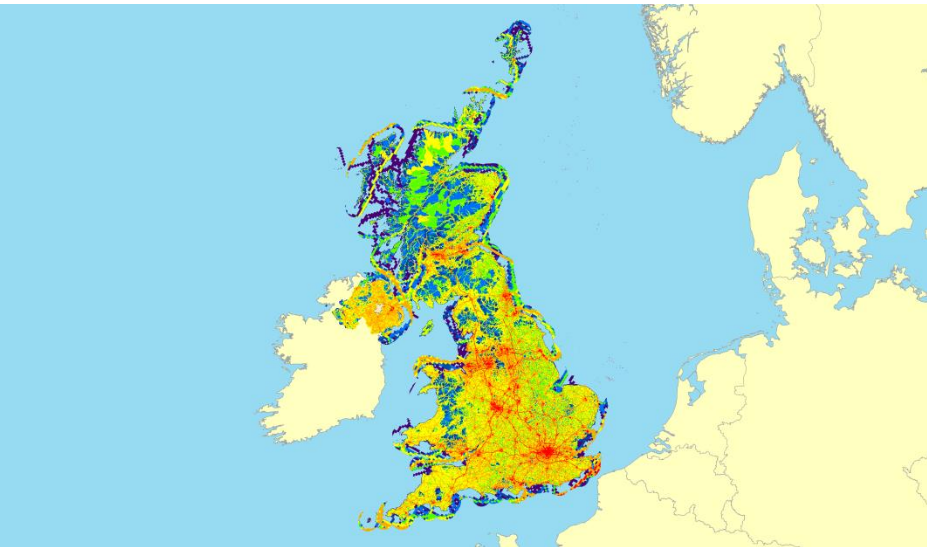
RICARDO-AEA

UK Emission Mapping Methodology 2009

A report of the National Atmospheric Emissions Inventory







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List of Abbreviations

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

Executive summary

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

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

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

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

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

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1 Introduction

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

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

A detailed report describing the methods used for calculating national total emission estimates under the NAEI and other outputs of the inventory system is published each year and can be found on the NAEI website at http://naei.defra.gov.uk/reports/ (Murrells et al, 2011).

1.1 Emission mapping scope and purpose

Emission maps are routinely produced within the NAEI for the 25 pollutants, listed below:

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

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

Table 1.1: UNECE Emissions Sectors Classification

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

The mapped emissions are made freely available in a neutral file format[1] on the NAEI web site at http://naei.defra.gov.uk/data/map-uk-das.

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

- The maps are frequently used as a starting point for many local emission inventories, which may then be used to assess current and future air quality;
- Emission estimates for point sources and emissions arising from the surrounding area are used in modelling studies as part of Environmental Impact Assessments by developers and their consultants.

The emission maps are used for a variety of Government policy support work at the national scale. In particular, spatially disaggregated emissions estimates (1x1 km) and road link-specific emissions information from the NAEI are used annually to underpin Defra's Modelled air quality data[2]. These models are incorporated into the UK's national air quality compliance assessments that are reported to the Commission under European Directives.

They are also used to compile and report the UK emissions to the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP). More specifically, the UK emissions are

[1] ASCII grid format
[2] http://uk-air.defra.gov.uk/data/modelling-data

aggregated to nomenclature for reporting (NFR) codes for Gridding and LPS (GNFR sectors[3]) at 50x50 km EMEP Grid spatial resolution. These datasets are available through the WedDab emission database[4].

Local area statistics are also compiled from the maps and related data e.g. the Local Authority level data on carbon dioxide emissions (Brophy, Tsagatakis, & Passant, 2010) and fuel use (Tsagatakis & Passant, 2010) which have been produced for Defra and DECC (formerly BERR) since 2003. As of March 2008, these datasets were classified as National Statistics.

1.2 Annual Cycle

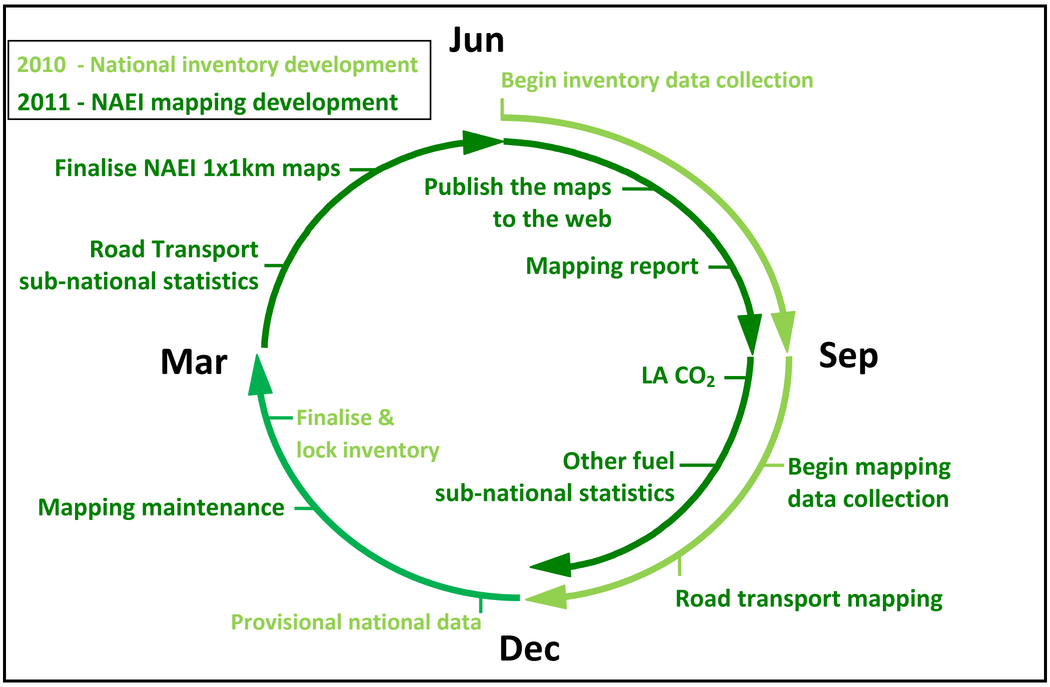
The NAEI is compiled on an annual basis. Each year the full inventory time-series is recalculated to take account of improved data inputs and any advances in methodology. Updating the full time-series is an important process as it ensures that the entire dataset uses the most current methodology. National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

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

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.

[3] http://www.ceip.at/fileadmin/inhalte/emep/doc/AnnexIII_Aggregation_gridded_data_300909.doc
[4] http://www.ceip.at/webdab-emission-database/

Figure 1.1: The annual NAEI mapping Cycle



1.3 Report Structure

The next section of this report (section 2) provides an overview of the emission sectors covered by the NAEI. Section 3 then describes the methods used to calculate distribution maps for these sectors across the UK. The compilation of the final emission maps and data products are covered in section 4. The quality and verification of the maps is assessed in section 5. Section 6 provides a summary of recommendations for improvements to the maps.

2 National Inventory Compilation

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

The NAEI obtains data on fuel consumption from the Digest of UK Energy Statistics (DUKES). National totals based on these data are further refined for some sectors taking into account other more detailed data from the regulators of industrial processes: the Environment Agency, the Scottish Environmental Protection Agency (SEPA) and the Department of the Environment Northern Ireland (DOENI). Emission estimates are calculated by applying an emission factor to an appropriate activity statistic. That is:

$$Emission = Factor \times Activity$$

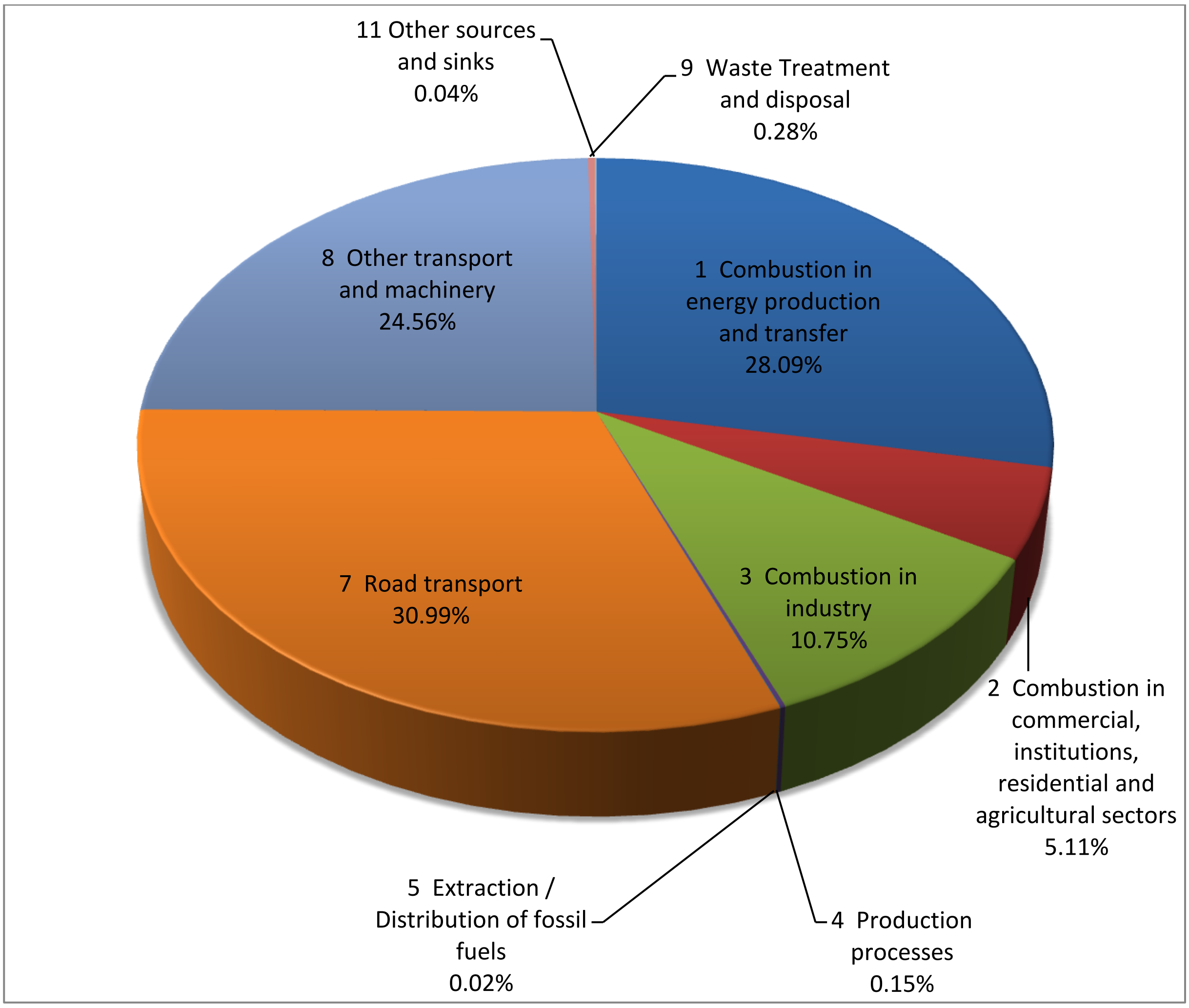
Emission factors are generally derived from measurements made on a number of sources representative of a particular emission sector. Examples of emission factors include the amount of NO_x emitted from a car per kilometre it travels and the amount of SO_2 emitted from a power station per tonne of coal burned.

Activity statistics are obtained from Government statistical sources, such as DUKES (DECC, 2010), Transport Statistics Great Britain (DfT, 2010a), and from organisations such as trade associations and research institutes e.g. the UK Petroleum Industries Association (UKPIA) provides data on the sulphur content of fuels, and the Institute of Grassland and Environmental Research (IGER) which provides data on livestock numbers and fertiliser usage.

A detailed breakdown of the NAEI source sectors for NO_X in 2009 is shown in Appendix 1, and a summary aggregated to UNECE SNAP sectors is shown in Figure 2.1. Emission estimates of NO_x are in fact compiled in considerably more detail. The NO_x inventory will be used throughout this report as an aide to illustrate the mapping methods used.

The relative contribution of emissions from different sectors varies by pollutant. The NAEI report (Murrells, et al., 2011) provides details of emissions by sector for all pollutants.

Figure 2.1: UK NO_X Emissions in 2009 by UNECE Source Sector



3 Methods for calculating emission distributions

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

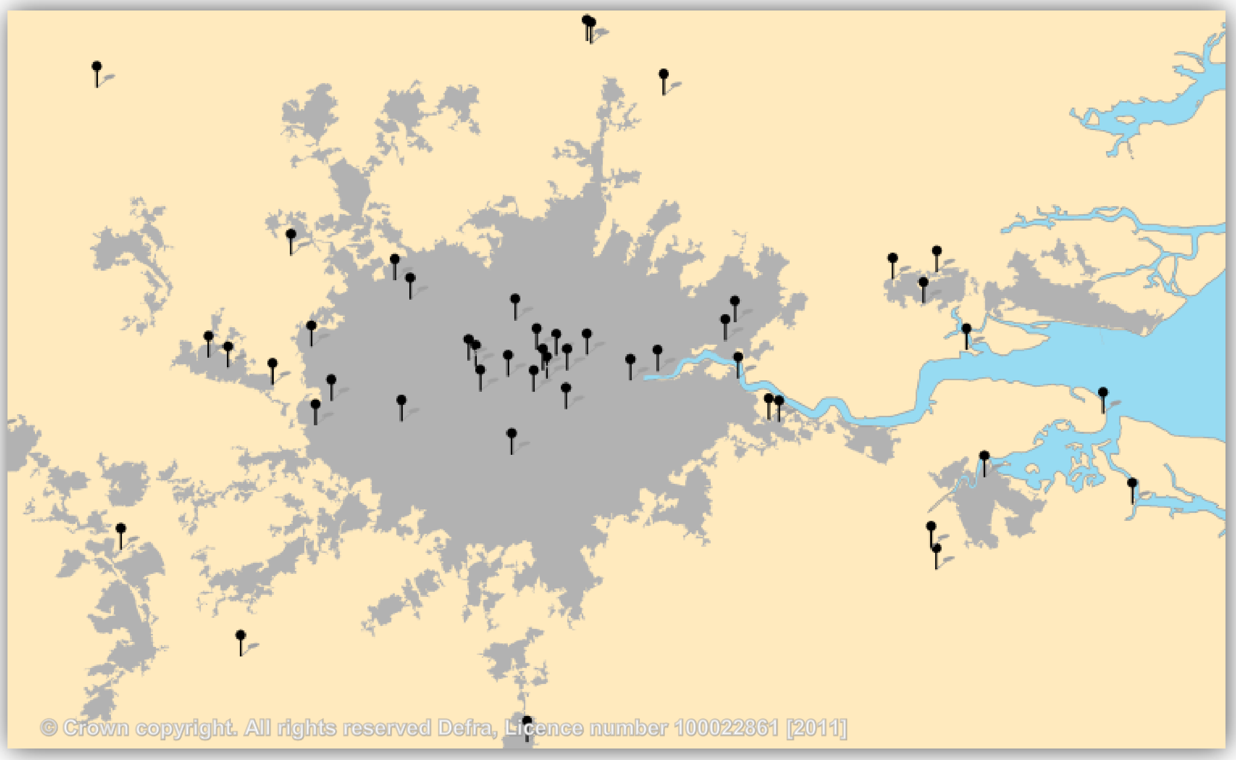
Table 3.1: Methods used to map emissions in each of the 11 UNECE source sectors

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

3.1 Large industrial and commercial sources

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

Figure 3.1: An example of industrial and commercial point sources around the Greater London Area



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

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

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

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

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

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

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

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

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

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

A further complication is that even where a given installation is present in both the EU ETS and other data sets, the exact scope of the emissions data may not be the same. For example, emissions data in the PI will include carbon dioxide from bio fuels, whereas the EU

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

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

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

It should be noted, however, that even given the comprehensive information compiled in the above registers and datasets, point source data are not available for all processes. For sources below the reporting thresholds described above or, in the case of processes regulated by local authorities, the NAEI may not collect any emissions data from the regulator. Furthermore, some point sources are not regulated. In these cases, point source data is 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 emissions as plants within the same sector which do report emissions. In cases where point source data are available for the sector from the PI, emissions data may be missing for a small proportion of sites, generally either because the process is small and emissions are below reporting thresholds or because the site closed that year and did not therefore submit a report. In these cases, emissions are calculated by assuming that these sites will emit at the same rate as other sites for which emissions data are available;

- Emissions can be distributed using surrogate data other than capacity. For example, in the case of Scotch malt whisky distilleries, emissions of VOC from distilling are distributed using capacity except in cases where this is not known and then the number of stills is used as a measure of the scale of operations and therefore emissions;
- Assuming that all plants in a given sector have equal emissions. In a few cases where there are relatively few plants in a sector but no activity data can be derived, emissions are assumed to be equal at all of the sites.

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

Figure 3.2: Point source emission fraction of NAEI UK total emissions for key pollutants and contributions of reported and estimated data in 2009

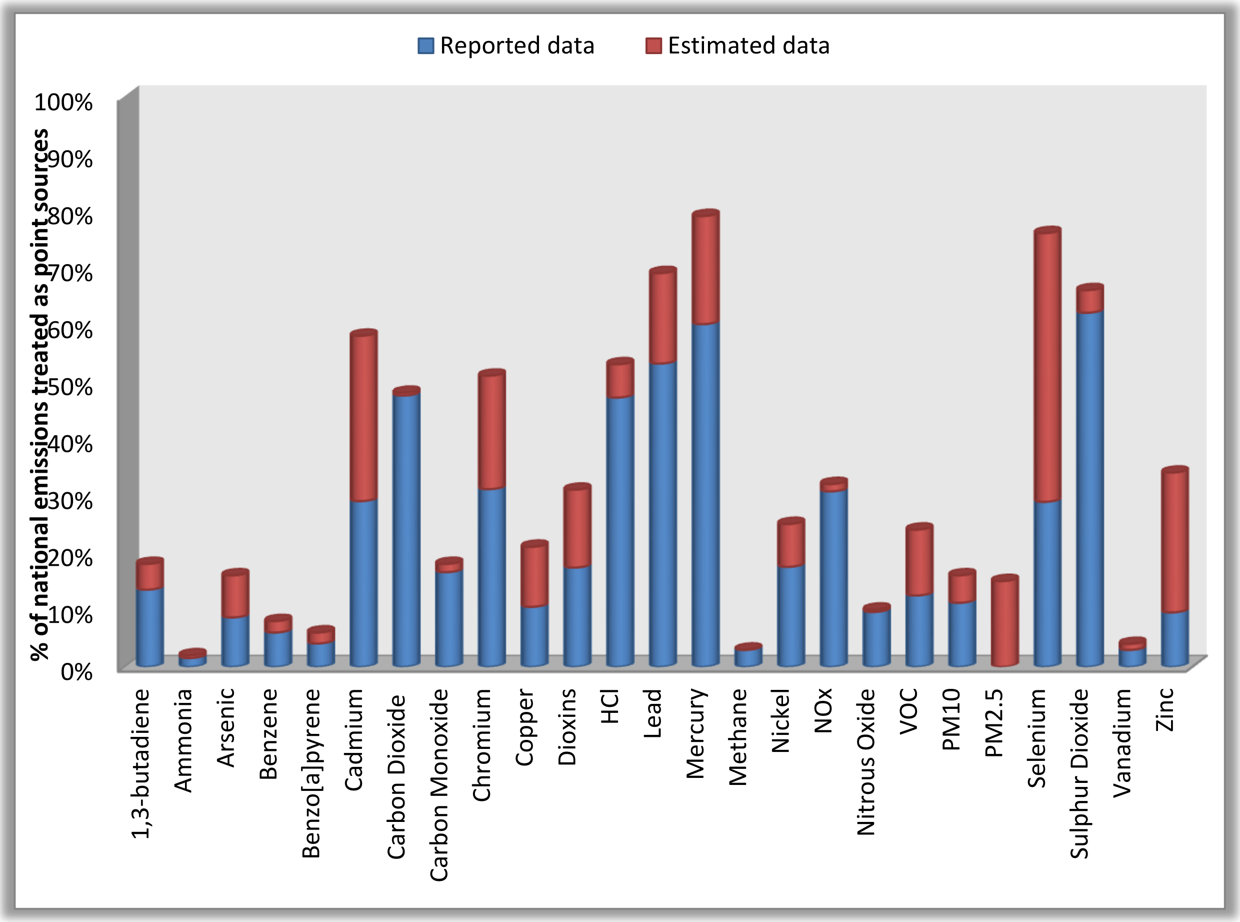


Figure 3.2 shows the contribution of point sources to UK total emissions for the NAEI's 25 core pollutants. The contribution from reported or estimated emissions is also indicated. In some cases, emissions data reported in the PI or similar sources must be 'interpreted' in order to yield point source data. An example would be the case of VOC emissions from a chemical process where emissions of individual VOC species' might be reported, but not emissions of total VOC. The NAEI team use expert judgement to decide whether to assume that the individual VOC species' reported were the only VOCs emitted or whether to make an

allowance for other species being emitted. In such cases, point source data are treated as NAEI calculated emission estimates rather than reported data. The calculated emissions also include all point source data based on data supplied by regulators for LAPC/APC processes.

The larger proportion of NO_X, SO_2, HCl and some of the heavy metals point source emissions are mapped based on reported data. This is because the main sources are power stations and other large combustion plant where the level of reporting is extremely high. However, 48% of VOC point source data are based on NAEI calculations, reflecting the need for further processing of reported data to yield suitable data. $PM_{2.5}$ emissions are calculated from PM_{10} reported and estimated emissions based on particulate speciation factors for each source type. The point source data for $PM_{2.5}$ is therefore 100% estimated.

Figure 3.2 also shows the percentage of national emissions which are mapped as point sources. For SO_2, some of the heavy metals and HCl, a large proportion of emissions are treated as point sources. For most other pollutants this percentage is less than 50% and often less than 20% of national emissions. This is due to the fact that a high proportion of emissions of these pollutants are from sources which cannot be treated as point sources (road transport, aircraft, shipping, domestic fires, small industrial combustion units, consumer-product use, agriculture, petrol stations, dry cleaning shops, gas pipelines etc.).

3.2 Other industrial, commercial and public sector consumers

As indicated above, the emissions at large point sources represent a substantial proportion of the total industrial and commercial fuel consumption. Subtracting the site-specific emissions from the NAEI sector total calculates a residual emission[5], which is treated as an 'area source'. This residual emission is allocated to the UK grid using distribution maps for each sector derived from employment statistics. Each distribution map provides the percentage of the UK's residual sector fuel consumption estimate to be allocated to each 1km^2.

The distribution maps used to provide spatial context to the area source emissions are not updated each year. Instead, they are updated when significant changes occur in the level of activity or when the data sets are considered to have aged sufficiently to warrant updating. The uncertainty arising in an over simplification of real world conditions using this approach is considered small compared with that introduced by the use of employment statistics as a surrogate for spatial distribution of activity in each sector and therefore, fuel consumption.

The distribution maps for other industrial, commercial and public sector activities were last updated for the 2006 inventory (King & Tsagatakis, 2008). The following data series 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; and
- Energy Consumption in the UK data on industrial and commercial sector fuel usage

The SIC codes in the IDBR database were matched with the energy datasets in order to calculate total employment for each energy sector. From this, fuel intensity per employee

[5] Residual emission = national total – point source emission total

was calculated. These intensities could then be applied to employment statistics aggregated to a 1 km^2 grid for the UK to make maps of fuel use.

In the case of industrial sectors this energy intensity calculation was done at the level of 4 figure SIC codes (over 250 separate industry types) to retain the level of detail required for the mapping; aggregation of SIC codes would have resulted in a reduction in the quality of the final distribution. Energy consumption data were available for coal, manufactured fuel (SSF), LPG, gas oil, fuel oil and natural gas. These were aggregated to calculate industry specific fuel intensities for coal, SSF, oil and gas.

For commercial and public service sectors the employment data were aggregated to the same sectors as the energy data. These sectors are presented in Table 3.2 below.

Table 3.2: Service sector energy consumption sub-sectors and NAEI sectors

Service sector energy consumption sub sectors	NAEI emissions sector
Commercial Offices	Commercial
Communication and Transport	Commercial
Hotel and Catering	Commercial
Other	Commercial
Retail	Commercial
Sport and Leisure	Commercial
Warehouses	Commercial
Education	Public admin and services
Government	Public admin and services
Health	Public admin and services

The IDBR employment data at local unit level were aggregated to 4 figure SIC codes at 1 km^2 resolution using grid references provided in the database. The employment totals for each sector were then multiplied by the appropriate fuel intensity values to make maps of fuel use across the UK. It has been assumed that fuel intensity for each sector is uniform across the sector. Although this latter assumption is likely to represent a simplification of real world conditions, it is necessary given the absence of more detailed estimates of fuel use.

The resulting fuel distributions were refined using a subsequent set of modelling steps, described below:

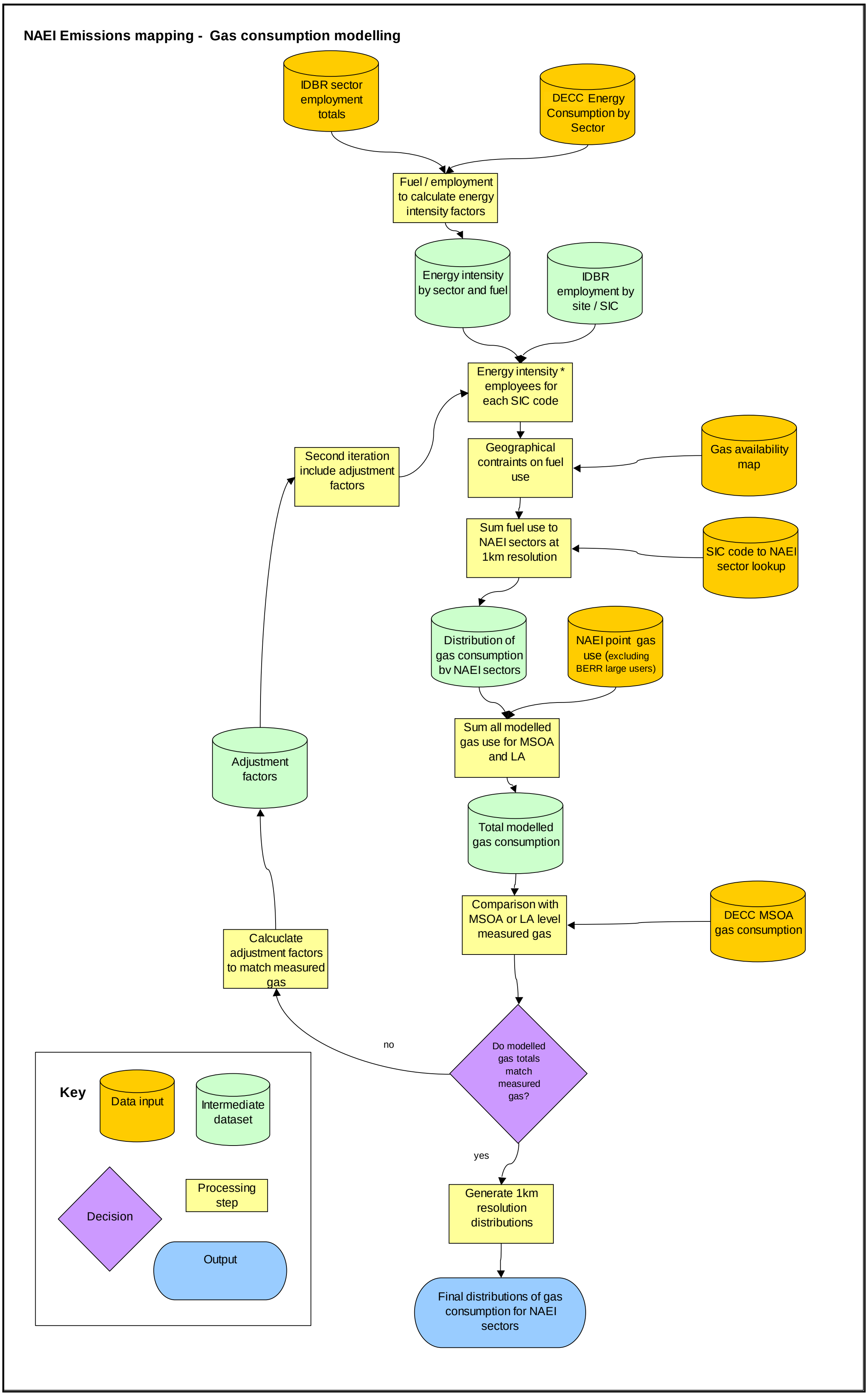
- Sites of employment corresponding to the locations of the highest emissions (as defined by the NAEI point source database) have been removed from the distributions to prevent double counting of emissions at these locations (emissions are mapped as point sources);
- High-resolution gas consumption data at Middle Layer Super Output Area (MSOA) level 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;

- Distributions of fuel and gas oil have been modified so that consumption is lower per employee in grid squares covered by Smoke Control Areas;
- The distribution of coal consumption has been limited to locations outside Smoke Control Areas;
- There have been no maps generated of Smokeless Solid Fuel consumption as part of this work. Table 4.6 of Energy Consumption in the UK indicates that there was only one sector using manufactured fuel (Manufacture of coke oven products). The fuel use in this sector was mapped predominantly by point sources.

Figure 3.3 summarises graphically the data flows and processes for the modelling undertaken for gas consumption.

Figure 3.3: Gas consumption modelling data and process flow



The fuel use calculated for each receptor grid cell was normalised by dividing it by the total fuel consumption for the relevant sector. This provided the required distribution maps giving the percentage of the total residual to be allocated to each 1 km square.

Further maps of employment have also been generated from the IDBR database to be used as proxy datasets for non-fuel based emissions distributions. Examples of these are dry cleaning, petrol stations and industrial chemical manufacture. Wood combustion by industry was distributed on the same basis as coal.

Further information on these processes, including data flows of other fuel types, can be found in documentation provided in the **Mapping small industrial emissions** (King & Tsagatakis, 2008).

3.3 Road transport

Hot exhaust emissions and the related fuel consumption estimates are calculated within the NAEI using fuel consumption and emission factors for each vehicle type. These in turn are calculated on the basis of the composition of the vehicle fleet (age profile and fuel mix). The resulting fuel consumption and emission factors are applied to detailed spatially resolved traffic movements. In addition the fleet mix varies by location and as a result different emission factors are applied to different road types in different geographical areas. Vehicle fleet age profiles and fuel mix are fixed at a national level.

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 calculate national fuel consumption and emission estimates for passenger cars, light goods vehicles (LGVs), rigid heavy good vehicles (HGVs), articulated HGVs, buses/coaches and mopeds/motorcycles. The vehicle classifications are further sub-divided according to 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 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, Euro 1, Euro 2 and Euro 3 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 respectively per kilometre driven for each detailed vehicle class and are taken from two distinct data sources:

- Vehicle emission test data provided by the Transport Research Laboratory (TRL) over different drive cycles from measurements on a limited sample of vehicles;
- Car manufacturers' data on CO_2 emissions and surveys with freight haulage companies on fuel efficiency of HGVs.

However, the amount of fuel that a vehicle consumes in travelling any given distance depends on many parameters such as; the driving cycle, how aggressively the vehicle is driven, the load applied to the engine, state of maintenance, tyre inflation and use of air conditioning etc. It is impossible to know about all these parameters for every vehicle on the road and averages have to be 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 largely from a database held by TRL of factors measured over different test cycles that simulate real world conditions (DfT, 2010b). However, we have had to fill in gaps using expert judgement, especially for more modern classes of vehicles and technologies that have yet to be tested. This is especially the case for large HGVs and buses where the test sample size is small; it is very expensive to carry out these tests and they require special facilities. Using average speed of a vehicle is itself crude, but so far, the only indicator of the way a vehicle operates. There could be many different cycles, all with the same average speed, that have different rates of acceleration and deceleration built into them and for each of these, the fuel consumption rate will be very different.

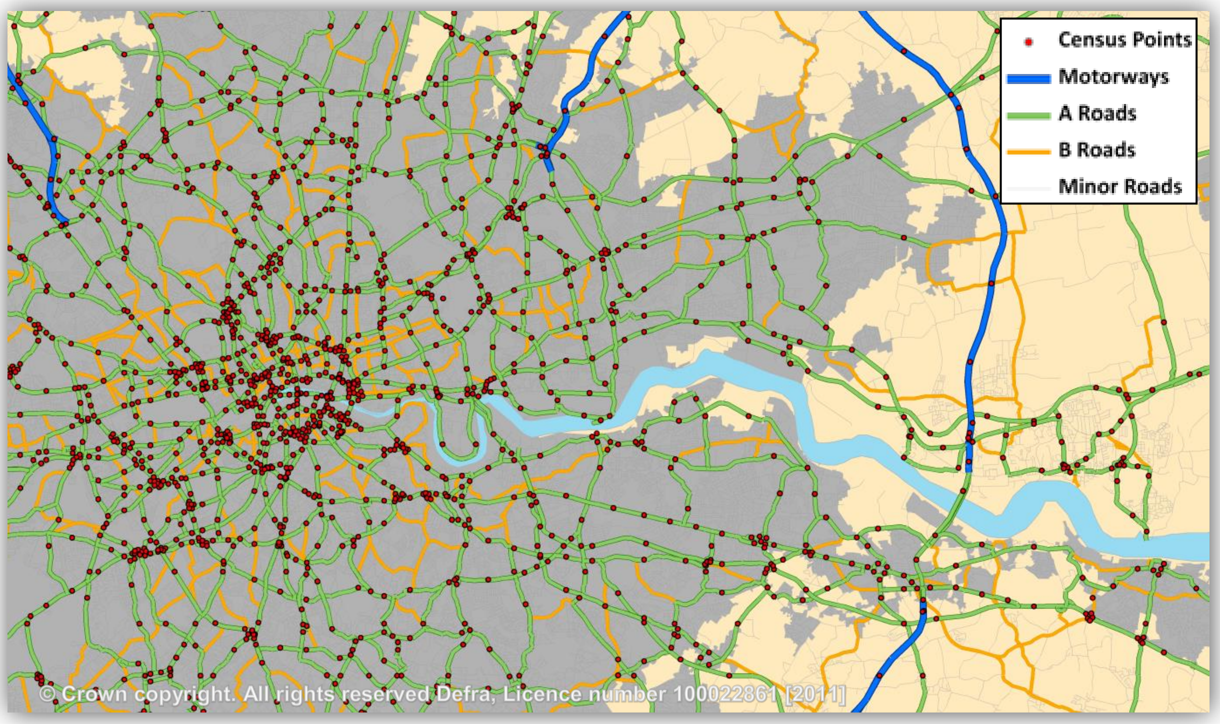
Emissions for the key air quality pollutants (NO_x, PM_{10}, $PM_{2.5}$, SO_2, NMVOC, Benzene, 1,3-butadiene, and CO) are calculated using speed related emission factors multiplied by vehicle flows on the road network. For other pollutants such as CO_2 and heavy metals, fuel consumption is used as a proxy for the distribution of emissions. The document **Changes made in the 2009 NAEI Road Transport Inventory** (Murrells, Pang, & Tsagatakis, 2011) describes the changes made to the information and method used to calculate the 2009 time series in fuel consumption and emissions by road transport.

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

3.3.2 Road transport mapping methodology

The base map of the UK road network used for calculating the hot exhaust road traffic emissions is derived from the Ordnance Survey Meridian 2 dataset. This provides locations of all roads (motorways, A-roads, B-roads and minor roads) in Great Britain. In addition, a dataset of roads in Northern Ireland was obtained from the Land & Property Services which is responsible for all Ordnance Survey of Northern Ireland. The traffic flow data is available on a census count point basis for both GB (DfT, 2010c) and Northern Ireland (Roads Service, 2010). However, the coverage in GB is considerably denser than that for Northern Ireland, although some new NI count points become available every year. Figure 3.4 shows part of the dataset described above.

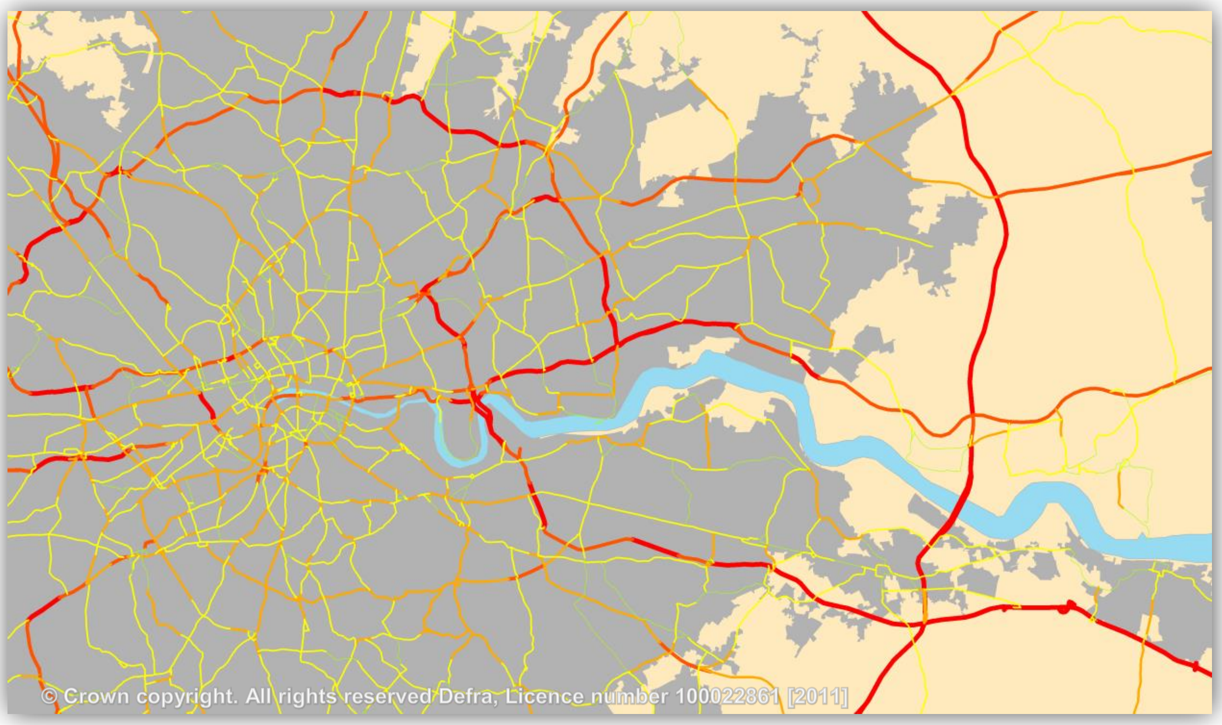
Figure 3.4: A map to illustrate the detail in the road network and count point database



The traffic flow data on major roads include counts of each type of vehicle as an annual average daily flow. These have been aggregated up to annual flows by multiplying by 365. The Annual Average Daily Flow (AADF) statistics take account of seasonal variation through the use of 'expansion factors' applied to the single day counts based on data from automatic counts for similar roads and vehicle types. Some Northern Ireland count points only record total vehicles, rather than a split of different vehicle types. An average vehicle split has therefore been applied to these.

Each traffic count point has been allocated to a section of the major road network according to the road name and its proximity to the road by using a GIS script – i.e. each link has the nearest count point with the same road name assigned to it (Figure 3.5).

Figure 3.5: Flows are assigned to the road links using a GIS script



On minor roads, traffic flow data are not available on a link by link basis for the majority of minor roads. However, data are available for a small number of roads and these have been used to enhance the accuracy of the mapping. Minor road count points have been allocated to minor roads using the approach for major roads described above. Local information applicable to each census point (Local Authority, Area type) is also generated.

Traffic flows on the majority of minor roads have been modelled using experimental statistics on average regional flows and fleet characteristics provided by data from DfT as in previous years. Regional average flows by vehicle type have been applied to each type of minor road (B and C roads or unclassified roads). For Northern Ireland, vehicle-specific minor road flows have been calculated from data in the Traffic and Travel Information 2009 report (Roads Service, 2010) which provides average flows for all vehicle types by minor roads and also average vehicle splits by the same road types.

Furthermore, minor road VKM estimates at a second tier level have been provided by DfT to ensure consistency between the NAEI and DfT modelling. These have been used to correct the estimates of VKM in the NAEI mapping on road links where average regional traffic flow was applied.

The age of the UK vehicle fleet is assumed not to vary regionally. The fuel split for passenger cars between petrol and diesel has been allocated with a different mix assumed for urban, rural and motorway roads (major and minor). 90% of the LGVs on all roads are diesel, and the remainder are assumed to be petrol. For other vehicles, it has been assumed that 100% of motorcycles are fuelled by petrol and 100% of heavy goods vehicles and buses run on diesel.

The next step after mapping vehicle movements is to apply the emissions and fuel consumption factors discussed earlier. Each major road link has been assigned an area type using the DfT definitions of urban area types shown in Table 3.3 below. Vehicle speeds have then been assigned to different road types (built up and non-built up A-roads and motorways) within each area type.

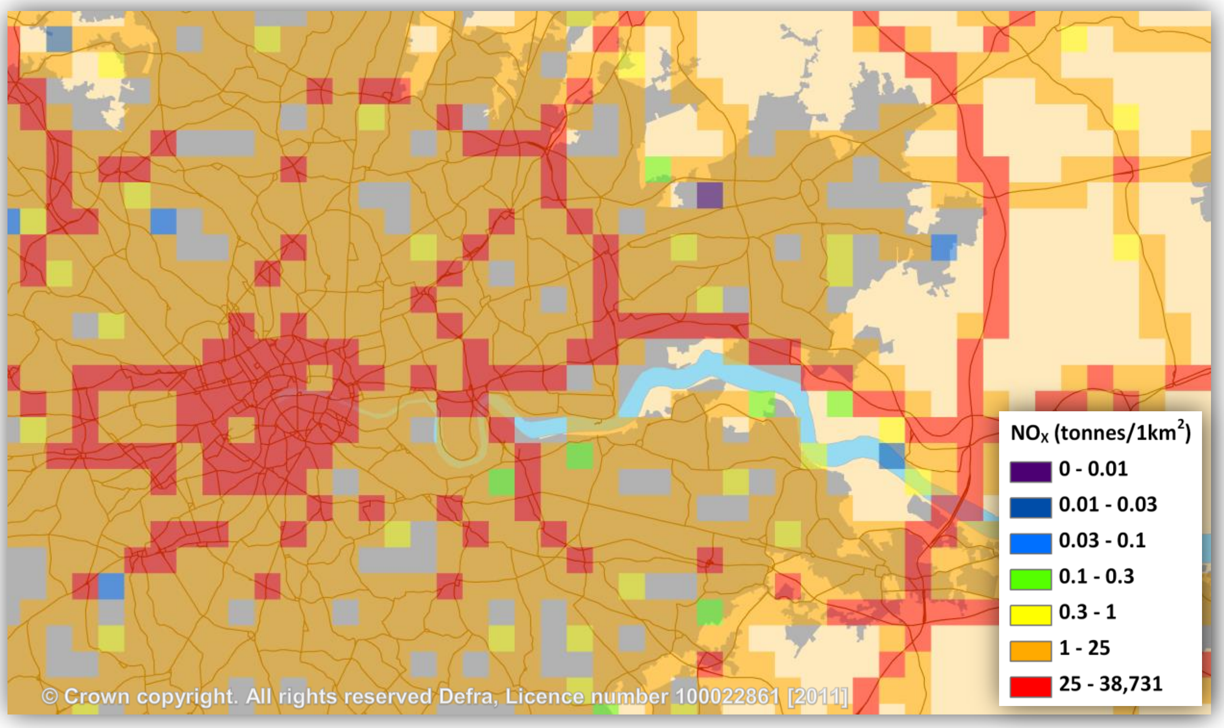
Table 3.3: Department for Transport Urban Area Type Classification

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

VKM estimates by vehicle type for each road link are multiplied by fuel consumption or emission factors taking into account the average speed on the road of concern. These calculations were performed for each major road link in the road network, resulting in maps of fuel use by fuel type and emissions by pollutant. Each road link is then split into sections of 1km grid squares which enable the mapping of emissions and energy estimates across the UK (Figure 3.6).

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 1 km^2 across the UK.

Figure 3.6: NO_X road transport emissions aggregated to 1 km^2 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 for cars by average trip length and trip type using the method described in the Greenhouse Gas Inventory report for 2009 (MacCarthy, et al., 2011). Cold start conditions in Northern Ireland are assumed to have similar characteristics to those in Great Britain. These data enable estimates of the associated emissions to be determined at the UK level.

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

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

PM_{10} and $PM_{2.5}$ emissions from brake and tyre wear and road abrasion are distributed using a 1 km^2 resolution map of estimated total vehicle kilometres on major and minor roads.

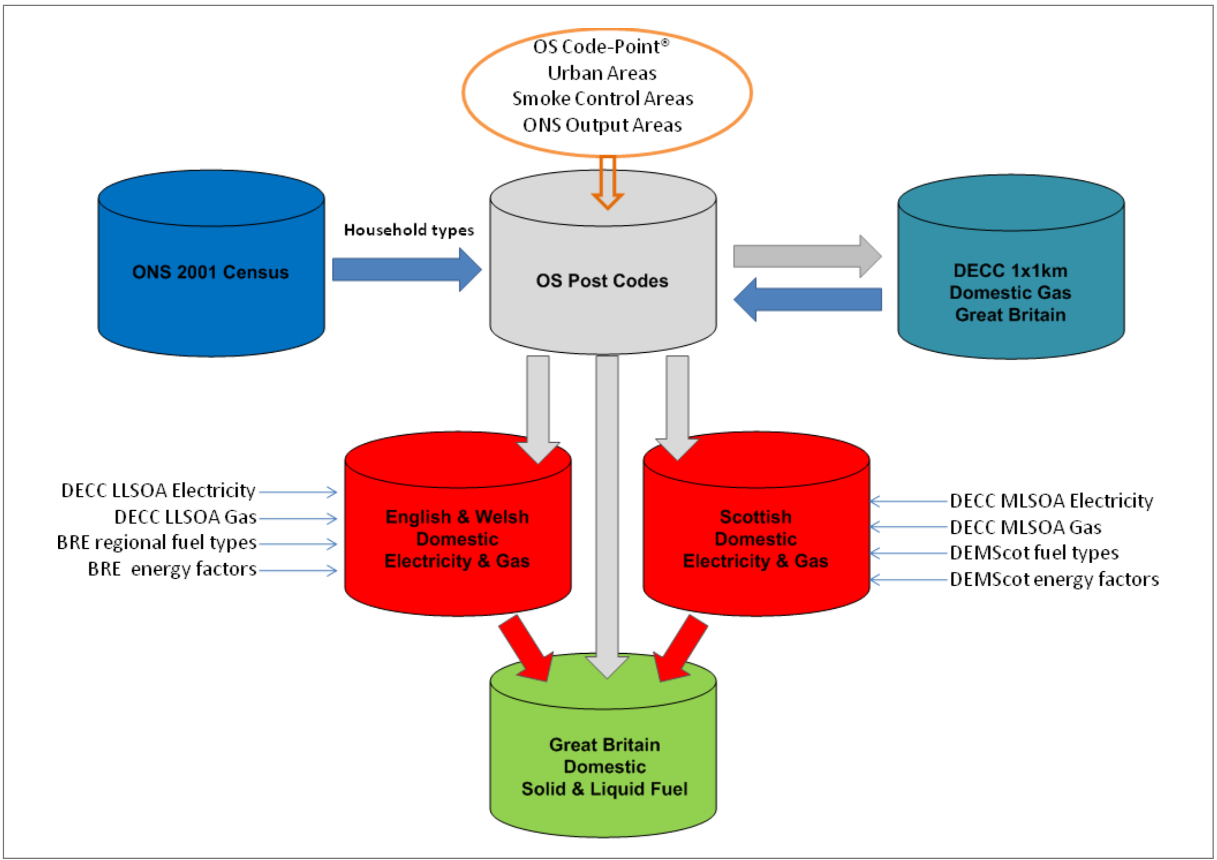
There are two other small sources of emissions from road traffic included in the inventory. These are combustion of waste lubricants and emissions from LPG vehicles. Both of these sources are distributed using estimates of total vehicle kilometres calculated from the NAEI maps of traffic flows.

3.4 Domestic

Methods for mapping of emissions from domestic fuel combustion across the UK have been realigned in terms of their conceptual approach within the 2009 emission maps. Two mapping methods we implemented; one method being applied to England, Scotland and Wales (Great Britain) and the other method to Northern Ireland. The approach was necessary owing to varying levels of data quality and availability in Northern Ireland compared to the rest of GB where higher resolution datasets were more readily available.

A summary of the methodology is provided below. Figure 3.7 presents a high level summary of the data model for GB which was built to manipulate and analyse the large quantities of data used in this study.

Figure 3.7: NAEI Domestic model diagram



The following data series were used in the domestic model:

1. Ordnance Survey Code-Point data[6]
2. Office for National Statistics 2001 Census returns on Household types
3. DECC sub-national energy consumption statistics:
   a. electricity[7] and gas[8] at Lower Level Super Output Area (LLSOA) 2008 for England and Wales
   b. electricity and gas at Middle Level Super Output Area (MLSOA) 2008 for Scotland
   c. 1x1km gas consumers & consumption for Great Britain
4. DEMScot: Domestic Energy Model data for Scotland (Scottish Government, 2010)

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

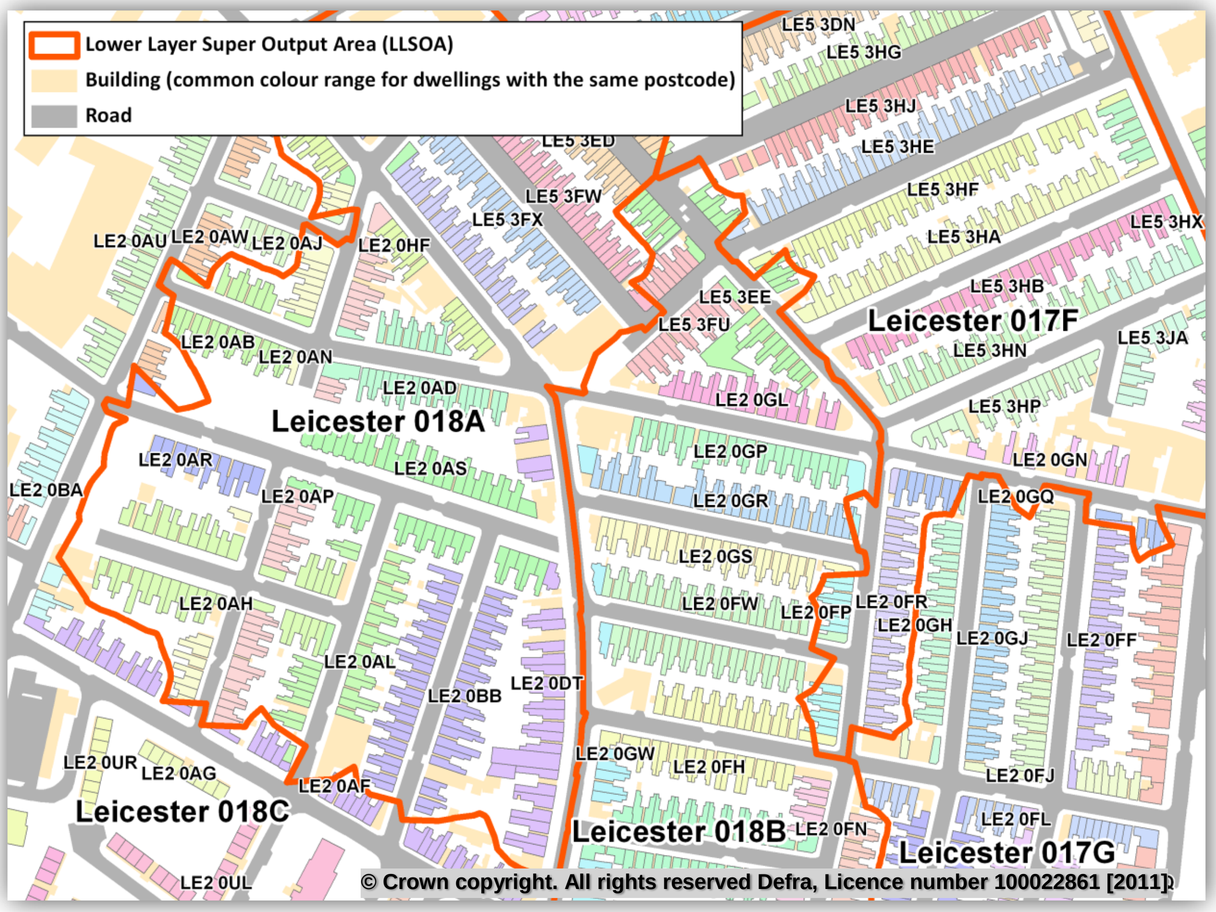
5. Data from BRE on total energy use by dwelling and fuel type and regional data on the numbers of households using different fuels (BRE, 2006)

A summary how these datasets were utilised in the model is given in Table 3.4.

Table 3.4: Description of methods using the above data series for Great Britain

Task & data series used	Application
1	OS Code Point geographies were used to generate a spatial resolved database at full postcode level. Post codes were also assigned urban area, Smoke Control Area and ONS Output Areas attributes (Figure 3.8).
2	ONS 2001 census returns on household types were used to calculate percentages of house types within each Output Area
3 a, b & c	Sub National energy statistics were used to generate domestic electricity and gas spatial distribution databases for England / Wales and Scotland respectively. Comparing the total number of dwellings within output areas, with gas and economy 7 consumers, a residual fuel component was estimated.
4 & 5	BRE and DEMScot domestic energy model assumptions used in combination with the postcode database to generate the domestic solid and liquid fuels distribution across Great Britain.

Figure 3.8: Sample of the combination of datasets used



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

It has been assumed that:

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

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

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

From these datasets an updated bottom-up approach to the characterisation of domestic fuel emissions was prepared using local data. The Table 3.5 below describes briefly how the datasets above have been used to compile the mapped emission estimates for Northern Ireland.

Table 3.5: Description of methods using the above data series for Northern Ireland

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

In order to verify the modelled data for domestic fuel consumption in Northern Ireland, a comparison has been made between the numbers of each household type using a certain fuel type within the model, and the corresponding data from the House Condition Survey. This is illustrated in the scatter plots below. Since the R^2 value is close to 1, this indicates that there is a good relationship between the datasets, giving confidence in the accuracy of the modelling approach.

Figure 3.9: Verification of liquid fuel use between NAEI modelling and House Condition Survey data in Northern Ireland

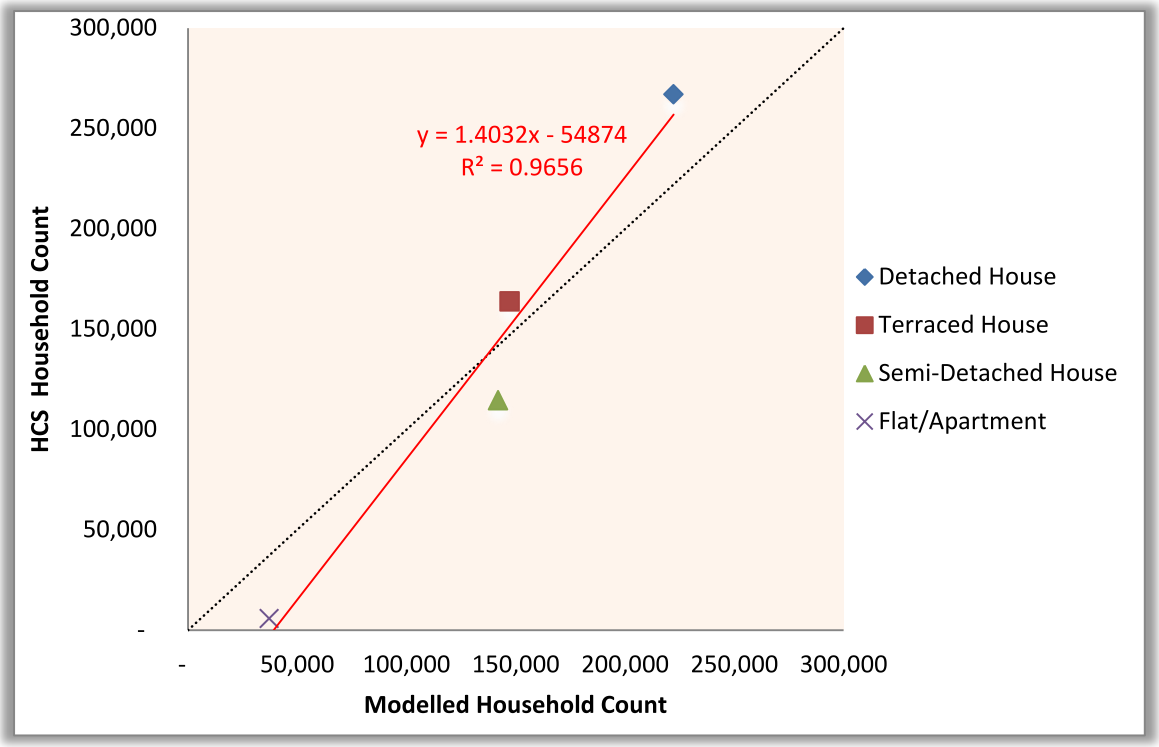
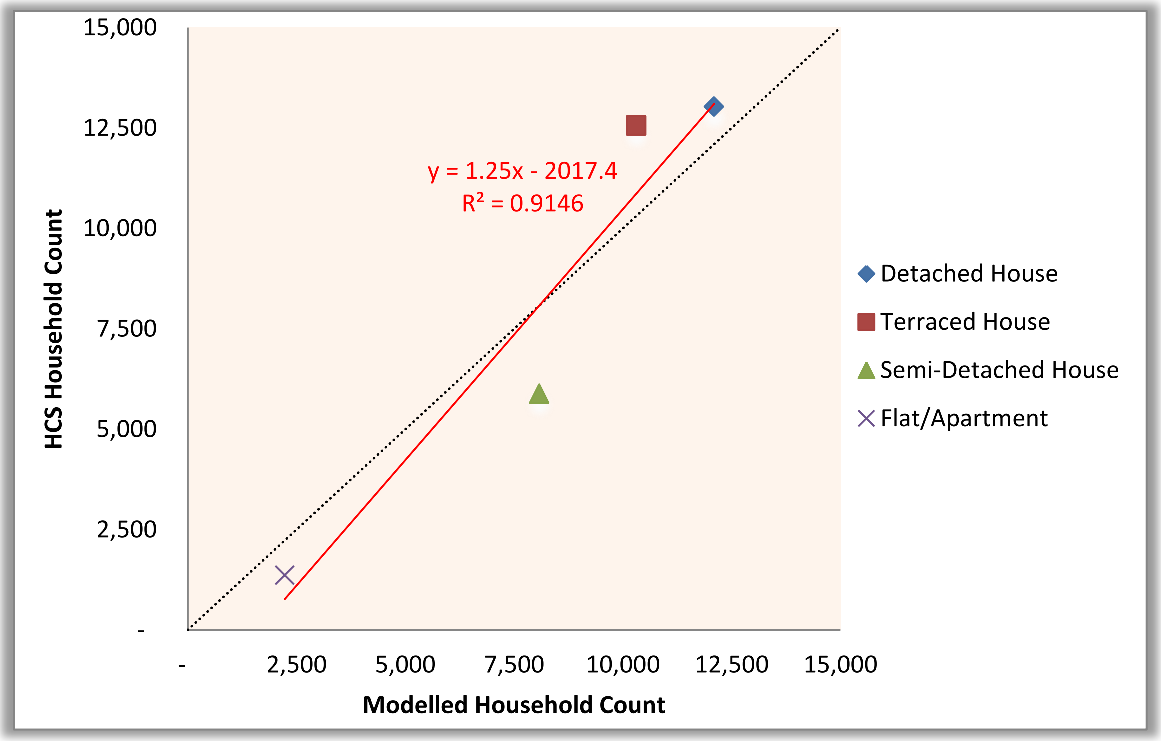


Figure 3.10: Verification of solid fuel use between NAEI modelling and House Condition Survey data in Northern Ireland



3.4.1 Other domestic emissions

The emissions from the domestic house and garden machinery sector are distributed across the UK using the population density map derived from 2001 Census data. The most detailed geographic level of Census data for England, Wales, Scotland and Northern Ireland were converted into a 1 km^2 resolution grid. In some rural areas where the census units were larger than 1 km^2, populations were estimated for individual grid squares on the basis of equal area weighting i.e. assuming an even distribution of population within each census area.

3.5 Agriculture

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

The distributions of ammonia, methane and N_2O emissions from agricultural sources were generated mapped at a 5 km^2 resolution by the Centre for Ecology and Hydrology (CEH). This work is undertaken as a subcontract of the NAEI. Data from the Agricultural Census for England, Scotland, Wales and Northern Ireland were combined with emission factors for livestock, fertiliser use and CEH Land Cover Map 2000 data within the AENEID model to calculate emissions maps. Ammonia, methane and N_2O emissions from other non-industrial sectors are also calculated by CEH as part of the same subcontract (Dragosits & Sutton, 2011a) & (Dragosits & Sutton, 2011b)

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

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

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

Agriculture stationary combustion has also been mapped using the IDBR employment data. The distribution of solid and liquid fuels was made based on the geographical distribution of gas availability, i.e. with these fuels located in grid squares with no gas available. The method used to calculate the gas availability distribution is explained in the supporting document **Mapping small industrial emissions** (King & Tsagatakis, 2008).

Agricultural off-road data are distributed using a combination of arable, pasture and forestry land use data. Each of these land cover classes was weighted according to the off-road machinery activity on each land use. This used data on the number of hours of use of tractors and other machinery on these land use types, sourced by Ricardo-AEA for improving the UK inventory in this sector.

3.6 Rail

A small number of updates on the rail link location have been incorporated in the 2009 emission maps, with higher priority given to the Greater London area.

The UK rail emissions are compiled using data for three locomotive journey types:

- Freight
- Intercity
- Regional

Emissions are calculated based on fuel use reported in DUKES. Rail emissions from diesel locomotives are distributed across Great Britain using maps of the UK rail network and details of the number of vehicle kilometres by journey type on each rail link. Emissions are distributed across the rail network by assigning an appropriate emission from each journey type to each rail link. The emissions along each rail link are assumed to be uniform along the length of the rail link, as no information on load variations along each rail link were available.

Within Northern Ireland, fuel consumption data for 2005 was provided by Northern Ireland train operators Translink and included weekly information for all the rail links of Northern Ireland. Fuel use estimates for 2005 have been distributed over a digital representation of the rail network derived from Ordnance Survey Northern Ireland datasets. These vector datasets were then converted to raster datasets to provide an accurate representation of the location of fuel used by rail transport in Northern Ireland at 1 km^2 grid resolution.

3.7 Shipping

The NAEI estimates emissions for:

- Coastal shipping
- Naval shipping
- International marine.

A new method has been used to estimate coastal and international marine emissions for the 2009 NAEI. The method is based upon data developed by 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)[9]. Previous emission estimates for coastal and international marine have been based on total deliveries of fuel oil, marine diesel oil and gas oil to marine bunkers and for national navigation given in national energy statistics (DECC, 2010). As in previous years, naval emissions are based upon fuel consumption data from the Sustainable Development and Continuity Division of the Defence Fuels Group of the Ministry of Defence.

Entec 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

[9] For additional information see MacCarthy et al., 2011 - http://uk-air.defra.gov.uk/reports/cat07/1103150849_UK_2011_CLRTAP_IIR.pdf.

- Vessel speed and the distance travelled (or the time spent travelling at sea)
- Time spent in port
- Installed emission abatement technologies

Emissions and fuel consumption estimates were calculated at a 5 km^2 grid resolution (based on the EMEP grid) for an emissions domain extending 200 miles from the UK coastline. The emissions were re-mapped to a 1 km^2 grid based on the OSGB grid system. Subsequently, emissions within UK territorial waters (within 12 nautical miles of the coastline) have been mapped as total emissions. A detailed split of emissions by historical NAEI shipping sectors (coastal shipping, international shipping and naval shipping) is not currently available.

3.8 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 1000m (equating to the takeoff and landing). Emissions estimates are calculated from the number of movements of aircraft by type at UK airports (data provided by the Civil Aviation Authority) and from estimates of fuel consumption for component phases of the take and landing cycle. Emissions from aircraft at cruise are also included in the NAEI although these emissions are not mapped.

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

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

3.9 Industrial off-road

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

3.10 Accidental fires and small scale west burning

The distribution of accidental fires across the UK is particularly uncertain. Distribution maps have been made using the Land Cover Map 2000 supplied by CEH. The land cover type has been matched to the type of accidental fire as shown in Table 3.6. 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 2001 population.

Table 3.6: 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

3.11 Landfill sites

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

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

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

Ammonia and methane emissions from landfills have been mapped at 5 km^2 resolution by CEH as part of a subcontract to the NAEI to map all non industrial ammonia emissions (Dragosits & Sutton, 2011b). This uses a combination of landfill site locations where available and population distributions to fill gaps where the landfill site locations are not available.

3.12 Offshore

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

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

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

3.13 Other sectors

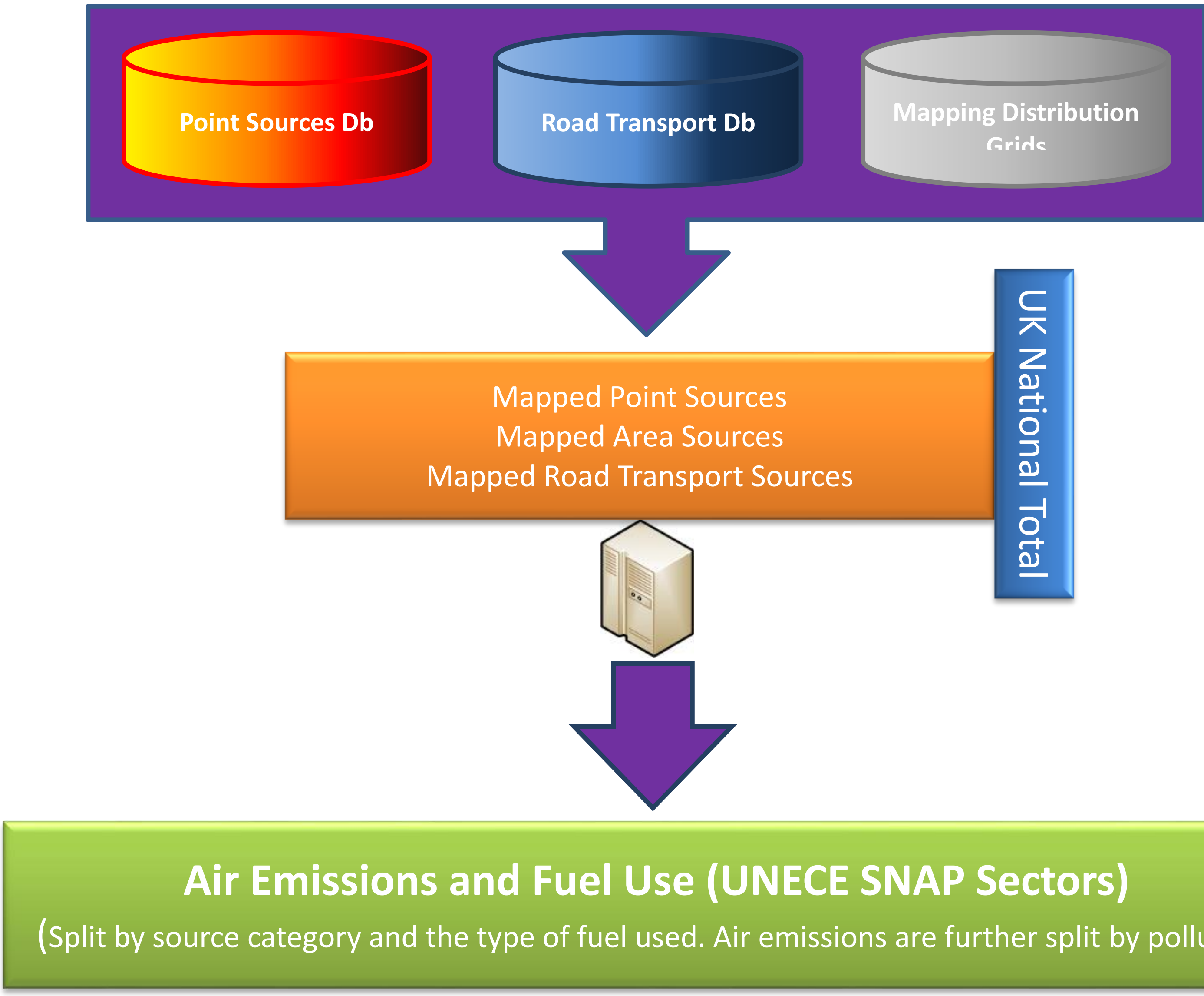
Emissions of PM_{10} from mines and quarries are distributed using data from the British Geological Survey on the locations of mines and quarries in the UK. This data set includes the location of the site and a brief description of products and commodities. There are no data on actual production amounts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

4 Emission maps and data products

4.1 Compilation of maps

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

Figure 4.1: GIS based methodology



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

Figure 4.2: UK total NO_X emissions in 2009

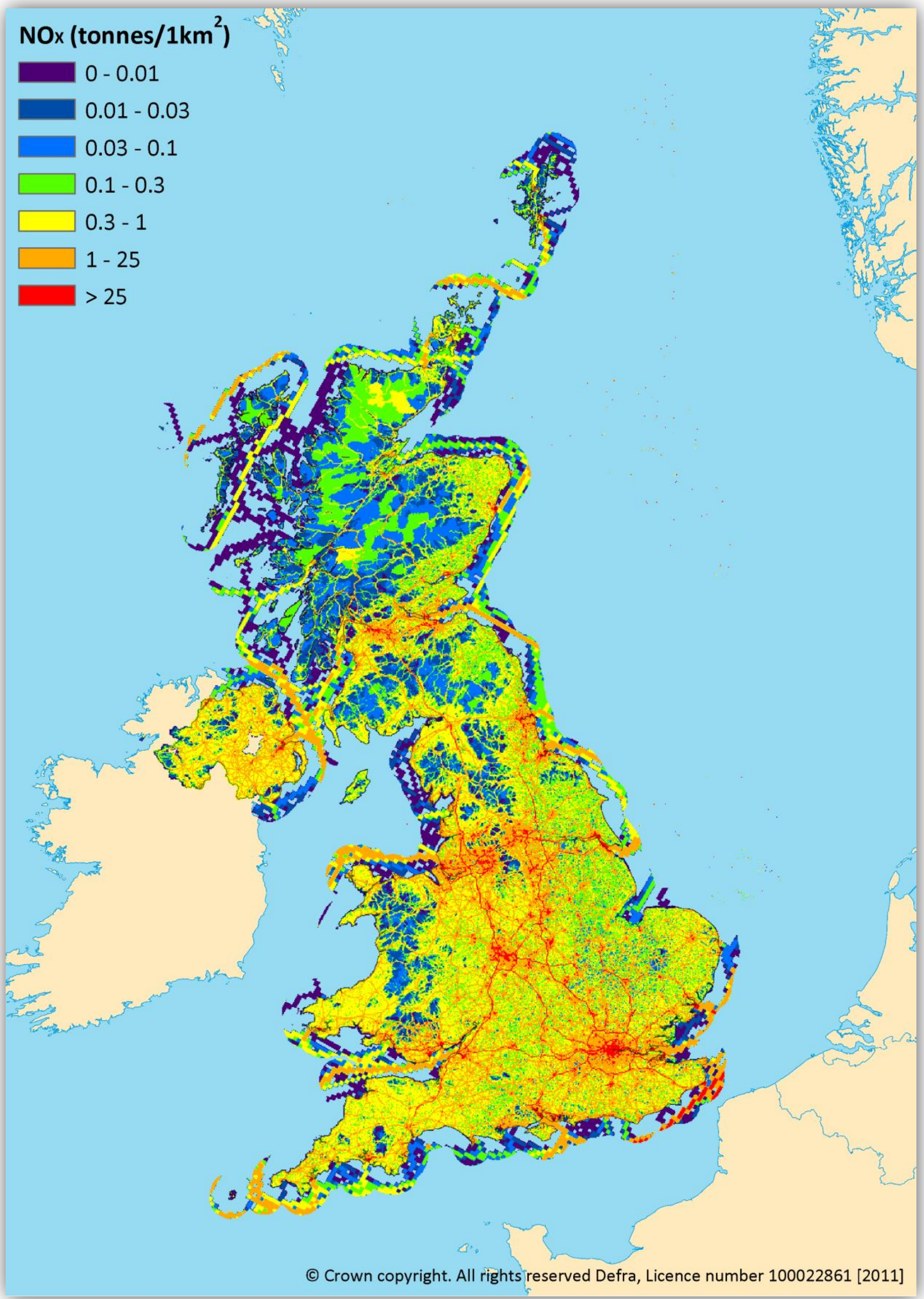


Figure 4.3: UK total PM_{10} emissions in 2009

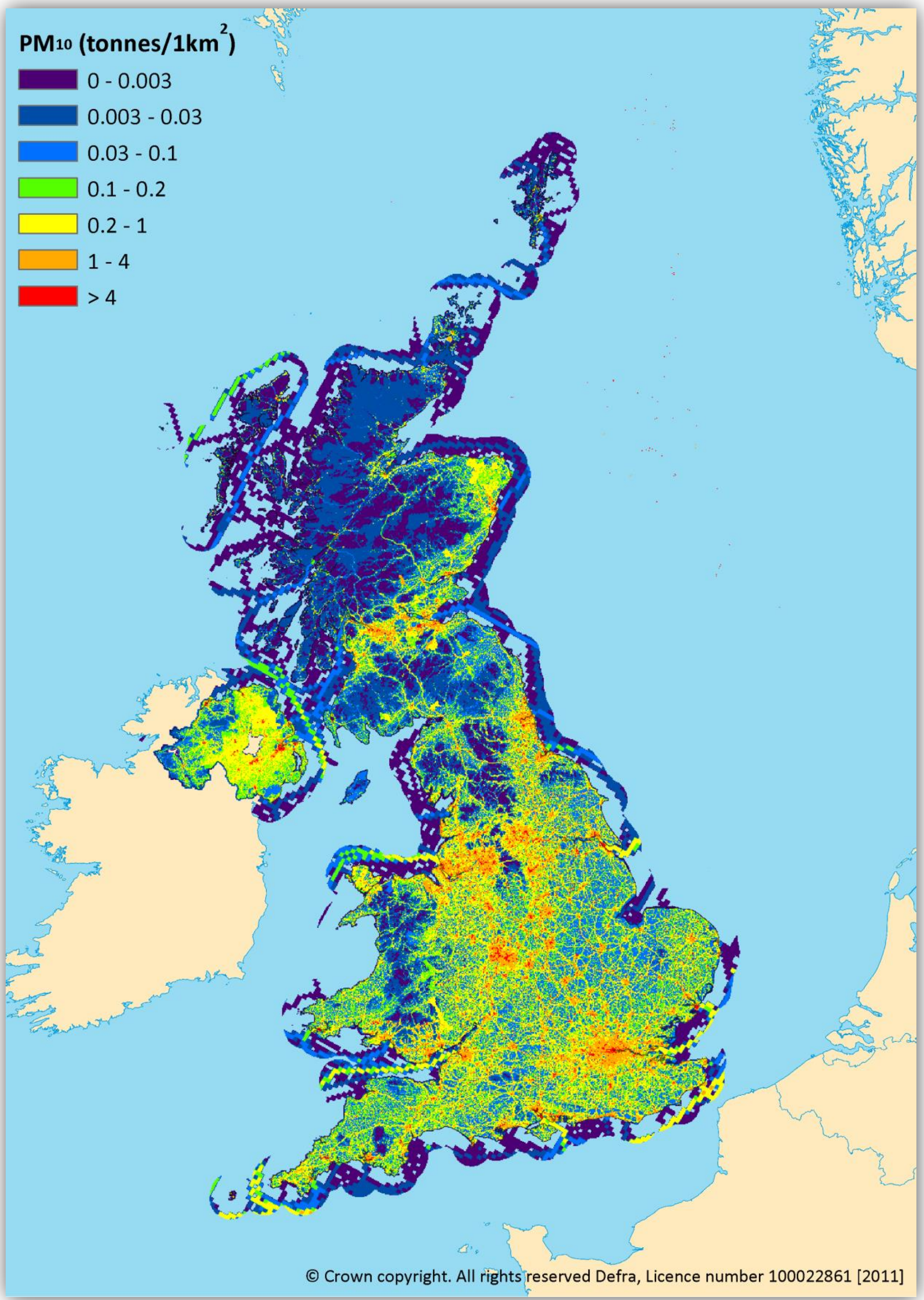
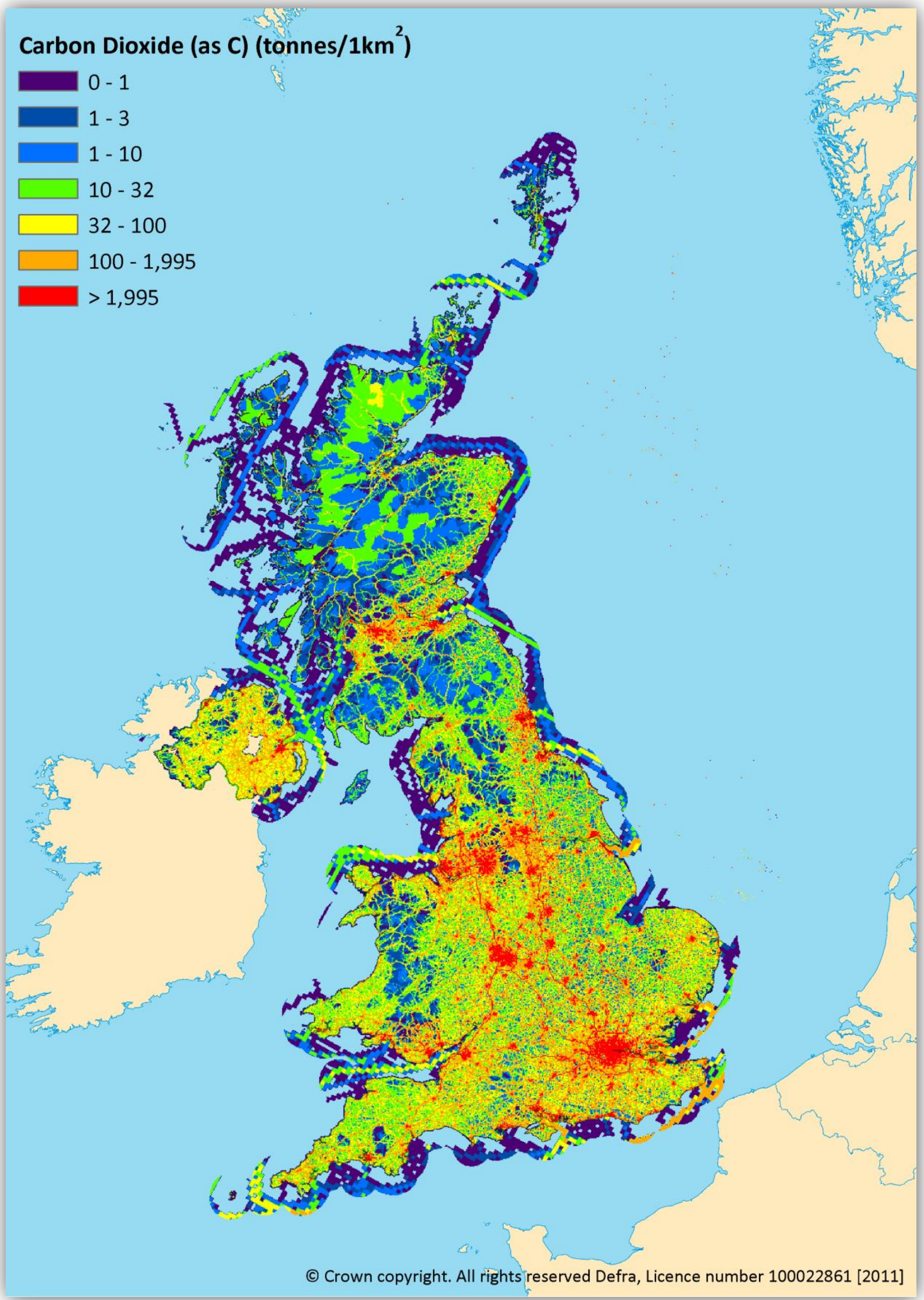


Figure 4.4: UK total CO_2 emissions in 2009



Further examples of the maps are shown in Appendix 2.

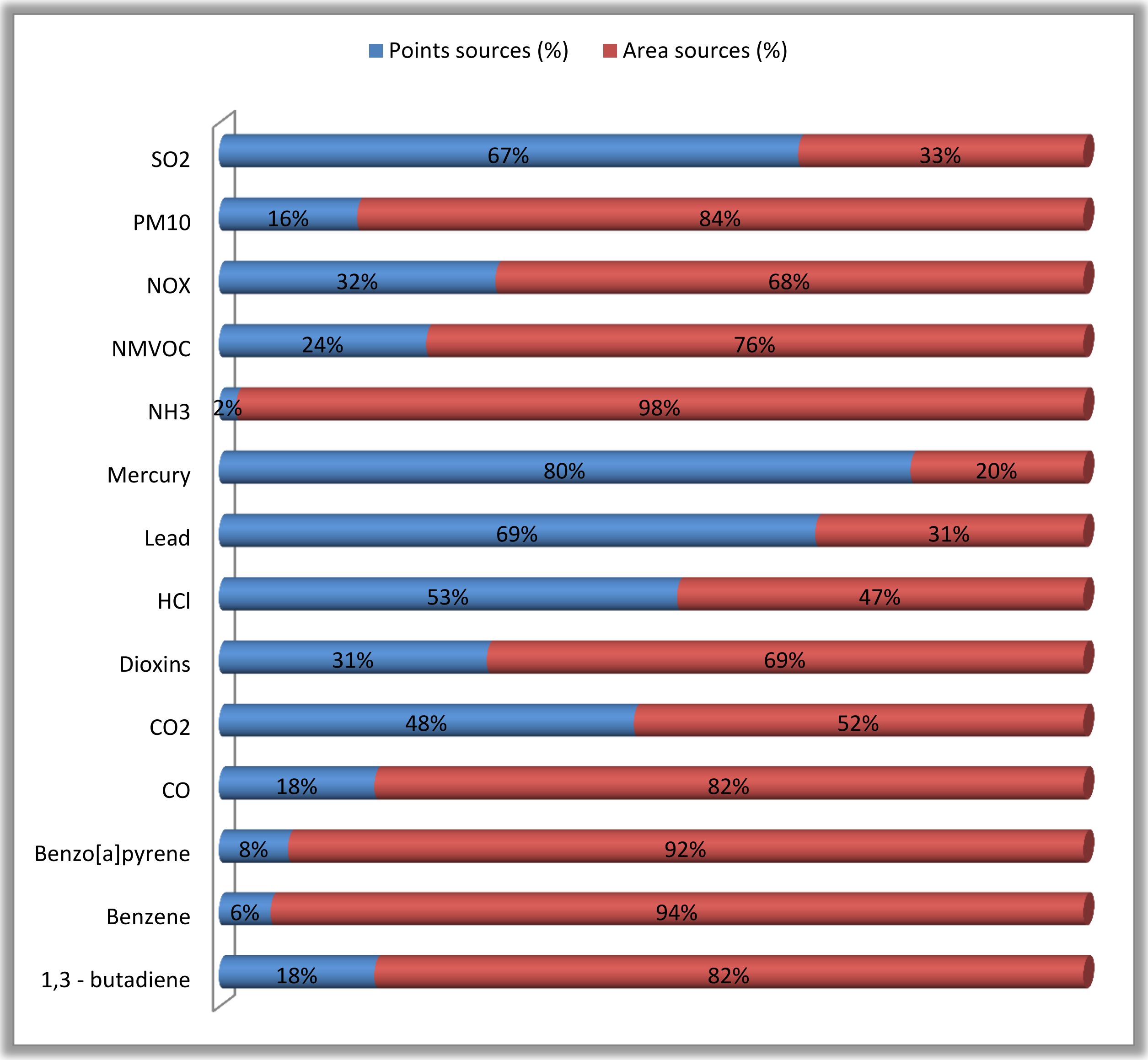
5 Quality of mapping verification

5.1 Estimating quality and uncertainty

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

One simple, semi-quantitative way of assessing the overall quality of the emission maps by pollutant is to compare the proportion of the national total emission which is mapped as point or area sources. Figure 5.1 shows these proportions for selected pollutants in 2009.

Figure 5.1: Contribution of point sources to mapped emission totals (2009)



Taking the proportion of point sources as a measure of quality, Figure 5.1 suggests that maps for lead, mercury, sulphur dioxide, hydrogen chloride and carbon dioxide are likely to be of higher quality than those for ammonia, benzo[a]pyrene, benzene and 1,3-butadiene for example. However, this assessment does not differentiate between point source data which are derived from good site-specific emissions data and those which are based on simple modelling, nor does it differentiate between area sources which are mapped using reliable appropriate surrogate statistics and those which use less optimal datasets.

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

$$\textbf{Emission}_{\textbf{A}} \textbf{ x Rating}_{\textbf{A}} \textbf{ + Emission}_{\textbf{B}} \textbf{ x Rating}_{\textbf{B}} \textbf{ etc. / Emission}_{\textbf{Total}}$$

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

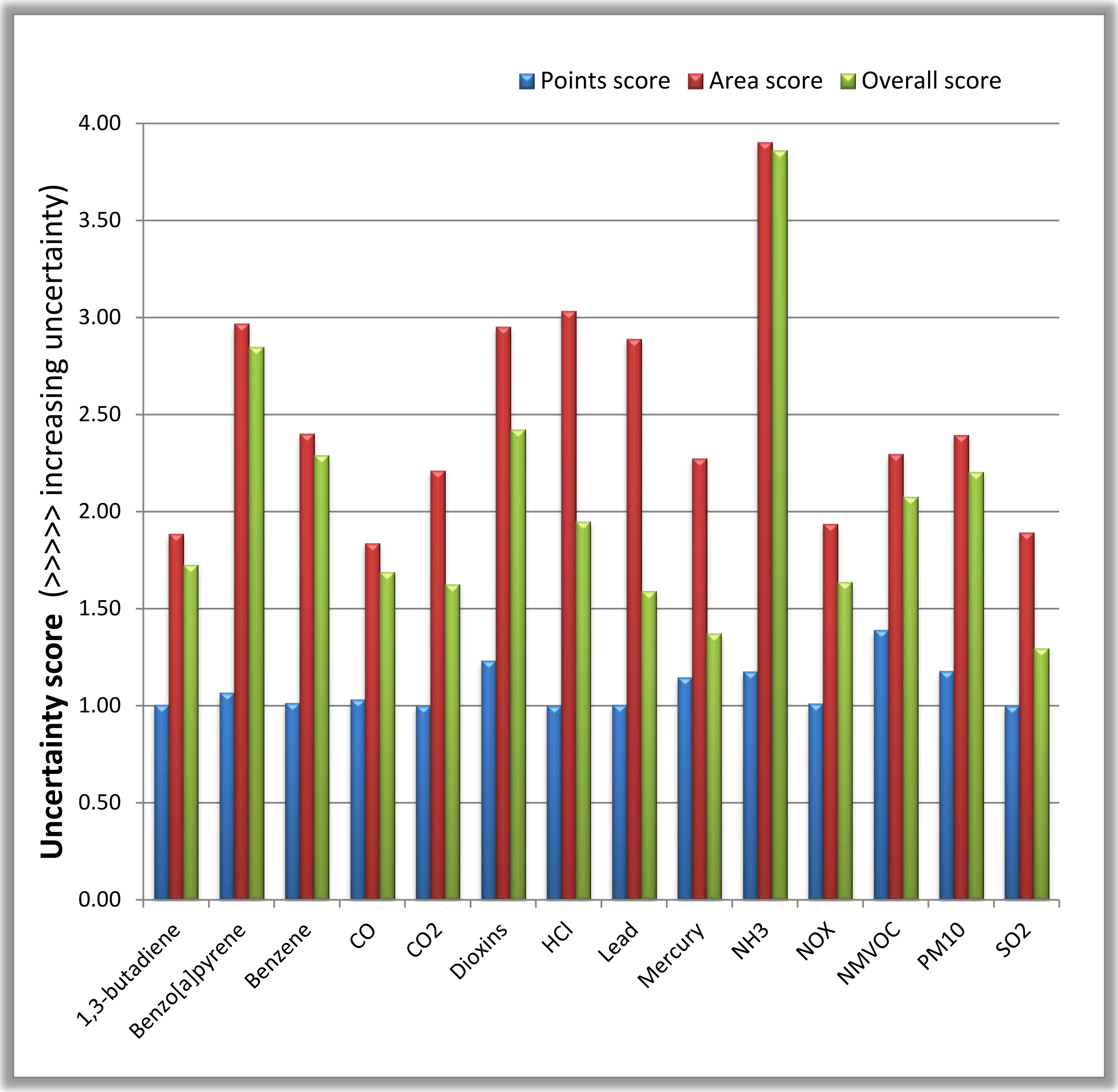
Rating_A, Rating_B etc. are the data quality ratings applied to the mapping of emissions from each of the sources in the inventory

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

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

A rating is defined for each of the above parameters and the mean is used as the overall data quality rating for the source sector. For example, a grid based on 2001 census population data has been allocated a rating of 2 since it is based on very accurate census data which is generalised across the 1 km^2 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 2009 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 aircrafts. The map for 1,3-butadiene and benzene are found to be more satisfactory using this method because a large proportion of the emissions are from the road transport sector which has good quality spatial distributions.

5.2 Verification

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

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

- A rural field comprising contributions from relatively distant major point and area sources such as power stations, large conurbations and transboundary sources. Measurements from monitoring sites well away from local sources, for example from rural stations within the UK's Automatic Urban and Rural Network[10] (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).

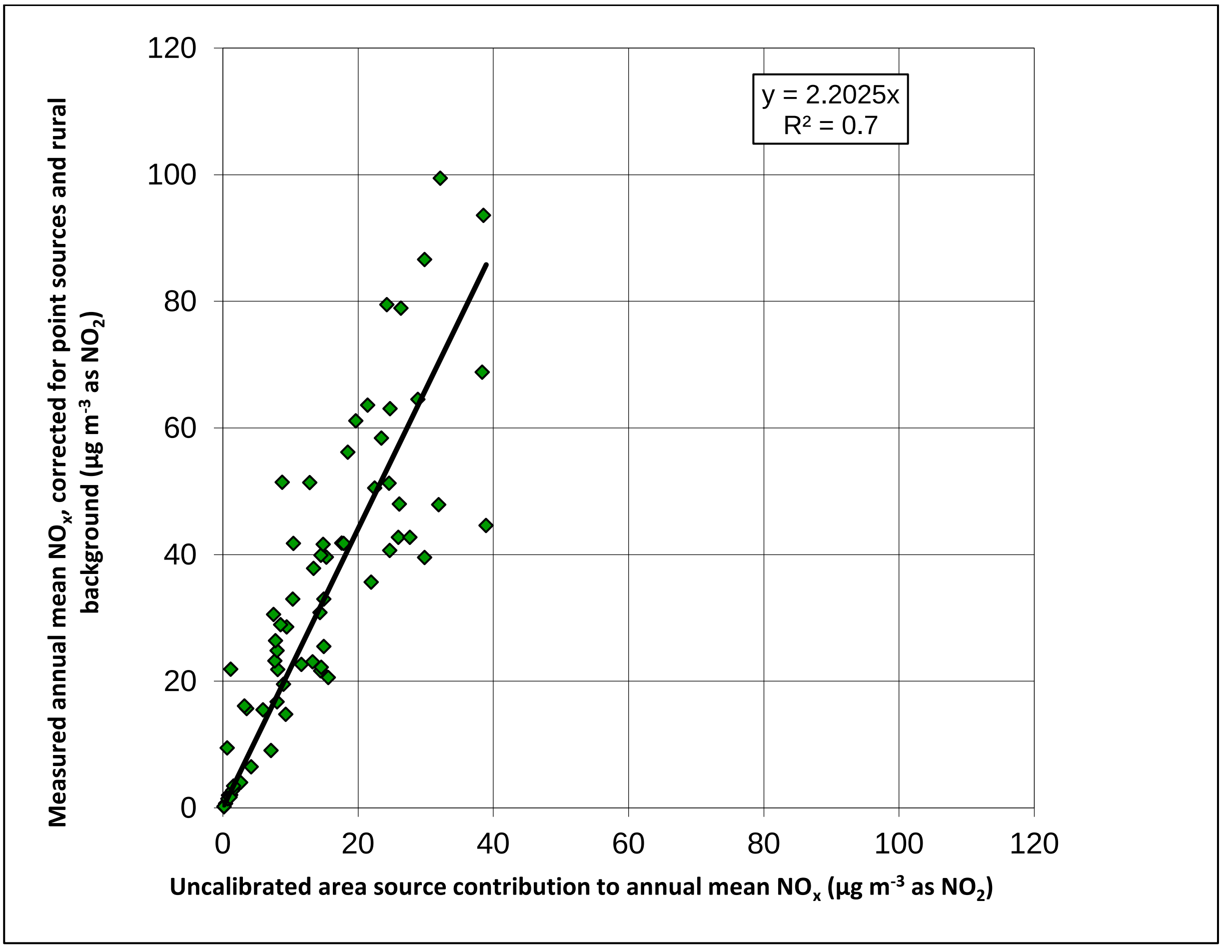
The NAEI area source maps are routinely used in air quality models to characterise the local contribution to ambient concentrations of air pollutants. National scale air quality modelling activities use emissions from the NAEI area source maps to model ambient concentrations across the whole UK (Grice, et al., 2011). As part of this work a dispersion kernel modelling approach is applied to the area source emission maps within an area of 33 km x 33 km square surrounding each receptor location, in order to calculate the uncalibrated contribution from area sources to the ambient concentration at a central receptor. Ambient measurements from monitoring sites are then used to calibrate this area source model. The strength of the relationship between measured concentrations and the model results provides an indication of the quality of the emission distribution as it compares actual concentrations measured with predicted concentrations from the mapped emissions.

Figure 5.3 shows calibration data for the area source NO_x model and identifies the relationship between area source emissions and measured annual mean NO_x concentrations at AURN monitoring stations. The modelled local emission contribution to overall annual mean NO_x concentration (X axis) is compared with the measured NO_x after removing the rural and point source contributions at each site (Y axis). Different dispersion kernels have been used to characterise the dispersion of pollutants in large conurbations, smaller urban areas and rural areas. The graph shows little scatter about the line of best fit but poor agreement between the scale of ambient concentrations estimated from measurements and modelled using the emission inventory in combination with the dispersion model. The degree of scatter about the line of best fit suggests that the spatial distribution of area source emissions remains well characterised by the emission inventory. The disparity between the scale of measured and modelled ambient concentrations can be understood as resulting from a combination of factors. Recent work has demonstrated that the ambient concentrations of NO_x and NO_2 have decreased less than suggested by current UK emission factors (Carslaw, et al., 2011). When combined with the cold conditions experienced during the year 2010 which will also have meant greater emissions than expected, this leads to a systematic underprediction by an uncalibrated model.

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

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

Figure 5.3: Calibration of area source NO_x model ($\mu g\ m^{-3}$, as NO_2) for 2010



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Appendix 1 – Detailed source sector breakdown of UK emissions of NO_X in 2009

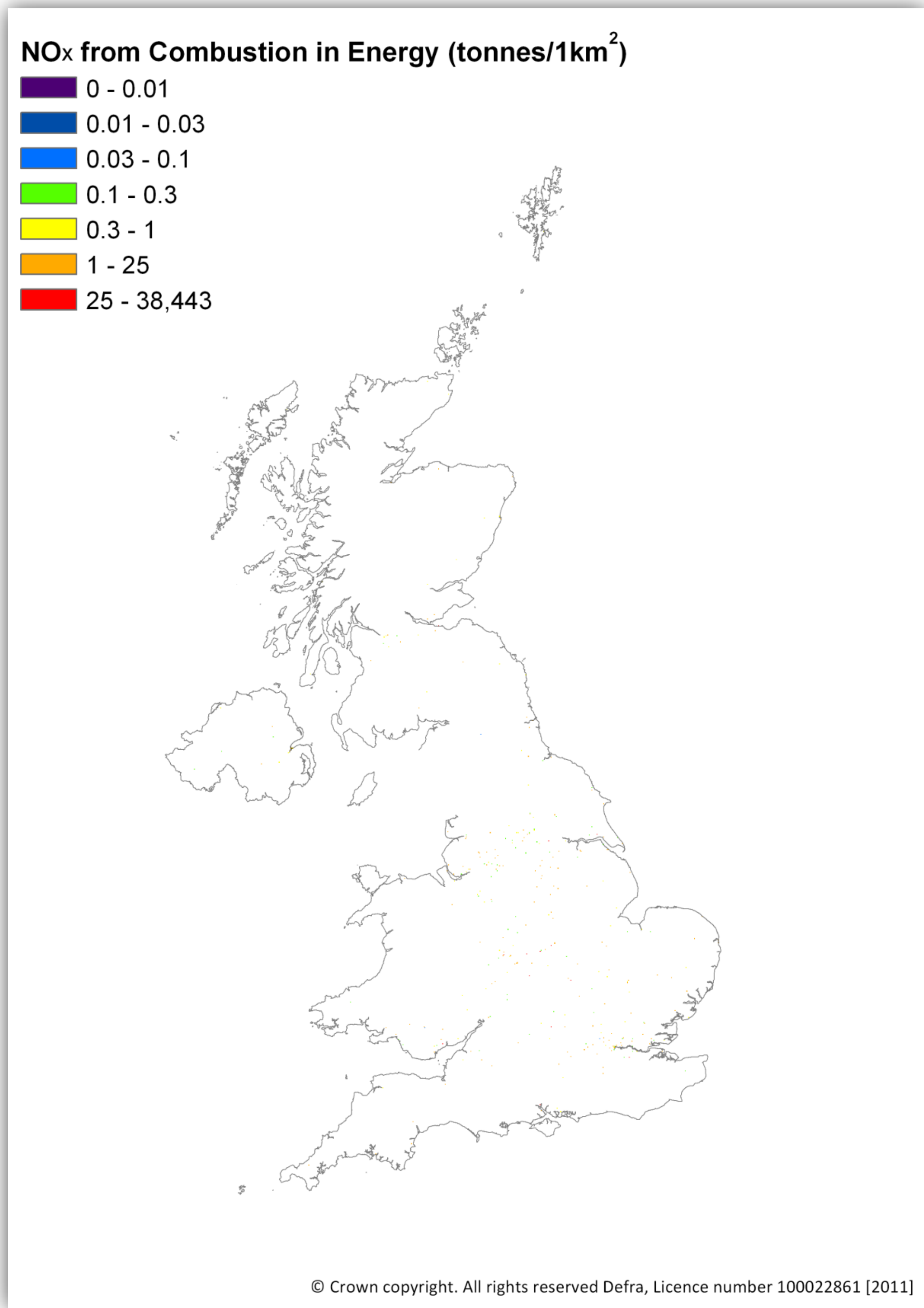
UNECE Source Sector	NAEI Detailed Source Sector	NO_X emission (tonnes)
1 Combustion in energy production and transfer	Coke production	5,402
	Collieries - combustion	160
	Gas production	1,127
	Gas Production - combustion at gas separation plant	1,057
	Gas Production - gas combustion	8,209
	Incineration - MSW	9,848
	Landfill gas combustion	2,653
	Oil Production - gas combustion	29,853
	Power stations	244,367
	Refineries - combustion	23,833
	Sewage gas combustion	770
1 Combustion in energy production and transfer total		**327,280**
2 Combustion in commercial, institutions, residential and agricultural sectors	Agriculture - stationary combustion	921
	Domestic combustion	39,506
	Miscellaneous industrial/commercial combustion	9,525
	Public sector combustion	9,600
	Railways - stationary combustion	30
2 Combustion in commercial, institutions, residential and agricultural sectors total		**59,582**
3 Combustion in industry	Ammonia production - combustion	1,330
	Autogenerators	14,674
	Blast furnaces	564

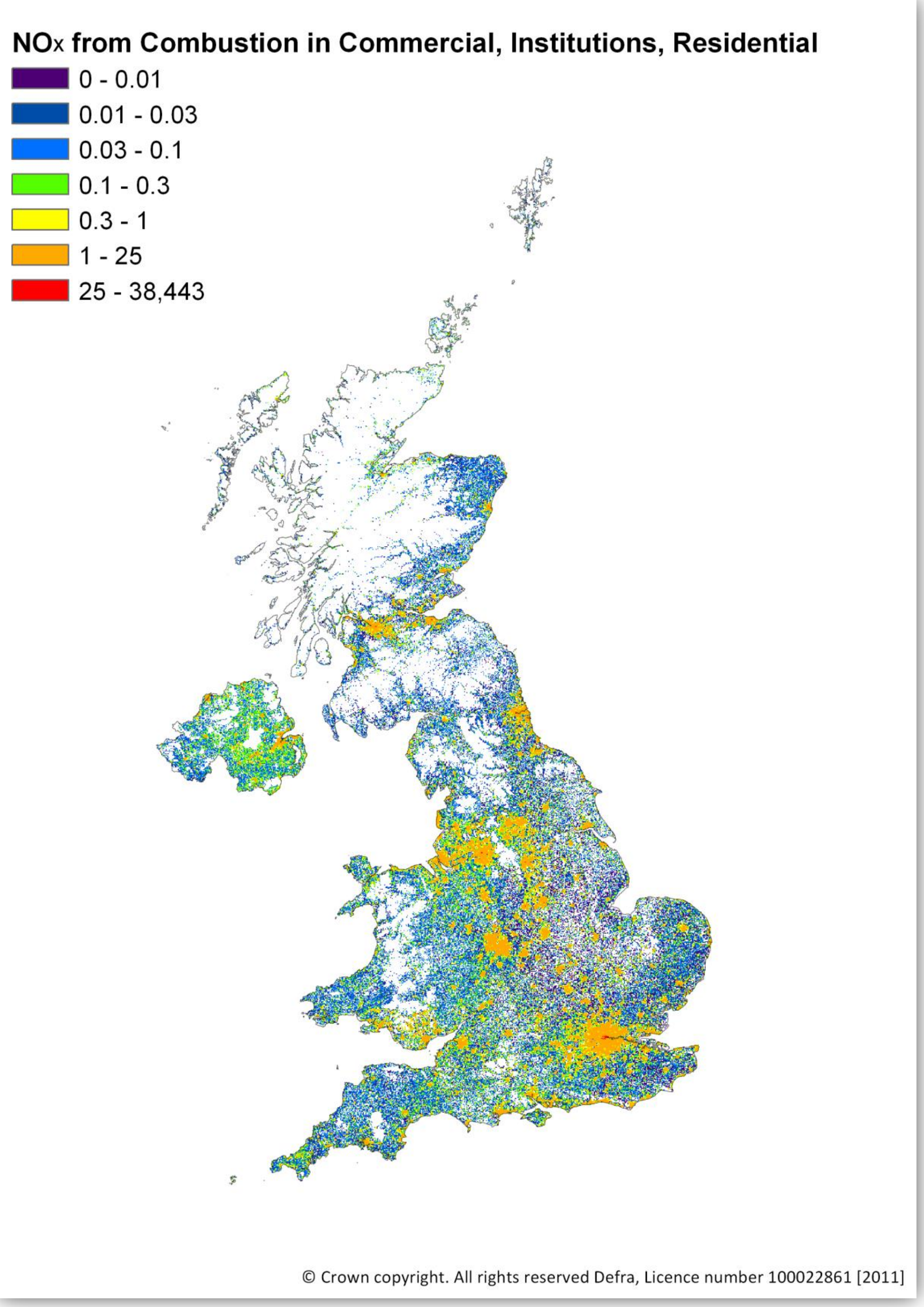
UNECE Source Sector	NAEI Detailed Source Sector	NO_X emission (tonnes)
	Cement - non-decarbonising	10,201
	Iron and steel - combustion plant	7,602
	Lime production - non decarbonising	1,863
	Other industrial combustion	82,666
	Sinter production	6,292
3 Combustion in industry total		**125,193**
4 Production processes	Basic oxygen furnaces	84
	Chemical industry - nitric acid use	420
	Electric arc furnaces	486
	Iron and steel - flaring	230
	Nitric acid production	252
	Primary aluminium production - anode baking	57
	Primary aluminium production - general	213
	Solid smokeless fuel production	7
4 Production processes total		**1,750**
5 Extraction / Distribution of fossil fuels	Gas Production - process emissions	18
	Oil Production - Offshore Well Testing	150
	Oil Production - process emissions	76
5 Extraction / Distribution of fossil fuels total		**244**
6 Solvents and other products		**0**
7 Road transport	Road transport - cars - cold start	3,875
	Road transport - cars non catalyst - cold start	93
	Road transport - cars with catalysts - cold start	7,693
	Road transport - LGVs - cold start	2,070
	Road transport - LGVs non catalyst - cold start	19
	Road transport - LGVs with catalysts - cold start	175
	Road transport - major roads	259,553
	Road transport - minor roads	87,580

UNECE Source Sector	NAEI Detailed Source Sector	NO_X emission (tonnes)
7 Road transport total		**361,059**
8 Other transport and machinery	Agriculture - mobile machinery	33,048
	Aircraft - military	4,524
	Aircraft - domestic take off and landing	1,725
	Aircraft - international take off and landing	10,005
	Aircraft - support vehicles	3,877
	Aircraft between UK and CDs - TOL	115
	Aircraft between UK and Gibraltar - TOL	12
	Aircraft between UK and other OTs (excl Gib.) - TOL	23
	Fishing vessels	260
	House and garden machinery	882
	Industrial off-road mobile machinery	81,447
	Railways - freight	19,699
	Railways - intercity	9,290
	Railways - regional	6,651
	Shipping - coastal	33,982
	Shipping - naval	16,302
8 Other transport and machinery total		**286,123**
9 Waste Treatment and disposal	Accidental fires - vehicles	18
	Crematoria	128
	Gas Production - gas flaring	262
	Incineration - animal carcases	245
	Incineration - chemical waste	151
	Incineration - clinical waste	234
	Incineration - sewage sludge	125
	Oil Production - gas flaring	1,706

UNECE Source Sector	NAEI Detailed Source Sector	NO_X emission (tonnes)
	Small-scale waste burning	396
9 Waste Treatment and disposal total		**3,264**
11 Other sources and sinks	Accidental fires - dwellings	93
	Accidental fires - forests	113
	Accidental fires - other buildings	160
	Accidental fires - straw	46
	Accidental fires - vegetation	38
11 Other sources and sinks total		**450**
Grand Total		**1,164,945**

Appendix 2 - 2009 NO_X emissions for all UNECE level 1 SNAP sectors




NOx from Combustion in Commercial, Institutions, Residential
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 38,443
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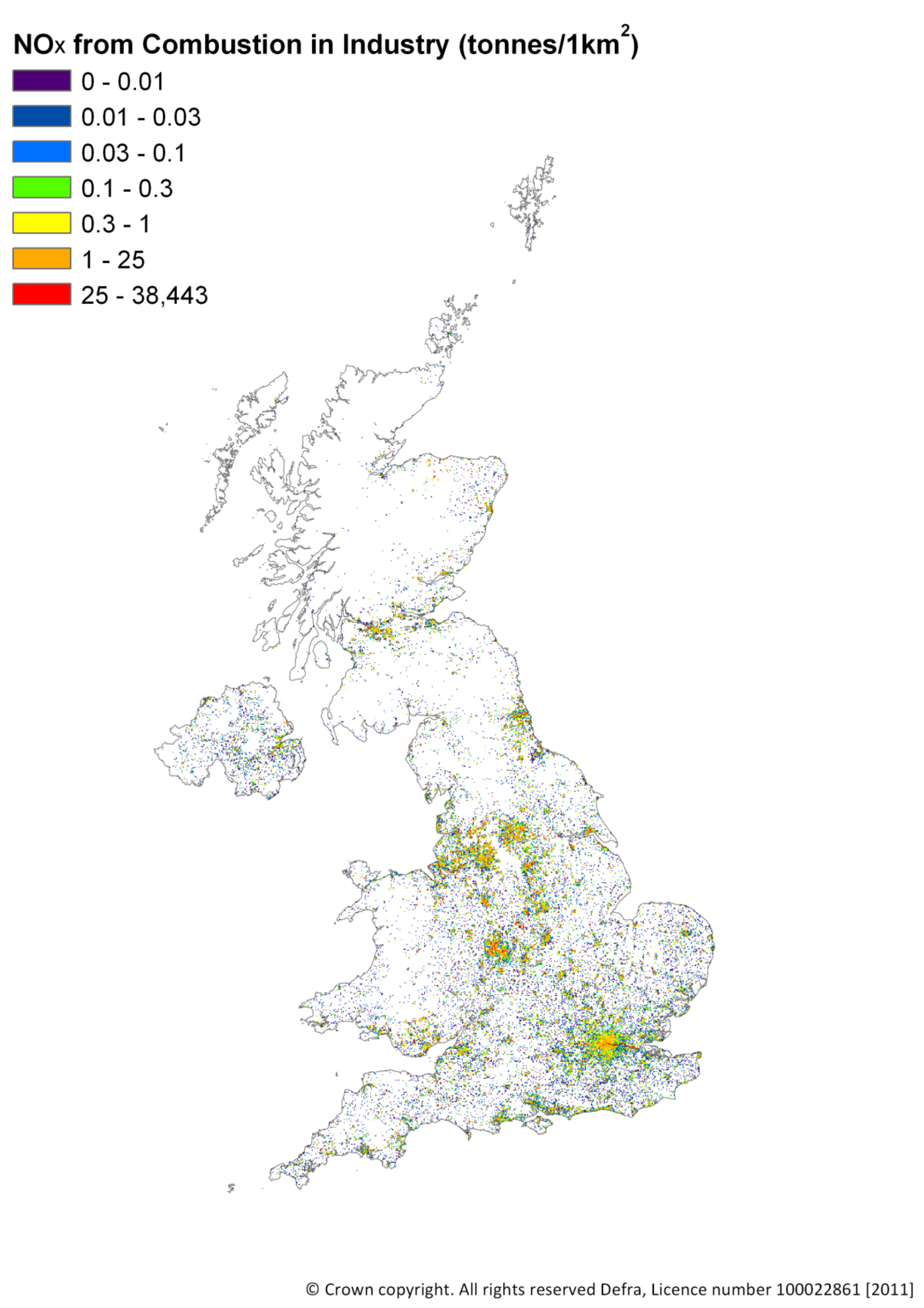
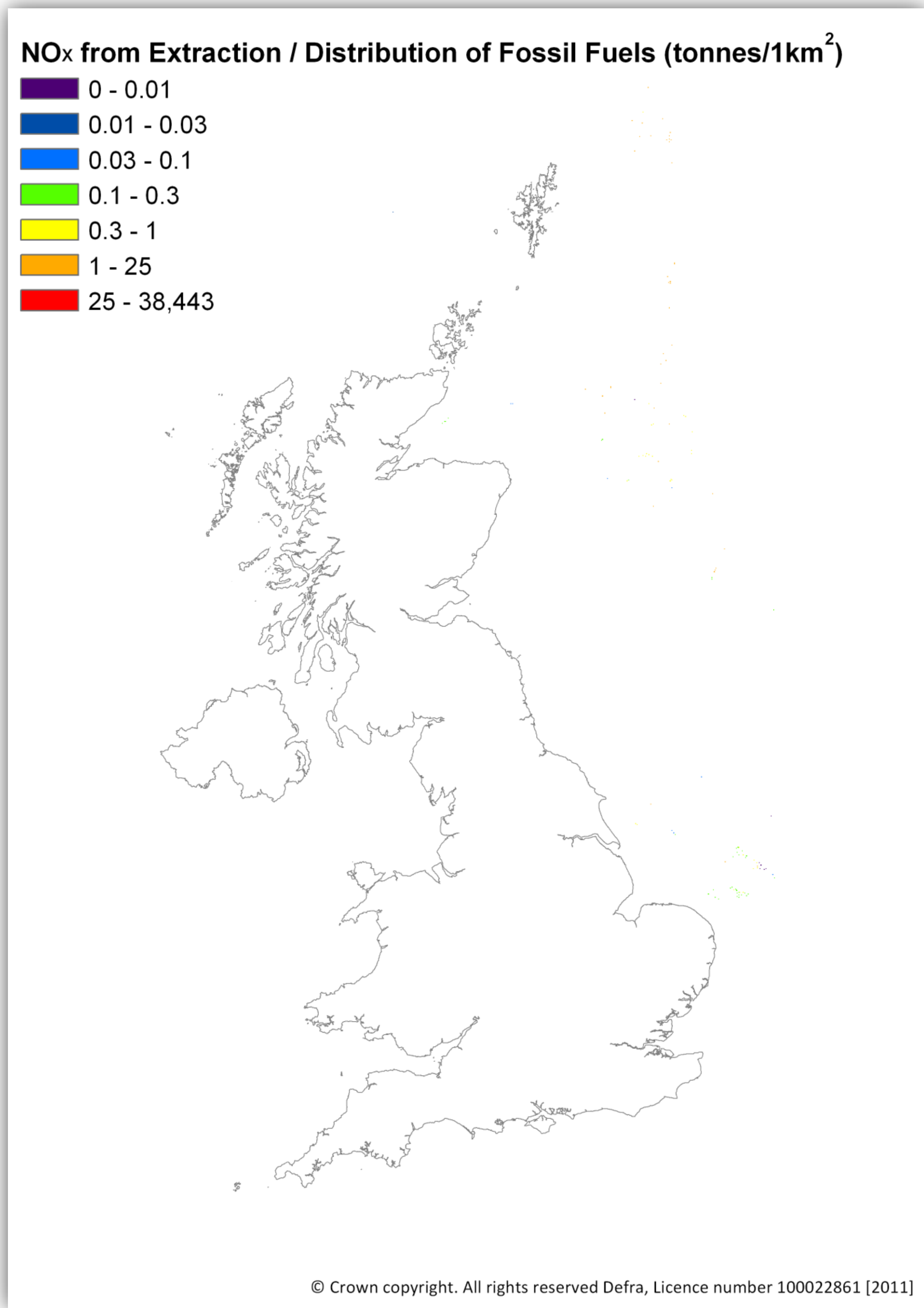

NOx from Combustion in Industry (tonnes/1km^2)
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 38,443
© Crown copyright. All rights reserved Defra, Licence number 100022861 [2011]


NOx from Extraction / Distribution of Fossil Fuels (tonnes/1km²)
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 38,443
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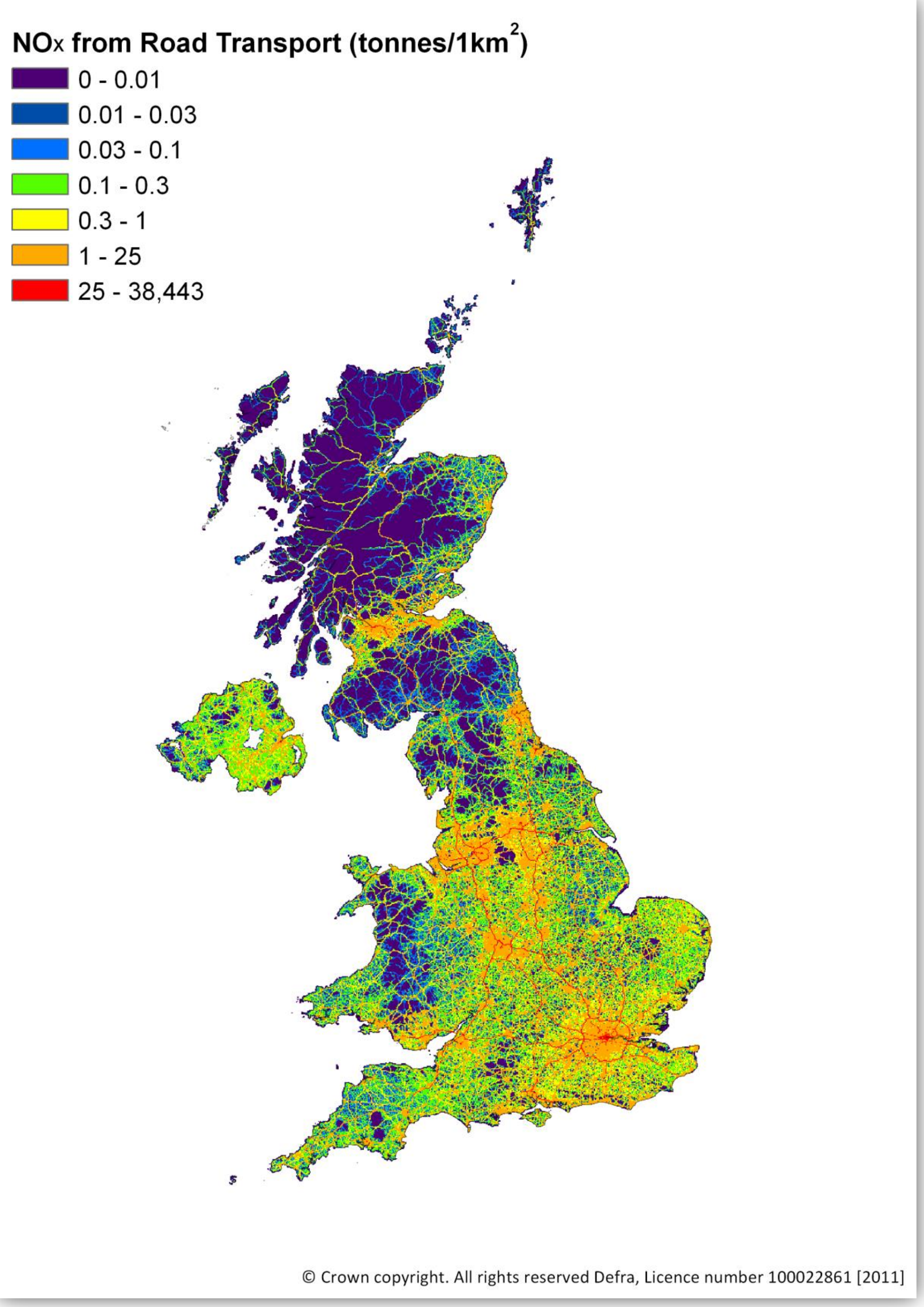
NOx from Road Transport (tonnes/1km²)
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 38,443
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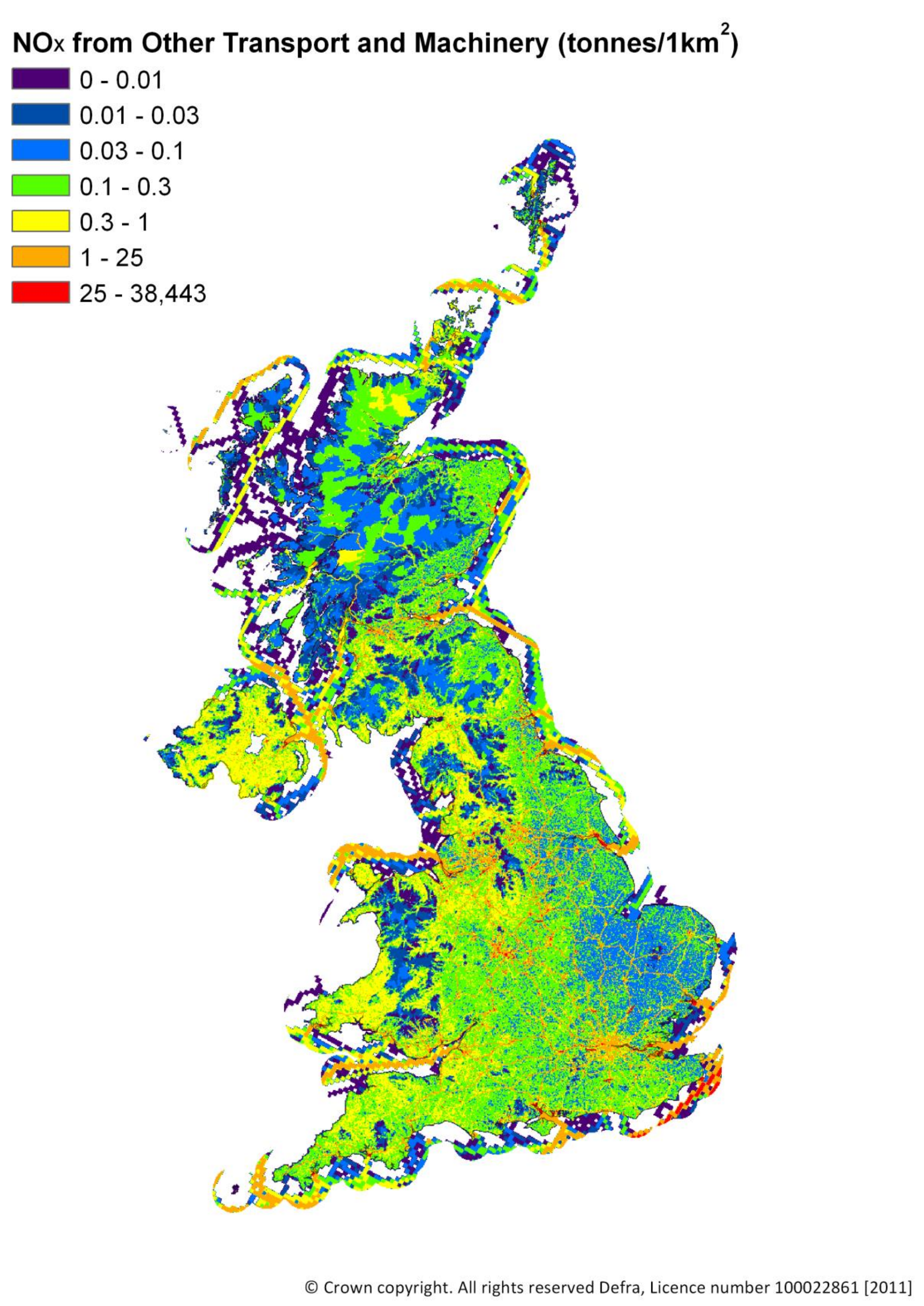
NOx from Other Transport and Machinery (tonnes/1km2)
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 38,443
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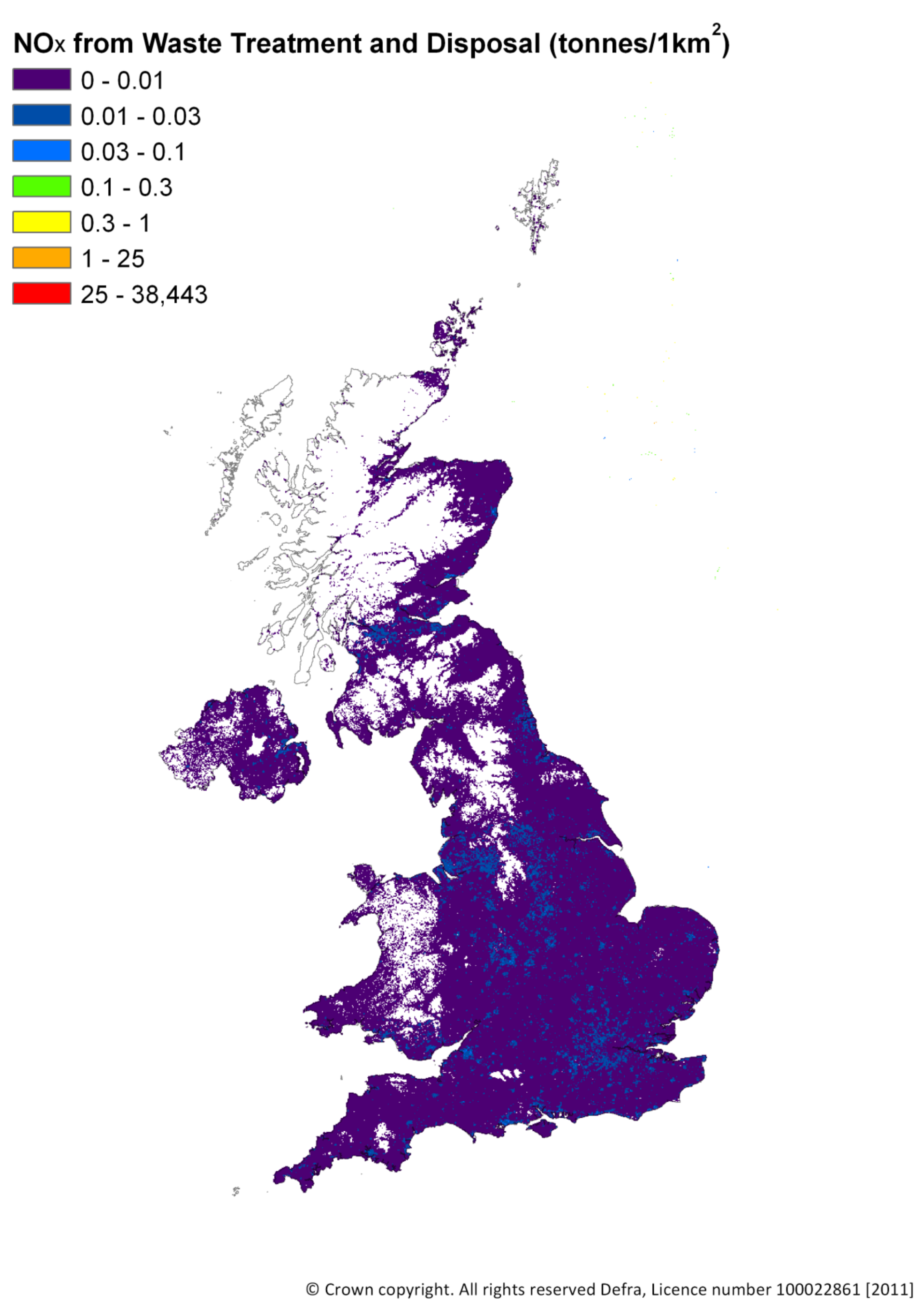
NOx from Waste Treatment and Disposal (tonnes/1km²)
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 38,443
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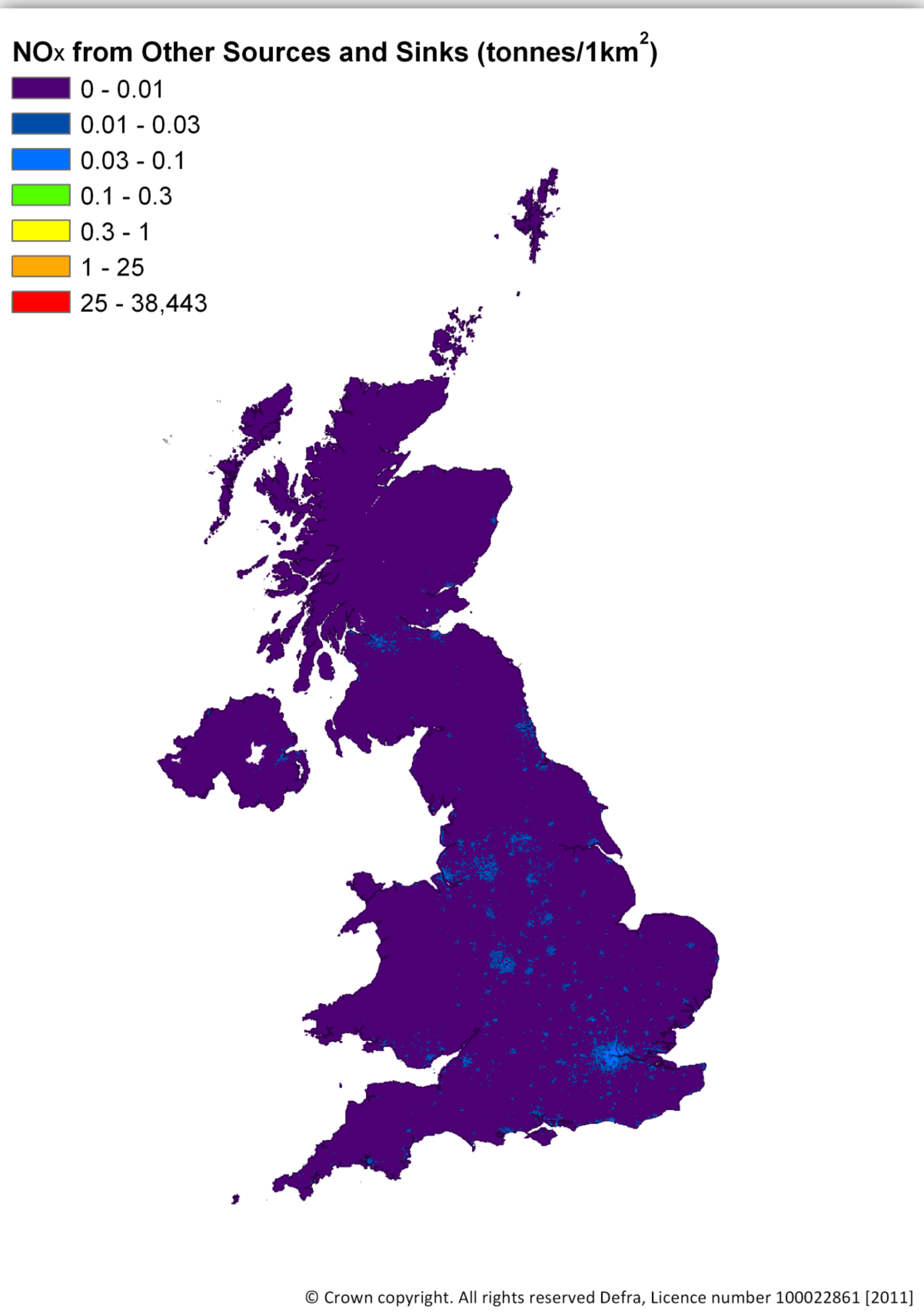
NOx from Other Sources and Sinks (tonnes/1km2)
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 38,443
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