National Atmospheric Emissions Inventory

Report

UK Emission Mapping Methodology 2007

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Executive Summary

Emission maps for the whole of the UK are routinely produced as part of the NAEI for 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 (NMVOC)	Lead
Sulphur dioxide	Mercury
Ammonia	Nickel
Benzo[a]pyrene	Selenium
Dioxins	Vanadium
Hydrogen chloride	Zinc

The maps are modelled estimates of emissions compiled at a 1 km^2 resolution. One set of maps is produced each year for the most recent NAEI year. The mapped emissions data are made freely available on the NAEI web site at http://www.naei.org.uk/data_warehouse.php and http://www.naei.org.uk/mapping/mapping_2007.php

The emission maps are used by AEA and other organisations 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. Local area statistics are also compiled from the maps and related data. For example Local Authority level data on carbon dioxide emissions and fuel use have been produced for Defra and DECC (formerly BERR) since 2003 using data from the NAEI mapping work. As of March 2008, these datasets were designated as National Statistics (King et al and Bush et al, 2008).

The geographical distribution of emissions across the UK is built up from distributions of emissions in each NAEI sector. These individual NAEI sector distributions are developed using a set of statistics appropriate to that sector. For large industrial 'point' sources, emissions are compiled from a variety of official UK sources (Environment Agency, Scottish Environmental Protection Agency, Local Authority data). For diffuse sources in the UK (known as 'area' sources), a distribution map is generated using appropriate surrogate statistics for that sector. The method used for each source sector varies according to the data available. This report describes the methods used to map each of the NAEI sectors. Possible improvements to the methods are also suggested and summarised in order of priority.

Uncertainty analyses have been undertaken to consider the variability in quality of the emission maps for a selection of the pollutants listed above. 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 emissions from point sources (SO_2, lead and mercury) whereas for pollutants with a greater proportion of their emissions in the area sources, have lower quality ratings (e.g. ammonia and benzo[a]pyrene).

The distribution of emissions presented in the NAEI maps has been verified for key pollutants for use 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 at automatic air quality monitoring sites.

Contents

1. Introduction

The UK National Atmospheric Emission Inventory (NAEI) and GreenHouse Gas Inventory (GHGI) are compiled by AEA on behalf of The Department for Environment Food and Rural Affairs, Department for Energy and Climate Change, Welsh Assembly Government, the Scottish Executive and the Department of the Environment for Northern Ireland. This report describes the methodology used to compile spatially disaggregated 1 km^2 resolution emissions maps under the NAEI system.

The NAEI is the standard reference for air emissions for the UK and provides annual estimates of emission for a wide range of important pollutants including air quality pollutants, greenhouse gases, regional pollutants leading to acid deposition and photochemical pollution, persistent organic pollutants and other toxic pollutants such as heavy metals. A spatially disaggregated 1 km^2 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://www.naei.org.uk/reports.php (Murrells et al, 2010).

1.1 EMISSION MAPPPING SCOPE AND PURPOSE

Emission maps are routinely produced as part of 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 (NMVOC)	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 1 km^2 resolution and are aggregated to UNECE Sectors using the SNAP 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 landuse change
11	Other sources and sinks

The emission maps are used by AEA and other organisations 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. Local area statistics are also compiled from the maps and related data. For example Local Authority level data on carbon dioxide emissions and fuel use have been produced for Defra and DECC (formerly BERR) since 2003 using data from the NAEI mapping work. As of March 2008, these datasets were classified as National Statistics (King et al and Bush et al, 2008).

The mapped emissions are made freely available in a neutral file format[1] on the NAEI web site at http://www.naei.org.uk/data_warehouse.php. 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.

[1] ASCII grid format

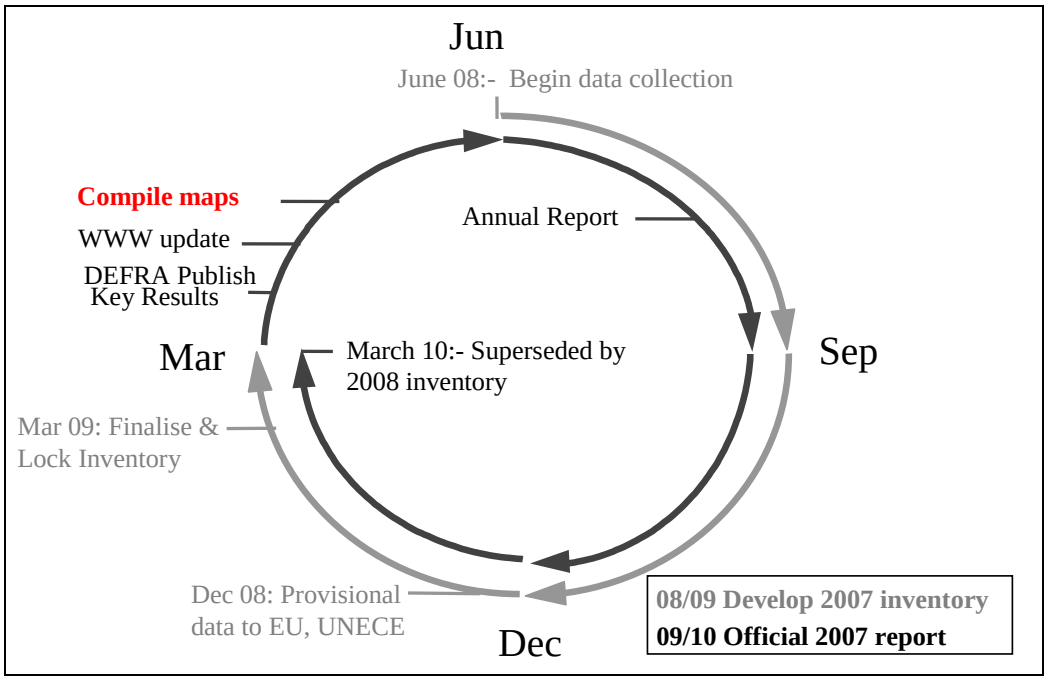
1.2 ANNUAL CYCLE

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 methodology that is the most current. National totals and temporal trends are reported to the European Commission (under the National Emission Ceiling Directive and the European Union Monitoring Mechanism), UN/ECE, UNFCCC and other international fora.

Historically, emission 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 has been calculated for end-user emission maps for CO_2 and sub-national energy consumption estimates. These maps and datasets (King et al and Bush et al 2008) have been 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**.

Figure 1.1 The Annual NAEI Cycle



1.3 REPORT STRUCTURE

The next section of this report provides an overview of the emission sectors covered by the NAEI (section 2). 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.

Two further documents support this report, providing detail information on the mapping of:

- **Mapping small industrial emissions**: A detailed description of the recent work to update the modelling of small industrial emissions.[2]
- **Point Source Fuel Use Estimates**: Explanation of the methods used to estimate fuel use and emissions at point sources[3]

Full details are available from the URL's provided.

[2] http://www.decc.gov.uk/assets/decc/statistics/climate_change/1_20090917091058_e_@@_localco2smallindustrial.pdf
[3] http://www.decc.gov.uk/assets/decc/statistics/climate_change/1_20100122174622_e_@@_pointsourcefuelests.pdf

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 of these sectors a national total emission is produced from a combination of reported emissions and estimated emissions. Reported emissions are obtained 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:

$$\text{Emission} = \text{Factor} \times \text{Activity}$$

Emission factors are generally derived from measurements made on a number of sources representative of a particular emission sector. Examples of emission factors are include the amount in 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 the Digest of UK Energy Statistics (BERR, 2008), Transport Statistics Great Britain (DfT 2008), and from other 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 2007 is shown in **Table 2.1** and a summary aggregated to UNECE sectors is shown in **Figure 2.1**. Emission estimates of NO_x are in fact compiled in considerably more detail, but the sectors presented in **Table 2.1** provide a clear demonstration of the level at which emissions are mapped. The NO_x inventory will be used throughout this report to help explain and illustrate the mapping methods used.

Figure 2.1 UK NO_X Emissions in 2007 by UNECE Source Sector

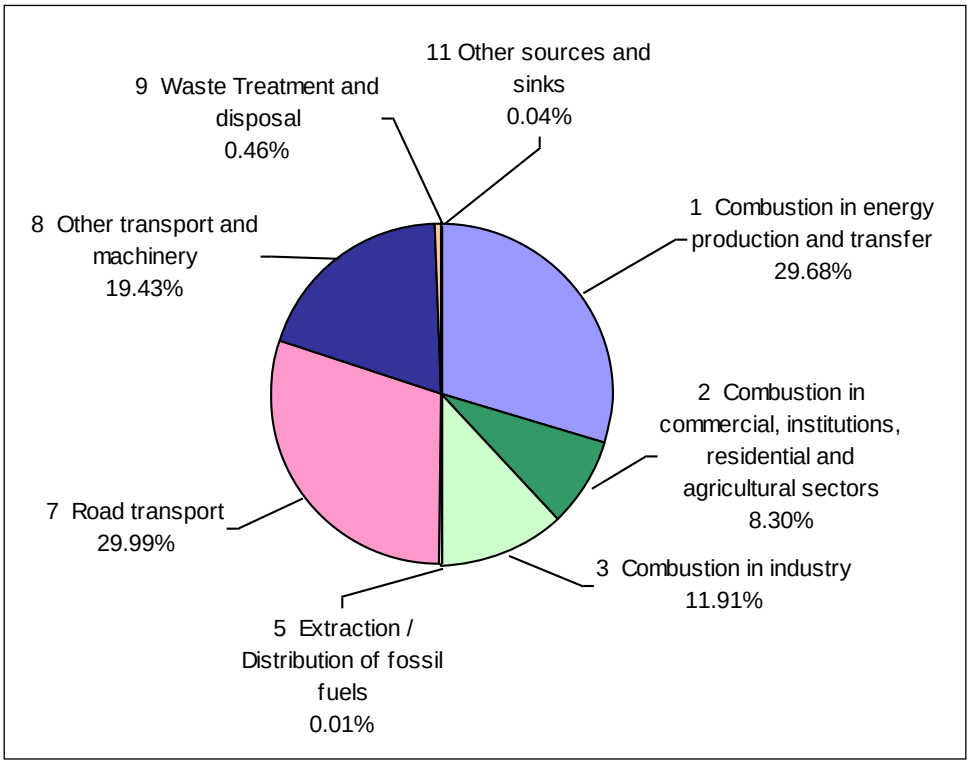


Table 2.1 Detailed source sector breakdown of UK emissions of NO_X in 2007

UNECE Source Sector	NAEI Detailed Source Sector	NO_X emission (tonnes)
1 Combustion in energy production and transfer	Coke production	6,016
	Collieries - combustion	196
	Landfill gas combustion	2,502
	Offshore oil and gas - own gas combustion	41,319
	Power stations	353,589
	Refineries - combustion	26,137
	Sewage gas combustion	474
	Gas separation plant - combustion	2,576
	Gas production	2,524
1 Combustion in energy production and transfer Total		**435,332**
2 Combustion in commercial, institutions, residential and agricultural sectors	Agriculture - stationary combustion	676
	Domestic combustion	98,734
	Miscellaneous industrial/commercial combustion	11,125
	Public sector combustion	11,104
	Railways - stationary combustion	32
2 Combustion in commercial, institutions, residential and agricultural sectors Total		**121,672**
3 Combustion in industry	Ammonia production - combustion	2,091
	Blast furnaces	762
	Cement - non-decarbonising	26,996
	Iron and steel - combustion plant	9,494
	Lime production - non decarbonising	3,798
	Other industrial combustion	104,927
	Sinter production	8,500
	Autogenerators	18,085
3 Combustion in industry Total		**174,653**
4 Production processes	Basic oxygen furnaces	138
	Chemical industry - nitric acid use	503
	Electric arc furnaces	325
	Nitric acid production	611
	Primary aluminium production - anode baking	84
	Primary aluminium production - general	275
	Solid smokeless fuel production	5
	Iron and steel - flaring	718
4 Production processes Total		**2,658**
5 Extraction / Distribution of fossil fuels	Offshore oil and gas - processes	22
	Offshore oil and gas - well testing	92
5 Extraction / Distribution of fossil fuels Total		**115**
7 Road transport	Road transport - cars - cold start	2,298
	Road transport - cars non catalyst - cold start	99
	Road transport - cars with catalysts - cold start	23,578
	Road transport - LGVs - cold start	1,805
	Road transport - LGVs non catalyst - cold start	8
	Road transport - LGVs with catalysts - cold start	489
	Road transport - major roads	302,060
	Road transport - minor roads	109,572
7 Road transport Total		**439,909**

UNECE Source Sector	NAEI Detailed Source Sector	NO_X emission (tonnes)
8 Other transport and machinery	Agriculture - mobile machinery	39,049
	Aircraft - military	7,517
	Aircraft - domestic take off and landing	1,887
	Aircraft - international take off and landing	10,760
	Aircraft - support vehicles	4,849
	House and garden machinery	913
	Industrial off-road mobile machinery	87,815
	Railways - freight	23,381
	Railways - intercity	9,139
	Railways - regional	6,180
	Shipping - coastal	63,349[4]
	Shipping - naval	9,240[4]
	Shipping - UK international	20,883[4]
8 Other transport and machinery Total		**284,961**
9 Waste Treatment and disposal	Accidental fires - vehicles	23
	Crematoria	129
	Incineration - animal carcases	245
	Incineration - chemical waste	267
	Incineration - clinical waste	463
	Incineration - MSW	3,165
	Incineration - sewage sludge	50
	Offshore oil and gas - flaring	2,057
	Small-scale waste burning	396
9 Waste Treatment and disposal Total		**6,795**
11 Other sources and sinks	Accidental fires - dwellings	103
	Accidental fires - forests	113
	Accidental fires - other buildings	201
	Accidental fires - straw	46
	Accidental fires - vegetation	58
11 Other sources and sinks Total		**520**
Grand Total		**1,466,616**

The relative contribution of emissions from different sectors varies by pollutant. The NAEI report provides details of emissions by sector for all pollutants covered by the NAEI (Murrells et al, 2010).

[4] This is an estimation, based on the NAEI shipping sectoral split and the UK shipping total emissions provided by ENTEC (ENTEC report to Defra, October 2008, Whall C et al, UK Ship Emissions Inventory 2007. Doc Reg No. 21897-01).

3. Methods for calculating emissions 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 a variety of official UK sources (Environment Agency, Scottish Environmental Protection Agency, Local Authority data). For sources that are distributed more widely across the UK (known as 'area' sources), a distribution map is generated using appropriate surrogate statistics for that sector. The method used for each source sector varies according to the data available. **Table 3.1** presents the types of mapping distributions used within each of the UNECE sectors. The mapping methods used to develop these distributions are explained in the following sections.

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

1 Combustion in energy production and transfer	**6 Solvent use**
points	population
offshore	points
IDBR employment	IDBR employment
2 Combustion in commercial, institutions, residential and agricultural sectors	landuse
points	**7 Road transport**
domestic fuel use	road transport
IDBR employment	**8 Other transport and machinery**
IDBR agriculture	agriculture
IDBR commercial and public fuel use	airports
3 Combustion in industry	other
points	rail
IDBR employment	shipping
IDBR industry fuel use	IDBR employment
4 Production processes	population
points	**9 Waste Treatment and disposal**
IDBR employment	landfill
shipping	landuse
road transport	offshore
population	points
other	IDBR employment
5 Extraction / Distribution of fossil fuels	**10 Agricultural, forests and landuse change**
points	agriculture
offshore	landuse
other	**11 Other sources and sinks**
domestic fuel use	landuse
population	other
	population

3.1 POINT SOURCES

A point source is an emission source at a known location such as an industrial plant or a power station. Emissions from point sources may represent sectors of the UK inventory either fully (such as power stations where the sector is made up of large operational facilities for which emission reporting is mandatory) or in part (such as combustion in industry, for which only the large sites within the sector are required to report emissions). In the latter case, the residual emission (i.e. the proportional of the national total emission not accounted for by individual installations) is mapped as an area source.

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 AEA Energy & Environment 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 annual. The quality and quantity of reported data increases in recent years and the level of reporting is very high from the second half of the 1990s onwards. From 1998 onwards, emission reporting is only required if 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. From 2004 onwards, the SPRI 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.

From 2004, the NAEI has utilised information from the EU-ETS to characterise the types and quantities of fuels consumed by operators registered with this scheme. This approach was developed for mapping of CO_2 point source emissions as part of the work on the Local and Regional CO_2 estimates for 2004 (King et al 2006) and is now used for estimation of emissions of all pollutants. In most cases the EU-ETS fuel consumption data were used to split PI/SPRI/ISR reported emissions between the various fuel types used at the facility. In other cases where PI/SPRI/ISR data were not available the EU-ETS data were used directly.

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 and for all years from 1992 onwards. The LCP data also includes 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 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 does not give this breakdown;
- United Kingdom Petroleum Industry Association (UKPIA) supply emission data for process sources of VOC and combustion processes at crude oil refineries;
- United Kingdom Offshore Operators Association (UKOOA) 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.

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 approach 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 AEA can be used to allocate the national emission estimate. This approach is, for example, used for bread bakeries where 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 plant which do not report emissions have similar rates of emissions as plant 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 plant 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 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.

Table 3.2 shows the contribution to UK total emission from point sources for 25 pollutants. The contribution from reported or estimated emission 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 therefore need 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 sources data based on data supplied by regulators for LAPC/APC processes.

The larger part of NO_X, SO_2, HCl and 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, 59% 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.

Table 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.).

Table 3.2 Point source emission fraction of NAEI UK total emissions for key pollutants and contributions of reported and estimated data.

Pollutant	% of national emissions treated as point sources	% of point source emissions from Reported data	% of point source emissions from Estimated data
1,3-butadiene	14%	92%	8%
Ammonia	2%	82%	18%
Arsenic	22%	48%	52%
Benzene	10%	87%	13%
Benzo[a]pyrene	6%	12%	88%
Cadmium	57%	48%	52%
Carbon Dioxide as Carbon	47%	99%	1%
Carbon Monoxide	28%	91%	9%
Chromium	52%	61%	39%
Copper	28%	56%	44%
Dioxins (PCDD/F)	19%	59%	41%
Hydrogen Chloride	70%	96%	4%
Lead	78%	73%	27%
Mercury	80%	69%	31%
Methane	1%	99%	1%
Nickel	37%	70%	30%
Nitrogen Oxides as NO2	33%	96%	4%
Nitrous Oxide	5%	81%	19%
Non Methane VOC	22%	20%	80%
PM10 (Particulate Matter < 10um)	22%	66%	34%
PM2.5 (Particulate Matter < 2.5um)	21%	0%	100%
Selenium	77%	42%	58%
Sulphur Dioxide	78%	96%	4%
Vanadium	5%	69%	31%
Zinc	54%	26%	74%

Further information on calculation of point source emissions estimates can be found in documentation provided in the **Point Source Fuel Use estimates**[5].

Possible future improvements:

The level of mapping using point source data is close to the maximum feasible level. However, some improvements may be realised in the future for medium-sized combustion plant and industrial

[5] http://www.decc.gov.uk/assets/decc/statistics/climate_change/1_20100122174622_e_@@_pointsourcefuelests.pdf

processes due to developments in emission trading, reporting of emissions from IPPC processes not previously regulated under IPC, and use of local inventory data.
The utilisation of EU-ETS data, and some fuel usage data in the Pollution Inventory has aided the development of point source data for combustion plant. However, the processing of the data from these sources is time-consuming and complex, and the differences between data in the EU-ETS datasets, the PI, SPRI, ISR, and national energy statistics given in DUKES present serious challenges with regard to reconciliation. It is the mapping team's expectation that the lead time in development of the point source data for medium-sized combustion plant will be 2-3 years and the extent of improvement in the quality of mapping that results, will depend upon developments in the EU-ETS, PI/SPRI/ISR and DUKES data sets.

Under the European Pollutant Release Inventory (EPER) Part A2 processes, regulated by local authorities, are required to report emissions and this has had a small beneficial impact on the mapping, with some limited additional data becoming available. However, due to the relatively high reporting thresholds used for EPER, few A2 processes need to provide emissions data, and this limits the usefulness of EPER for UK mapping work. The migration of EPER to the European pollutant release and transfer register (E-PRTR) for the 2007 reporting year is however, expected to have an impact on the quantity of data available for use in the mapping and warrant evaluation when these datasets become available.

Local inventory data are potentially useful contributors for national emission maps. However there are a number of barriers to the use of such data.

1 Obtaining data from local inventory studies is time-consuming since the detailed data are not readily available via the internet, instead for example data must be obtained through negotiation with the individual data holders.
2 Once obtained, considerable resources are required to convert the data into the formats used for national maps.
3 The quality of local inventory data is not known, but review of some local inventory data has indicated that, in a few cases where comparable data are available in the national inventory, the local data are probably not as reliable. These cases related to Part B processes emitting VOC.
4 Using data from local inventories creates a problem in that these inventories provide an incomplete picture of emissions from a sector. Unlike EPER, EU-ETS or PI/SPRI/ISR data which are available for the UK as a whole, using data from a few local inventories would mean that points data included processes from some areas but not for others. This would have to be addressed by the mapping process but it would make the process much more complicated.

In view of the difficulties listed above, there has been only limited incorporation of point source data from local inventories have been incorporated to date in the national maps. This does not preclude the use of this kind of dataset, but reflect the resource-intensive nature of the task and relative benefits of the improvements gained.

3.2 INDUSTRIAL AND COMMERCIAL SECTORS

The industrial sectors in the NAEI are mapped using a combination of point source estimates of emissions and area source employment based distributions. For some sectors the NAEI's UK total emissions estimate is entirely accounted for by point source emissions. In this instance all of the emissions are mapped as point sources. In other cases there are sectors that are have no identified point sources, in which case all emissions are mapped as an area source. Many sectors however, are comprised of a combination of point source and area source emissions. In this situation point source emissions are mapped explicitly and the remaining residual emission[6] is treated as an 'area source' and distributed across the UK using modelled high resolution (1 km^2) emission distributions based on detailed employment and fuel use data. Small industrial combustion is an example of a sector for which the area source distribution is particularly important but there are also some identified point sources.

Emissions distribution maps for the small industrial combustion, public services, commercial and agriculture (stationary combustion) sectors have been updated for the 2006 inventory. The method used is described in the document **Mapping small industrial emissions**[7]. The following data sets are used:

- Office of National Statistics Inter-Departmental Business Register (IDBR) 2007 which provides data on employment at business unit level by Standard Industrial Classification (SIC) code; and
- BERR Energy Consumption in the UK data on industrial and commercial sector fuel usage for 2005. (BERR, 2007b)

The SIC codes in the IDBR database were matched with the BERR energy datasets in order to calculate total employment for each of the BERR energy sectors. From this, a fuel intensity per employee is calculated. These intensities are then being applied to employment statistics aggregated to a 1 km^2 grid for the UK to make maps of fuel use.

In the case of the industrial sectors this energy intensity calculation has been 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. BERR fuel data was 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 tranches equivalent to the energy data provided by BERR. These sectors are presented in **Table 3.3**.

Table 3.3 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

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

[7] http://www.decc.gov.uk/assets/decc/statistics/climate_change/1_20090917091058_e_@@_localco2smallindustrial.pdf

Employment data at local unit level were aggregated to 4 figure SIC codes at 1 km^2 resolution using grid references provided in the IDBR 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 have been 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 has further limited to outside the locations of Smoke Control Areas.
- There have been no maps generated of Smokeless Solid Fuel consumption as part of this work. According to the BERR dataset (Energy Consumption in the UK Table 4.6) there is only one sector using manufactured fuel (Manufacture of coke oven products). The emissions from this sector will be mapped predominantly by point sources and any residual will be mapped using an employment distribution.

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.

3.3 ROAD TRANSPORT

Mapping methods for road transport emissions and fuel estimates for 2007 are described in the following section. Improvements made to the 2007 dataset are summarised at the end of the section.

Hot exhaust emission 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 from 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 a certain 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. 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 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 amounts of acceleration and deceleration built into them and for each of these, the fuel consumption rate will be very different.

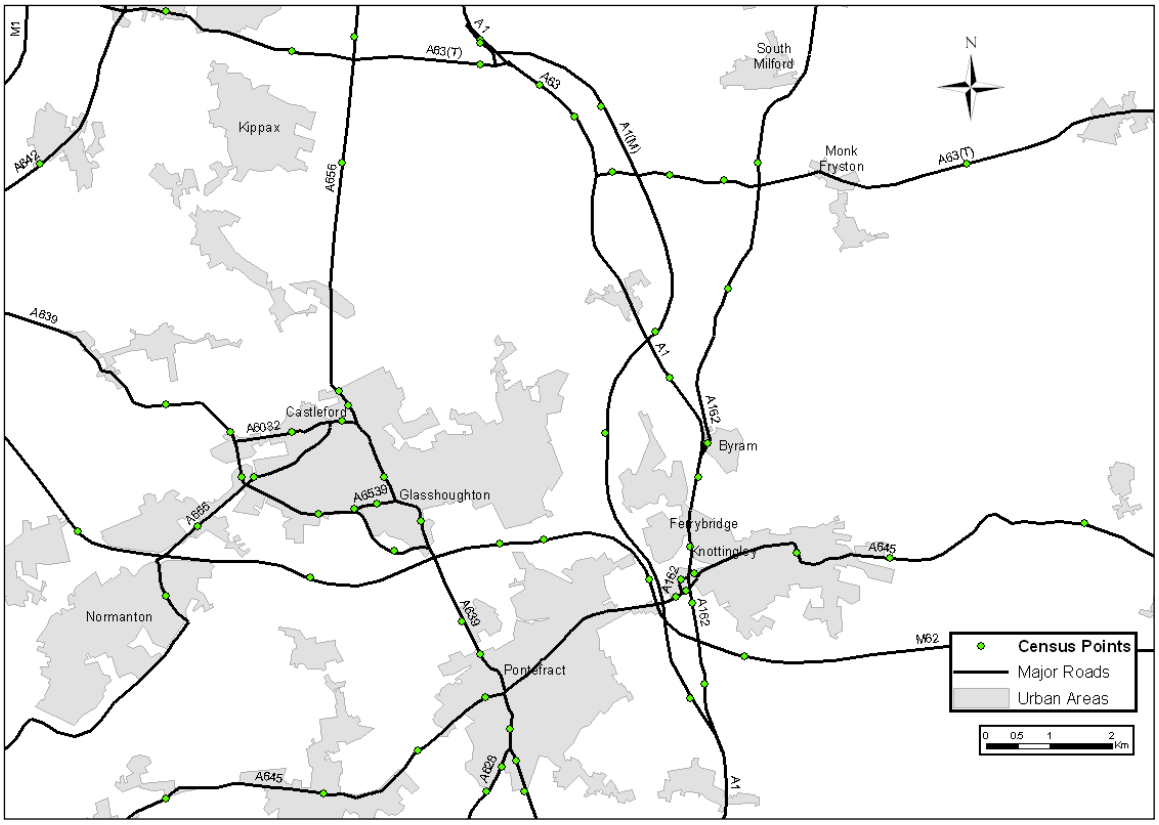
Emissions for the key air quality pollutants (NO_x, PM_{10}, $PM_{2.5}$, SO_2, NMVOC, Benzene, 1,3-butadiene, and CO) are calculated using speed related emission factors multiplied by vehicle flows on the road network. For other pollutants such as CO_2 and heavy metals, fuel consumption is used as a proxy for the distribution of emissions.

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

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 dataset (see **Figure 3.1**). This provides locations of all roads (motorways, A roads, B roads and Unclassified roads) in Great Britain. In addition a dataset of roads in Northern Ireland was obtained from the Department of Environment Northern Ireland (DoE NI).

Figure 3.1 A map to illustrate the detail in the road network and count point database.



3.3.2.1 Mapping traffic on major roads

Traffic flow data for major roads (A-roads and motorways) is available on a census count point basis for both GB (DfT, 2008) and Northern Ireland (Roads Service, 2009). However, the coverage in GB is considerably more dense than that for NI, although some new NI count points become available every year. The traffic flow data includes counts of each type of vehicle as an annual average daily flow. These have been aggregated up to annual flows by simply multiplying by 365. The Annual Average Daily Flow statistics take account of seasonal variation through the use of 'expansion factors' applied to the single day counts based on data from automatic counts for similar roads and vehicle types. Some Northern Ireland count points only record total vehicles, rather than a split of different vehicle types. An average vehicle split has therefore been applied to these.

Each traffic count point has been allocated to a section of the major road network according to the road name and its proximity to the road – i.e. each link has the nearest count point with the same road name assigned to it. Calculations of emissions and fuel use have been done at the 1 km^2 resolution level by splitting each road link using an intersection with a 1 km^2 grid. Vehicle kilometres of travel (VKM) by each vehicle type were calculated from the traffic flow rates, fuel splits and the lengths of each road type.

Further improvements have been made this year to the allocations of count points to road links to improve the accuracy of this allocation and to remove and replace redundant, older count points from the dataset.

3.3.2.2 Mapping traffic on minor roads

The method for mapping traffic movements on minor roads has been significantly improved for the 2007 inventory.

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. Where these data are available they have been used to enhance the accuracy of the mapping. Minor road count points have been allocated to minor roads in using the major roads approach described above. Local information applicable to each census point (Local Authority, Area type) is also generated.

Traffic flows in the majority of minor roads have been modelled using experimental statistics on average regional flows and fleet 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 2007 report which provides average flows for all vehicle types by minor roads and also average vehicle splits by the same road types.

A key improvement in the minor road traffic mapping method for 2007, is the use of VKM estimates at county level (DfT *pers comm. 2008*). This dataset has been provided by DfT to ensure consistency between the NAEI and DfT modelling and has been used to correct the estimates of VKM in the NAEI mapping at a county level.

3.3.3 Vehicle fleet composition

The age of the fleet is not varied regionally. The fuel split for passenger cars between petrol and diesel has, however, been revised with a different mix now assumed for urban, rural and motorway roads (major and minor), as outlined in the “Improvements for 2007” section below. 90% of the LGVs on all roads are diesel, the remainder being 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.

3.3.4 Fuel consumption calculations

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

Each major road link has been assigned an area type using the DfT definitions of urban area types shown in **Table 3.4** below. Vehicle speeds have then been assigned to different road types (built up and non-built up A-roads and motorways) within each area type.

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 according to the Local Authority

boundaries which then allow aggregation of fuel consumption estimates for each Local Authority across the UK.

Table 3.4 Department for Transport Urban Area Type Classification

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

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 and the results are aggregated to LA boundaries for the fuel consumption estimates published by DECC.

3.3.5 Improvements for 2007

Methodologies for calculating fuel consumption and emissions are periodically updated as our understanding of the factors that affect them improves. Also, the input data used to calculate them are updated as DfT revises information, provides more detail in the information gathered and as new information becomes available. Consequently, revisions to the trends in calculated road transport fuel consumption and emissions are inevitable as the science and evidence base improves. The NAEI uses consistent data and approaches to meet the needs of Greenhouse Gas Inventory compilations and those for air quality pollutant emissions.

A number of changes were made to the information and methods used to calculate the 2007 time-series in fuel consumption and emissions by road transport. A summary is provided here however more detail is given in the methodology annex of the National Greenhouse Gas Inventory report (NIR)[8]

Changes to Petrol Car and Diesel Car Share on Different Road Types:

The new methodology takes account of the fact that diesel cars travel more miles in a year than petrol cars. The DfT traffic census counts only the number of cars and makes no distinction between petrol and diesel cars. Until now, vehicle licensing statistics on the population of petrol and diesel cars in each year have been used to define a fuel split to the number of vehicle kilometres travelled which we applied equally to all road types. For the first time this year, data were obtained from DfT from an independent survey which shows the annual mileage done by diesel cars is on average around 1.6 times higher than that travelled by petrol cars. Thus the split of VKM has been modified to take account of that and derived different petrol car/diesel car mixes on different road types on the assumption that the additional mileage done by diesel cars is done mainly through travelling greater distances on motorways.

[8] www.airquality.co.uk/reports/cat07/0905131425_ukghgi-90-07_Annexes_Issue2_UNFCCC_Final.pdf

Licensing statistics indicate that 24% of passenger cars in the fleet run on diesel in 2007. **Table 3.5** shows the percentage of diesel cars on urban, rural and motorway roads estimated for 2007 on the basis of the mix in the fleet and the additional mileage done by diesel cars relative to petrol cars.

Table 3.5 Percentage of diesel cars on each main road type in 2007

Road type	% diesel cars on road
Urban	24%
Rural	36%
Motorway	45%

This change has led to an overall increase in diesel car activity and hence fuel consumption compared with the previous year's estimates and the new method and assumptions have been applied to all previous years on the basis that this has been a long-term trend.

Fuel consumption by HGVs was slightly modified due to changes in the time-series of miles per gallon fuel efficiency rates that are published for these types of vehicles by DfT based on the Continuous Survey of Road Goods Transport.

Changes to Vehicle Speed Data on Different Road Types:

The NAEI method uses average speed data for different vehicle types on many different types of roads and uses these to calculate average fuel consumption and emission factors for each vehicle type/road type combination used in the national inventory and the mapping.

DfT periodically carry out traffic surveys and report speed data in various publications. Much more detailed speed data have become available in recent years. The NAEI undertook a major review of speed data from more recent DfT publications, communications and from the London Atmospheric Emissions Inventory and as a consequence has revised the speed data used. The changes led to a revision in the fuel consumption factors used. The changes were significant on some road types, but over all types of roads the changes partly cancelled out so the change in speed data did not have a significant effect on the national inventory. However, the changes on specific roads in specific areas would be emphasised in the mapping.

The changes made to the fuel consumption factors used in this year's inventory will manifest themselves differently in different areas and local authority regions. This is because the fuel consumption factors were modified to varying degrees for different vehicle types – some were changed considerably, while others were hardly changed at all. Therefore the overall impacts of the changes in a given local authority region will depend on the different types of vehicles travelling on these roads, as surveyed by DfT.

Summary of improvements to road transport mapping for the 2007 inventory

- Major road census point allocations to road links were improved in some places
- Minor road census point allocated to relevant road links using the appropriate parameters where available
- Minor road DfT county level VKM estimates was used to reconcile regional stats to county level
- Allocation of roads to Local Authorities was improved
- Updated speed data and changes to fuel consumption factors were implemented for some road types
- Improved estimates of the petrol and diesel fuel split in the vehicle fleet. This split now varies by road type

3.3.6 Other Road transport emissions

Cold start emissions are produced from vehicles before the engine has reached normal operating temperature. Estimates for 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 2006 (Choudrie et al 2008). 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 using the COPERT II methodology (EEA 1997).

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 (Ntziachristos and Samaras 2000) model for cold-starts.

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 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.

Possible future improvements to road transport emissions distributions:

- Adapt the revised national totals for 2008
- Incorporate TRL emission factors

3.4 DOMESTIC FUEL USE

The NAEI's approach to modelling domestic fuel use for the 2007 remains unchanged from the methodology developed for the 2005 release of the NAEI. In summary this methodology draws heavily on modelling of domestic fuel use within Great Britain for the 2004 Local and Regional CO_2 Emission Estimates (King et al 2006) and incorporates updates to the core datasets underlying the modelling approach for Northern Ireland developed for the 2002 NAEI (Pye and Vincent, 2003).

A summary of the methodology is provided below.

3.4.1 Domestic fuel mapping in Great Britain.

The revised method for mapping domestic fuel use within Great Britain makes use of newly available data which enable significant improvements to be made to the distributions of domestic fuel use. New distributions of domestic gas, coal, oil and smokeless solid fuels were produced for Great Britain for the 2004 inventory emission maps.

New data made available by DECC (formerly BERR and DTI) provides high resolution maps of domestic gas use across Great Britain. This dataset characterises the number of gas customers and amounts of gas used per 1 km^2 for 2005, and data on electricity use, specifically type 2 meters (economy 7 type meters).

In addition, data supplied by BRE on behalf of Defra for this work, provided estimates of total energy use by dwelling type and by fuel type and also regional data on the numbers of households using different fuels (BRE 2006). Gas consumption accounts for 72% of domestic non-electricity energy use, therefore the new high resolution gas data provides a huge improvement in our understanding of the spatial distribution of fuel consumption in Great Britain.

In providing improved fuel use estimates, the method first calculated the amount of gas use in a 1 km^2 and compared this with a theoretical quantity of gas consumption on the basis of complete gas take-up by the housing stock, i.e. every dwelling using the average gas demand for that dwelling type. The difference between the actual gas consumption and this theoretical amount was then calculated and the number of households this represented apportioned to different fuels. This apportionment was based on Economy 7 electricity use, assumptions about fuel use within and outside smoke control areas and regional data from BRE on fuel usage by household type.

It has been assumed that:

- Coal is burnt exclusively outside Smoke Control Areas
- Oil is burnt outside the biggest cities (of greater than 250,000 populations) 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

The new maps represent a significant improvement on the previous domestic consumption maps as result of the new data sources and new modelling techniques. Initial validation of the results (King et al 2006) has shown a relatively good correlation between the model results and the BRE regional data, although there are some quite large differences. Further validation of modelled data is planned as part of the continued development of the emission maps. Full details of this mapping methodology can be found in King et al 2006.

3.4.2 Domestic fuel mapping in Northern Ireland

The new gas consumption data and BRE fuel use data used in updating mapping approach in Great Britain are not available in Northern Ireland. As a result, and also taking into account availability of updates to the core datasets underlying existing approaches to domestic fuel mapping for Northern

Ireland, it was decided to maintain the existing methodology and update the datasets used previously (Pye and Vincent, 2003).

The fuel use grids have been generated from a wide range of data sources including:

- Northern Ireland Housing Executive household data (supplied by the NIHE 2006 PRAWL property database)
- Gas household data (supplied by Phoenix Gas 2005)
- Belfast household data (from fuel use survey undertaken by Belfast City Council 2001)
- Northern Ireland Census output area households data (supplied by the 2001 Census)
- The Northern Ireland Interim House Condition Survey 2004.
- The Northern Ireland 2005 Home Energy Conservation Report
- Other household data not covered by the above (from number of sources, including Housing Condition Survey (HCS) data).
- Household fuel use survey data from 16 Northern Ireland Local Authorities collected under their obligations to Review and Assessment of air quality under the UK's Air Quality Strategy (AQS)

Using these data it was possible to update the bottom up approach developed by Pye and Vincent (2003). The fuels used by the Northern Ireland housing stock was characterised as follows:

1. Geographic household distribution. Derived from the 2001 Census at an output area level and scaled to 2004 using information from the 2004 HCS and 2005 HECA report for Northern Ireland.
2. Fuels used in the NIHE social housing stock. Derived from the NIHE's 2005 PRAWL database.
3. Fuels used in the private housing stock. Derived from the 2001 detailed HCS, scaled to 2004 using information from the 2004 HCS and 2005 HECA report for Northern Ireland.
4. Distribution of Households connected to gas. Derived from Phoenix Gas 2005.
5. Fuels used in Belfast. Derived from 2001 Belfast City Council fuel use survey
6. Geographical distribution of Smoke Control Areas. Derived from GIS data provided by DoE Northern Ireland.

Using these data a detailed estimate of domestic fuel use across Northern Ireland was possible using datasets more appropriate to the current timeframe. Full details of the methodology that was followed for Northern Ireland are available in Pye and Vincent (2003).

3.4.3 Domestic House and Garden Machinery

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.

Possible future improvements to domestic fuel use emissions distributions:

- Improve emission estimates for both historic and projected domestic gas combustion
- Update methods and underlying datasets for emissions estimates from domestic fuel use into the 2008 NAEI

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 2002a) 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 are 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 and Sutton 2008, Dragosits et al 2008).

Emissions from agricultural off-road machinery and vehicles are distributed using a combination of arable, pasture and forestry land use data. Each of these land cover classes are weighted according to the off-road machinery activity on each land use, which in turn is based on data for the average usage (in hours) for tractors and other machinery on these land use types.

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.

Agricultural stationary combustion is mapped using IDBR employment data for the agricultural sector. Gas use is constrained to gas consumption zones as described in Section 3.2 and solid and liquid fuels are assumed to be used in other areas.

Possible future improvements:

- Update of livestock and poultry distributions used for particulate matter mapping.

3.6 RAIL

UK rail emissions are compiled using data for three locomotive journey types: freight, intercity and regional. Emissions are calculated based on fuel use reported in DUKES. Rail emissions from diesel locomotive are distributed across Great Britain using maps of the UK rail network and details of the number of vehicle kilometres by journey types 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, no information on load variations along each rail link being 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 Northern Ireland rail network derived from Ordnance Survey Northern Ireland. 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.

Possible future improvements:

- Update emission mapping distribution grids using more up-to-date GIS data
- Extend scope of rolling stock EFs
- Investigate availability of base data improvements or activity data updates (DfT rail movements survey and the ACTRAFF dataset currently used by the LAEI for rail emission calculations)

3.7 SHIPPING

Shipping emissions within the NAEI have historically been calculated at a national level based on fuel sales:

- Fuel sales for ships confined to UK waters (Coastal shipping)
- UK bunker fuel sales corrected for estimation of emissions in port and cruise in UK waters only (other UK shipping)

The NAEI has historically provided UK emission estimates for coastal shipping, international shipping and naval shipping based on fuel consumption data provided by DUKES. However, these emission estimates have uncertainties associated with the quality, completeness and coverage of the fuel consumption data and are based on the refiners' best estimate of the split of the fuel data between different activities (e.g. domestic or international shipping). More specifically, for shipping, these emission estimates are based on UK fuel sales, so vessels bunkering outside the UK are not included in the emission estimates, although these vessels may also be operating within UK waters. Further complexities are introduced when assigning a geographical distribution to the fuel consumption statistics and the associated emissions.

In 2008, Entec UK Limited (Entec), working under sub-contract to the NAEI developed a detailed gridded ship emissions inventory for UK waters. This work used up to date 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 latest 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

Emissions and fuel consumption estimates for 2007 were calculated at a 5 km^2 grid resolution (based on the EMEP grid) for an emissions domain extending 200 miles from the UK coastline (Whall et al, 2008).

Outputs from the ENTEC shipping emissions study have been incorporated into the NAEI maps for 2007. In doing so, emissions estimates based on a 5 km^2 EMEP grid, have been 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 currently not available.

Possible future improvements:

- Distribute national total based on ENTEC Emission Factors / activities
- Provision of a spatially disaggregated split in emission by sector

3.8 AIRCRAFT

The NAEI estimates national total emissions from aircraft occurring below 1000m from ground level (equating to the take off and landing). These are calculated from the number of movements of aircraft by type at UK airports provided by the Civil Aviation Authority and 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 compilation of the emission maps, the locations of airports and their ground level footprints have been revised and mapped with the use of satellite imagery. Take off and landing emissions have been 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 100 m. For smaller airports all emissions are mapped evenly over the airport footprint.

The revised 2007 emission maps for aircraft emissions represent a significant improvement on the previous maps, provide a useful split of emissions occurring on the ground and in the air for the air pollution modelling community. In addition, emissions for some airports were distributed too widely, some emissions being distributed over flight paths which will have been above 1000 m.

3.9 ACCIDENTAL FIRES AND SMALL SCALE WASTE BURNING

The distribution of accidental fires across the UK is uncertain. Distribution maps have been made using the CEH Land Cover Map 2000. 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 distribution described in section 3.4 above.

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

Possible future improvement:

- The land cover data could be augmented using regional fire statistics to improve the distribution of emissions.

3.10 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.

Locations of landfill sites have been obtained from the Environment Agency for England and Wales, from SEPA for Scotland and from DOENI for Northern Ireland. Very little quantitative information on the sizes of the sites was available and no information was available about closed sites. Therefore a simple map of landfill locations is used to distribute national total emissions from landfills.

Ammonia 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 and Sutton 2007). This uses a combination of landfill site locations where available and population distributions to fill gaps where the landfill site locations are not available.

Possible future improvement:

- Improve data on the locations and sizes of landfill sites and proportional emission rates, both active and closed.

3.11 OFFSHORE

Emissions from offshore installations are provided by UKOOA. These include:

- Offshore flaring,
- Offshore loading,
- Offshore own gas use,
- Offshore oil and gas operations.

These estimates are aggregated for the UK totals. For the UK emission maps, the reported emissions by installation are assigned to locations provided by the UK Hydrographic Office based on the Company Name and field location.

Diesel and gas oil fuel use at offshore facilities is incorporated in the NAEI coastal shipping sector as the majority of fuel burned by offshore operations is for shipping.

Possible future improvement:

- Update coordinates of offshore installations and proportional emission rates

3.12 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 is 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 1 km^2 resolution maps are compiled within a GIS. The maps for each sector are generated summing distributed proportions of the NAEI national total. Area source emissions are aggregated to the 11 UNECE source sectors. Emissions at point sources are then added to make a UK total emission map such as that shown in **Figure 4.1** below. **Figure 4.2** shows the locations of the point sources.

Figure 4.1 UK Total NO_X emissions for 2007 in tonnes per 1 km^2

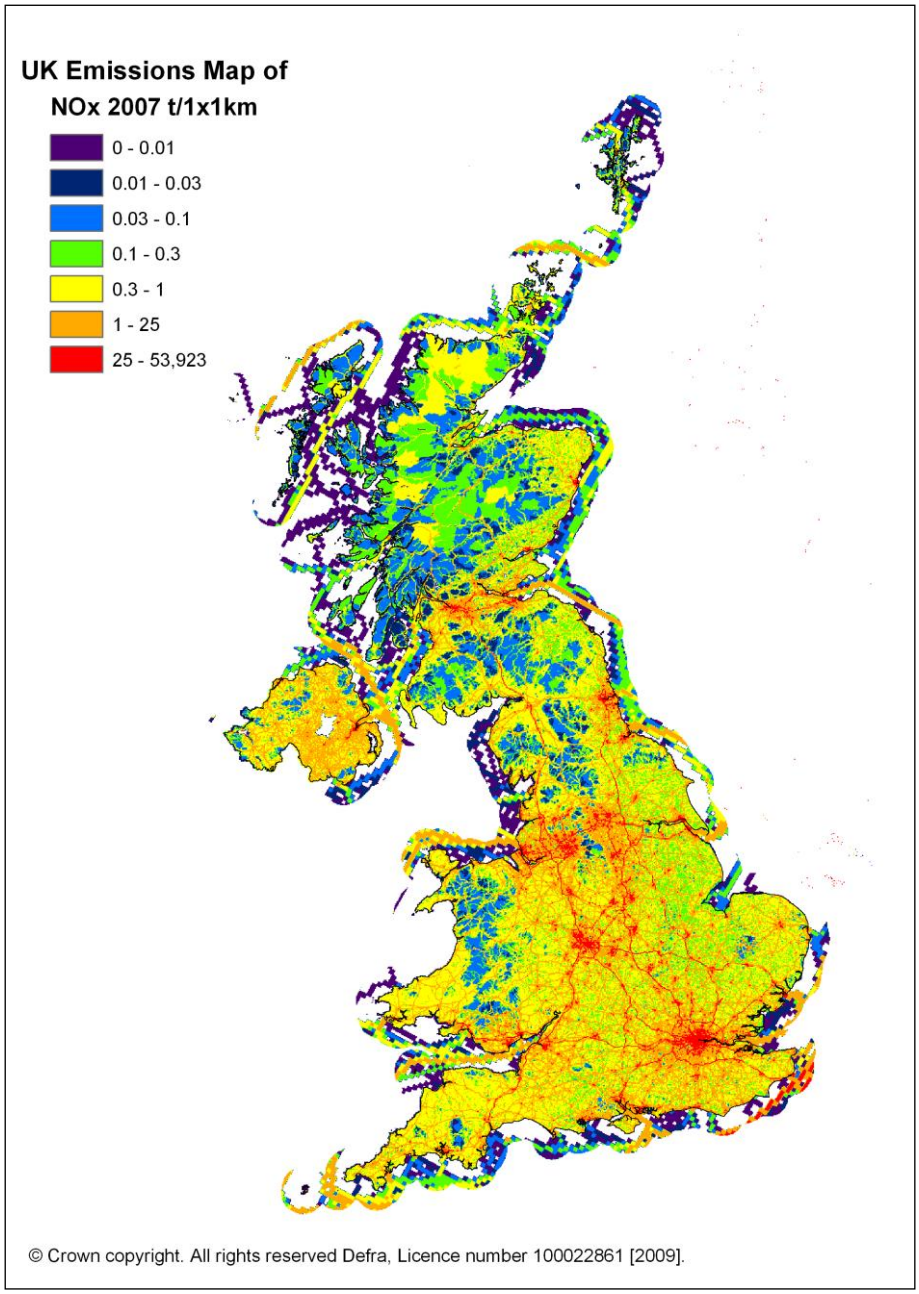
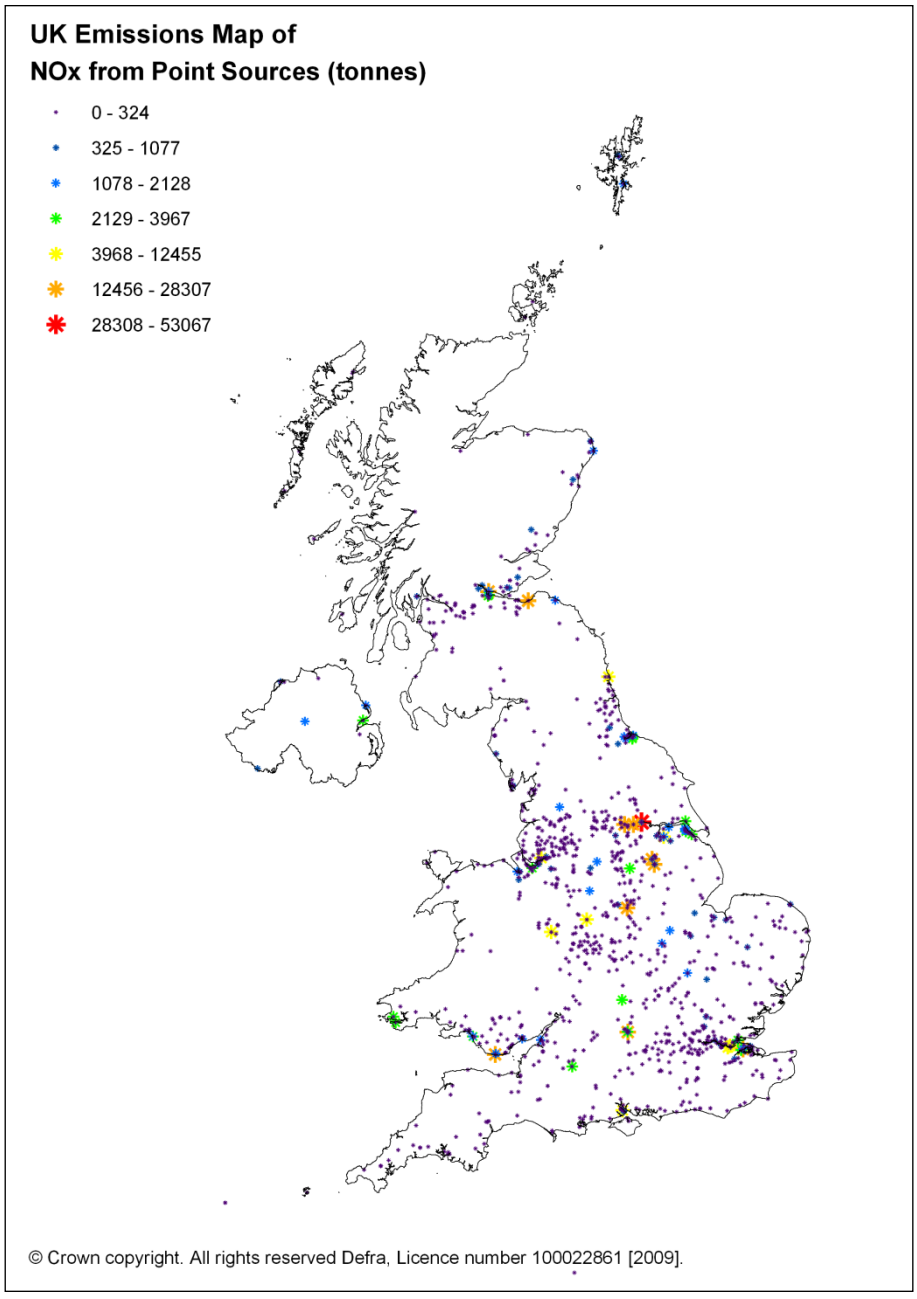


Figure 4.2 NO_X emissions at point sources in 2007 in tonnes



Further examples of the maps are shown in **Annex 1**.

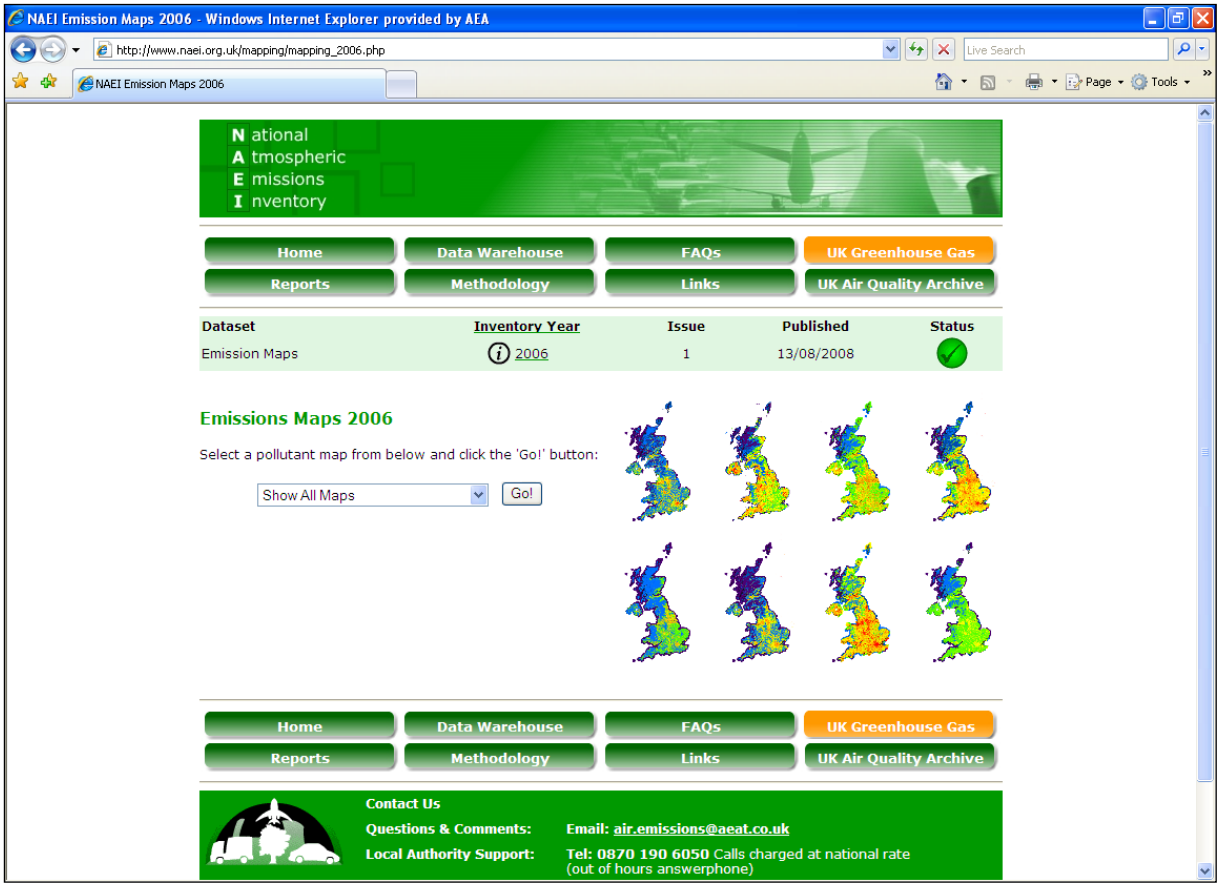
4.2 DATA PRODUCTS

Local authority data:

- The full spatial inventory is available on the NAEI website at http://www.naei.org.uk/datawarehouse
  The 1 km^2 resolution inventory is divided into separate files for each pollutant for each local authority. It is intended that these files are used to aid local authorities in developing their own emission inventories.

Full UK maps:

- The full UK area emissions maps are also available individually by pollutant at http://www.naei.org.uk/mapping/mapping_2007.php (in ASCII format). Point source data is available in Excel files.
- The full mapped inventory for all pollutants is also available on CD (email air.emissions@aeat.co.uk)



5. Quality of mapping and 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 being based on a large quantity of reliable data used for regulatory purposes. As we have seen, area source emissions are mapped using a variety of surrogate data types of varying data quality. Even though in all cases every attempt is made to utilise the highest quality datasets (within the budgetary constraints of the mapping task), in some cases the surrogate statistics used may be poorly suited to this task.

One simple way of assessing the quality of mapping might therefore be to compare the proportion of the national emission of each pollutant which is mapped as point or area sources. **Table 5.1** shows these proportions for selected pollutants.

Table 5.1 Contribution of point sources to mapped emission totals (2007)

Pollutant	Points sources (%)	Area sources (%)
1,3 - butadiene	14%	86%
Benzene	10%	90%
Benzo[a]pyrene	6%	94%
CO	28%	72%
CO2	47%	53%
Dioxins	19%	81%
HCl	70%	30%
Lead	78%	22%
Mercury	80%	20%
NH3	2%	98%
NMVOC	22%	78%
NOx	33%	67%
PM10	22%	78%
SO2	78%	22%

Taking the proportion of point sources as a measure of quality, **Table 5.1** suggests that maps for SO_2, HCl, mercury, hydrogen chloride and lead are likely to be of higher quality than those for PM_{10} and VOC, for example. However, this assessment does not differentiate between point source data which are derived from good site-specific emissions data and that which is 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:

$$Emission_A \times Rating_A + Emission_B \times Rating_B \text{ etc.} / Emission_{Total}$$

Where:

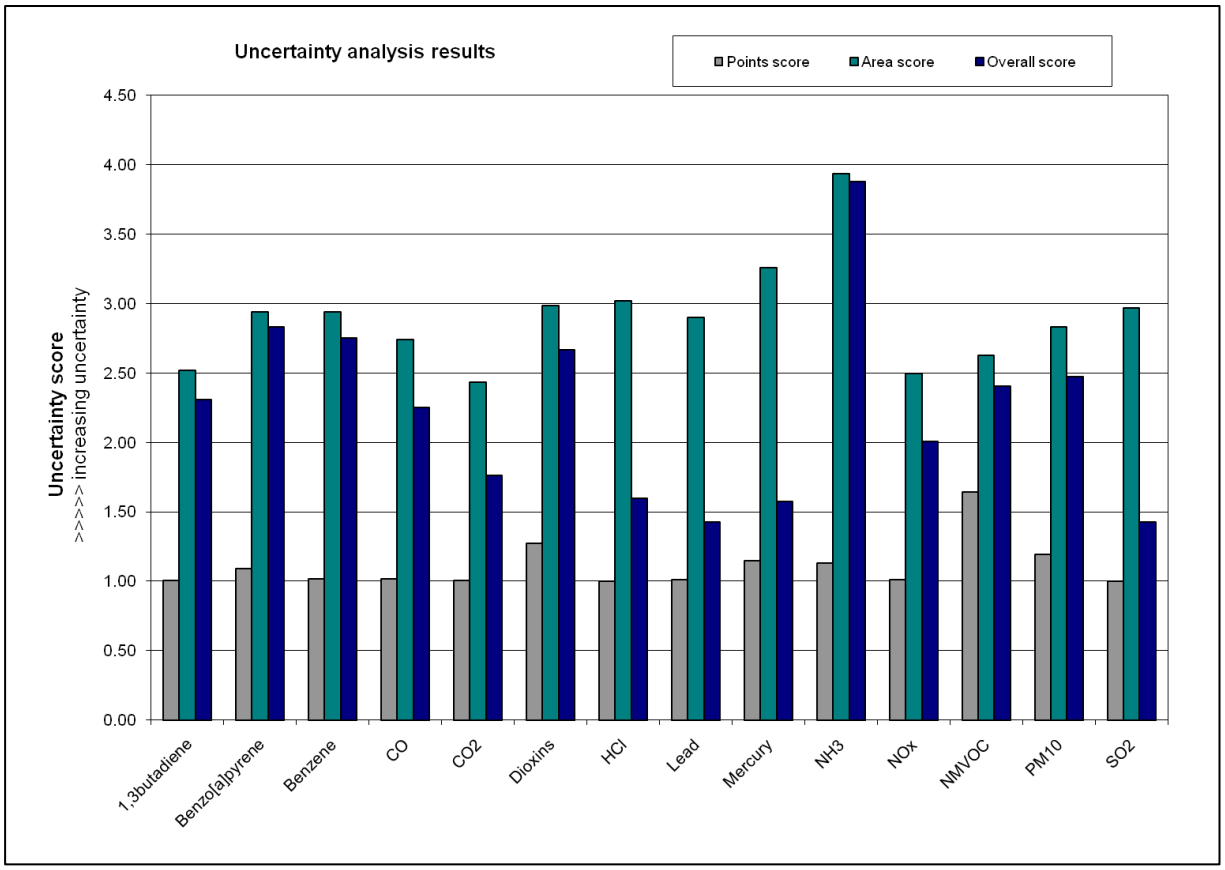
$Emission_A$, $Emission_B$ etc.	are the emissions of the pollutants from each of the sources in the inventory
$Rating_A$, $Rating_B$	are the data quality ratings applied to the mapping of emissions from each of the sources in the inventory

Some general rules have been applied when defining data quality ratings for mapping procedures. Point source data from the PI, industry or 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 resolution. 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 5.1** shows the resulting confidence ratings for the NAEI pollutant maps.

Figure 5.1 Confidence ratings for mapping elements of the 2007 NAEI



These data quality ratings show a broadly similar pattern to those observed in the assessment of proportions emitted by point and area source (**Table 5.1)**. Although there are some differences, e.g. the map for dioxins is considered of lower quality using the detailed assessment above because although nearly a third of emissions are from point sources, many of the area source emissions are from sectors that are difficult to map accurately such as small scale waste burning. The map for 1,3-butadiene is 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. The reliability of emissions maps should be verified if they are to be used to model potential exceedances of air quality objectives. 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.

Measured annual mean background concentrations can be considered to be made up of three parts:

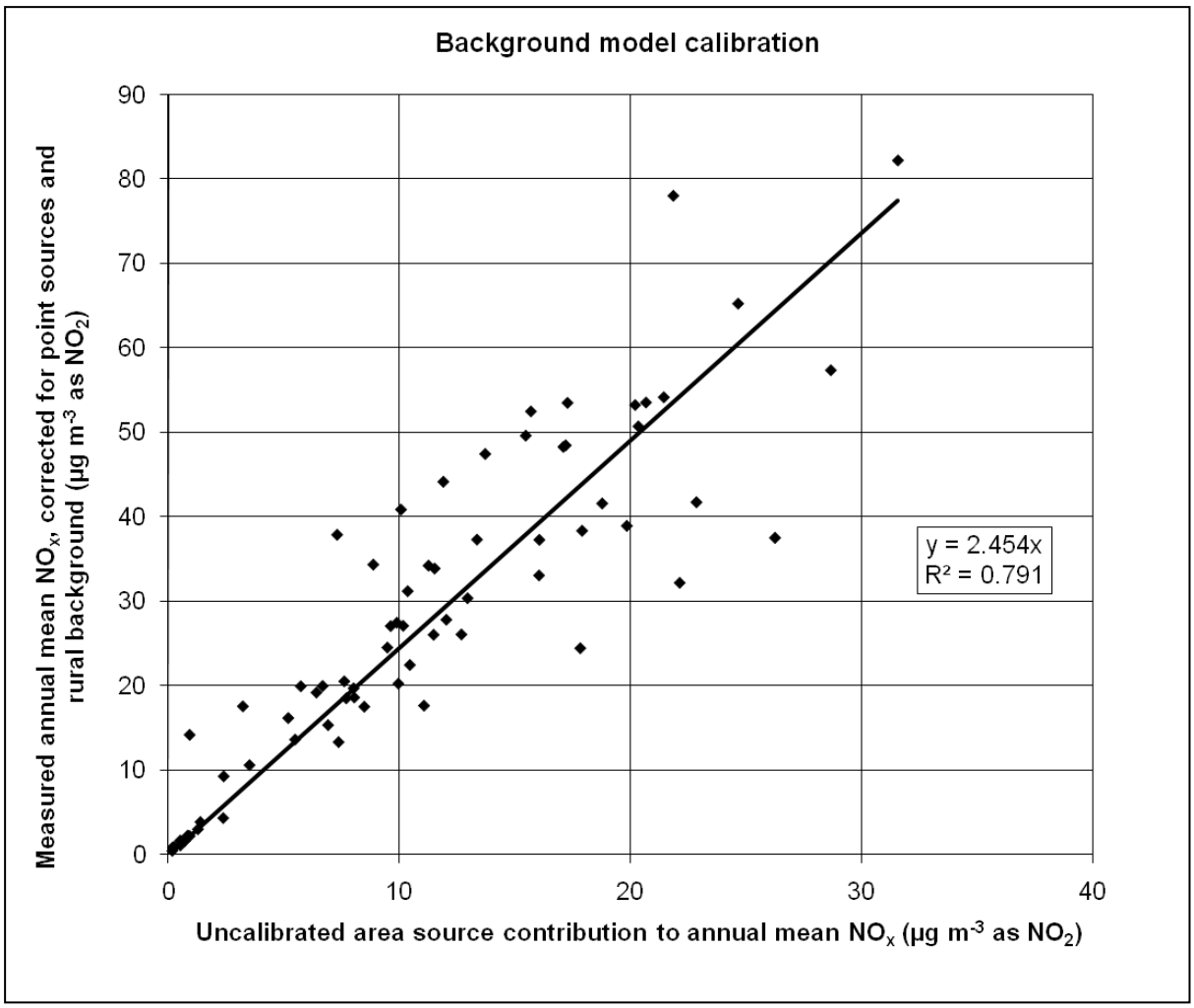
- A rural contribution: from relatively distant major point and area sources such as power stations or large conurbations. Measurements from monitoring sites well away from local sources, from rural sites within the UK Acid Deposition Secondary Network, for example, provide good indications of the spatial variation of concentrations due to distant sources.
- A point source concentration: modelled using dispersion models based on data from individual industrial sites
- A contribution from more local emissions

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 modelling activities have modelled ambient concentrations resulting from local emissions to ambient concentrations (Grice et al, 2010). As part of this work a dispersion kernel modelling approach is applied to the emissions from an area of 33 km^2 in order to calculate the uncalibrated contribution from area sources to the ambient concentration at a 1 km^2 grid of receptors. Ambient measurements 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 predict concentrations from the mapped emissions.

Figure 5.2 shows calibration data for the area source NO_x model and identifies the relationship between are source emissions and measured annual average air concentrations at urban automatic monitoring sites. The modelled local emission contribution to overall annual mean NOx 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 and smaller urban areas and rural areas. Thus the graph shows good agreement between the estimate of ambient concentrations from local sources calculated from measurements and from the emission inventory using the dispersion model. The gradient is significantly different from unity, suggesting that the area source model requires the application of this scaling factor. The scatter about the best fit line is low, suggesting that the area emission inventory provides a good characterisation of the spatial distribution of emissions.

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.

Figure 5.2. Calibration of area source NO_x model (µg m^{-3}, as NO_2) for 2008



6. Summary of recommendations for improvements

The NAEI work programme has a key objective of continuous improvement in response to changing data requirements, data availability, new research and policy directions. This applies as much to the mapping of emissions (as to the compilation of the National totals.

From 2008 onwards, at the start of each NAEI annual cycle, a horizon scanning report will be prepared. This will consider the latest developments in data, the evolution of policy and needs for the emission maps as a whole. From this review a detailed set of recommendations for continuous improvement will be made to Defra and the Devolved Administrations. This will, in-turn, prioritise the focus of the NAEI's annual maintenance and development initiatives for the emission maps.

This report has described the methods used to produce the NAEI emission maps for 2007. A number of recommendations have been made for improvements to the quality of the maps. These are listed below and will form the basis for maintenance items to be taken forward for prioritisation in the horizon scanning report.

Domestic fuel use

- Improve emission estimates for both historic and projected domestic gas combustion
- Update and where possible improve methods and underlying datasets for mapping emissions estimates from domestic fuel use into the 2008 NAEI

Shipping:

- Distribute national total based on ENTEC Emission Factors / activities
- Investigate provision of sectoral split by coastal shipping, international shipping and naval shipping

Railways:

- Update emission mapping distribution grids using more up-to-date GIS data
- Extend scope of rolling stock EFs
- Investigate availability of base data improvements or activity data updates (DfT rail movements survey and the ACTRAFF dataset currently used by the LAEI for rail emission calculations)

Agriculture:

- Update of livestock and poultry distributions used for particulate matter mapping.

Landfills:

- Improve data on the locations, capacity and proportional emission rates of landfill sites, both active and closed.

Accidental fires:

- Investigate augmentation of updated land cover data with regional fire statistics for improved emissions mapping

Offshore:

- Update coordinates of offshore installations and proportional emission rates

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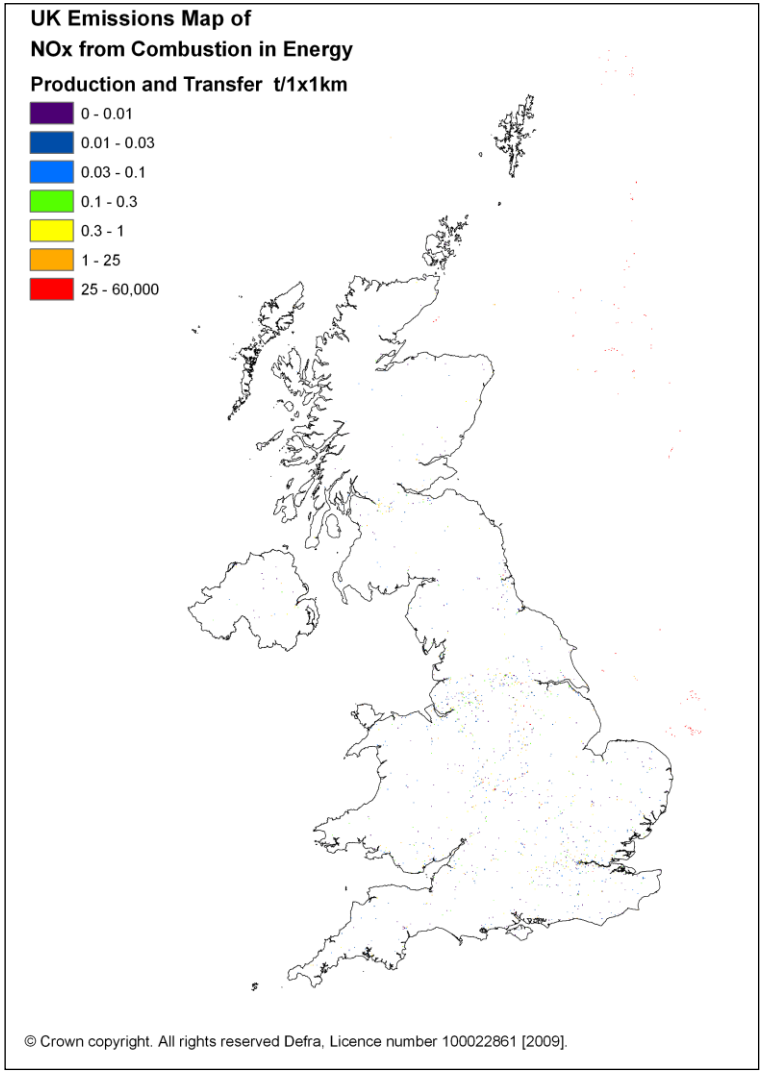
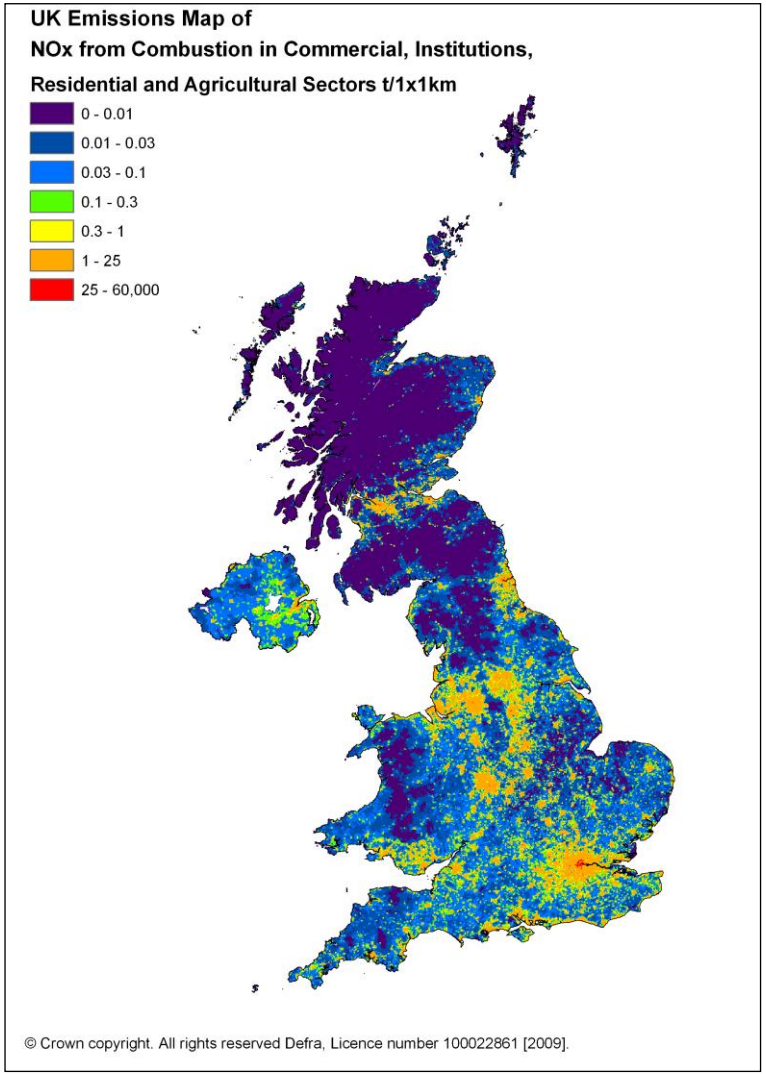
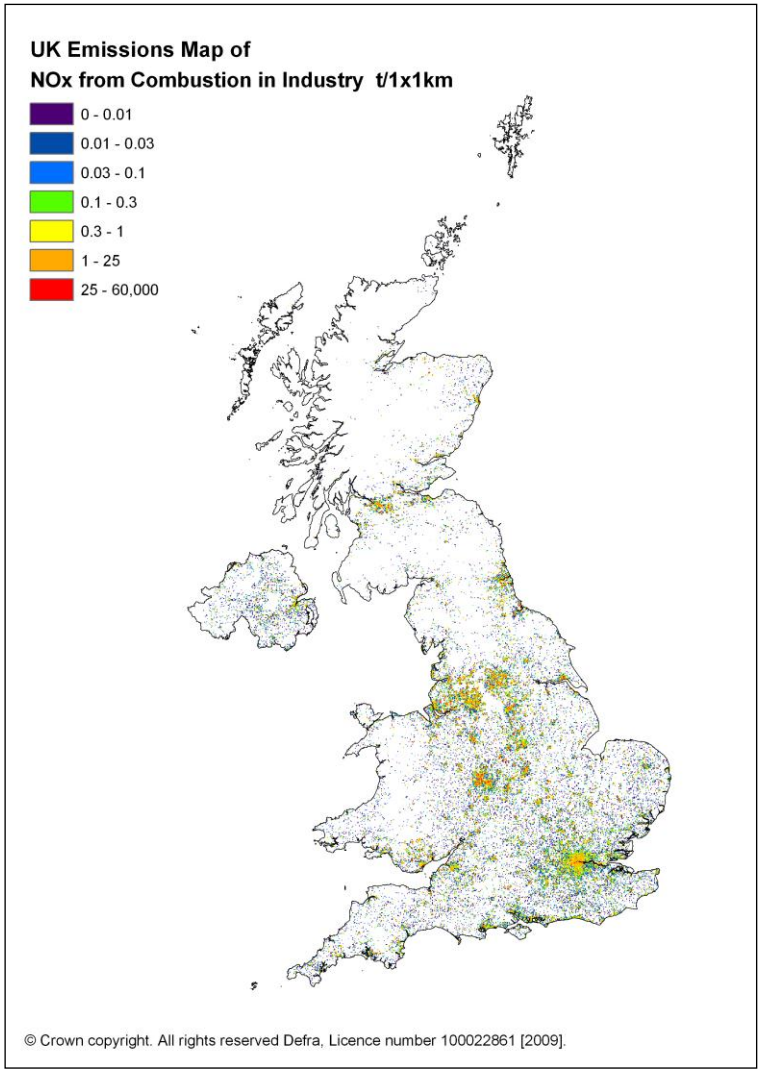
Annex 1 Mapped 2007 NO_X emissions for all UNECE level 1 SNAP sectors






UK Emissions Map of
NOx from Combustion in Industry t/1x1km
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 60,000
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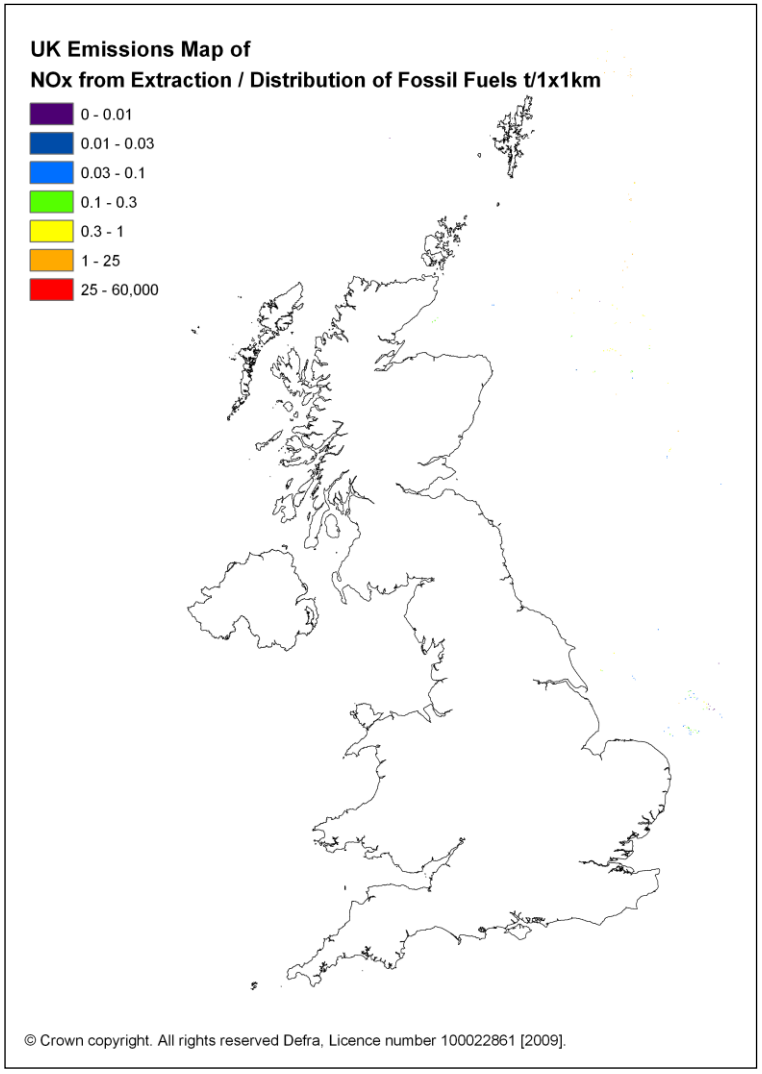
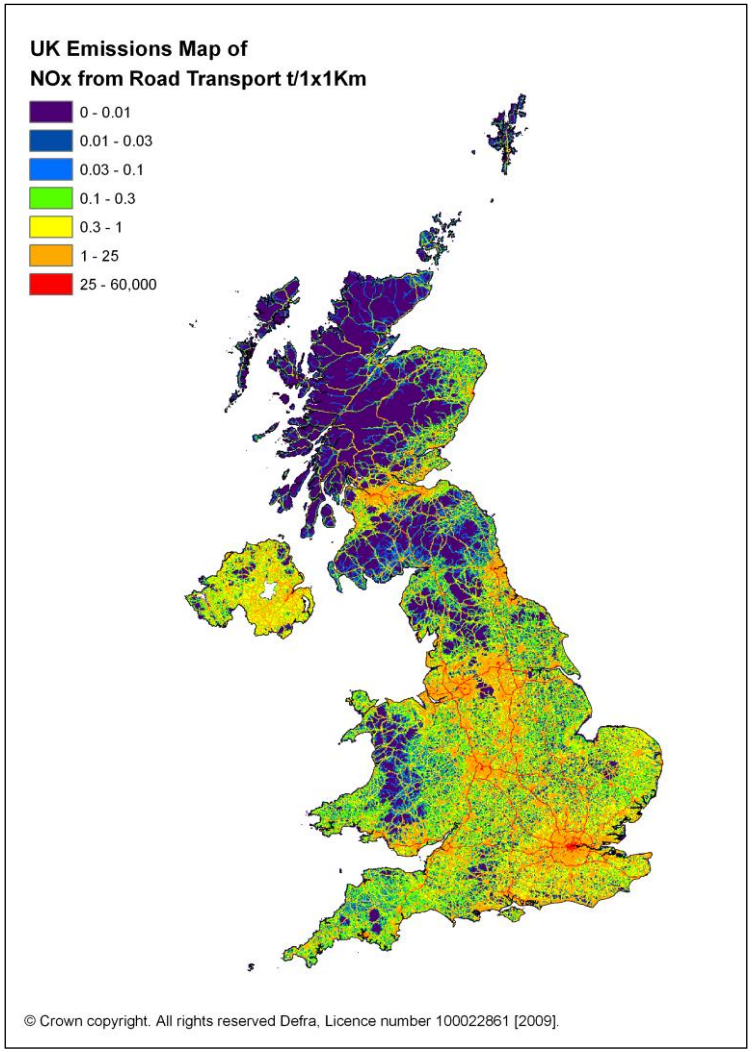
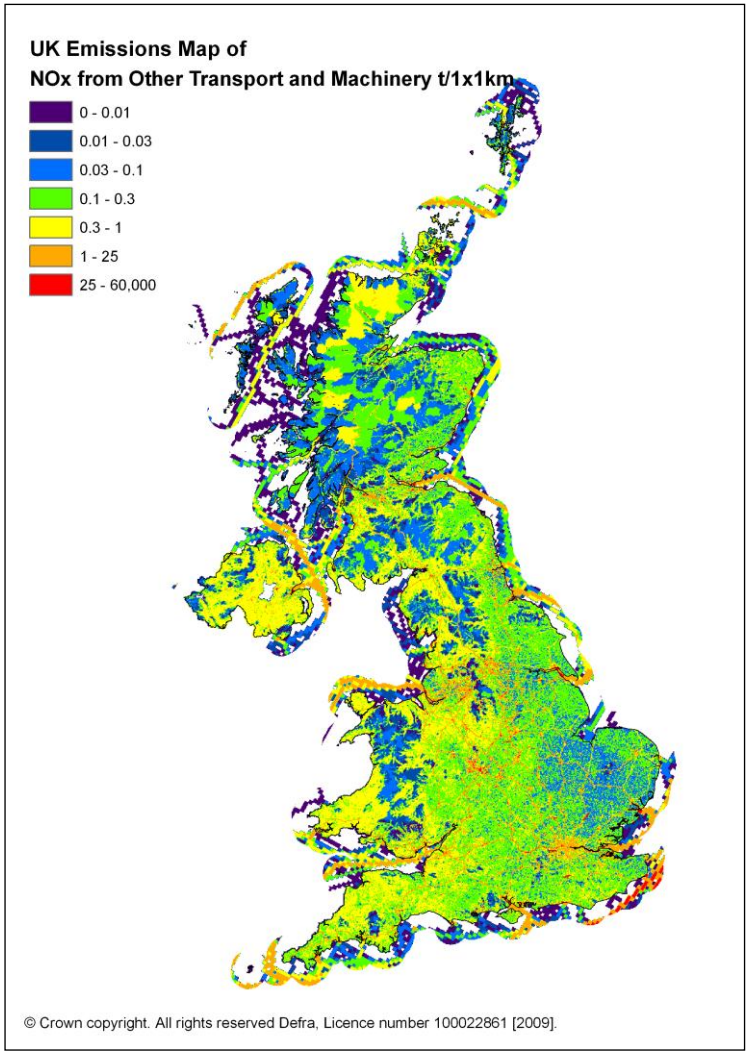

UK Emissions Map of
NOx from Extraction / Distribution of Fossil Fuels t/1x1km
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 60,000
© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009].


UK Emissions Map of
NOx from Road Transport t/1x1Km
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 60,000
© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009].


UK Emissions Map of
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0.3 - 1
1 - 25
25 - 60,000
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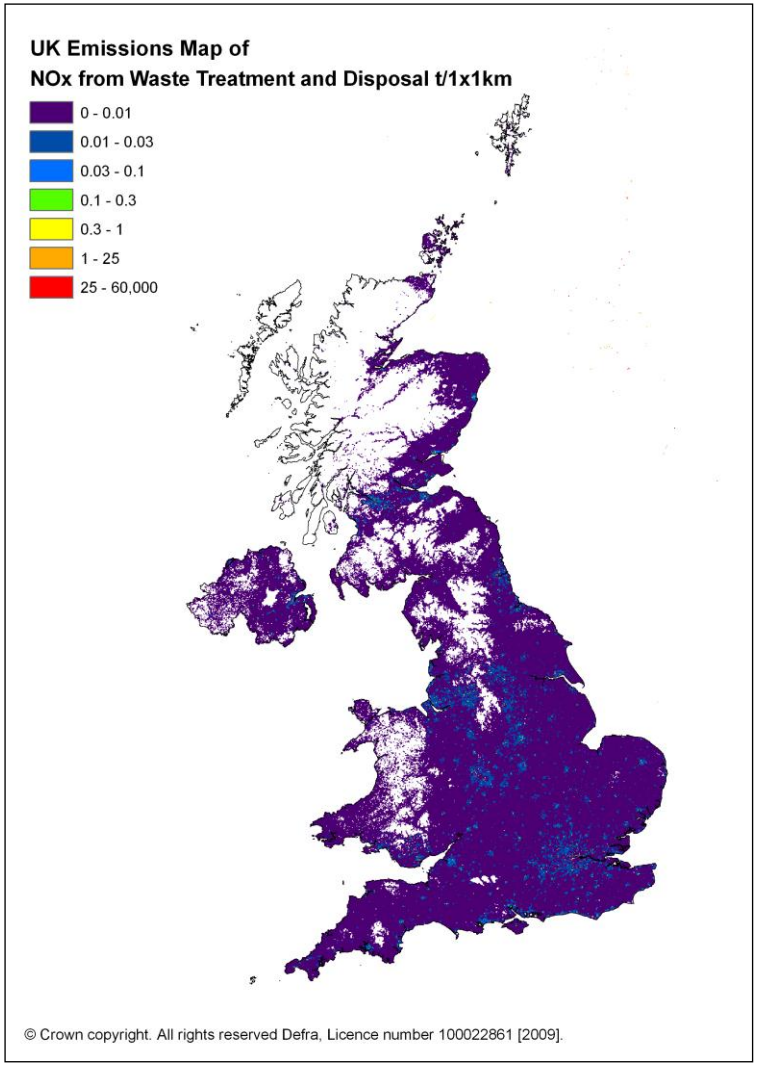
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0 - 0.01
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0.03 - 0.1
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1 - 25
25 - 60,000
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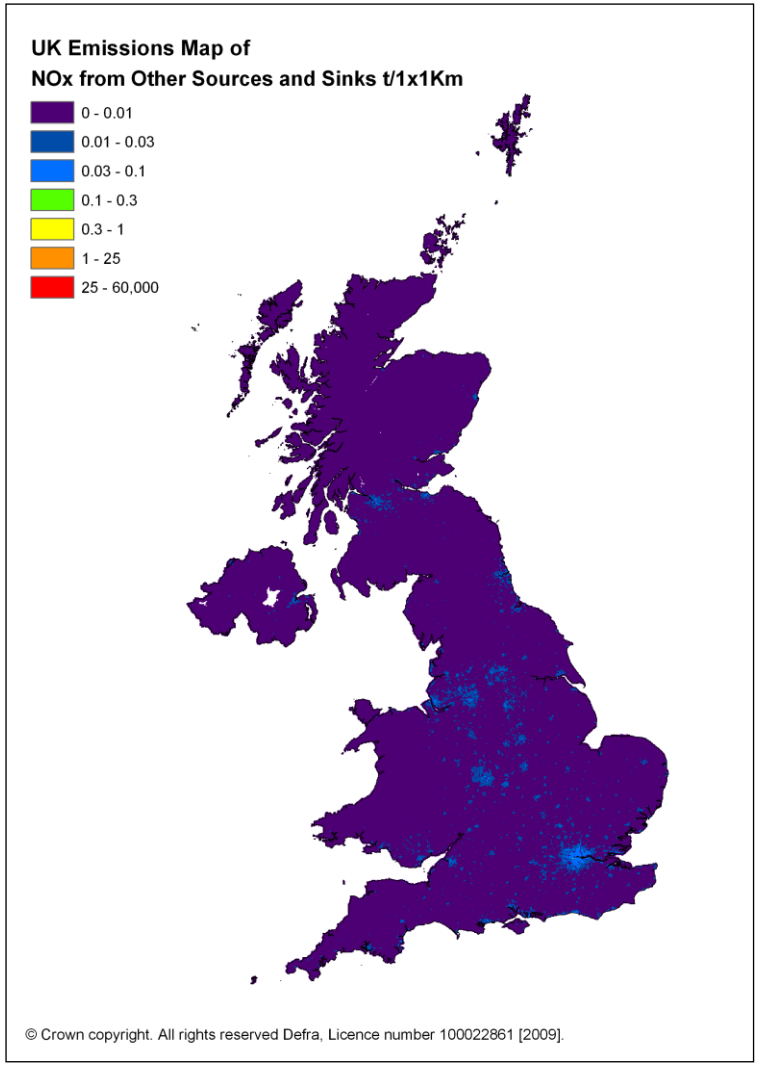
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NOx from Other Sources and Sinks t/1x1Km
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0.01 - 0.03
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0.1 - 0.3
0.3 - 1
1 - 25
25 - 60,000
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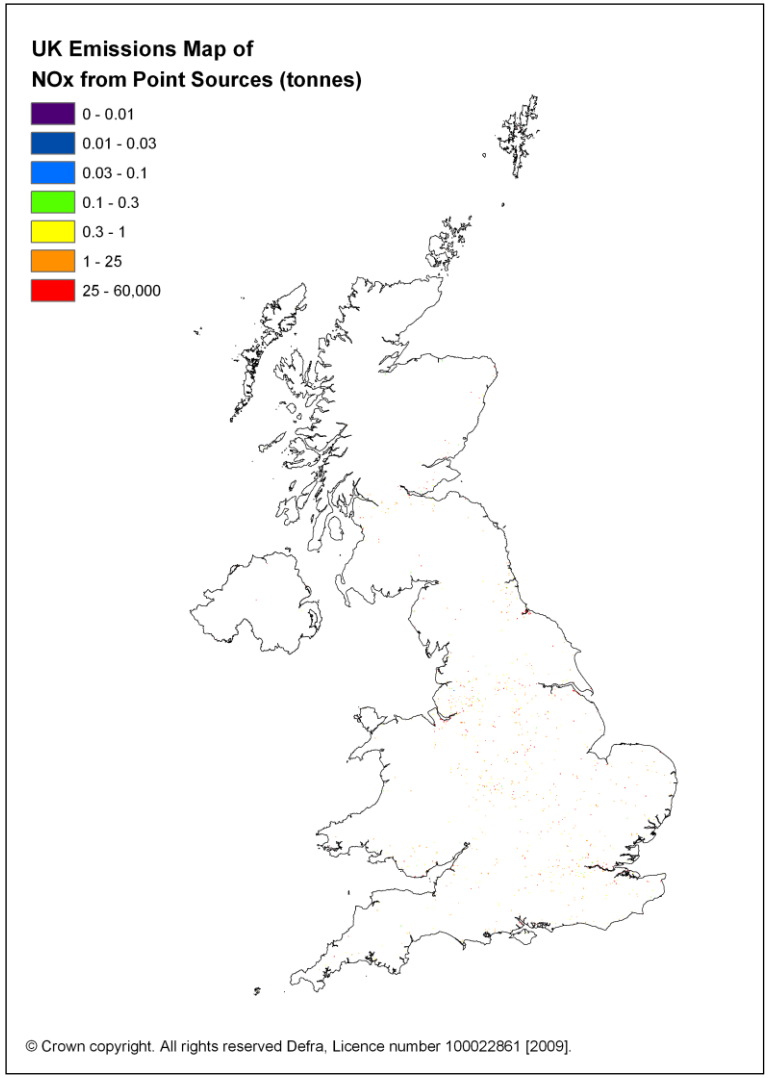
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0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 60,000
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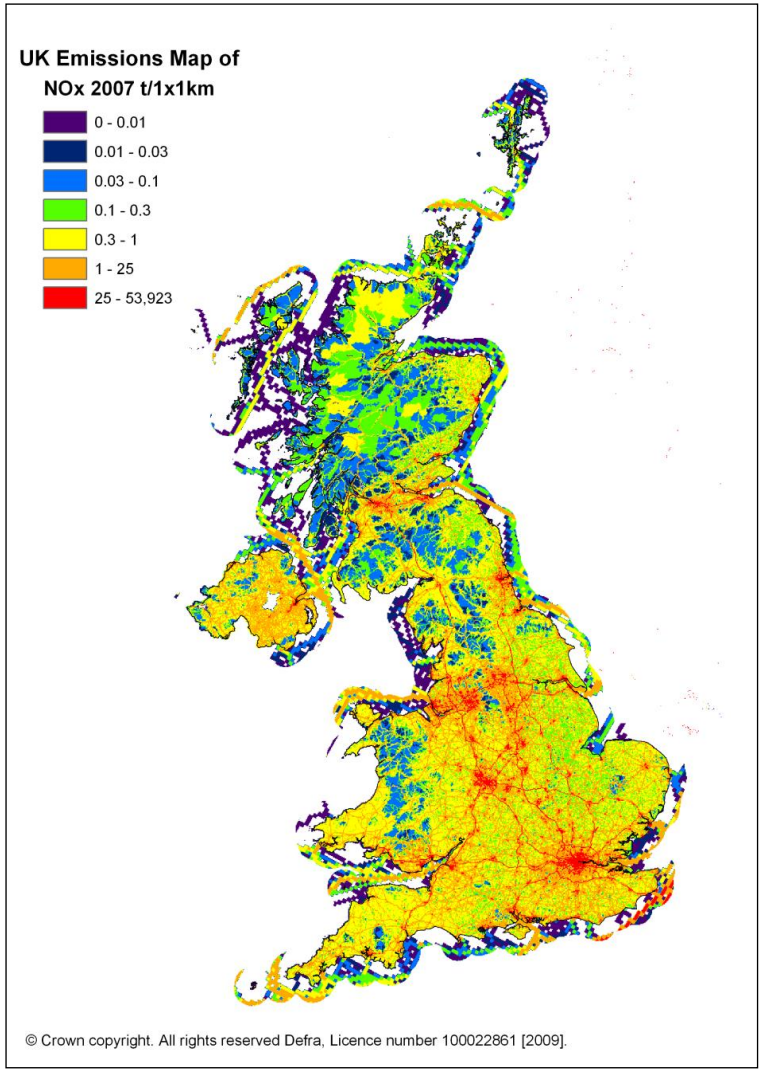
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NOx 2007 t/1x1km
0 - 0.01
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0.1 - 0.3
0.3 - 1
1 - 25
25 - 53,923
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