
	Motorboats / workboats (e.g. canal boats, dredgers, service boats, tourist boats, river boats)	8,681
	Personal watercraft e.g. jet ski	339
	Railways - freight	21,229
	Railways - intercity	8,430
	Railways - regional	10,850
	Sailing boats with auxiliary engines	85
	Shipping - coastal	24,276
	Shipping - naval	17,473
	Shipping - UK international	303,897
8 Other transport and machinery total		**502,307**
9 Waste Treatment and disposal	Accidental fires - vehicles	17.94097125
	Crematoria	126.2687415
	Incineration - animal carcases	245
	Incineration - chemical waste	229.0622023
	Incineration - clinical waste	197.4385968
	Incineration - sewage sludge	133.8353063
	Small-scale waste burning	220.4499652
	Upstream Gas Production - flaring	148
	Upstream Oil Production - flaring	1849.655261
9 Waste Treatment and disposal total		**3,168**

11 Other sources and sinks	Accidental fires - dwellings	93.37319518
	Accidental fires - forests	113.184
	Accidental fires - other buildings	160.1840312
	Accidental fires - straw	45.72161765
	Accidental fires - vegetation	37.88098039
11 Other sources and sinks total		**450.3438245**
Grand Total		**1,334,307**

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