National
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Inventory

Report

NAEI UK Emission Mapping Methodology 2006

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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	N_2O
Benzene	Methane
Carbon monoxide	Arsenic
Carbon dioxide	Cadmium
Particulate matter (PM_{10} and $PM_{2.5}$)	Chromium
Nitrogen oxides (NO_x)	Copper
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 1km 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 www.naei.org.uk/data_warehouse.php and http://www.naei.org.uk/mapping/mapping_2006.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 BERR respectively since 2003 using data from the NAEI mapping work. As of March 2008, these datasets were reclassified 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 sources that are distributed 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. 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 priory at the end of the report.

Uncertainty analysis has 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 (SO2, lead and mercury) whereas pollutants with a large amount of emissions from very disparate sources such as agriculture and waste burning have lower quality ratings (eg. 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 rates 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 Green House Gas Inventory (GHGI) are compiled by AEA on behalf of the Department for Environment, Food and Rural Affairs (Defra) and the Devolved Administrations. This report describes the methodology used to compile spatially disaggregated 1x1 km 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 spatial disaggregated 1x1 km inventory is produced each year.

A detailed report describing the methods used for calculating national total 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 (Dore et al, 2008).

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	N_20
Benzene	Methane
Carbon monoxide	Arsenic
Carbon dioxide	Cadmium
Particulate matter (PM_{10} and $PM_{2.5}$)	Chromium
Nitrogen oxides (NO_x)	Copper
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 1x1 km 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 BERR respectively since 2003 using data from the NAEI mapping work. As of March 2008, these datasets were reclassified as National Statistics (King et al and Bush et al, 2008).

The mapped emissions are made freely available 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.

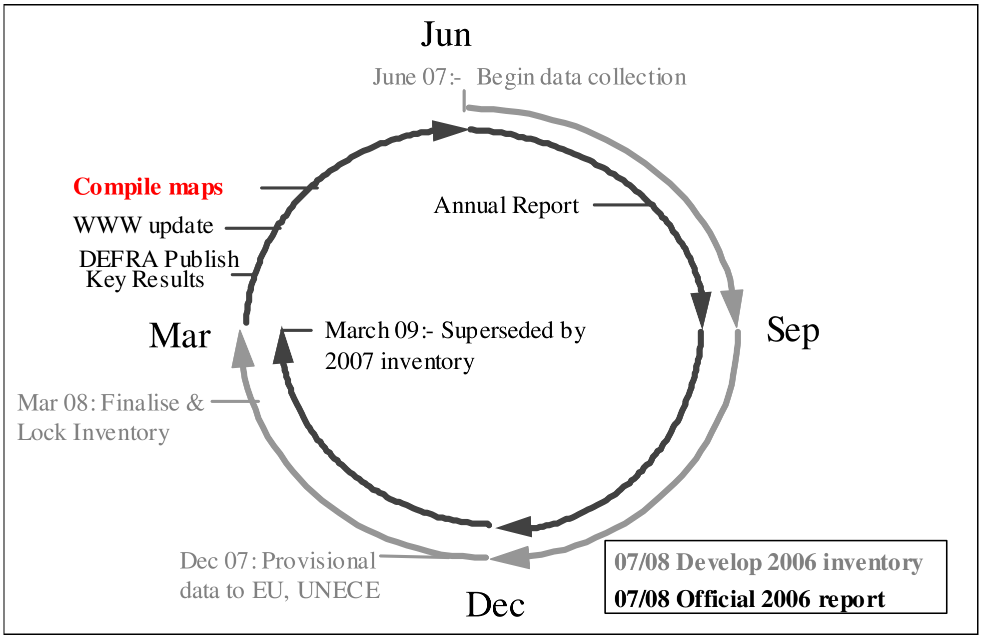
1.2 ANNUAL CYCLE

The NAEI is compiled on an annual basis. Each year the full time inventory series is recalculated to take account of improved data inputs and any advances in the 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 UN/ECE, UNFCCC and other international fora.

Emission maps have in the past only been routinely compiled for the latest year in the time series. Hence, there has in the past been no consistent set of historic emissions maps for the full inventory time series. 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 Local Authority fuel use estimates. These maps and datasets (King et al and Bush et al 2008) have been developed in support of national policy on energy consumption and carbon emissions. There is a commitment in future years also to back-calculate the emissions maps for these metric to take into account improvements in methodology so 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 accompany this report:

- **Mapping small industrial emissions**: A detailed description of the recent work to update the modelling of small industrial emissions.[1]
- **Point Source Fuel Use Estimates**: Explanation of the methods used to estimate fuel use and emissions at point sources[2]

[1] http://www.defra.gov.uk/environment/statistics/globatmos/download/regionalrpt/local-regionalco2-mappingsmallemissions.pdf

[2] http://www.defra.gov.uk/environment/statistics/globatmos/download/regionalrpt/local-regionalco2-fueluseestimates.pdf

2. National Inventory Compilation

The NAEI is divided into 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 compiled 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 on a number of sources representative of a particular source sector. Examples of emission factors are include the amount in tonnes of NO_x 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, 2007), Transport Statistics Great Britain (Dft 2007), and from other organisations such as trade associations and research institutes - for example the UK Petroleum Industries Association (UKPIA) provide data on the sulphur content of fuels, and the Institute of Grassland and Environmental Research (IGER) provide data on livestock numbers and fertilizer usage.

A detailed breakdown of the NAEI source sectors for NO_X in 2006 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 2006 by UNECE Source Sector

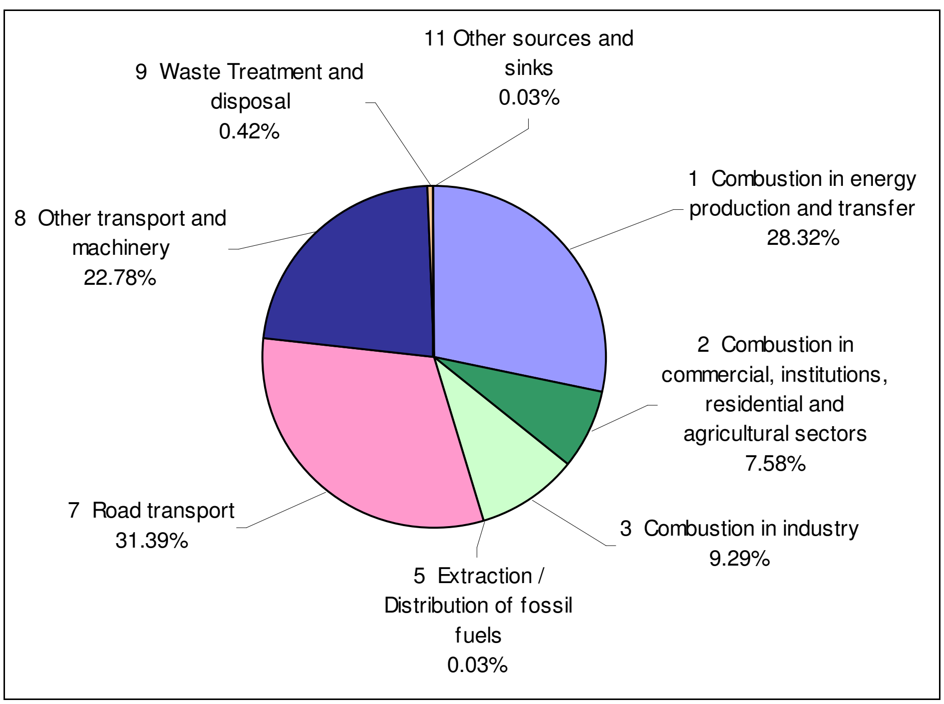


Table 2.1 Detailed source sector breakdown of UK emissions of NO_X in 2006

UNECE Source Sector	NAEI Detailed Source Sector	NO_X emission (tonnes)
1 Combustion in energy production and transfer	Coke production	5,360
	Collieries - combustion	197
	Landfill gas combustion	1,410
	Offshore oil and gas - own gas combustion	39,745
	Power stations	384,105
	Refineries - combustion	28,124
	Sewage gas combustion	253
	Gas separation plant - combustion	2,349
	Gas production	3,039
1 Combustion in energy production and transfer Total		**464,582**
2 Combustion in commercial, institutions, residential and agricultural sectors	Agriculture - stationary combustion	686
	Domestic combustion	103,725
	Miscellaneous industrial/commercial combustion	6,682
	Public sector combustion	13,158
	Railways - stationary combustion	32
2 Combustion in commercial, institutions, residential and agricultural sectors Total		**124,282**
3 Combustion in industry	Ammonia production - combustion	737
	Blast furnaces	804
	Cement - non-decarbonising	28,893
	Iron and steel - combustion plant	10,158
	Lime production - non decarbonising	3,962
	Other industrial combustion	81,127
	Sinter production	8,819
	Autogenerators	17,939
3 Combustion in industry Total		**152,440**
4 Production processes	Basic oxygen furnaces	134
	Chemical industry - nitric acid use	369
	Electric arc furnaces	545
	Nitric acid production	622
	Primary aluminium production - anode baking	84
	Primary aluminium production - general	279
	Solid smokeless fuel production	6
	Iron and steel - flaring	589
4 Production processes Total		**2,629**
5 Extraction / Distribution of fossil fuels	Offshore oil and gas - processes	408
	Offshore oil and gas - well testing	100
5 Extraction / Distribution of fossil fuels Total		**508**
7 Road transport	Road transport - cars - cold start	1,807
	Road transport - cars non catalyst - cold start	243
	Road transport - cars with catalysts - cold start	49,489
	Road transport - LGVs - cold start	1,776
	Road transport - LGVs non catalyst - cold start	11
	Road transport - LGVs with catalysts - cold start	708
	Road transport - major roads	348,179
	Road transport - minor roads	112,790
7 Road transport Total		**515,003**

UNECE Source Sector	NAEI Detailed Source Sector	NO_X emission (tonnes)
8 Other transport and machinery	Agriculture - mobile machinery	45,497
	Aircraft - military	5,449
	Aircraft - domestic take off and landing	1,697
	Aircraft - international take off and landing	7,178
	Aircraft - support vehicles	5,229
	House and garden machinery	921
	Industrial off-road mobile machinery	94,880
	Railways - freight	22,604
	Railways - intercity	9,111
	Railways - regional	6,114
	Shipping - coastal	122,130
	Shipping - naval	16,489
	Shipping - UK international	36,490
8 Other transport and machinery Total		**373,788**
9 Waste Treatment and disposal	Accidental fires - vehicles	25
	Crematoria	129
	Incineration - animal carcases	245
	Incineration - chemical waste	345
	Incineration - clinical waste	463
	Incineration - MSW	3,353
	Incineration - sewage sludge	50
	Offshore oil and gas - flaring	1,839
	Small-scale waste burning	396
9 Waste Treatment and disposal Total		**6,845**
11 Other sources and sinks	Accidental fires - dwellings	107
	Accidental fires - forests	113
	Accidental fires - other buildings	189
	Accidental fires - straw	46
	Accidental fires - vegetation	56
11 Other sources and sinks Total		511
Grand Total		**1,640,588**

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 (Dore et al, 2008).

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

Sector	Mapping method
1 Combustion in energy production and transfer	points offshore IDBR employment
2 Combustion in commercial, institutions, residential and agricultural sectors	points domestic fuel use IDBR employment IDBR agriculture IDBR commercial and public fuel use
3 Combustion in industry	points IDBR employment IDBR industry fuel use
4 Production processes	points IDBR employment shipping road transport population other
5 Extraction / Distribution of fossil fuels	points offshore other domestic fuel use population
6 Solvent use	population points IDBR employment landuse
7 Road transport	road transport
8 Other transport and machinery	agriculture airports other rail shipping IDBR employment population
9 Waste Treatment and disposal	landfill landuse offshore points IDBR employment
10 Agricultural, forests and landuse change	agriculture landuse
11 Other sources and sinks	landuse 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 includes data for 2002 and then from 2004 onwards. 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.

Since 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 and is far less useful;
- 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 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. Some sources are not required to report emissions if these are below a specified threshold 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 points 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 in nine cases, 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 10 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
13-butadiene	12%	42%	58%
Ammonia	2%	82%	18%
Arsenic	19%	42%	58%
Benzene	11%	74%	26%
Benzo[a]pyrene	6%	14%	86%
Cadmium	59%	47%	53%
Carbon Dioxide as Carbon	48%	98%	2%
Carbon Monoxide	24%	90%	10%
Chromium	54%	67%	33%
Copper	28%	53%	47%
Dioxins (PCDD/F)	25%	59%	41%
Hydrogen Chloride	74%	96%	4%
Lead	74%	34%	66%
Mercury	76%	71%	29%
Methane	1%	81%	19%
Nickel	29%	65%	35%
Nitrogen Oxides as NO2	32%	94%	6%
Nitrous Oxide	9%	94%	6%
Non Methane VOC	20%	28%	72%
PM10 (Particulate Matter < 10um)	20%	53%	47%
PM2.5 (Particulate Matter < 2.5um)	18%	0%	100%
Selenium	65%	43%	57%
Sulphur Dioxide	78%	97%	3%
Vanadium	3%	70%	30%
Zinc	34%	29%	71%

Further information on calculation of point source emissions estimates can be found in documentation provided in the **Point Source Fuel Use estimates**[3] accompanying this report.

Possible future improvements:
The current 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

[3] http://www.defra.gov.uk/environment/statistics/globatmos/download/regionalrpt/local-regionalco2-fueluseestimates.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, and ISR, and national energy statistics given in DUKES present serious challenges with regard to reconciliation. It is the mapping teams 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.

Local inventory data are potentially useful 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 e.g. on the internet but must instead be obtained through negotiation with the data holders.
2. Once obtained, considerable resources would be 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 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. The remaining emission is then treated as an 'area source' and distributed across the UK using modelled high resolution (1km) 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**[4] accompanying this report. 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 was calculated. These intensities could then be applied to employment statistics aggregated to a 1x1 km grid for the UK to make maps of fuel use.

In the case of the industrial sectors this energy intensity calculation was done at the level of 4 figure SIC codes (over 250 separate industry types) to retain the level of detail required for the mapping; aggregation of SIC codes would have resulted in a reduction in the quality of the final distribution. 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

The IDBR employment data at local unit level were aggregated to 4 figure SIC codes at 1x1 km resolution using grid references provided in the database. The employment totals for each sector were then multiplied by the appropriate fuel intensity values to make maps of fuel use across the UK. It has been assumed that fuel intensity for each sector is uniform across the sector. Although this latter

[4] http://www.defra.gov.uk/environment/statistics/globatmos/download/regionalrpt/local-regionalco2-mappingsmallemissions.pdf

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 a 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.

3.2.1 Summary of improvements for 2006

The modelling described above is an update of previous work for the NAEI maps. The key elements of the improvement are:

- Updated data from the IDBR data reflecting current levels of employment in all sectors;
- Updated data on fuel consumption by sector from BERR;
- Much better quality measured gas consumption data from BERR, both at 1km resolution and at the MSOA and Scottish Intermediate Geography level, and LA level in Northern Ireland;
- Revised assumptions regarding solid and liquid fuel consumption including adjustments for oil use in London based on the LAEI.

3.3 ROAD TRANSPORT

Hot exhaust emissions and the related fuel consumption 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) from the DVLA's national licensing data and are based on the assumption that the fleet mix is the same everywhere on the UK road network. There are currently no regional variations in either the age of the fleet or the fuel mix.

3.3.1 Emission factors and fuel consumption factors

Fuel consumption factors, emission factors and traffic data for six classes of vehicles are used to estimate national fuel consumption and emissions 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 the pollutants nitrogen oxides, particulate matter, carbon monoxide and hydrocarbons but not to CO_2 or fuel consumption. Nevertheless, the Euro standards are a convenient way to represent the stages of improvement in vehicle or engine design that have led to improvements in fuel economy and are related to the age and composition profile of the fleet. For example, the proportion of pre-Euro 1, 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 depends on many parameters including frequency and rates of acceleration / deceleration, how aggressively the vehicle is driven, how much load is applied to the vehicles engine, its state of maintenance, tyre inflation and use of air conditioning.

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. For some of the more modern classes of vehicles and technologies that have yet to be tested, however, AEA has ;used its expert judgement to populate missing information. 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 hot exhaust road traffic emissions is derived from the Ordnance Survey Meridian dataset (see **Figure 3.1**), supplied to Defra under the pan-Government licensing agreement[5]. 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). This provides all major roads and most minor roads (but not all unclassified roads).

Traffic flow data for major roads (A roads and motorways) are available on a census count point basis for both GB (DfT, 2007) and Northern Ireland (Roads Service, 2007). However, the coverage in GB is considerably more dense than that for Northern Ireland. The traffic flow data includes counts of each type of vehicle as an annual average daily flow. These have been aggregated up to annual flows by 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 assigned to it. Calculations of emissions and fuel use have been done at the 1km resolution level by splitting each road link using an intersection with a 1km grid.

The detailed traffic data described above are not available for minor roads on a link by link basis. Instead regional average flows by vehicle type have been applied to each type of minor road – B and C roads or unclassified roads. These data were obtained from Department for Transport (DfT, 2007). For Northern Ireland vehicle-specific minor road flows have been calculated from data in the Traffic and Travel Information 2003 report which provides average flows for all vehicle types by minor roads and also average vehicle splits by the same road types.

It has been assumed that there are no regional variations in either the age of the fleet or the fuel mix. The fuel splits for passenger cars and LGVs in 2006 are provided in **Table 3.4**. 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.

[5] Defra, Licence number 100018880, 2008

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

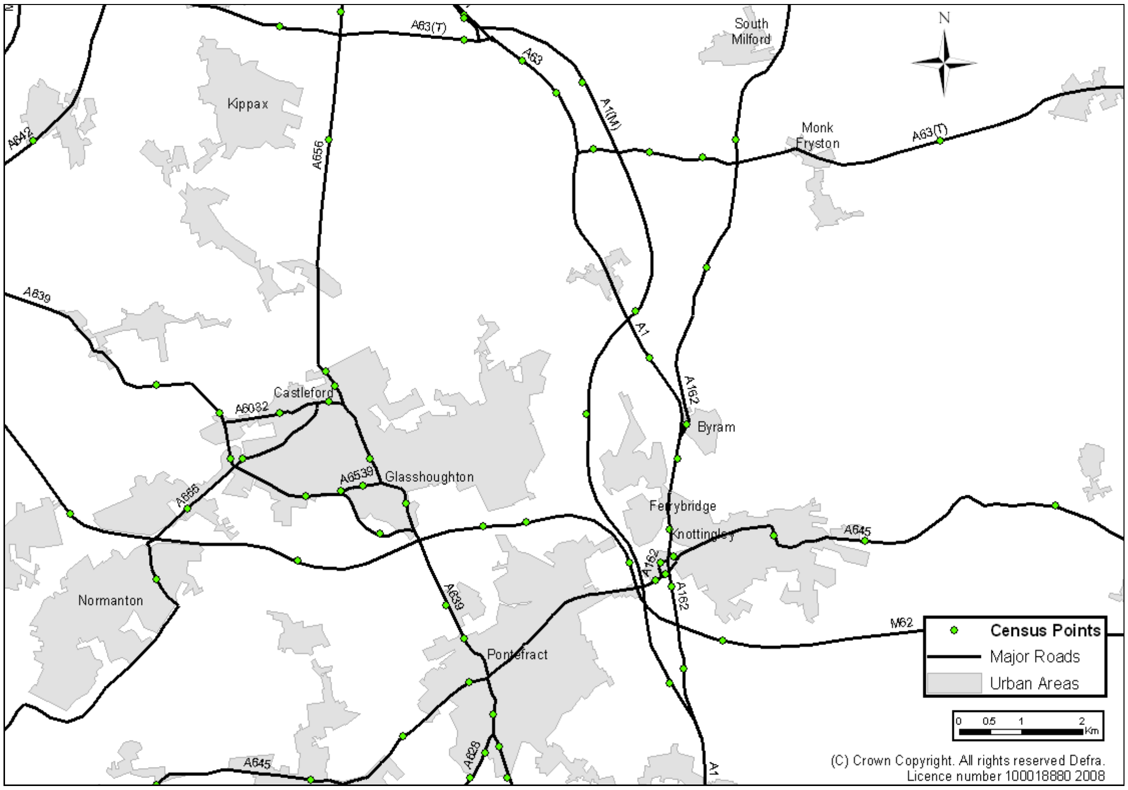


Table 3.4 UK fuel split by vehicle type on minor roads 2006

Vehicle	Fuel type	% of fleet
Cars	Diesel	19.3
Cars	Petrol	80.7
LGVs	Diesel	90.6
LGVs	Petrol	9.4

Each major road link has been allocated to a geographical area type using the DfT definitions of urban area types shown in **Table 3.5** 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 based on information provided by DfT which is described in the Greenhouse Gas Inventory report for 2006 (Choudrie et al, 2008).

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. VKM data are then multiplied by fuel consumption or emission factors taking into account the 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 aggregated to 1km resolution across the UK.

For 2006, it was assumed that the spatial pattern of UK vehicle kilometres (VKMs) on minor roads was the same as that modelled for 2003. Total 2006 VKM totals for GB (DfT 2007) and Northern Ireland (Roads Service, 2007) were distributed across this pattern to generate revised minor road km maps for 2006.

Table 3.5 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

Although, AEA recognises that the use of an average speed approach to estimating emissions greatly simplifies real world conditions, previous work has shown that for national scale modelling of vehicle emissions it is sufficient to calculate emissions from emission factors in g/km related to the average speed of the vehicle in the drive cycle (Zachariadis and Samaras, 1997)..

3.3.3 Improvements to fuel consumption estimates for the 2006 inventory

Some of the fuel consumption factors used in the NAEI road transport emissions estimates have been revised in the 2006 inventory. These revisions were based on new data and better understanding of the effects of technology. Some changes were made to those factors that had previously been estimated after discussions with engineers at DfT. Another important revision was made to the fuel consumption rates used for HGVs. More direct use was made of statistics published by DfT from an annual survey of hauliers on the average miles per gallon of lorries of different sizes. These data deliver an improvement in the representivity of average HGV fuel consumption rates and reflect the types of conditions actually experienced on UK roads, including for example the typical load factor (a measure of how fully loaded a vehicle is by weight). The data published each year by DfT give a complete time-series of fuel efficiency of lorries and were used in conjunction with existing fuel consumption-speed relationships to estimate fuel consumption by different types of lorries on different types of roads[6].

In previous releases of the NAEI, it has always been the case that NAEI UK fuel consumption estimates exceeded the national fuel sales figures quoted in DUKES for a given year. In the 2005 version of the inventory, the calculated consumption of diesel exceeded the DUKES figure for 2005 by 17% and for petrol by 12%. Using the new fuel consumption factors in this year's inventory has considerably reduced this discrepancy (compare blue highlighted figures in **Table 3.6** and **Table 3.7**) so that now the calculated total for diesel consumption in 2005 is 3% less than the DUKES figure and the calculated total for petrol consumption is 2% more than the DUKES figure; the comparisons between model and DUKES figures are similar for 2006.

The changes made to the fuel consumption factors have also affected the distribution of fuel used by different vehicle types and **Table 3.6** shows the breakdown in the modelled fuel consumption values by vehicle type for 2005 based on the 2005 version of the inventory (2005 GHGI) and the figures for 2005 and 2006 from this year's version of the inventory (2006 GHGI)[7]. Comparing fuel consumption estimates with a 2005 and 2006 base inventory methodology provides an indication of the affect of methodological changes, whereas comparing fuel consumption estimates for 2005 and 2006 using the 2006 base inventory provides an indication of 'actual' changes in fuel consumption between these years due to changes in traffic and fuel efficiencies of vehicles.

[6] Subsequent to the calculation of HGV fuel consumption estimates DfT revised their estimates based on concerns with their published data (DfT pers comm., August 2008).
[7] These figures are the 'raw' modelled estimates before normalising to the DUKES totals. International guidelines for reporting CO_2 emissions state that emissions must be based on the amount of fuel purchased in each country. To satisfy this requirement, the GHGI therefore applies a normalisation procedure to the calculated fuel consumption (and hence CO_2 emissions) to ensure they add up to the figures for petrol and diesel consumption reported in DUKES.

Table 3.6 Fuel consumption calculated in the 2005 and 2006 versions of the GHGI from traffic data and fuel consumption factors for individual types of vehicles.

Mt fuel		2005 GHGI	2006 GHGI	
		2005	2005	2006
Cars	Petrol	19.97	18.07	17.70
	DERV	4.89	4.36	4.68
	All Cars	24.86	22.42	22.38
LGV	Petrol	0.50	0.45	0.45
	DERV	5.78	5.15	5.23
	All LGV	6.27	5.59	5.68
HGV	Artic	7.16	4.12	4.19
HGV	Rigid	3.54	3.93	3.97
ALL HGV		10.71	8.05	8.16
Buses		1.35	1.35	1.38
Motorcycles		0.16	0.16	0.15
All DERV		22.72	18.90	19.46
All Petrol		20.62	18.68	18.29
All Vehicles		**43.34**	**37.57**	**37.76**

N.B No normalisation applied to results to match with data in DUKES.

Table 3.7 Fuel consumption statistics derived from DUKES 2005 and 2006

Mt Fuel	DUKES 2005	DUKES 2006	
	2005	2005	2006
All DERV	19.44	19.43	20.14
All Petrol	18.47	18.47	17.88

N.B a small fraction of the reported fuel use for road transport is assumed to be off road machinery and vehicles to these numbers are not exactly the same as those reported in DUKES.

Previous work (Bush et al, 2007) has explained observed differences in the GHGI calculated fuel and DUKES by the prevalence of fuel tourism, especially amongst hauliers, purchasing diesel on the European continent. However, model uncertainty must be considered a contributing factor. The fact that the calculated fuel consumption is now so much closer to the DUKES figures is encouraging, and the trend seems to be consistent over a long time series. The fuel tourism factor is therefore likely to be smaller than previously thought.

3.3.4 Improvements to road transport mapping for the 2006 inventory

Each year we receive a new database of traffic counts from DfT and DoENI and these are used to update the allocation of count points to the road network. In addition, checks are performed on this allocation to ensure that as far as possible the most up to date data are used at each location.

Significant effort has been invested in the 2006 maps to check the allocation and to remove old / redundant count points. It is not possible within time and budget constraints to undertake a comprehensive check of all data but roads with new count points and the highest flows were prioritised.

3.3.5 Other road transport related emissions

Cold start emissions are those emissions from vehicles that are produced before the engine has reached normal operating temperature. Estimates for Great Britain of the distance travelled by vehicles whilst producing cold start emissions 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 emissions are assumed to have similar characteristics in Northern Ireland. This data enables estimates of the associated emissions to be determined at the UK level using the COPERT II methodology (COPERT II 1997).

The trip types used in the 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.

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 1km resolution map of estimated total vehicle kilometres on major and minor roads.

Possible future improvements to road transport emissions distributions:

- Update minor roads datasets and assumptions
- Update to cold start emission distributions of using 2001 Census data and 2005 employment distributions.
- Incorporation of appropriate information on regional/national vehicle fleet composition and speed assumptions from local inventories..

3.4 DOMESTIC FUEL USE

The NAEI's approach to modelling domestic fuel use for the 2006 remains unchanged from the 2005 release (Bush et al, 2007). 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 2008) and updates to the core datasets underlying the modelling approach for Northern Ireland undertaken for the 2002 NAEI and under other Defra studies (Pye and Vincent, 2003).

A summary of the methodology is provided below.

3.4.1 Domestic fuel mapping in Great Britain.

The improved method for mapping domestic fuel use within Great Britain makes use of newly available data from DTI and BRE to 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 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 1km square 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 from DTI provides a huge improvement in understanding 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 1km square 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 was assumed to have the same distribution as coal

The new maps represent a significant improvement on the previous domestic maps as result of the new data sources and new modelling techniques. Initial validation of the results (King et al 2006) shows a relatively good correlation between the model results and the BRE regional data. There are still some quite large differences but given the uncertainties in this work this is not surprising. 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 DTI 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 this 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 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 timeframe covered by the 2005. 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 in the NAEI source called Domestic house and garden machinery 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 1km resolution grid. In some rural areas where the census units were larger than 1km squares 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:

- Updates to the existing methods which operate on 2003/4 base data

3.5 AGRICULTURE

Emissions of PM_{10} and $PM_{2.5}$ from agricultural livestock and poultry sources are distributed using agricultural census data. Very detailed, farm level data was obtained from Defra for England (Defra 2002a). This was used to generate 1km resolution datasets for different livestock types and for 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 cow and sheep livestaock. All non-urban land was used to distribute pigs and poultry numbers. The resulting distributions for England, Scotland Wales and Northern Ireland were combined, 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 have been mapped at a 5km 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 and fertilizer 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 have also been calculated by CEH as part of the same subcontract (Dragosits and Sutton 2008, Dragosits et al 2008).

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

Incineration of animal carcases are 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:

- Increase in resolution of the CEH maps to 1km to integrate better with the NAEI maps.
- Update of livestock and poultry distributions used for particulate matter mapping.

3.6 RAIL

The 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 the 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. 2005 fuel use estimates have been distributed over a digital representation of the Northern Ireland rail network derived from Ordnance Survey Northern Ireland raster datasets to provide an accurate representation of the location of fuel used by rail transport in Northern Ireland

Possible future improvements:

- Updated GB train movements and the inclusion of fuel consumption estimates would also improve this distribution.

3.7 SHIPPING

UK shipping totals are calculated at a national level. These estimates include:

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

The shipping emissions are distributed over the UK as follows. Emissions are assigned to port areas and coastal zones according to ship arrival data provided by DfT (2004). The port area emissions are mapped on the approximate port locations. The cruise emissions are assigned to the area of the coastline nearest to the relevant port and within 12km of the shore, based on an inverse distance weighting. This gives a rough approximation of where shipping is likely to be.

Possible future improvements:

- Incorporation of appropriate and relevant outputs of the review of shipping emissions (ENTEC, 2008)

3.8 AIRCRAFT

The NAEI includes national total aircraft emissions occurring below 1000m from the ground during take off and landing. These are calculated from the number of aircraft movements at UK airports on an individual airport basis according to the mix of aircraft types at each airport. Aircraft cruising emissions are also included in the NAEI but not in the maps because these cannot be assigned to grid squares on the ground.

Take off and landing emissions are allocated to the individual airports on the basis of the modelled emissions at each airport. At each airport the emissions are then distributed either across a pattern of take off and landing emissions routes which vary by pollutant (these patterns were modelled for the larger airports by London Research Centre for the NAEI), or for the smaller airports simply across the land area covered by the airport.

UK total emission estimates from airport support vehicles are distributed over the physical airport area based on aircraft arrival statistics for each airport.

Possible future improvements:

- Update of the take off and landing patterns for the large airports and the addition similar patterns for other airports.

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 3.8**. 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 3.8 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 were 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 were 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 5km 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, 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 installation reported emissions 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.

3.12 OTHER SECTORS

Natural emissions are distributed using 1km resolution land cover maps derived from the Land Cover Map 2000 data from the Centre for Ecology and Hydrology (CEH). For example emissions from forests comprise NMVOC emissions from natural processes. These are mapped using the CEH woodlands land cover types (broad leaved/mixed woodland and Coniferous woodland classes). The NAEI also includes emissions from land use change resulting from deforestation resulting in emissions of NO_x and CO_2. These emissions are mapped using the same woodlands map as above.

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 1km grid squares and PM_{10} emissions distributed on this basis.

4. Emission maps and data products

4.1 COMPILATION OF MAPS

The 1km 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 2006 in tonnes per $1km^2$

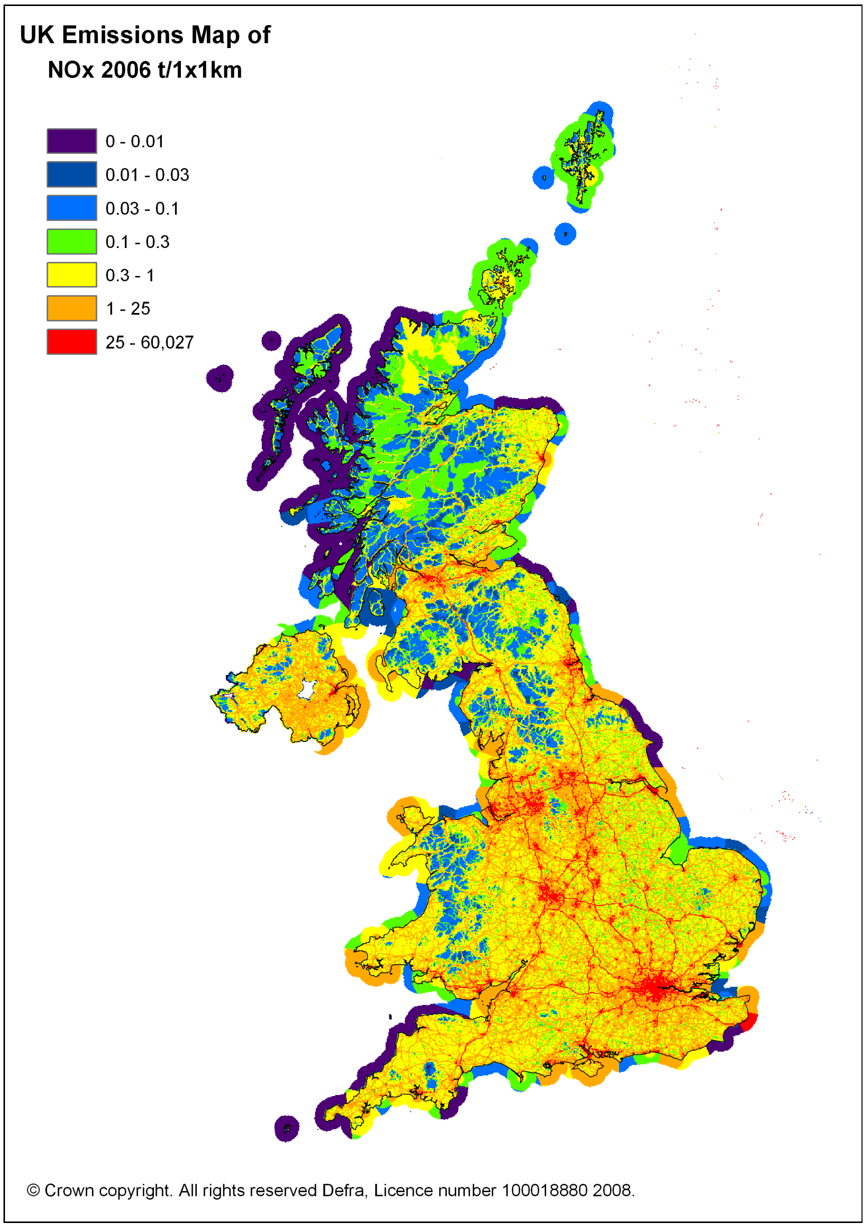
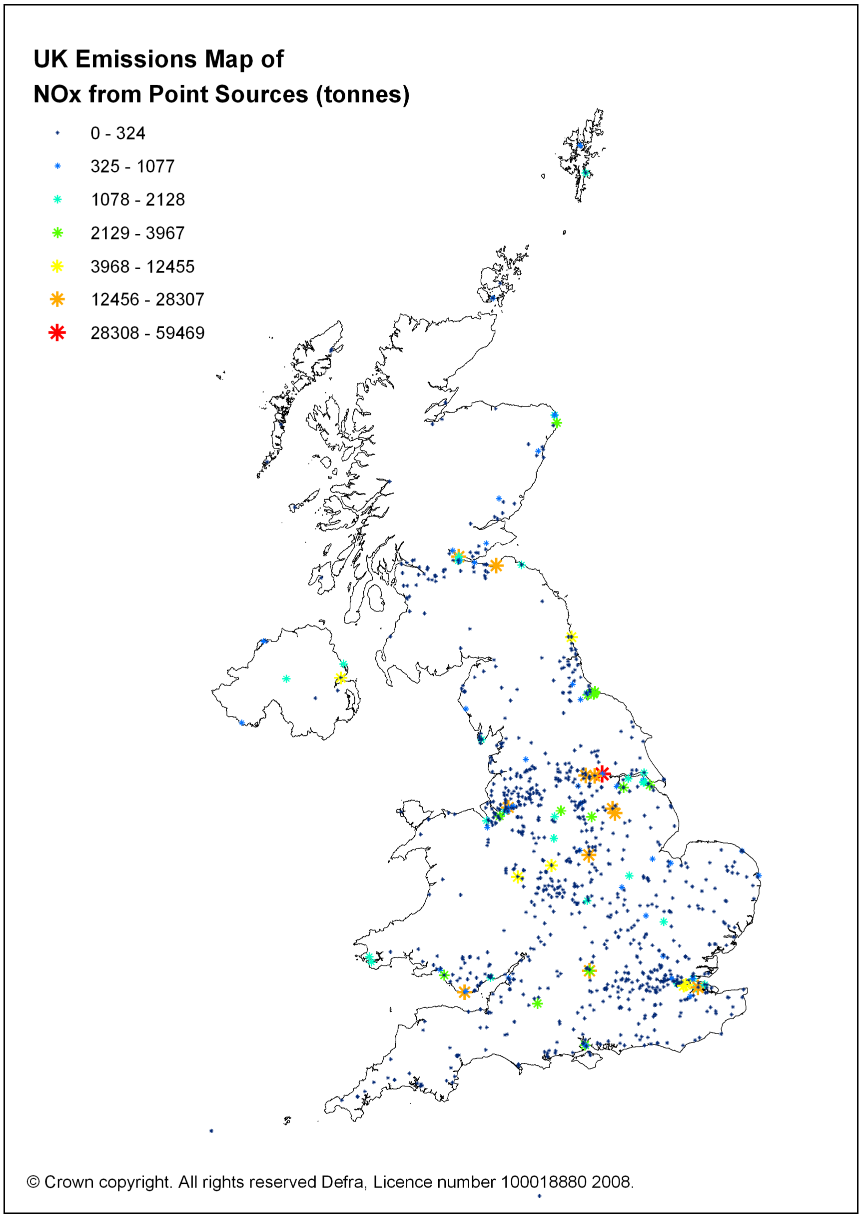


Figure 4.2 NO_X emissions at point sources in 2006 in tonnes



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

4.2 DATA PRODUCTS

Local authority data:

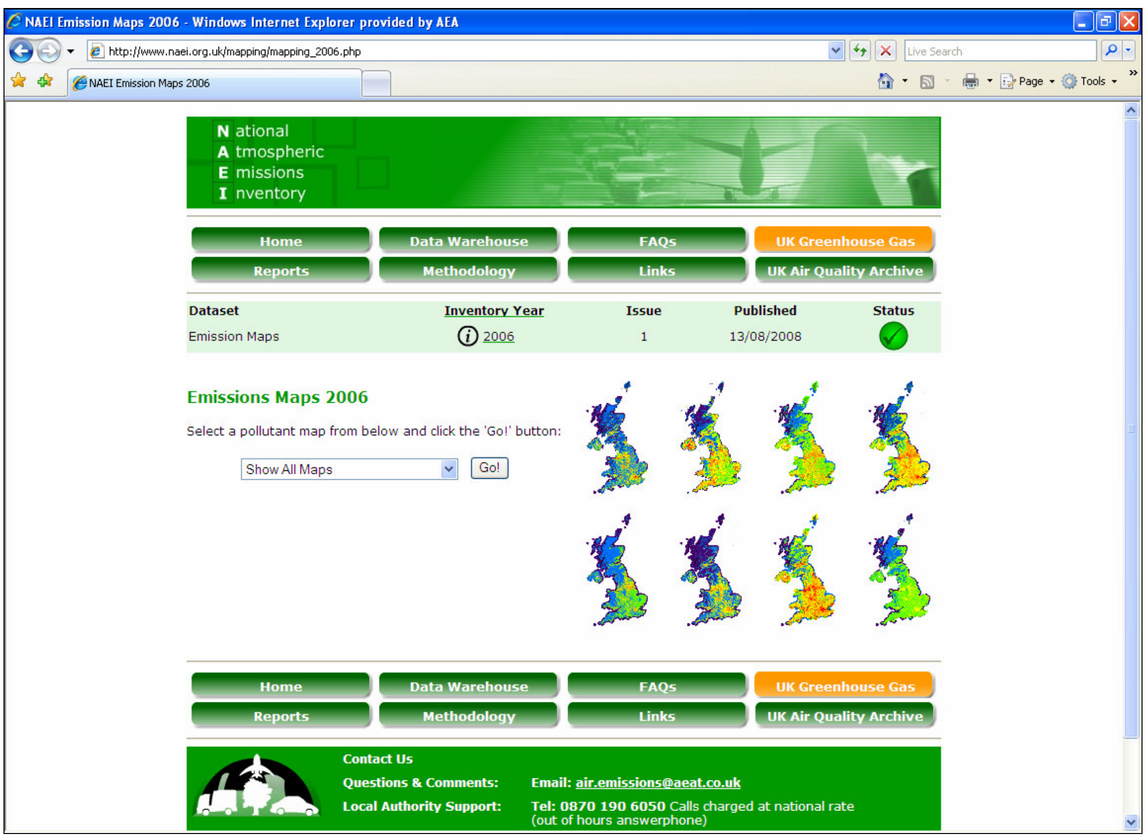
- The full spatial inventory is available on the NAEI website at http://www.naei.org.uk/datawarehouse
  The 1km resolution inventory is divided into separate files for each pollutant for each local authority. It is intended that these files are used to aid local authorities in developing their own emission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

Public access to the mapped emissions:

- Website users can also find emissions data for individual postcode locations. This is available at http://www.naei.org.uk/mapping/mapping_2006.php.

Full UK maps:

- The full UK area emissions maps are also available individually by pollutant at http://www.naei.org.uk/mapping/mapping_2006.php (in ASCII (.txt) 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, mapping using point source data is be expected to give the most accurate results since it relies on a large quantity of generally reliable data. Area source emissions are mapped using a variety of surrogate data types of varying data quality. In some cases the surrogate statistics may be poorly suited to this task, but in all cases the highest quality datasets are sought within the budgetary constraints of the mapping 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 (2006)

Pollutant	Points sources (%)	Area sources (%)
1,3 - butadiene	12%	88%
Benzene	6%	94%
Benzo[a]pyrene	11%	89%
CO	24%	76%
CO_2	48%	52%
Dioxins	25%	75%
HCl	74%	26%
Lead	74%	26%
Mercury	76%	24%
NH_3	2%	98%
NMVOC	20%	80%
NO_x	32%	68%
PM10	20%	80%
SO_2	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 good appropriate statistics and those which use less appropriate surrogate ones.

A more sophisticated approach therefore is to use 'data quality ratings' of between 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 thus:

$$\text{Emission}_A \times \text{Rating}_A + \text{Emission}_B \times \text{Rating}_B \text{ etc./ Emission}_{Total}$$

Where:

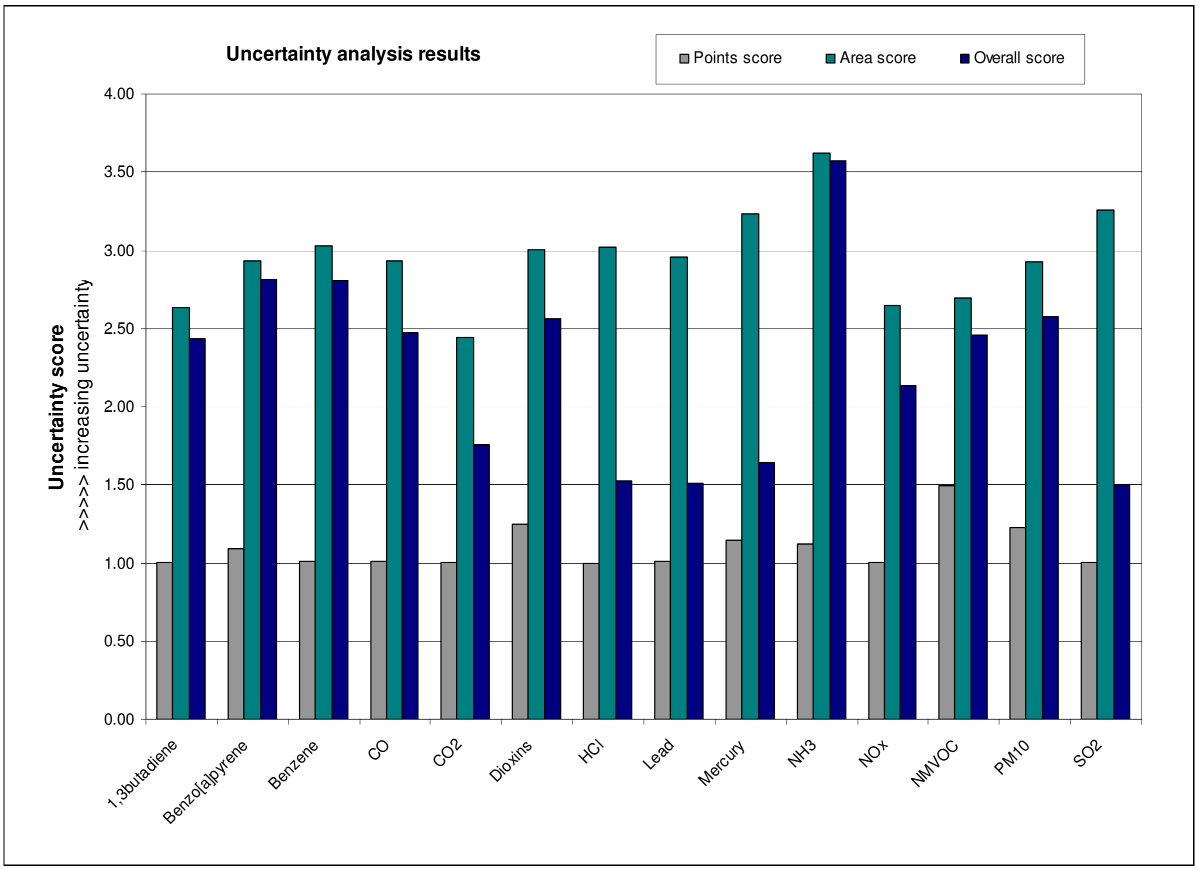
Emission_A, Emission_B etc.	are the emissions of the pollutants from each of the sources in the inventory
Rating_A, Rating_B	are the data quality ratings applied to the mapping of emissions from each of the sources in the inventory

Some general rules of thumb have been followed when choosing 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. Mapping of area sources is by use of various 'grids' which are spatially resolved data such as traffic flows, population or employee numbers. Quality ratings for each set of area/line sources are allocated following 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 applied to each of the above and the mean is used as the data quality rating for that set of area source data. 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 1km 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 2006 NAEI



These data quality ratings show a broadly similar pattern to the assessment of the proportions of point and area source data in **Table 5.1**, although there are some differences, for example the map for dioxins is considered of lower quality using the detailed assessment 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 the spatial distribution of atmospheric emissions are a key input to any air quality assessment. The reliability of emissions maps should be verified if they are to be used to model potential exceedances of air quality objectives. 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.

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

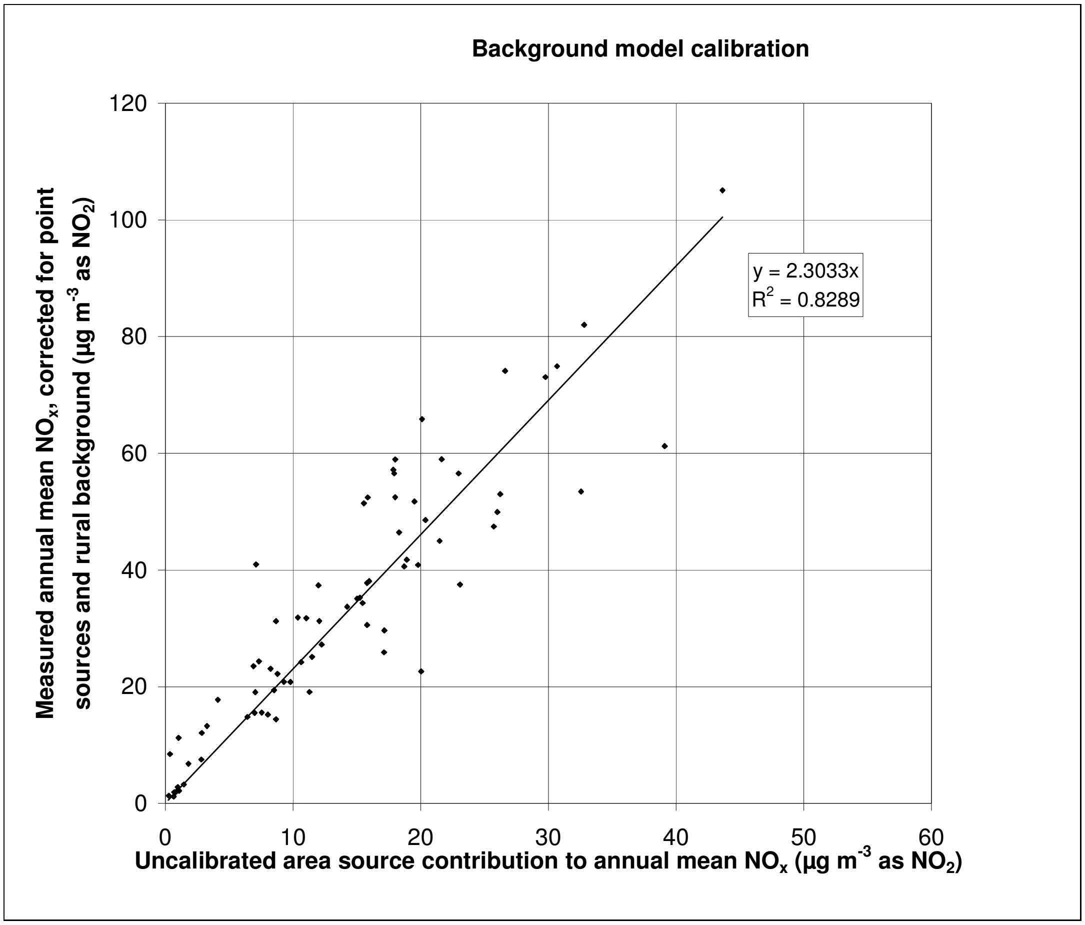
- A rural contribution: from relatively distant major point and area sources such as power stations or large conurbations. Measurements from monitoring sites well away from local sources, from rural sites within the UK Acid Deposition Secondary Network, for example, provide good indications of the spatial 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 ambient concentrations of air pollutants. National scale modelling activities have used The PCM model to calculate the ambient concentrations resulting from local emissions to ambient concentrations (Kent et al, 2007). A dispersion kernel is applied to the emissions from an area of 33 km x 33 km in order to calculate the uncalibrated contribution from area sources to the ambient concentration at a 1 km x 1km grid square receptor. Ambient measurements are then used to calibrate the 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 the emissions mapped.

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 combustion, secondary and mechanically generated coarse particles.

Figure 5.2. Calibration of area source NO_x model (µg m^{-3}, as NO_2) for 2007



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 2006. 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 mapping horizon scanning report. .

Road transport:
- Update minor roads datasets and assumptions
- Update to cold start emission distributions of using 2001 Census data and 2005 employment distributions.
- Incorporation of appropriate information on regional/national vehicle fleet composition and speed assumptions from local inventories.

Domestic fuel use
- Updates to the existing methods which operate on 2003/4 base data

Shipping:
- Incorporation of appropriate and relevant outputs of the review of shipping emissions (ENTEC, 2008)

Point sources:
- Evaluate the incorporation of fuel use information by installation from the Environment Agency PI datasets
- Evaluate the incorporation of information on Local Authority regulated processes (Part B/A2s) as part of the e-PRTR and EPER
- Evaluation the incorporation of survey data on boiler operation in the London area made available via the London Atmospheric Emissions Inventory (LAEI) .

Railways:
- Updated GB train movements and the inclusion of fuel consumption estimates.

Agriculture:
- Increase in resolution of the CEH emission maps to 1km to integrate better with the NAEI maps.
- Update of livestock and poultry distributions used for particulate matter mapping.

Airports:
- Update of the take off and landing patterns for the large airports and the addition similar patterns for other airports.

Landfills:

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

Accidental fires:

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

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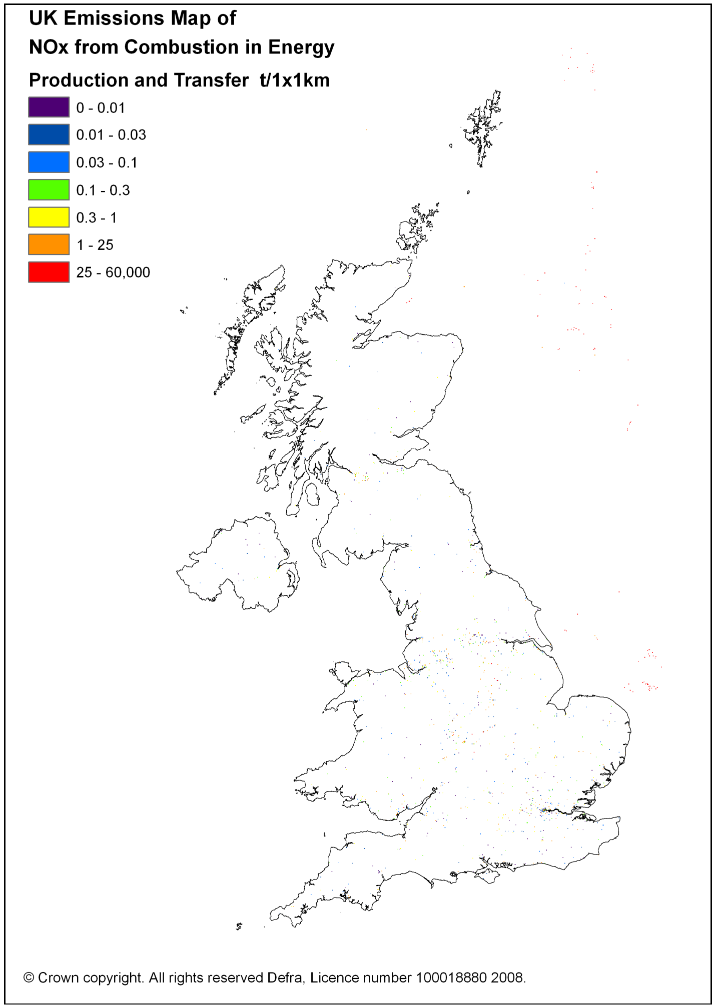
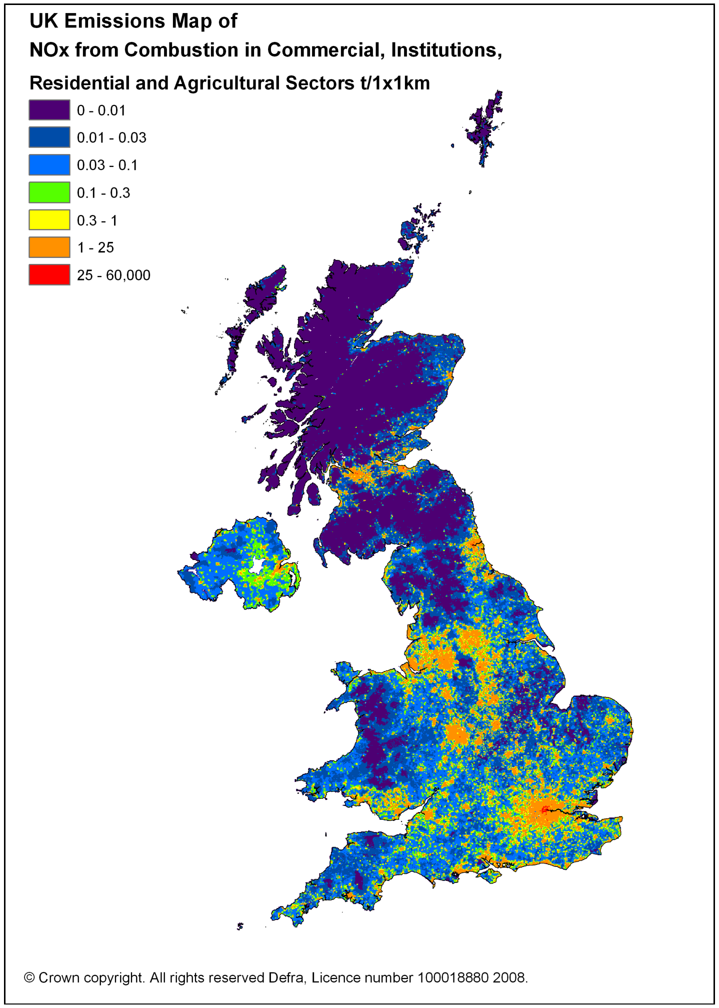
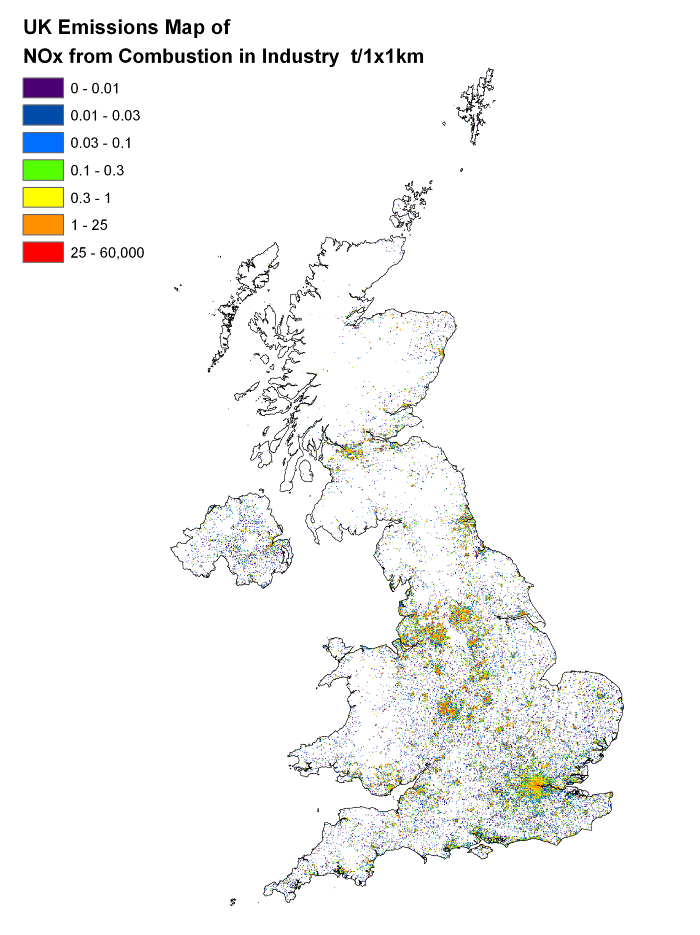
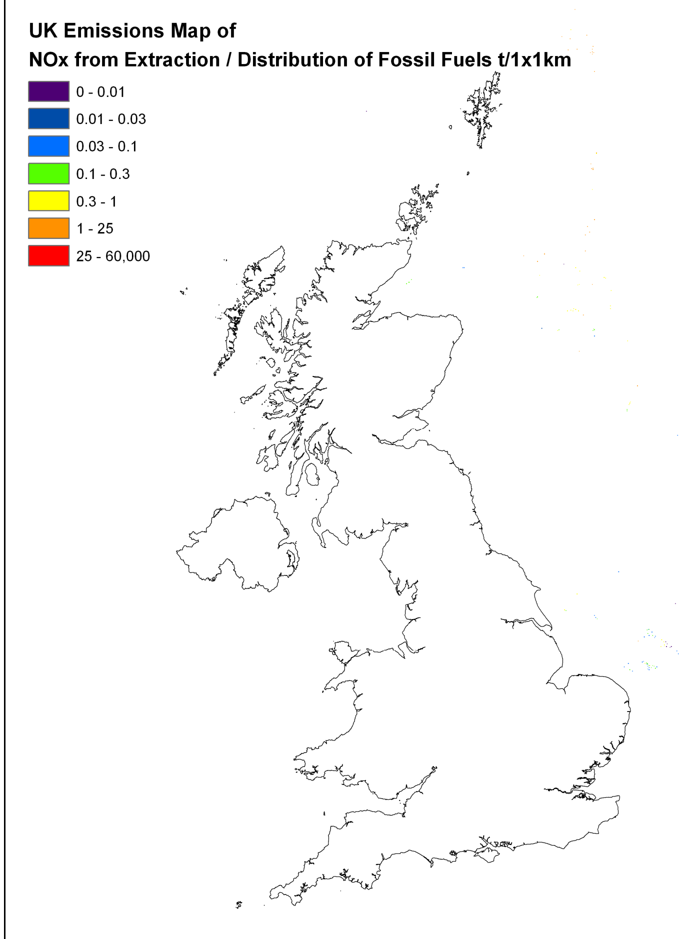
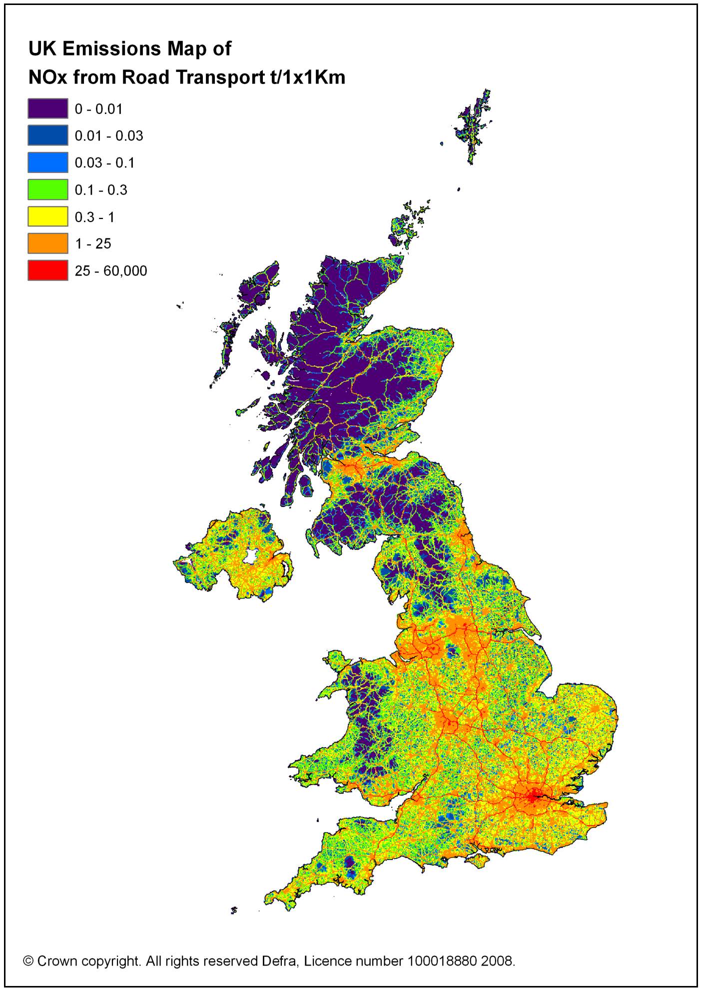
Annex 1 Mapped 2006 NO_X emissions for all UNECE level 1 SNAP sectors






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


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


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
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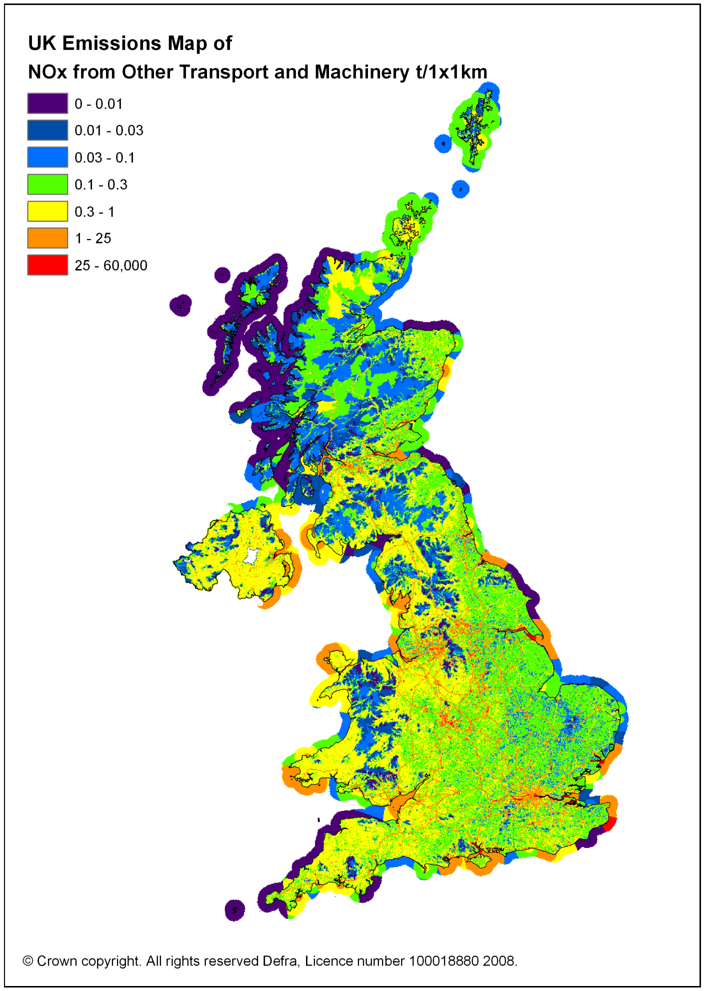
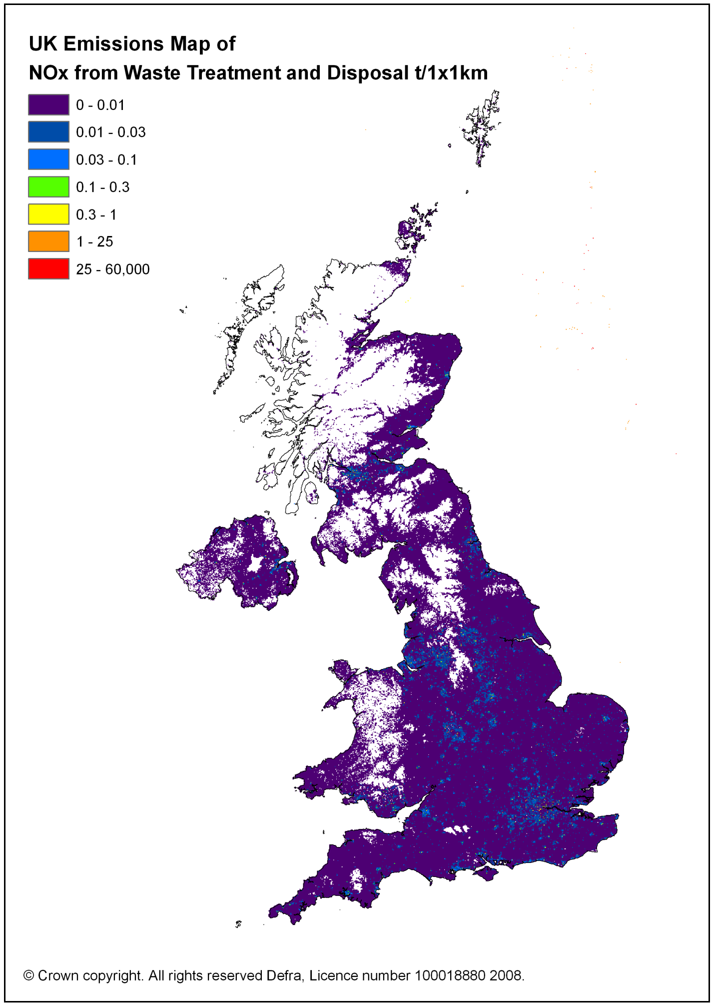

UK Emissions Map of
NOx from Other Transport and Machinery t/1x1km
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 60,000
© Crown copyright. All rights reserved Defra, Licence number 100018880 2008.


UK Emissions Map of
NOx from Waste Treatment and Disposal 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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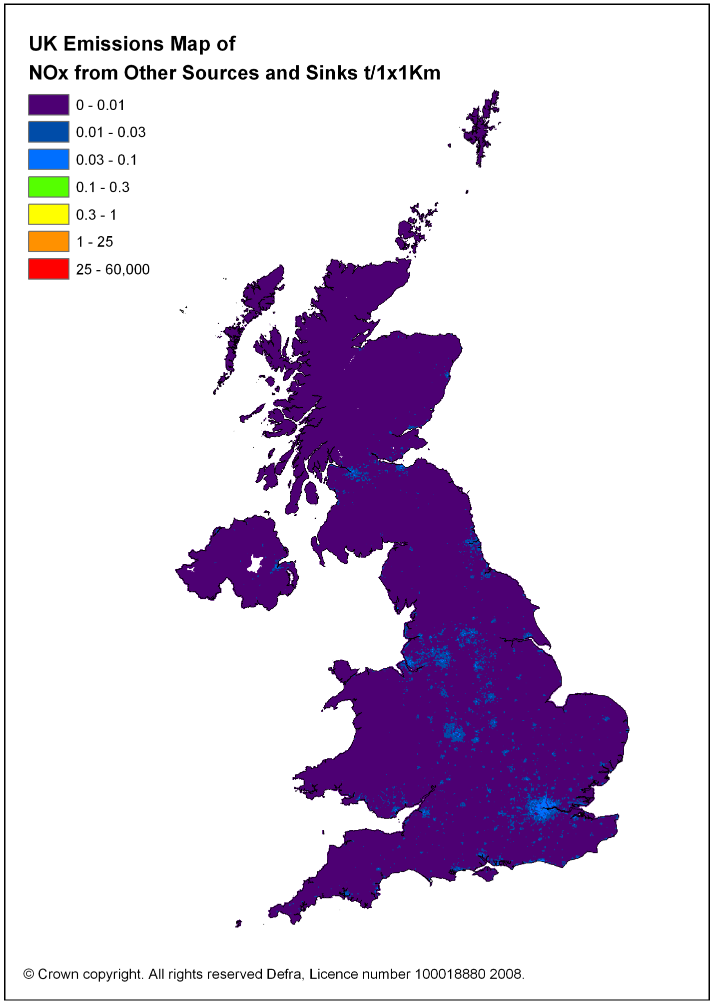
UK Emissions Map of
NOx from Other Sources and Sinks t/1x1Km
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 60,000
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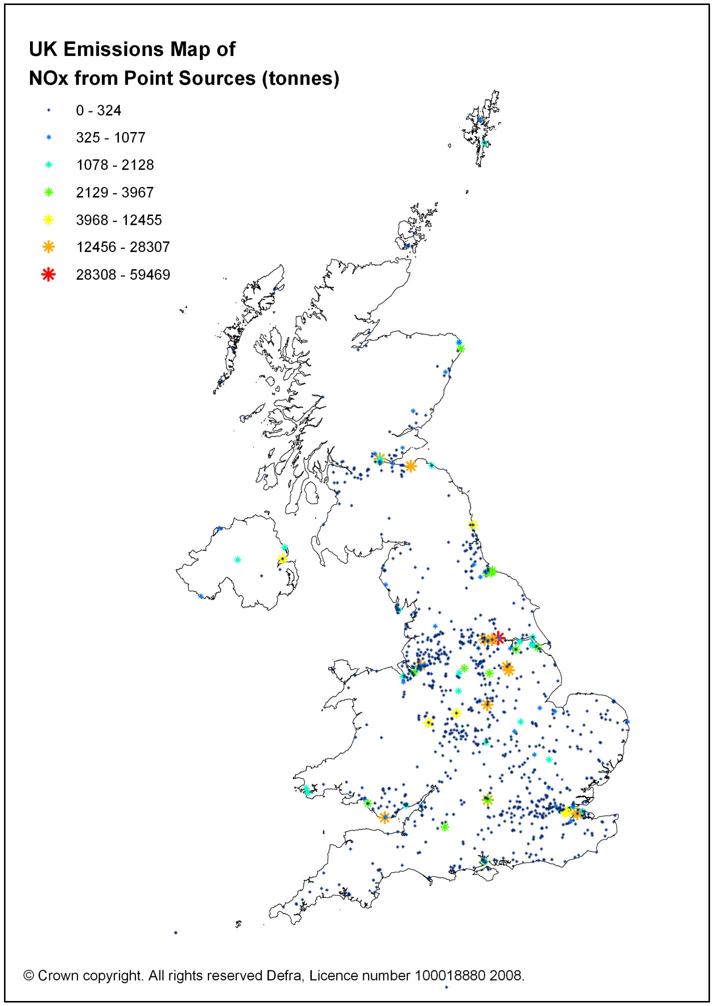
UK Emissions Map of
NOx from Point Sources (tonnes)
0 - 324
325 - 1077
1078 - 2128
2129 - 3967
3968 - 12455
12456 - 28307
28308 - 59469
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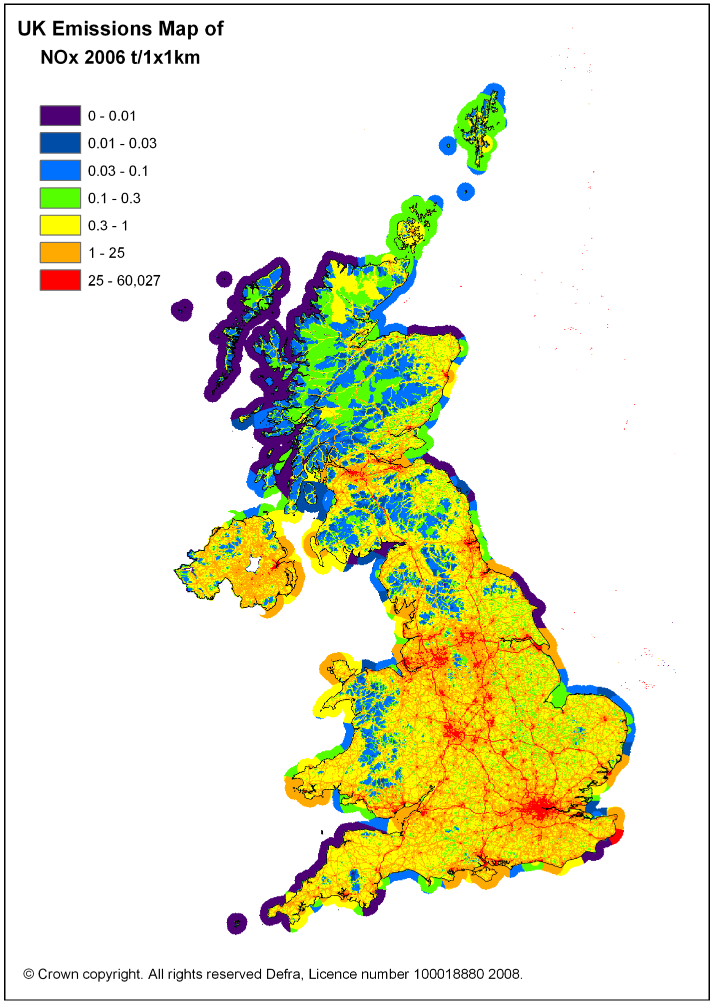
UK Emissions Map of
NOx 2006 t/1x1km
0 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 25
25 - 60,027
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