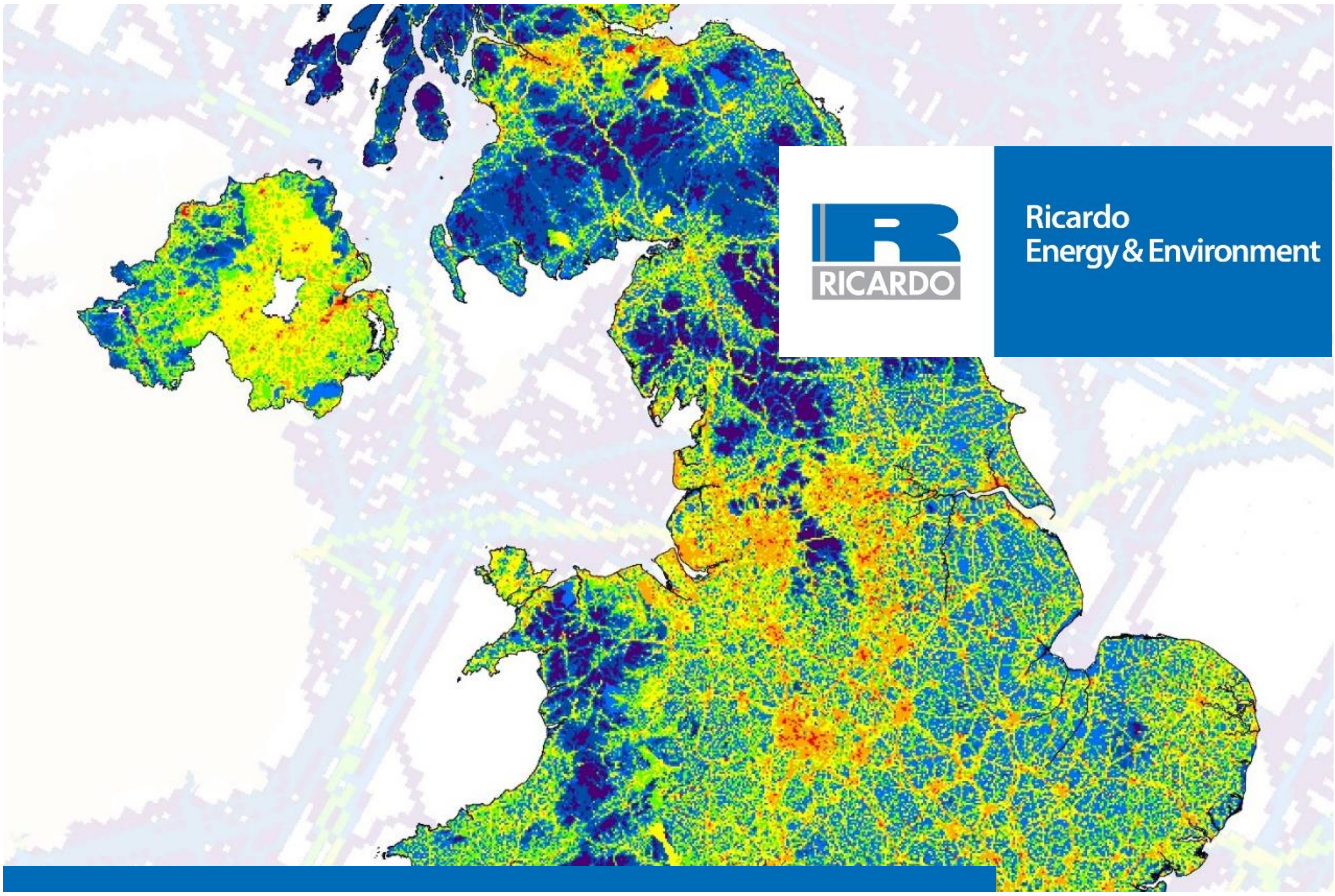

Ricardo Energy & Environment

UK Emission Mapping Methodology

A report of the National Atmospheric Emission Inventory 2013

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List of Abbreviations

AADF	Annual Average Daily Flow
ANPR	Automatic Number Plate Recognition
BSOG	Bus Service Operators Grant system
CLR-TAP	Convention on Long-range Transboundary Air Pollution
DECC	Department of Energy and Climate Change
DOENI	Department of the Environment Northern Ireland
DUKES	Digest of UK Energy Statistics
Defra	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
DVLA	Driver and Vehicle Licensing Agency
EA	Environment Agency
EEMS	Environmental and Emissions Monitoring System
EMEP	European Monitoring and Evaluation Programme
ETS	Emissions Trading System
GHG	Greenhouse Gases
GIS	Geographic Information Systems
HGVs	Heavy goods vehicles
IDBR	Inter-Departmental Business Register
IGER	Institute of Grassland and Environmental Research
INSPIRE	Infrastructure for Spatial Information in Europe
LA	Local Authority
LAPC/APC	Local Authority Pollution Control/Air Pollution Control
LGVs	Light goods vehicles
MSOA	Middle Layer Super Output Area
NAEI	National Atmospheric Emissions Inventory
NFR	Nomenclature for Reporting
NISRA	Northern Ireland Statistics and Research Agency
NRS	National Records of Scotland
NRW	Natural Resources Wales
ONS	Office for National Statistics
OS	Ordnance Survey
SECA	Sulphur Emission Control Area
SEPA	Scottish Environmental Protection Agency
SNAP	Selected Nomenclature for reporting of Air Pollutants
TRL	Transport Research Laboratory
UKPIA	UK Petroleum Industries Association
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 in the National Atmospheric Emissions Inventory (NAEI). The maps provide spatially resolved modelled estimates of emissions compiled at 1x1km resolution for each sector. One set of maps is produced for the most recent inventory year. Maps for 2013 have been produced this 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 data sources and methods that are individually tailored to each sector. For large industrial and commercial sources, emissions are compiled based on data from a variety of official UK regulatory sources. For diffuse emission sources distribution maps are generated using appropriate surrogate statistics for each sector. The method used for each source sector varies according to the data available.

Emission maps are a crucial evidence base supporting a variety of Government policy support work at the national level. In particular, the maps are used as input into a programme of air pollution modelling studies. They also provide a spatial overview of emissions and are used to compile and report gridded emissions to the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLR-TAP). Local area statistics are compiled from the maps and related data as well. For example, carbon dioxide emissions from fuel use at the Local Authority level have been produced for Defra and DECC since 2005 using data from the NAEI's mapping work. As of March 2008, these datasets were designated as National Statistics. In addition, the emission maps provide an illustrative and intuitive way engaging with non-technical audiences who may wish to find out about emissions in their area.

Uncertainty analyses have been undertaken to consider the accuracy of the emission maps for some of the major air quality pollutants and greenhouse gases. Quality ratings have been used for this purpose. 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 of Energy and Climate Change (DECC), the Welsh 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 1x1km grid resolution[1] 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, 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 using the latest version of the national inventory.

A series of reports describing the methods used for calculating national total emission estimates under the NAEI and other outputs of the inventory system are 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[2], listed below:

1,3-butadiene	Nitrous oxide[1]
Benzene	Methane[1]
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[1]	Nickel
Benzo[a]pyrene	Selenium
Dioxins	Vanadium
Hydrogen chloride	Zinc

The maps provide modelled estimates of the distribution of emissions at a 1x1km resolution[1] and are aggregated to UNECE sectors using the Selected Nomenclature for reporting of Air Pollutants (SNAP). The SNAP reporting sectors used are shown in Table 1.1 below. Data for large point sources are reported separately.

[1] Mapped outputs for ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O) are produced under the same framework, but some important sources are limited to 5x5 km resolution due to non-disclosure constraints.
[2] 23 pollutants plus 4 particulate matter size fraction

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

Mapped emissions are made freely available in a neutral file format[3] on the NAEI web site at http://naei.defra.gov.uk/data/map-uk-das. The maps are also available through an online interactive GIS tool at http://naei.defra.gov.uk/data/gis-mapping. Both formats provide a valuable resource for user groups interested in local air quality and greenhouse gas emissions:

- The maps are frequently used as a starting point in the compilation of local emission inventories, which may then be used to assess the status of 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.

The emission maps provide an important evidence base that is used to support a variety of policies at UK and Devolved Administration (DA) Government scales. In particular, spatially disaggregated emissions estimates (1x1km)[4] and road link-specific emissions information from the NAEI are used annually to underpin Defra's modelled air quality data[5]. These models are incorporated into the UK's national air quality compliance assessments that are reported to the Commission under European Directives[6 & 7].

They are also used to compile and report on emissions as part of the UK's commitment to the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP).Under this reporting convention UK emissions are aggregated to the prescribed nomenclature for reporting sectors (NFR and GNFR sectors) and mapped to the 50x50 km EMEP Grid spatial resolution and more recently to a 0.1ºx0.1º Long/Lat grid in a geographic coordinate system (WGS84). These datasets are available through the WedDab emission database[8].

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[3] ASCII grid format
[4] Mapped outputs for ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O) are produced under the same framework, but some important sources are limited to 5x5 km resolution due to non-disclosure constraints.
[5] http://uk-air.defra.gov.uk/data/modelling-data
[6] Fourth Daughter Directive 2004/107/EC (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32004L0107)
[7] The Air Quality Framework Directive 2008/50/EC (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0050)
[8] http://www.ceip.at/webdab-emission-database/

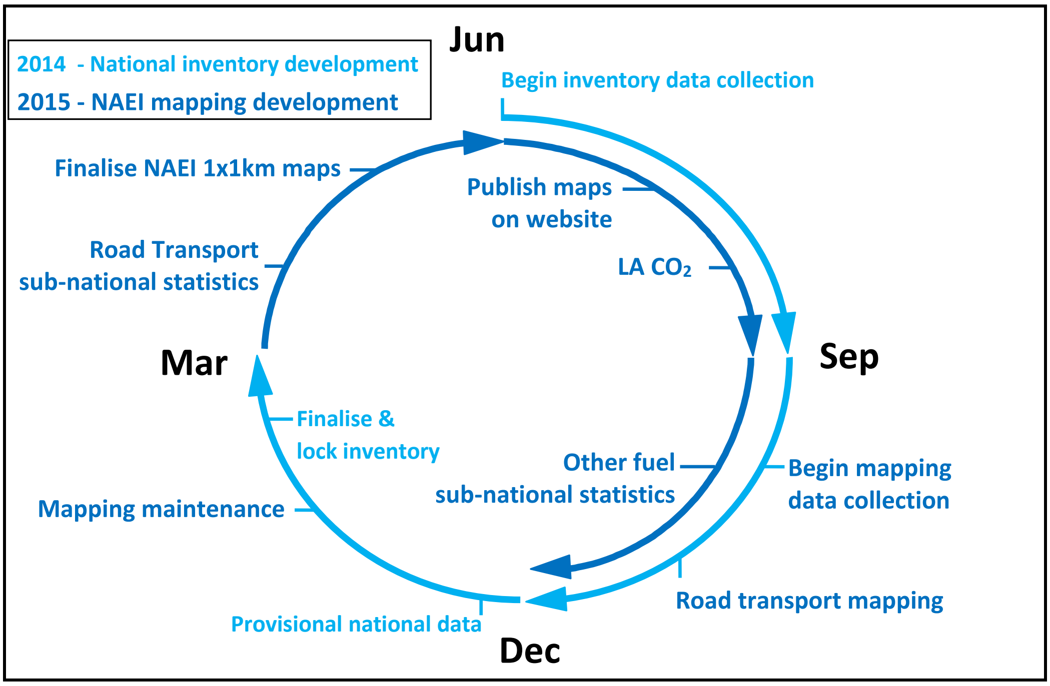
Local area statistics are also compiled from the maps and related data e.g. the Local Authority level data on carbon dioxide emissions[9] and fuel use[10] which have been produced for Defra, DECC and DA's since the 2005 release. As of March 2008, these datasets were classified as National Statistics (DECC, 2015) subject to implementing a small number of requirements across the range of DECC statistics (UK Statistics Authority, 2009).

1.2 Annual cycle of map compilation

The NAEI is compiled on an annual basis. Each year the full inventory time-series (1990 – latest year) is recalculated to take account of improved data inputs and any advances in compilation methods. Updating the full time-series is an important process as it ensures that the entire dataset is calculated 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), UNECE, UNFCCC and other international fora.

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, since 2006, a time-series relative to a 2005 base year has been calculated for CO_2 end-user emission maps 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 2013 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.

[9] https://www.gov.uk/government/statistics/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics-2005-2013

[10] 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 emissions defined by reported activity data and estimates based on modelling (i.e. minor road traffic emissions are modelled from regional flow and fleet mix data, with emissions from commercial & public sectors described by an employment based energy consumption model adjusted by recorded levels of gas consumption).

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 the industrial and energy generation sectors taking into account other more detailed data from the regulators of industrial processes: the Environment Agency (EA), the Scottish Environmental Protection Agency (SEPA), Natural Resources Wales (NRW) 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 provide the relationship between the amount of pollution produced and the amount of raw material processed or number of product units produced. These 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.

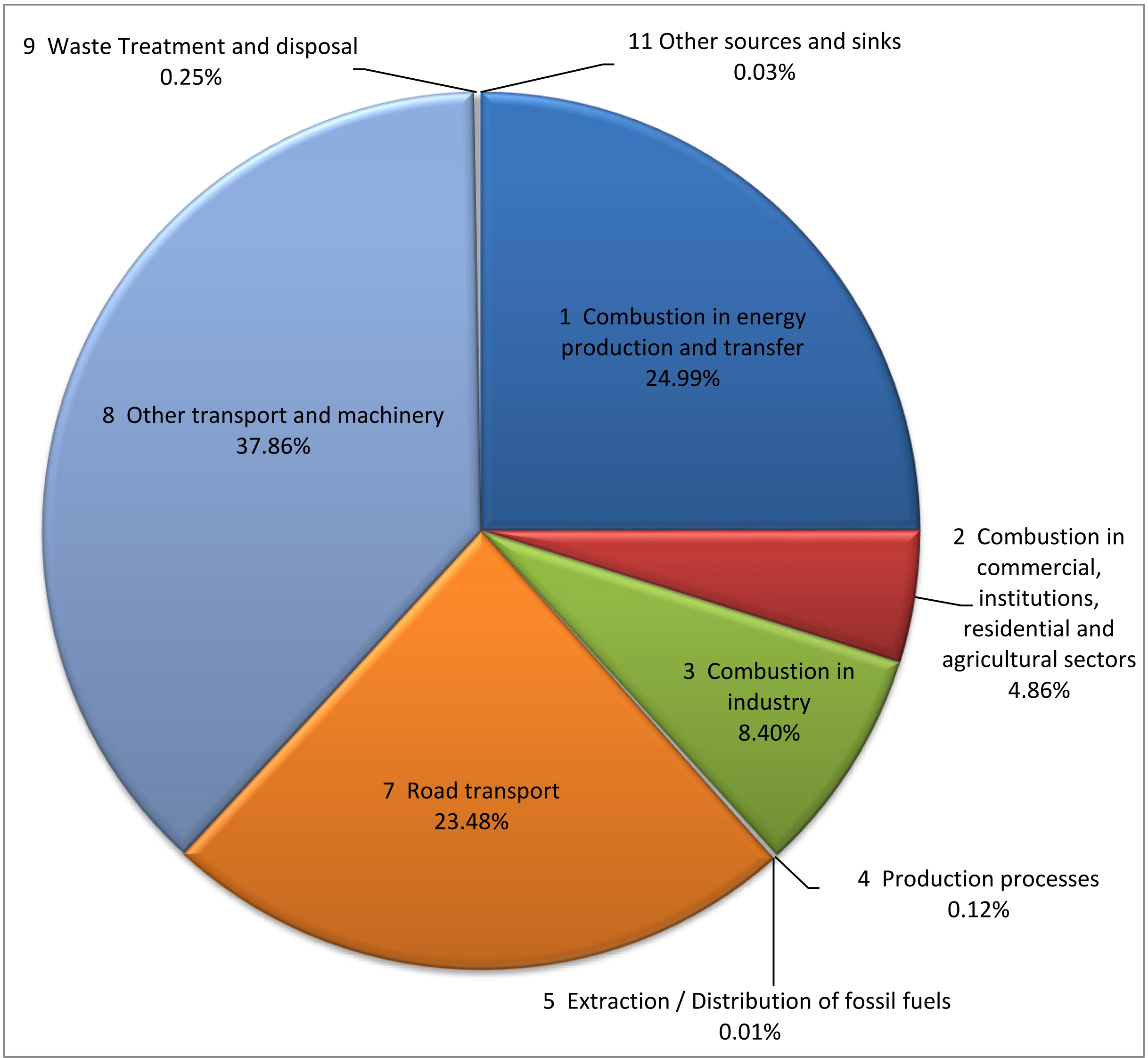
Activity statistics are obtained from Government statistical sources, such as DUKES[11], Transport Statistics Great Britain[12] alongside those from organisations such as trade associations and research institutes (e.g. the UK Petroleum Industries Association (UKPIA) provides data on the sulphur content of fuels, and the Institute of Grassland and Environmental Research (IGER) provides data on livestock numbers and fertiliser usage).

A detailed breakdown of the NAEI source sectors for NO_X in 2013 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 than this. 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 (Misra, et al., 2015) and UK Greenhouse Gas Emissions (DECC, 2015)[13] documents provide details of emissions by sector at a national level.

[11] https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes
[12] https://www.gov.uk/government/statistics/transport-statistics-great-britain-2013
[13] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/407432/20150203_2013_Final_Emissions_statistics.pdf

Figure 2.1: UK NO_X Emissions in 2013 by UNECE Source Sector



3 Methods for calculating emission distributions

A spatial characterisation of emission distributions across the UK is built up from several 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 EA, SEPA, NRW, DOENI and Local Authorities. These enable both the geographic location and the magnitude of the emissions to be well characterised. For other smaller and more widely distributed sources (known as ‘area’ sources) less detailed information on the location and magnitude of emissions is available. For these sources, 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 (described back in Table 1.1) within the NAEI. The mapping methods used to develop these distributions are explained in the following sections.

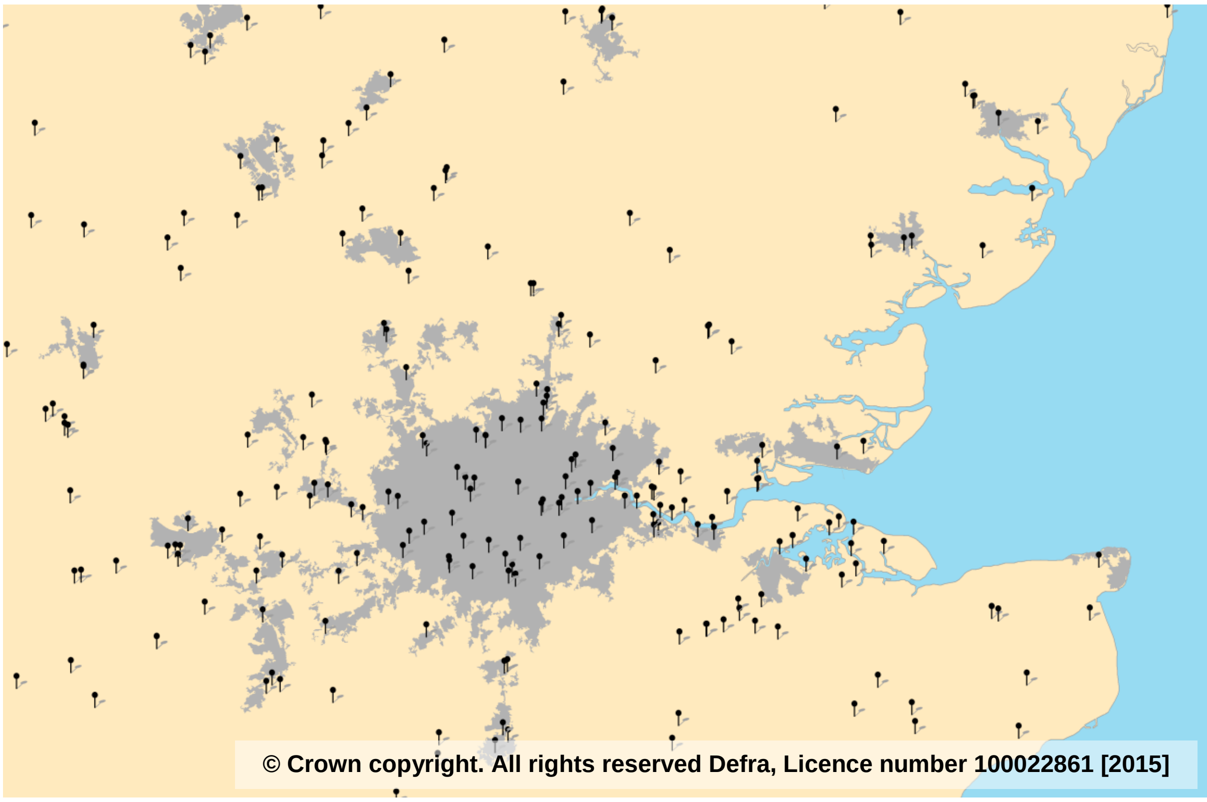
Table 3.1: Methods used to map emissions in each of the 11 UNECE emission sectors

Method	Report Location	UNECE Emission Sectors										
		1	2	3	4	5	6	7	8	9	10	11
Agriculture	Section 3.5 (p.20)								✓		✓	
Airports	Section 3.9 (p.23)								✓			
Domestic	Section 3.4 (p.16)		✓			✓						
IDBR agriculture	Section 3.2 (p.9)		✓									
IDBR commercial & public	Section 3.2 (p.9)		✓									
IDBR employment	Section 3.2 (p.9)	✓	✓	✓	✓		✓		✓	✓		
IDBR industry	Section 3.2 (p.9)			✓								
Landfill	Section 3.12 (p.24)									✓		
Land-use	Multiple Sections						✓			✓	✓	✓
Offshore	Section 3.13 (p.24)	✓				✓				✓		
Other	Section 3.14 (p.25)				✓	✓			✓			✓
Points Sources	Section 3.1 (p.6)	✓	✓	✓	✓	✓	✓			✓		
Population	Multiple Sections				✓	✓	✓		✓			✓
Rail	Section 3.6 (p.20)								✓			
Road transport	Section 3.3 (p.12)				✓			✓				
Shipping	Section 3.7 (p.21)				✓				✓			

3.1 Large industrial and commercial sources

The NAEI receives detailed data on individual large point sources in the industrial and commercial sector. 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 solely 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 portion of the national total emission not released by installations represented by point sources) 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 regulated under the Integrated Pollution Control (IPC) or Integrated Pollution Prevention and Control (IPPC) regulatory regimes are made available to the NAEI by the Environment Agency's Pollution Inventory (PI), by the Scottish Environment Protection Agency's Scottish Pollutant Release Inventory (SPRI), by the Northern Ireland Pollution Inventory (NIPI). Some additional information is made available directly from process operators or trade associations;

[2] Point sources registered with and trading emission credits under the EU-Emissions Trading System (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 included in group 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 completeness of reporting for the largest point sources 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 point sources do not have to report emissions. The reporting thresholds mean that data can be much more limited for sectors that consist mainly of medium rather than large industrial operations (for example industrial combustion) where it is far more likely that emissions will be below the reporting threshold.

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

Of the process operators and trade associations providing emissions data directly to Ricardo-AEA notable inclusions are:

- Tata Steel 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 fuel combustion and for non-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/NIPI 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, that data for the same installations 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/NIPI relate to processes that are permitted under EU ETS. Identifying the same installation 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 team'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 prior to 2012 (EUETS phase III). 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 Environmental and Emissions Monitoring System 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 and NIPI. 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/NIPI 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 installations. For those sites with emissions below the reporting thresholds described above, or for most sites regulated by local authorities, the NAEI may not collect any emissions data from the regulator. Furthermore, some industrial emission sources are not regulated. In these cases, any 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 where data exists, which are comparable in size and with similar abatement measures in place (where recorded).
- Emissions can be distributed using surrogate data other than capacity. For example, in the case of 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 as a surrogate, many of the approaches listed above will yield emission estimates which are subject to higher uncertainties than the emissions reported by site operators in the PI/SPRI/NIPI or EU ETS etc. 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 emissions across the whole of the UK using much less targeted surrogate data, such as employment data or population, which are likely to be poorly correlated to emissions.

The Local and Regional CO_2 technical report (MacCarthy, 2014) 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 these site-specific emissions from each NAEI sector total calculates a residual emission[14], which is mapped 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 1x1km.

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 a separate document - **Employment based energy consumption mapping in the UK** (Tsagatakis I. , 2015)**[15]** - on the gov.uk website. The following data sets were 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[16].
- Energy Consumption in the UK (ECUK) data on industrial and service sector fuel usage[17].

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[14] Residual emission = national total – point source emission total
[15] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/437429/Employment_based_energy_consumption_in_the_UK.pdf
[16] http://www.ons.gov.uk/ons/about-ons/products-and-services/idbr/index.html
[17] https://www.gov.uk/government/statistics/energy-consumption-in-the-uk (Industrial and Services tables)

- 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.
- Xoserve's Off-Gas Postcode dataset[18]
- Business Register and Employment Survey (BRES) annual employment estimates for the UK split by Region and Broad Industry Group (SIC2007)[19]

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

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

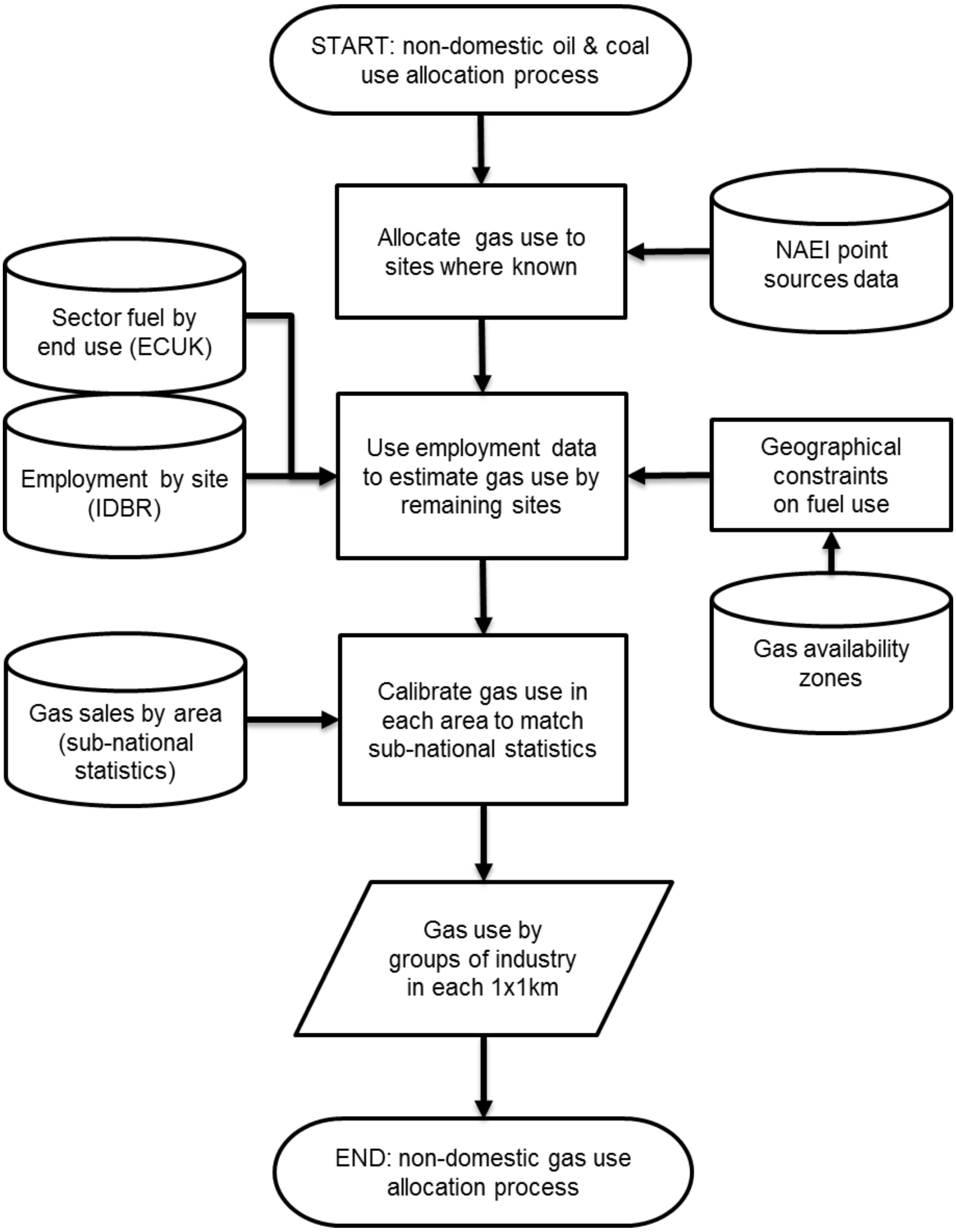
The resulting fuel distributions have been refined using a subsequent set of modelling steps:

- 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).
- 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.
- 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.

Figure 3.2 shows the process to convert industrial & commercial fuel usage from individual employment sites into emissions

[18] www.xoserve.com/wp-content/uploads/Off-Gas-Postcodes.xlsx
[19] http://www.ons.gov.uk/ons/rel/bus-register/business-register-employment-survey/index.html

Figure 3.2: Non-domestic gas use allocation process



3.3 Road transport

Hot exhaust emissions from road vehicles and the related fuel consumption estimates are calculated within the NAEI using fuel consumption and emission factors for each vehicle type. These emission factors 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 estimated within each of the Devolved Administrations derived using Regional Vehicle Licensing Statistics (DVLA) and the DfT's Automatic Number Plate Recognition (ANPR) database. Therefore, 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 4[20] (v8.1);
- Car manufacturers' data on CO_2 emissions and surveys with freight haulage companies on fuel efficiency of HGVs; and
- 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 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 (MacCarthy *et al*, 2015). 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.

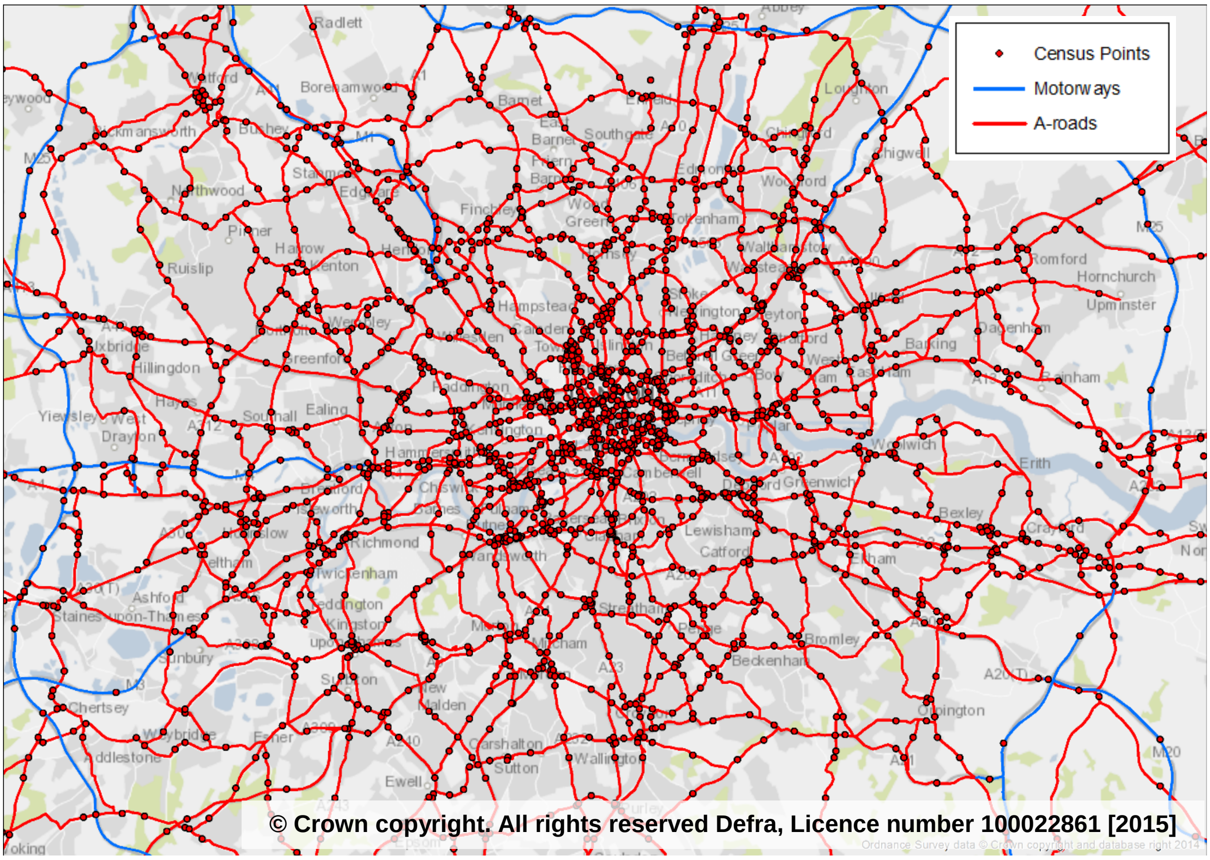
The emission maps are calculated from the speed related emission factors multiplied by vehicle flows. The method for calculating these maps is described in the next section.

[20] 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.

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 provided 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 are available on a census count point basis for both Great Britain (DfT, 2014) and Northern Ireland (Transport NI, 2014). Figure 3.3 shows part of the dataset described above.

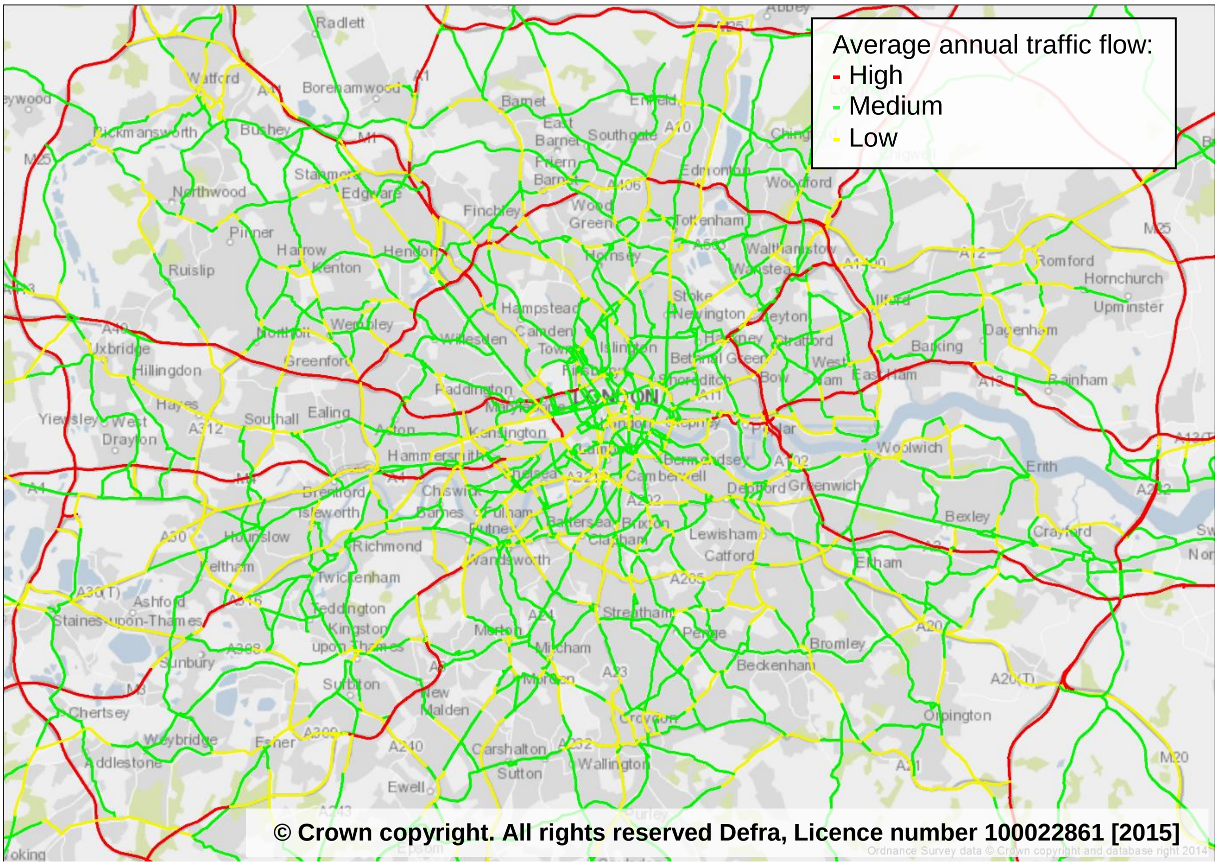
Figure 3.3: A map to illustrate the detail in the road network and count point database



The traffic flow data on major roads includes counts of each type of vehicle as an annual average daily flow. These were aggregated up to annual flows. 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 was 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



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 were used to enhance the accuracy of the mapping. Minor road count points were allocated to minor roads in a similar way to that described for major roads. Traffic flows in the majority of minor roads were 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 were applied to each type of minor road – B and C roads or unclassified roads. These data were obtained from the Department for Transport. For Northern Ireland vehicle-specific minor road flows were calculated from data in the 2013 Traffic and Travel Information report (Transport NI, 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) were analysed to ensure consistency between the NAEI and DfT modelling and were used to correct at County level the estimates of vehicle kilometres in the NAEI mapping.

The next step after mapping vehicle movements was to apply the emissions and fuel consumption factors discussed earlier. Each major road link was assigned an area type using the DfT definitions of urban area types shown in Table 3.2below. Vehicle speeds were assigned to different road types (built up and non-built up A-roads and motorways) within each area type.

Table 3.2: Department for transport urban area type classification

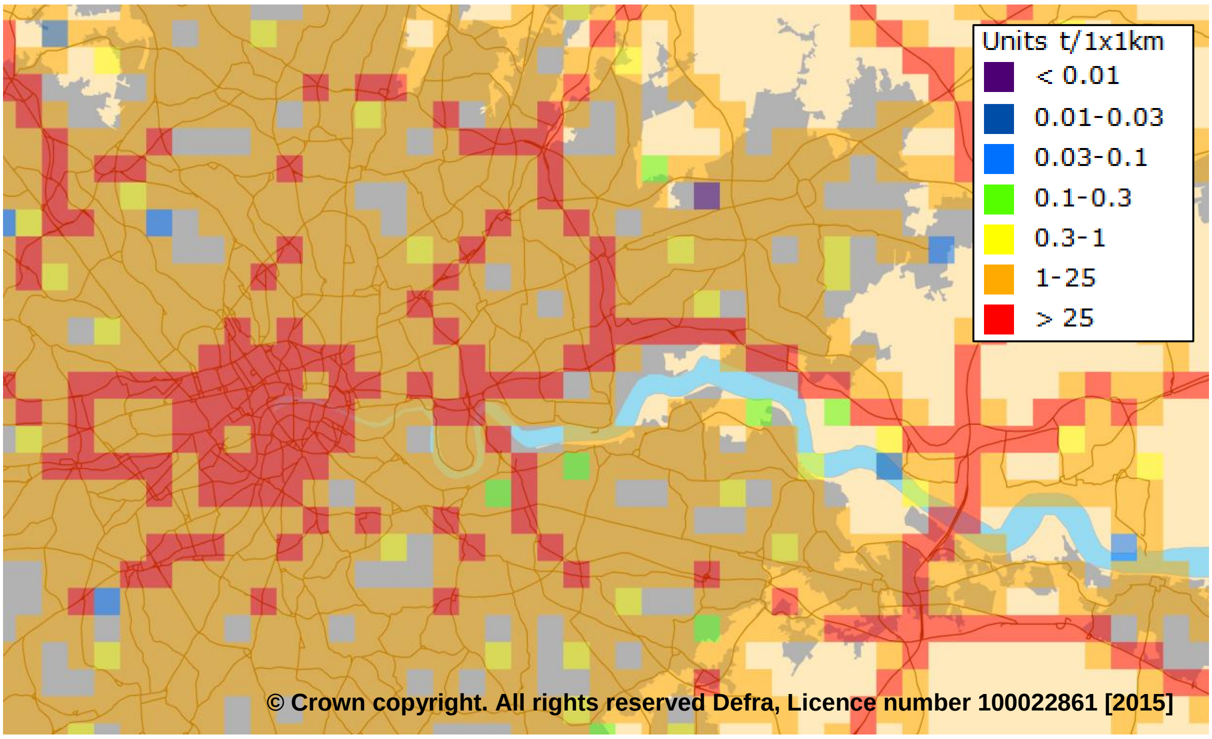
Area Type ID	Description	Population
1	Central London	N/A (Geographically defined)*
2	Inner London	N/A (Geographically defined)*
3	Outer London	N/A (Geographically defined)*
4	Inner Conurbations	N/A (Geographically defined)*
5	Outer Conurbations	N/A (Geographically defined)*
6	Urban Big	> 250,000
7	Urban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

* Geographically unique areas not distinguished by the DfT classification, which are defined on a geographic basis by Ricardo. Conurbations include the Greater Manchester and West Midlands built-up areas.

Vehicle Kilometres (VKM) estimates by vehicle type for each road link were 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 was then split into sections of 1 km grid squares which enabled 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 1x1km across the UK.

Figure 3.5: NO_X road transport emissions aggregated to 1x1km 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 the mapping of cold start emissions are classified as 'home to work', 'home to other locations' and 'work based' trips. 'Home to work' related emissions were distributed across the UK using detailed population data from the 2011 census on whether people use their car as their method of transport to work. Emissions for trips from home to other locations were mapped using data on car ownership, once again collected from the 2011 census. Work based cold start emissions were mapped on a distribution of all employment across the UK. These were reconciled with the outputs from DfT's TEMPRO model (DfT, 2013). Predicted population movements by mode of transport in the TEMPRO model were produced through reconciling the National Trip End Model (NTEM) version 6.2 (April 2011) datasets[21], which contains a long-term travel response to demographic and economic trends within Wales, Scotland and the 9 regions of England. A comparable NTEM dataset representative of current socioeconomic conditions in Northern Ireland was recently commissioned by the Department for Regional Development, and is expected to be included in future releases. The ratio of Northern Ireland to UK cold-start emissions, for each pollutant, was 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 were 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 were distributed using a 1x1km 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 - combustion of waste lubricants and emissions from LPG vehicles. Both of these sources were distributed using estimates of total vehicle kilometres calculated from the NAEI maps of traffic flows.

3.4 Domestic

Sub-national energy statistics at 1x1km were used to generate domestic gas use spatial distribution for England, Wales and Scotland. For Northern Ireland, gas connections information for domestic properties provided by SSE Airtricity[22] and Firmus Energy[23].

Domestic oil and solid fuel use distributions were created by spatially resolving detailed local information on central heating and house type data from the 2011 census with data from 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[24], 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[25]. The census data were combined with full-address matched dwelling locations from Ordnance Survey data to give a more accurate distribution of households at 1x1km resolution. The following data series were used in the domestic model:

21 https://www.gov.uk/government/publications/tempro-downloads/tempro
22 http://www.airtricitygasni.com/at-home/
23 http://www.firmusenergy.co.uk/
24 http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/maps/index.html
25 http://www.metoffice.gov.uk/climate/uk/ws/

1. **Ordnance Survey (OS) AddressBase products;**

    a) OS AddressBase Premium
    The AddressBase data links any property address to its location on the map. It was created through matching the Royal Mail's postal address file (PAF) to building locations contained in the OS Topography Layer, to provide precise coordinates for each of the 24.7 million residential properties in Great Britain.

    b) Ordnance Survey of Northern Ireland (OSNI) Pointer
    The Pointer address product is the most comprehensive and authoritative address database for Northern Ireland, containing location data for just under 740,000 residential address records. Each record adheres to the OS common address standard.

2. **2011 Census returns on dwelling type and central heating fuel types (2001 Census data was used in the previous methodology);**

    a) Office for National Statistics (ONS) – cross-tabulated records [26]
    - *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).*
    - *Output Area (OA) information of dwelling type (only) contained in census tables 'KS401EW' for the 10 regions of England and Wales allowed for a more spatially detailed analysis.*[27]

    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*[28].
    - 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).[29]

3. **DECC National Household Model (NHM) 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

4. **Time-series statistics**
    a) DECC Sub-national gas connections data by area for England, Scotland & Wales[30]
    b) Natural Gas Suppliers gas connections data for Northern Ireland
    c) DCLG Housebuilding statistics: permanent dwellings started and completed[31]

A summary of how these datasets were utilised in the model is given in Table 3.3.

[26] www.ons.gov.uk/ons/guide-method/census/2011/census-data/2011-census-data-catalogue/commissioned-tables/index.html
[27] http://www.ons.gov.uk/ons/datasets-and-tables/index.html
[28] http://www.scotlandscensus.gov.uk/ods-web/data-warehouse.html
[29] http://www.ninis2.nisra.gov.uk/public/Theme.aspx
[30] https://www.gov.uk/government/collections/sub-national-gas-consumption-data#lsoa-msoa-data
[31] https://www.gov.uk/government/statistical-data-sets/live-tables-on-house-building

Table 3.3: Description of methods using the above data series

Task and data series used	Application
1	OS AddressBase Premium geographies were used to generate a spatially resolved database of ONS/NRS 2011 census dwelling types distributed within the Census output area boundaries by unique address level coordinates of residential structures within each of England/Wales and Scotland's Output Area's (OA). Where evidence of areas with natural gas availability, Xoserve's Off-Gas Postcode dataset[32] has been used to identify dwellings with no gas. For Northern Ireland, a fully standardised geo-referenced address layer was retrieved from the OSNI Pointer dataset and combined with NISRA 2011 census household type returns at the Small Area (SA) level. SAs on average contain 155 households a figure comparable to OA's within England / Wales which on average contain 125 households.
2	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.
3	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 and solid fuel central heating returns occurring in matching house types of that OA. The DECC NHM is a domestic energy policy and analytical tool constructed from the national housing surveys (English Housing Survey and Scottish House Condition Survey) to characterise Great Britain's housing stock. The Welsh housing stock model is derived from a reweighting of the English Housing Survey, with insufficient information available for the inclusion of Northern Ireland. Energy statistics for 'Western Scotland' were deemed most appropriate (building forms and climate) to represent the domestic energy factors within Northern Ireland.
4	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 forward, and therefore produce domestic fuel activity for post-2011 years.

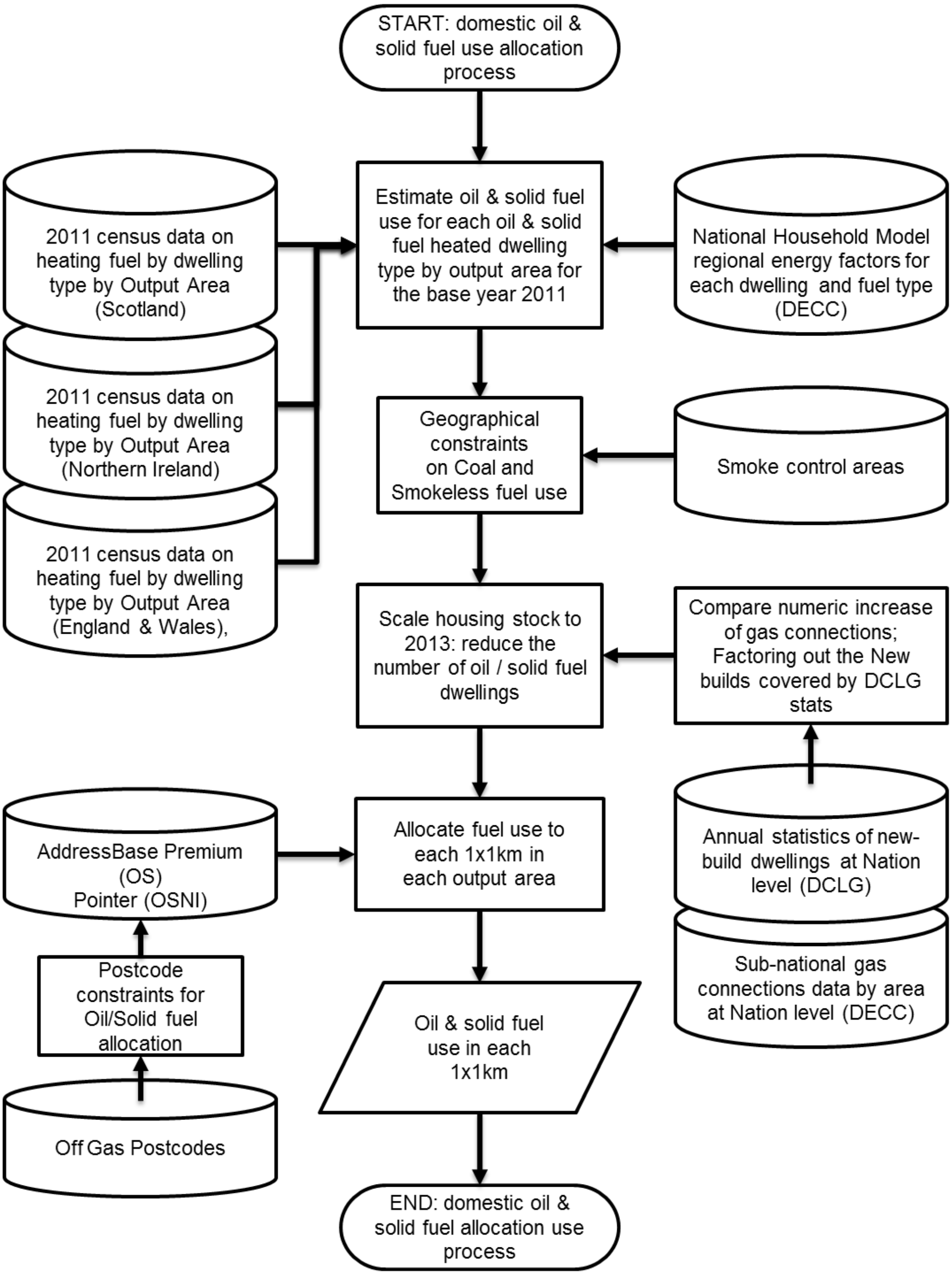
[32] www.xoserve.com/wp-content/uploads/Off-Gas-Postcodes.xlsx

Furthermore, it was 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.
- LPG is burnt in off gas grid output areas, where census returns gas central heating

Figure 3.6 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 3.6: Domestic oil and coal use allocation process



3.5 Agriculture

Emissions of PM_{10} and $PM_{2.5}$ from agricultural livestock and poultry sources were 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 1x1km 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. 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 5x5 km 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 2007 data within the AENEID model to calculate emissions maps.

A small proportion of emissions from the incineration of animal carcases were mapped as a point source e.g. for large facilities. For the majority of national total emissions, however, little is known about the location of this activity. As a result, the residual was mapped as an area source across all UK arable land.

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

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

Agriculture stationary combustion was also mapped using the IDBR employment data and the UK agriculture energy consumption by fuel (ECUK Table 5.1c)[33]. 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** and further detailed in the supporting document *Employment based energy consumption mapping in the UK* (Tsagatakis I. , 2015).

Agricultural off-road emissions were distributed using a combination of arable, pasture and forestry land use data. Each of these land cover classes were 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 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 was updated for the 2011 emission maps. The emissions were spatially disaggregated using data from the Department for Transport's Rail Emissions Model (REM). This provided emission estimates for each strategic route in Great Britain for passenger and freight trains. The emissions along each rail link were assumed to be uniform along the length of the rail link, as no information on either load variation or when engines were on or off is yet available. 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.

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

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 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. For the remaining 48 stations activity was assigned to a single 1x1km grid.

3.7 Shipping

The NAEI includes emissions estimates for:

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

The mapping method used 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).

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 5x5km grid resolution (based on the EMEP grid) for an emissions domain extending 200 miles from the UK coastline.

The revised MARPOL[37] Annex VI Regulations came into force in July 2010. A new method was used to estimate coastal and international marine emissions for the 2012-2013 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 2013 fuel consumption, growth factors were applied to the 2007 fuel consumption in each grid square. The same growth factors were applied to domestic and international shipping and for all types of movements.

Different emissions factors for key pollutants were used for grids within Sulphur Emission Control Area (SECA) and non-SECA and for the different movement types, in order to take into account MARPOL and the SCMFD.

The emission estimates in 5x5km EMEP grid squares were re-mapped to a 1x1km grid based on the OS Great Britain grid system. This was achieved by intersecting these two datasets. The misalignment between these two different spatial reference systems 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 3.6 below illustrates the two separate types of data that were combined.

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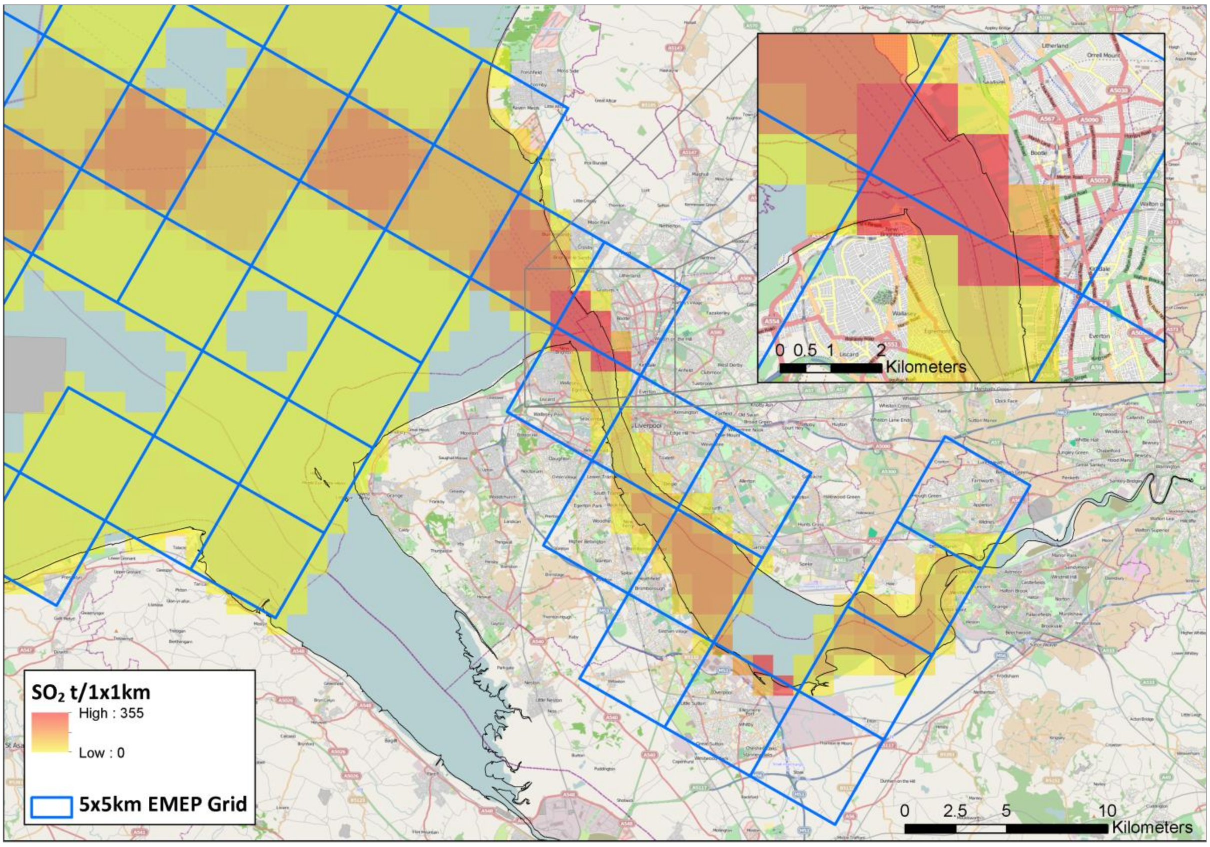
[34] http://www.heritage-railways.com/index.php
[35] http://www.heritagerailwaysmap.co.uk/
[36] http://www.steamrailwaylines.co.uk/index.htm
[37] The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes.

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 by fuel oil (RO) and gas oil (MGO and MDO) and was used in the NAEI gridded outputs.

Figure 3.6: SO_2 emissions at 1x1km 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 British Waterways (now the Canal and Rivers Trust), 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 Northern Ireland were provided by Waterways Ireland 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. Where data gaps were identified, additional activity data were taken from the 'Members' area of the Association of Inland Navigation Authorities website[38].

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.

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) as such activities tend to be more prevalent at larger airports, where greater movement by aircraft on the ground is often required. The former was 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 were 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 mapped 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. The NAEI team have reviewed the employment dataset for the 2013 maps 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 waste burning

The distribution of accidental fires across the UK is particularly uncertain. Distribution maps were made using the Land Cover Map 2007 supplied by CEH[39]. The land cover type was matched to the type of accidental fire as shown in Table 3.4. 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.

[38] http://www.aina.org.uk/members.aspx
[39] http://www.ceh.ac.uk/landcovermap2007.html

Table 3.4: 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, which are allocated to the energy sector. These emissions are mapped as point sources. The second sector comprises emissions from the landfill sites themselves, which are allocated to the waste sector. This sector was mapped as an area source as gas release has the potential to occur across these open-surface waste sites (uniform release rates are assumed across individual sites due to limitations in the spatial information).

The level 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 arising 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; and
- 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).

3.13 Offshore oil and gas

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 were split into emissions from fixed platforms and mobile units such as diving support vessels and drill rigs. 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, however, it was 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. However, for the purposes of modelling long range air pollution from these sources, this is not a significant problem. Similarly there is no population exposure to released pollutants from these sources within their vicinity, other than workers present on the platforms themselves, as there might be for terrestrial industrial installations. 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

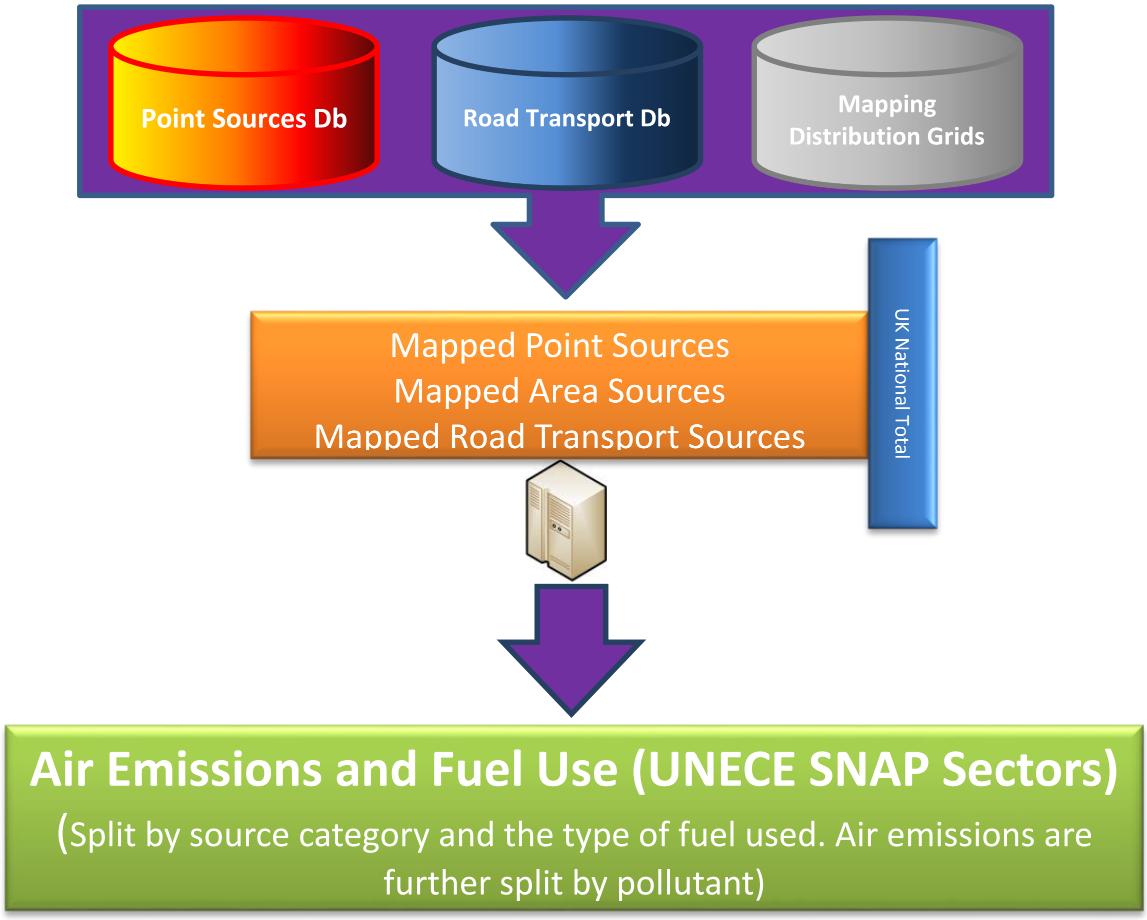
Emissions of PM_{10} from mines and quarries were distributed using data from the British Geological Survey on the locations of mines and quarries in the UK. This data set includes the location of the site and a brief description of products and commodities. There are no data on actual production amounts for each mine or quarry. Regional production statistics for the various commodities were 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 were 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 1x1km[40] 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 (GNFR[41] sectors for international reporting), and point source emissions aggregated to a 1x1km 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.

[40] Mapped outputs for ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O) are produced under the same framework, but some important sources are limited to 5x5 km resolution due to non-disclosure constraints
[41] http://www.ceip.at/fileadmin/inhalte/emep/doc/AnnexIII_Aggregation_gridded_data_300909.doc

Figure 4.2: UK total PM_{10} emissions in 2013

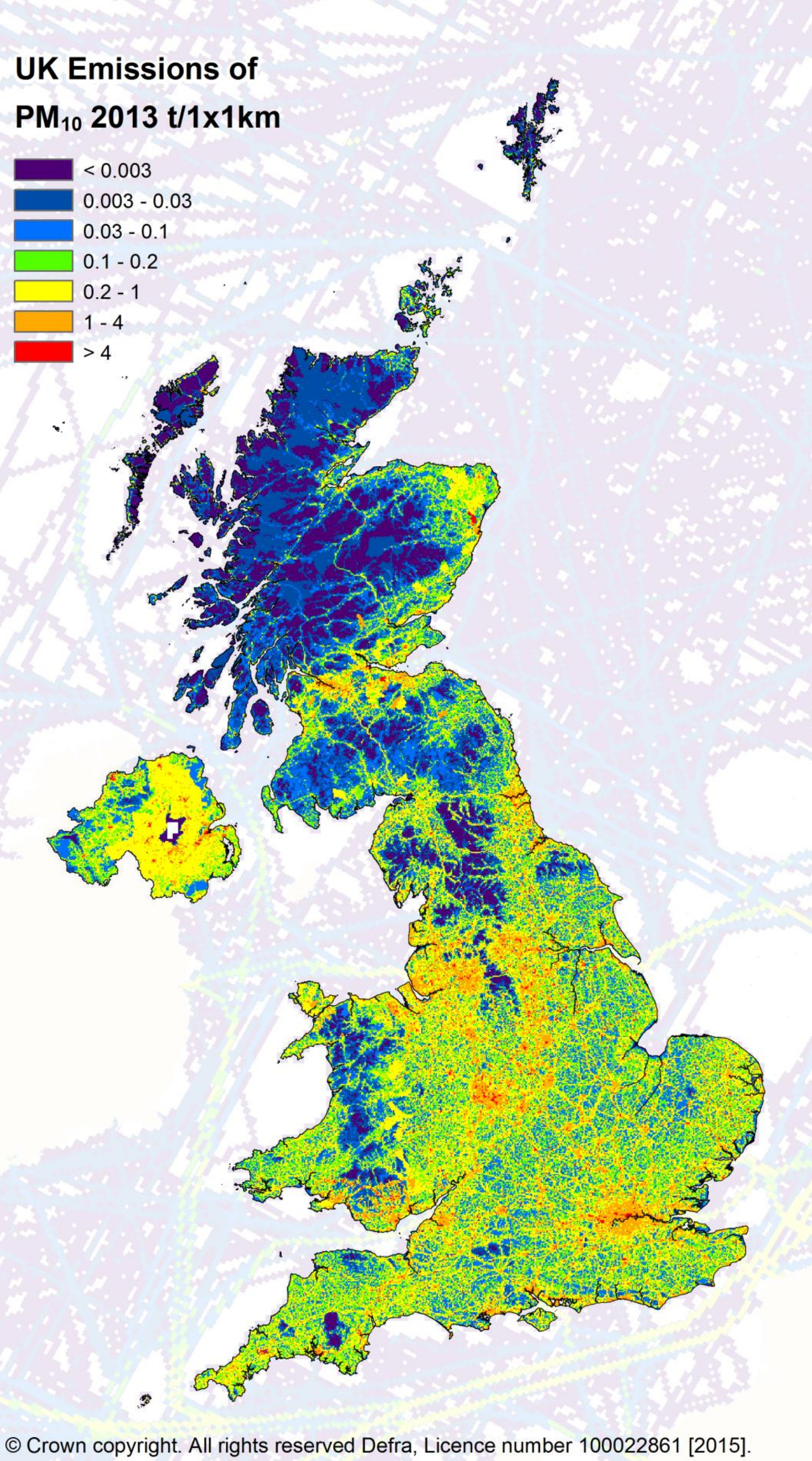


Figure 4.3: UK total SO_2 emissions in 2013

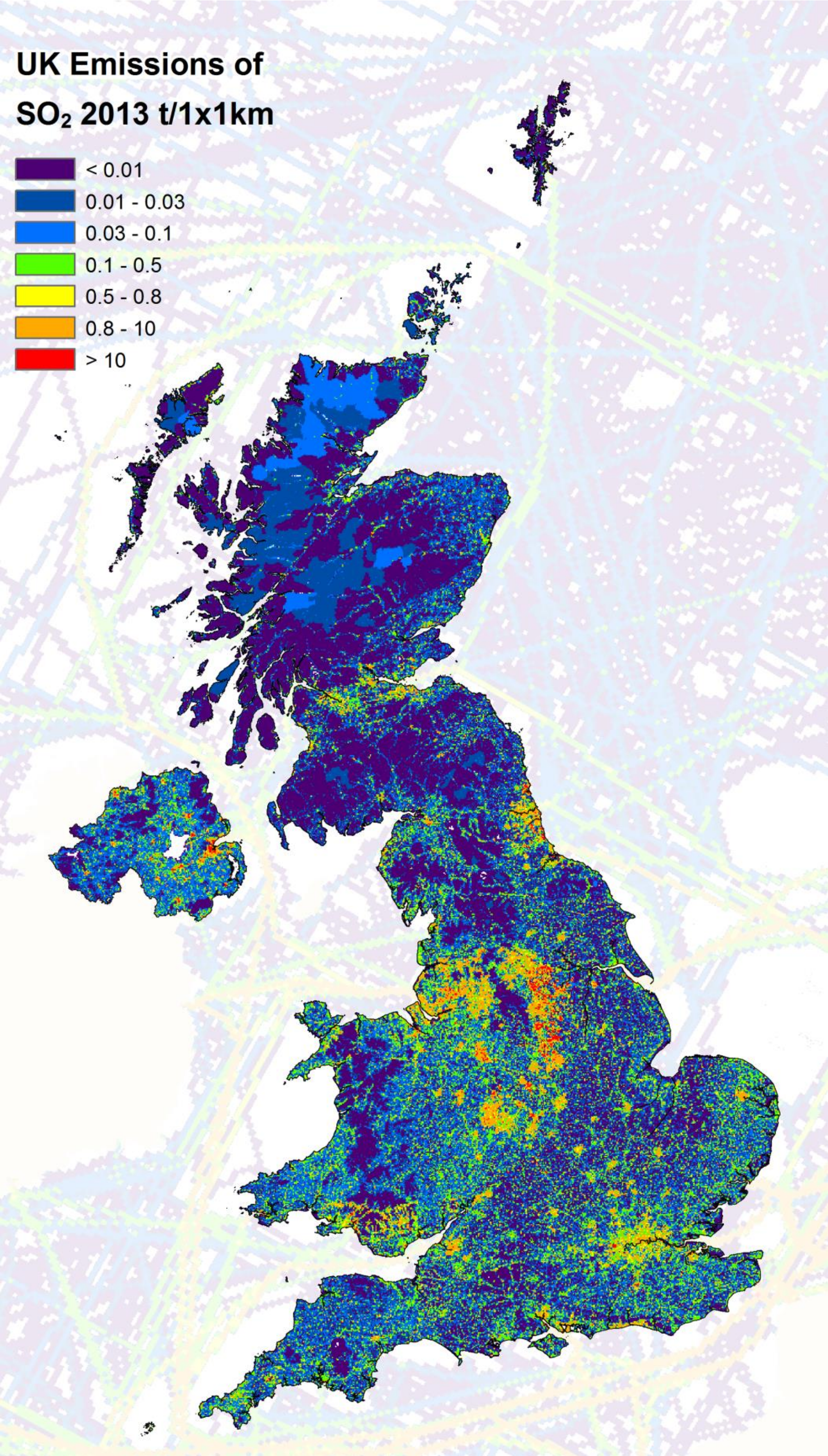
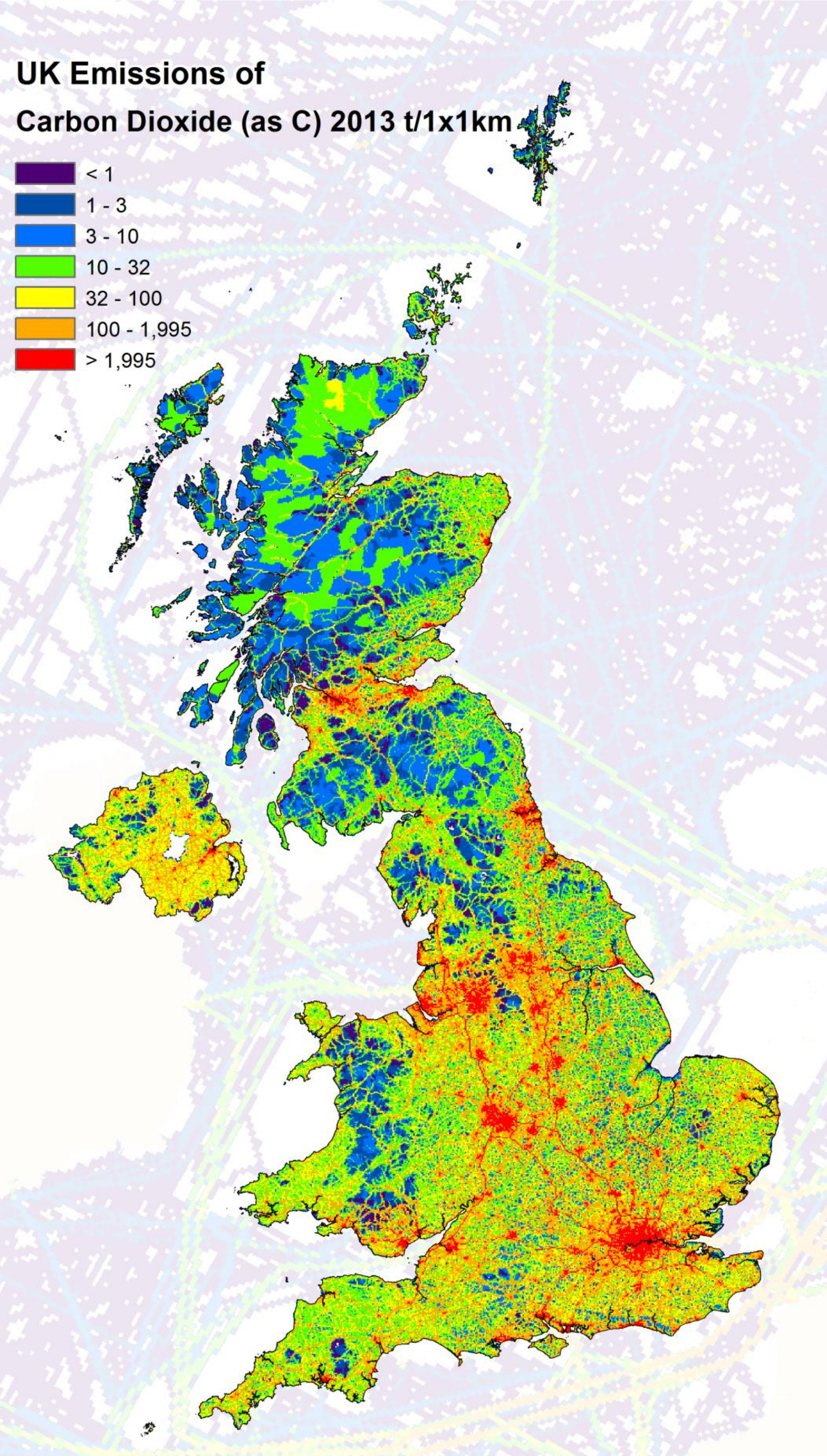


Figure 4.4: UK total CO_2 emissions in 2013



5 Quality of mapping verification

The national quality of mapped emissions is achieved via a semi-quantitative and quantitative approach outlined in following sections. It should be noted that these assessments of uncertainty do not include an assessment of uncertainty of the emissions themselves. MacCarthy et al (2015) provide a comparison of NAEI emissions in respect to the Digest of UK Energy Statistics (DUKES).

The semi-quantitative way of assessing the overall emission map quality by pollutant, involves simply comparing the proportion of emissions mapped as point or area sources against the national total. Greater certainty is associated with emissions from point sources, as the emissions are geographically constrained to a particular location (i.e. Industrial stacks). In terms of emission outputs, point sources are often directly monitored by abatement systems and/or have a record of the materials processed on site, used to inform the mapping.

A quantitative approach for assessing uncertainty in the pollutant maps is subsequently achieved through the inclusion of adjustment factors to emissions associated with different polluting activities. This better represents the uncertainty in the geographic distribution of emissions at area sources, with area source grids based on actual production/emission data providing a low adjustment factor.

Verification, involving the comparison of independently derived data (i.e. ambient monitoring) and model outputs to provide a 'reality check' on the emissions estimates is briefly outlined, and discussed in further detail by Brookes et al (2015).

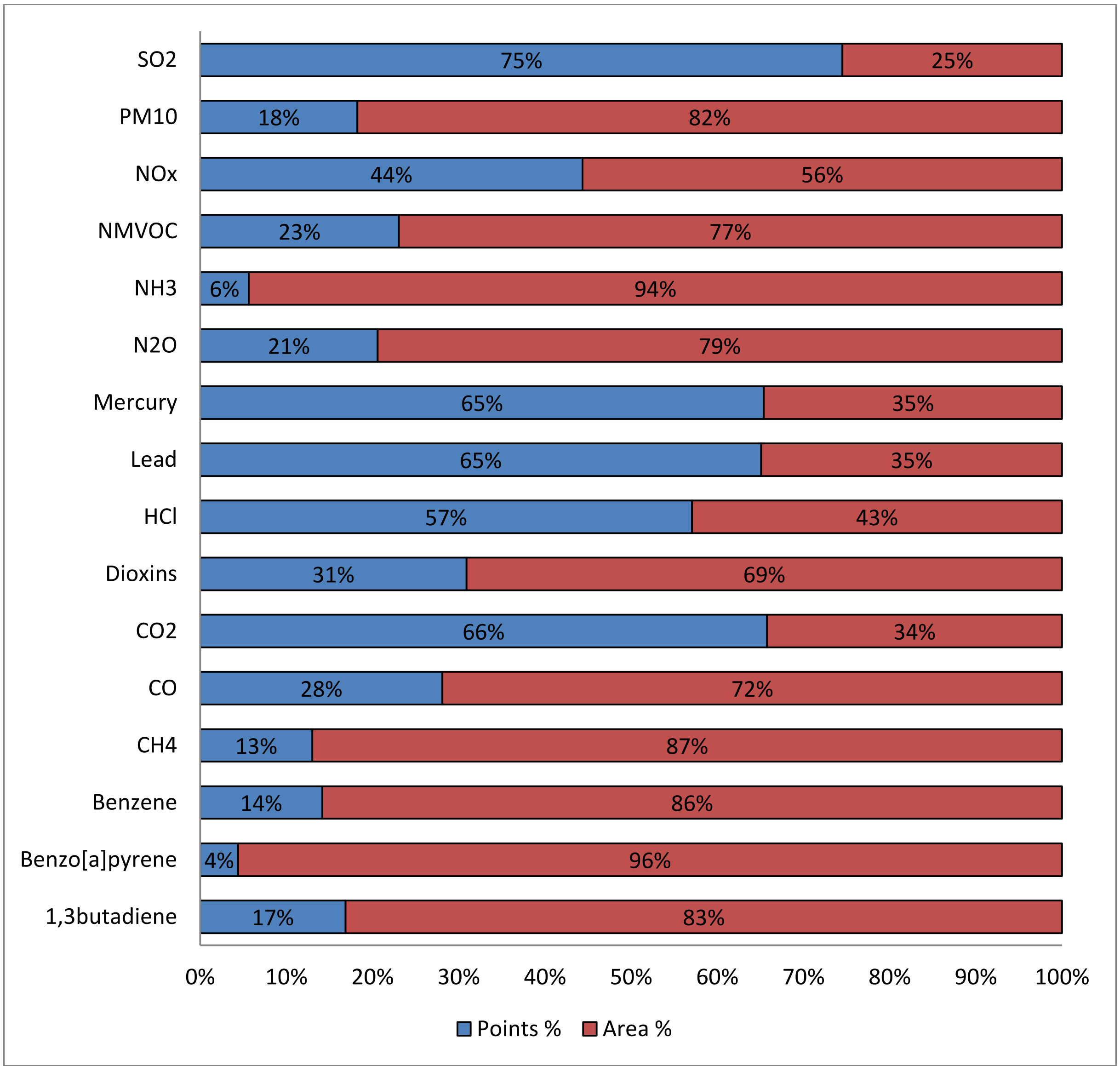
5.1 Estimating quality and uncertainty

As noted in previous sections, the mapping of emissions has been divided into point and area sources. In general, mapped point source data are 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. The NAEI team seek to constantly improve the accuracy of area source mapping by using new, updated and additional data and information when this becomes available.

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.

Taking the proportion of point sources as a measure of quality, Figure 5.1 indicates that maps for lead, mercury, sulphur dioxide, hydrogen chloride and carbon dioxide are likely to be of higher quality than those for ammonia 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.

Figure 5.1: Contribution of point sources to mapped emission totals (2013)



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.

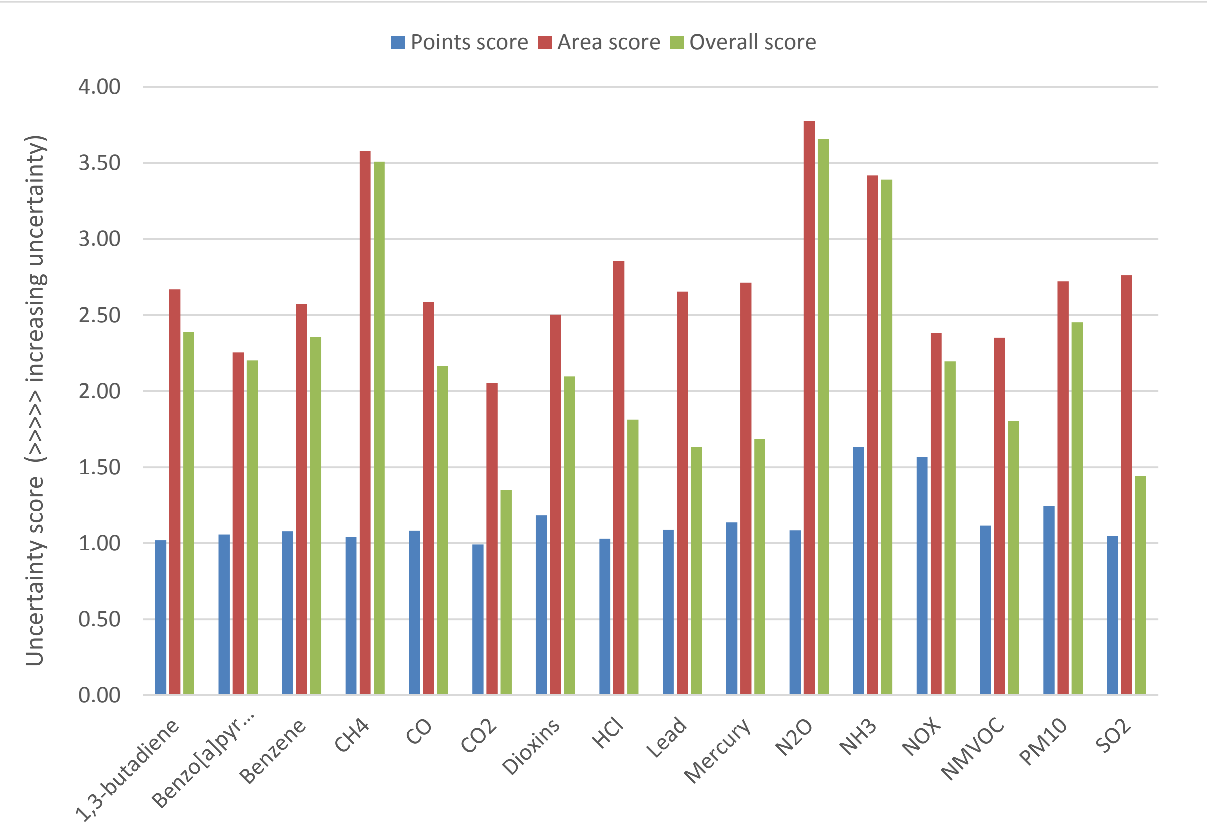
Table 5.1: Spatial uncertainty scoring system

Emission	Score		Typical remark
Area	1	Highest	Use of grids based on actual capacity/production/emissions data for a given source
Area	2		Use for grids which is based on good, relevant, data at high level of definition but with maybe some minor shortcomings (e.g. road transport and population emissions)
Area	3		Use of grids which are believed to be fairly good, albeit with some significant shortcomings (e.g. grids based on employment data which define a particular sector)
Area	4		Use of grids which are believed to be fairly poor with major shortcomings (e.g. grids based on employment data where a sector cannot be clearly defined, such as the 'fabrication of metal products')
Area	5	Lowest	Low quality grids (e.g. use of population or general employment statistics to map a specialised sector with limited numbers of processes or highly regionalised presence. These include cider manufacture, marine coating etc.)
Point	1	Highest	Operator data available for some or all points
Point	2	Lowest	Modelled data

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 1x1km 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 2013 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 nitrous oxide (N_2O), ammonia (NH_3) and methane (CH_4) show the highest overall uncertainty score, with substantial - ammonia (78.6%), methane (48.0%) and nitrous oxide (79.7%) - contributions originating from the agricultural practices (UNECE 10) and even though all the data are 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

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[42] (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. As part of this work, a dispersion kernel modelling approach is applied to the area source emission maps within an area of 33x33km 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.

Further information about the comparison of monitoring and mapped area sources is described in the report ‘UK modelling under the Air Quality Directive (2008/50/EC) for 2013 covering the following air quality pollutants: SO_2, NO_x, NO_2, PM_{10}, $PM_{2.5}$, lead, benzene, CO, and ozone’ (Brookes, et al., 2014).

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

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Appendix 1 – Detailed source sector breakdown of UK emissions of NO_X in 2013

UNECE Source Sector	NAEI Detailed Source Sector	NO_X emission (tonnes)
1 Combustion in energy production and transfer	Coke production	5,844
	Collieries - combustion	191
	Gas production	1,990
	Incineration - MSW	5,584
	Landfill gas combustion	17,018
	Power stations	240,689
	Refineries - combustion	25,617
	Sewage gas combustion	3,000
	Unknown	2
	Upstream Gas Production - fuel combustion	7,799
	Upstream oil and gas production - combustion at gas separation plant	1,826
	Upstream Oil Production - fuel combustion	34,121
1 Combustion in energy production and transfer total		**343,681**
2 Combustion in commercial, institutions, residential and agricultural sectors	Agriculture - stationary combustion	1,001
	Domestic combustion	39,846
	Incineration - MSW	156
	Miscellaneous industrial/commercial combustion	14,766
	Public sector combustion	11,041
	Railways - stationary combustion	3
2 Combustion in commercial, institutions, residential and agricultural sectors total		**66,813**
3 Combustion in industry	Ammonia production - combustion	1,178
	Autogenerators	11,922
	Blast furnaces	572
	Cement - non-decarbonising	11,276
	Chemicals (combustion)	15,109
	Food & drink, tobacco (combustion)	9,490
	Iron and steel - combustion plant	10,169
	Lime production - non decarbonising	6,725
	Non-Ferrous Metal (combustion)	1,043
	Other industrial combustion	36,236
	Pulp, Paper and Print (combustion)	3,907
	Sinter production	7,967
3 Combustion in industry total		**115,595**

UNECE Source Sector	NAEI Detailed Source Sector	NO_X emission (tonnes)
4 Production processes	Basic oxygen furnaces	141
	Chemical industry - nitric acid use	459
	Electric arc furnaces	316
	Iron and steel - flaring	666
	Nitric acid production	109
	Primary aluminium production - general	2
	Solid smokeless fuel production	5
4 Production processes total		**1,697**
5 Extraction / Distribution of fossil fuels	Upstream Oil Production - offshore well testing	91
5 Extraction / Distribution of fossil fuels total		**91**
6 Solvents and other products total		
7 Road transport	Road transport - cars - cold start	7,399
	Road transport - cars with catalysts - cold start	4,193
	Road transport - LGVs - cold start	2,159
	Road transport - LGVs with catalysts - cold start	110
	Road transport - major roads	215,602
	Road transport - minor roads	93,488
7 Road transport total		**322,951**
8 Other transport and machinery	Agriculture - mobile machinery	20,047
	Aircraft - military	4,367
	Aircraft - domestic take-off and landing	1,510
	Aircraft - international take-off and landing	9,319
	Aircraft - support vehicles	3,066
	Aircraft between UK and CDs - TOL	96
	Aircraft between UK and Gibraltar - TOL	12
	Aircraft between UK and other OTs (excl Gib.) - TOL	15
	Fishing vessels	1,681
	House and garden machinery	836
	Industrial off-road mobile machinery	33,457
	Inland goods-carrying vessels	99
	Motorboats / workboats (e.g. canal boats, dredgers, service boats, tourist boats, river boats)	8,816
	Personal watercraft e.g. jet ski	351
	Railways - freight	20,266
	Railways - intercity	8,249
	Railways - regional	7,216

UNECE Source Sector	NAEI Detailed Source Sector	NO_X emission (tonnes)
	Sailing boats with auxiliary engines	88
	Shipping - coastal[43]	24,379
	Shipping - naval	14,500
	Shipping - UK international[43]	362,285
8 Other transport and machinery total[43]		**520,656**
9 Waste Treatment and disposal	Crematoria	357
	Incineration - animal carcases	245
	Incineration - chemical waste	235
	Incineration - clinical waste	169
	Incineration - sewage sludge	123
	Small-scale waste burning	221
	Upstream Gas Production - flaring	171
	Upstream Oil Production - flaring	1,893
9 Waste Treatment and disposal total		**3,415**
11 Other sources and sinks	Accidental fires - dwellings	73
	Accidental fires - forests	133
	Accidental fires - other buildings	66
	Accidental fires - straw	46
	Accidental fires - vegetation	115
	Accidental fires - vehicles	13
11 Other sources and sinks total		**445**
Grand Total[43]		**1,375,345**

[43] Includes activity emitted outside the UK territory, but within the extent of the emission maps as they get published

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