UK Emissions of Air Pollutants 1970 to 2001

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August 2003

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Executive Summary

1 This is the 15th annual report from the UK National Atmospheric Emissions Inventory (NAEI), and is produced by the National Environmental Technology Centre.

2 **UK air pollutants -** This report presents the latest estimates of emissions to the atmosphere from the UK for the period 1970 to **2001.** 44 pollutant species are included in the 2001 annual inventory including 10 pollutant groups (NMVOC, Particulate Matter, PCDD/F, PAH, PCB, HFC, PFC, SCCP, PCN and PBDE). Size fractionation is available for particulate matter and speciation is available for: 500 NMVOCs, oxidation states of Hg, Ni and Cr, 11 PAHs and 209 PCBs. The pollutants considered in this report are:

Greenhouse Gases
- carbon dioxide, CO_2
- methane, CH_4
- nitrous oxide, N_2O
- hydrofluorocarbons (HFC)
- perfluorocarbons (PFC)
- sulphur hexafluoride (SF_6)

Acidifying Pollutants & Ozone Precursors
- nitrogen oxides, NO_x
- sulphur dioxide, SO_2
- non-methane volatile organic compounds (NMVOC) *
- ammonia, NH_3
- hydrogen chloride, HCl
- hydrogen fluoride, HF

Persistent Organic Pollutants
- polycyclic aromatic hydrocarbons (PAH) * †
- dioxins and furans (PCDD/F)
- polychlorinated biphenyls (PCB) *
- pesticides:
  - lindane, hexachlorobenzene, pentachlorophenol
- short-chain chlorinated paraffins (SCCPs)
- Polychlorinated Napthalenes (PCNs)
- polybrominated diphenyl ethers

Air Quality Strategy Pollutants
- particulate matter, PM_{10} *
- black smoke
- carbon monoxide, CO
- benzene
- 1,3-butadiene
- PAH * †

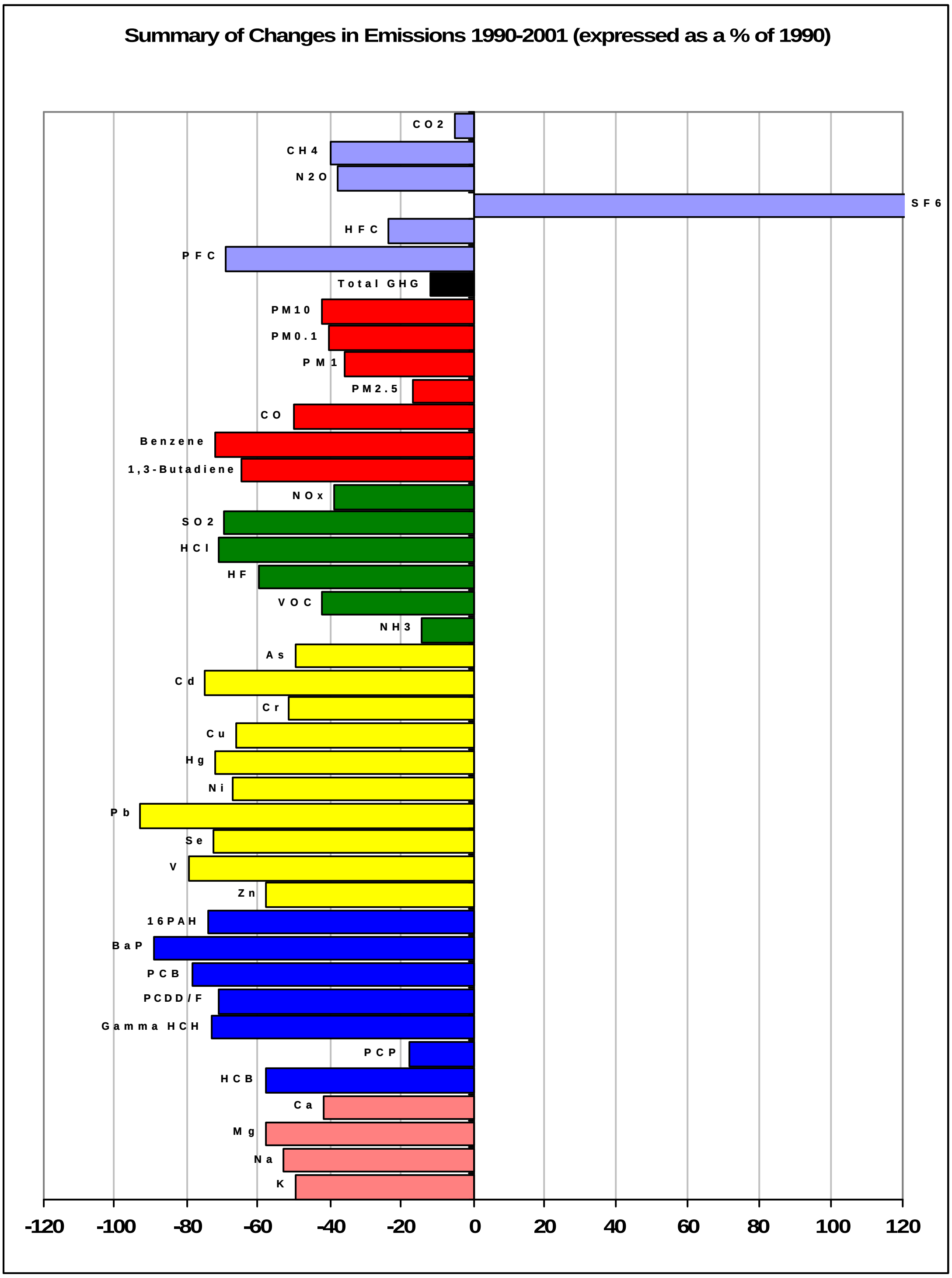
Base Cations
- calcium, Ca
- magnesium, Mg
- sodium, Na
- potassium, K

Heavy Metals
- arsenic, As
- cadmium, Cd
- chromium, Cr *
- copper, Cu
- lead, Pb
- mercury, Hg *
- nickel, Ni *
- selenium, Se
- vanadium, V
- zinc, Zn
- Beryllium, Be
- Manganese, Mn
- Tin, Sn

* Pollutant emissions are given as a total emission and speciated emissions. Particulate matter emissions are given as PM_{10} , $PM_{2.5}$, $PM_{1.0}$ and $PM_{0.1}$.

† Benzo[a]pyrene is included in the Air Quality Strategy, but appears in this report in the chapter on Persistent Organic Pollutants, as it is a PAH.

The change in emissions for these pollutants, is summarised in the following plot. The change is given as the difference between the 1990 and 2001 emissions, expressed as a percentage of the 1990 values.



The greenhouse gas SF_6 is the only pollutant showing an increase across this period. SF_6 emissions arise from a relatively small number of sources (magnesium production, high voltage switchgear, electronics and manufacture of trainers), with most of these giving increased emissions since 1990.

However, these emissions of SF_6 should be placed in context by considering the other greenhouse pollutants. Comparison of the 1990 and 2001 emissions of a basket of six greenhouse gases indicates a 12% decrease in the contribution to global warming. Therefore the impact of the increased SF_6 emissions is more than counteracted by the decreased emissions of other greenhouse gases (see Figure 2.1).

3 **CO_2 –** Emission estimates for CO_2 (as Carbon) from the UK show a decrease of 4.9% between 1990 and 2001, giving an emission of 151.7 Mt of carbon in 2001. The most significant reductions arise from the public power and industrial combustion sectors. 2001 road transport emissions account for 21% of the total emission and indicate a reasonably constant absolute emission since 1997.

4 **CH_4 -** Estimates of methane emissions show a decrease of 40% from 1990 to 2001, giving emissions of 2.20 Mt of carbon equivalent in 2001. The largest sources are landfills, agriculture, natural gas distribution and coal mining. Reduction is largely due to the decline in the coal mining industry. Increased levels of methane recovery on landfill sites have also contributed.

5 **N_2O -** UK emissions of nitrous oxide were 0.136 Mt of carbon equivalent in 2001, corresponding to a decrease of 38% between 1990 and 2001. Emissions of nitrous oxide are dominated by agricultural emissions and the production of nylon and nitric acid. Reductions have primarily arisen from the production processes sector. Emission estimates of N_2O are highly uncertain (see Section 2.6).

6 **HFC, PFC and SF_6-** The UK emissions in 2001 were HFCs: 2.4 Mt of carbon equivalent, PFCs: 0.19 Mt of carbon equivalent and sulphur hexafluoride: 0.5 Mt of carbon equivalent. These correspond to reductions of 24% and 69% for HFC and PFC respectively. The increase in SF_6 has been discussed above in point 2.

7 **PM –** The UK emissions of PM_{10} declined by 42% between 1990 and 2001, giving an emission of 0.18 Mt in 2001. This reflects a trend away from coal use particularly by domestic users. Coal combustion and road transport together contribute 45% of UK emissions of PM_{10} in 2001. PM_{10} emissions from road transport have shown a steady decline across recent years. Other PM size fractions are also included in this report. $PM_{2.5}$ emissions have also fallen, but by a smaller amount, the largest source sector being road transport, accounting for 29% of the 2001 total emission.

8 **BS -** Black smoke emissions in the UK have significantly declined (by some 75% between 1970 and 2001). Emissions in 2001 were estimated to be 268 kt.

9 **CO -** Emissions in 2001 (3.74 Mt) represent a 50% reduction on the emission in 1990. UK emissions of CO are dominated by those from road transport (62% of UK emissions in 2001). The change in emissions between 1990 and 2001 is dominated by the reduction in emissions from the road transport sector, caused by the increased use of catalytic converters in cars.

10 **Benzene** –Benzene emissions have decreased by 72% between 1990 and 2001, giving an emission of 15.4 kt in 2001. Fuel combustion in the road transport sector is the most significant source of benzene, accounting for some 34% of the 2001 UK emission. The use of benzene in the chemical industry gives rise to stack and fugitive emissions. These emissions sum to contribute 10% to the UK total emission.

11 **1,3-Butadiene** – Emissions in 2001 were estimated to be 4.5 kt, representing a decrease of 64% between 1990 and 2001. Emissions of 1,3-butadiene are dominated by fuel combustion in the road transport sector, which account for some 78% of the 2001 UK emission. There have been significant reductions in the emissions from this sector due to the increase in the number of cars equipped with catalytic convertors.

12 **NO_x -** UK emissions of NO_x were 2.76 Mt in 1990. Emissions have fallen significantly to 1.68 Mt in 2001, representing a 39% reduction on the 1990 emissions estimate. This is primarily a consequence of: abatement measures in road transport, abatement measures in coal fired

power stations and the increased use of other fuels for power generation. Road transport and coal combustion combine to account for 66% of UK emissions in 2001.

13 **SO_2 -** UK emissions of sulphur dioxide have fallen from 3.72 Mt in 1990 to 1.13 Mt in 2001, representing a decrease of 70%. This is a result of reduced emissions from the industrial and public power sectors arising from the decreasing use of coal and increasing use of abatement equipment. However, coal combustion still accounts for 74% of the 2001 UK SO_2 emissions.

14 **HCl -** UK emissions of hydrogen chloride have decreased by 71% between 1990 and 2001, giving an emission of 0.08 Mt in 2001. This reduction is largely as a result of declining coal use.

15 **NMVOC -** UK emissions of NMVOC are estimated as 2.60 Mt for 1990 and 1.51 Mt for 2001, a decrease of 42%. The observed decrease arises primarily from the road transport and industrial sectors.

16 **NH_3 -** The total UK emission of ammonia for 2001 is estimated at 0.29 Mt, compared to the 1990 estimate of 0.34 Mt, giving a 15% reduction. The agricultural sector dominates the ammonia emissions, and emissions have decreased substantially since 1999. There have been increases in the emissions from the road transport sector (caused by increased use of catalytic convertors), but these have been more than offset by the impact of decreased agricultural livestock numbers.

17 **HF –** The total HF emissions for 2001 are estimated to be 4.2 kt, representing a 60% reduction on the 1990 emission estimates. As with HCl the dominant source is coal combustion for public power.

18 **POPs –** The 2001 UK emissions of persistent organic compounds may be summarised as follows: 2193 t **PAH** (USEPA 16), 357 gTEQ **PCDD/F** (grammes of "toxic equivalent" of dioxins & furans) and 1.56 t **PCB**. Emissions from all three of these pollutant groups have greatly decreased. Emissions in 2001 equate to decreases of 73%, 70% and 78% on the 1990 emission, for PAHs, PCDD/Fs and PCBs respectively.

19 **Pb -** UK Emissions of lead have declined sharply following reductions in the lead content of leaded petrol, and the increased use of unleaded and lead replacement petrol. Emissions in 2001 are estimated to be 0.19 kt, a decrease of 93% on the 1990 estimates. Road transport now contributes only 66% to UK emissions total in 2001. Emissions of other metals are also reported, and show a strongly declining trend- ranging from 49-80% decreases on the 1990 estimates.

20 The 2001 emission inventory indicates that the dominant sources of many of the air pollutants are from road transport and the use of coal (see table below).

Road Transport and Coal Combustion Contribution to Emissions of Selected Pollutants (2001)

Pollutant	Total Coal Combustion	Road Transport	Total Contribution
HCl	98%	0%	**98%**
Sn	97%	1%	**98%**
Mn	90%	0%	**90%**
HF	88%	0%	**88%**
Be	51%	29%	**80%**
1,3-Butadiene	0%	78%	**78%**
SO_2	74%	0%	**74%**
16 PAHs	21%	51%	**72%**
Se	70%	1%	**71%**
CO	5%	62%	**67%**
NO_x	20%	46%	**66%**
Mg	63%	0%	**63%**
As	60%	0%	**60%**
Na	58%	0%	**58%**
Cu	51%	1%	**52%**
K	51%	0%	**51%**
PM_{10}	25%	19%	**45%**
Carbon	23%	21%	**44%**
Benzene	6%	36%	**42%**
Benzo[a]pyrene	32%	8%	**40%**

It is therefore likely that future trends in emissions will be substantially determined by market demand and UK Government/devolved administration policies associated with these areas.

21 A copy of this report may be found at the NAEI web site (http://www.naei.org.uk) along with a facility for local interrogation of the data and links to data on emissions in other countries.

Contents

8 REGIONAL EMISSION ESTIMATES

9 FOOT AND MOUTH ANIMAL PYRES

ANNEX 1 DEFINITIONS OF UN/ECE SOURCE SECTORS

The Appendices associated with this report are now no longer included in the hard copy, but are still available. They may be accessed through the NAEI website: http://www.naei.org.uk/
where they are listed with the electronic version of this report.

The Appendices at this website include tabulated data, and a detailed methodology of the NAEI.

1. Introduction

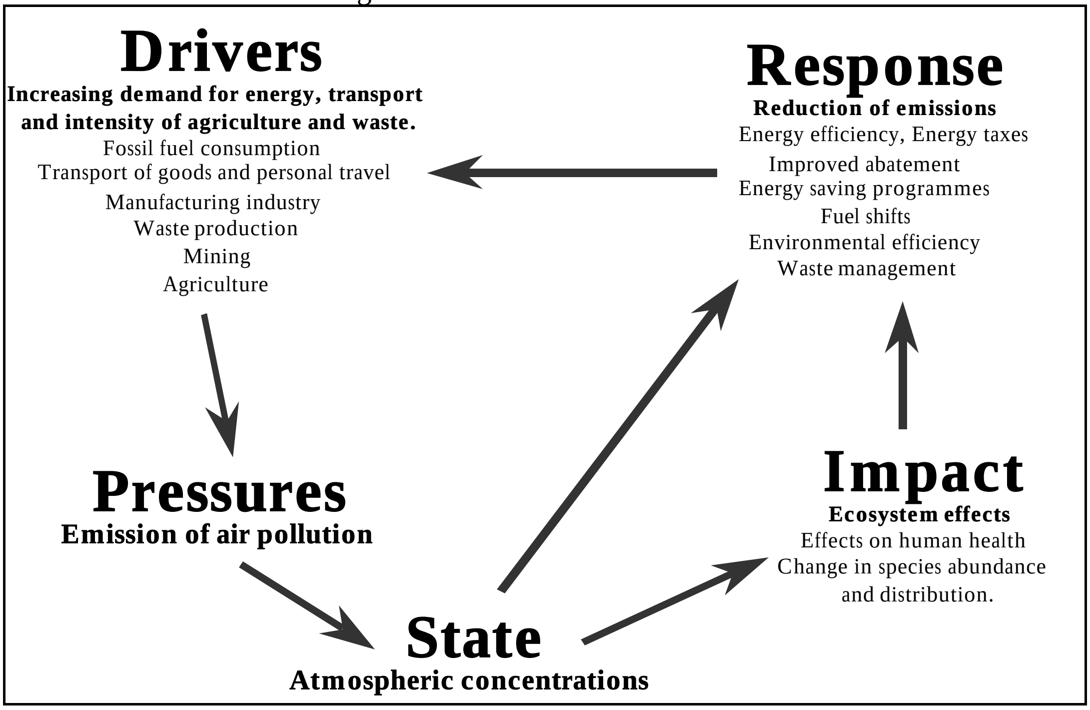
1.1 AN INTRODUCTION TO EMISSION INVENTORIES

Emission inventories play an important role in assessing the effects of anthropogenic (man-made) activity on atmospheric pollution. The principal demands for energy, transportation, materials and food may be regarded as the "***drivers***" for the production of air pollutants. In order for an economy to continue to develop in a sustainable way these sources of pollution must be managed. To do this we must understand the "***impacts***"- i.e. what types of pollution affect which parts of the environment or human health, and to what extent. To decide whether action is necessary we also need to know the "***state***" of the environment- i.e. to evaluate whether the levels in the environment exceed those which will cause environmental harm.

In taking appropriate action we must be able to respond in a focused way to control and reduce pollution while avoiding larger-scale damage to economic development. ***Emission inventories*** provide policy makers and the public with an understanding of the key polluting sources or the "***pressures***", how these sources have developed with economic growth and how they are likely to contribute to pollution in the future. This understanding is essential for a focused "***response***" to the problems associated with air pollution and to meet the demands of sustainable development.

Figure 1.1 shows how our understanding of the ***pressures*** (through emission inventories) interact with other areas of environmental knowledge such as ***impact*** assessment and monitoring (***state***). Figure 1.1 also clearly shows the relationship between: emission inventories, economic activity and effective environmental policy.

Figure 1.1 "DPSIR" Relational Diagram



1.2 THE UK NATIONAL ATMOSPHERIC EMISSIONS INVENTORY

The UK National Atmospheric Emission Inventory (NAEI) is compiled by the National Environmental Technology Centre on behalf of the Department for Environment, Food and Rural Affairs (Defra) Air and Environment Quality (AEQ) Division and the devolved administrations. Related work on greenhouse gas emissions is also conducted for the Global Atmosphere Division of the Department. The NAEI is the standard reference air emissions inventory for the UK and includes emission estimates for a wide range of important pollutants. These include: greenhouse gases, regional pollutants leading to acid deposition and photochemical pollution, persistent organic pollutants and other toxic pollutants such as heavy metals. The full range of pollutants is summarised in Table 1.1. Where possible, estimates are presented for 1970-2001. However, for some pollutants, e.g. ammonia, there is insufficient information to produce a 1970-2001 time series and estimates are presented from 1990-2001.

Emission inventories serve several important functions, as explained in Section 1.1. The following highlight several of the more important uses of the UK NAEI:

1. **Provision of Public Information-** The data from the NAEI is made available to the public in various forms (see Section 1.2.3). The aim is to make information available in an easily understandable format, informing the public of emissions in their area as well as making national emissions data available. The NAEI is paid for by tax payers money, through the Government, and consequently it is important to maintain a high public profile and accessibility to the work. A copy of this report is available on the internet at http://www.naei.org.uk. Further information can be found in Section 1.2.3.

2. **Development of policy-** The data from the NAEI is used to inform development of policies to tackle emissions of air pollutants and greenhouse gases.
    - **Identification of Primary Sources-** The NAEI compiles emissions from all possible anthropogenic and natural sources (where information allows). Consequently it is simple to determine which source sectors are the major emitters of individual pollutants.
    - **Temporal and Spatial Trend Assessment-** The NAEI provides information to allow temporal trend analysis as it is compiled annually (from 1970 for most pollutants). UK maps are also generated for several of the pollutants, allowing spatial trends to be assessed.
    - **Inventory Comparisons-** Mapped emission inventories exist for a number of cities across the UK. In some cases the techniques used to compile these emission inventories differ from the NAEI. As a result comparison with the NAEI highlights the potential strengths and weaknesses of the different techniques.
    - **National Modelling Studies-** The NAEI is used in a variety of modelling studies investigating spatial and temporal trends in deposition and concentration of pollutants. Furthermore, it is possible to use the NAEI alone to investigate the impact on emissions of particular future policy scenarios.
    - **Local Support-** Data from the NAEI is frequently used by Local Authorities to support air quality assessments, and aid the generation of local policy.

3. **National and International Reporting-** The NAEI provides the official air emissions estimates for the UK. National and International reporting requirements are given in more detail in the following Sections.

4. **Progress on Complying with National and International Commitments-** The annual inventory provides an important assessment tool for policy makers. The inventory is used to monitor progress towards emission limits and ceilings at both the national and international level, and is therefore an important tool in assessing the effectiveness of existing policy measures.

1.2.1 International Commitments

The NAEI provides the UK air emission data for submission to United Nations Economic Commission for Europe (UN/ECE) and the United Nations Framework Convention on Climate Change (UNFCCC). Under the UNFCCC, the UK is committed to developing, publishing and regularly updating national emission inventories of greenhouse gases using reporting guidelines from the Intergovernmental Panel on Climate Change (IPCC). The inventories for both direct greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) and indirect greenhouse gases (nitrogen oxides, carbon monoxide and non-methane volatile organic compounds) are drawn from the UK NAEI emissions data included in this report. Likewise, NAEI estimates of emissions of nitrogen oxides, carbon monoxide, ammonia, sulphur dioxide, NMVOC, persistent organic pollutants and heavy metals are submitted to UN/ECE under the Convention on Long-Range Transboundary Air Pollution (CLRTAP). NAEI data are also provided to international emission inventory activities such as the EC's CORINAIR and EUROSTAT inventories. The UK inventory team play an important role in the development of international guidelines by the European Environment Agency and the UN/ECE which aims to achieve a consistent set of good quality inventories for all European countries. More information may be found at the EMEP and UNFCCC websites at:

http://www.emep.int/ and http://www.unfccc.de/

Not all international reporting of emissions are drawn from the UK NAEI. One exception is the EC's forthcoming EPER (European Pollutant Emissions Register) which arises from the IPPC Directive. The Environment Agency's Pollution Inventory (PI) will provide data for the EPER for England and Wales. Scotland are in the process of constructing their own PI equivalent, and Northern Ireland will also need to consider compiling these data.

1.2.2 National Information

The NAEI is a key database used to provide air emissions data to the public, UK Government, the devolved administrations, Local Authorities and private sector organisations. Many of the specific policy uses have been outlined above, but there are a number of other ways in which the data is used. Several are given below:

- A significant amount of time is spent providing detailed emission estimates, output from scenario analysis and supporting information to Defra and the devolved administrations. This information is required for a wide variety of uses- from long-term policy support to specific short-term issues.

- A great deal of information is made available to other organisations working on Defra projects, or projects for the devolved administrations. This ensures a high level of consistency and efficiency.

- Mapped emission inventories for the UK are generated on a 1x1km scale. These 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.

- There is a two way exchange of data with Trade Associations. This ensures that the NAEI and the Trade Associations can arrive at emission estimates that are truly representative.

- Emission factor data is fed into the UK's Emission Factor Database for access by Local Authorities.

Table 1.1 Pollutants Covered by the Inventories

Pollutant		**Range of Estimates**[1]	**Type of Pollutant**[2]
Carbon Dioxide	CO_2	1970-2001	G
Methane	CH_4	1970-2001	G
Nitrous Oxide	N_2O	1990-2001	G
Hydrofluorocarbons	HFC	1990-2001	G
Perfluorocarbons	PFC	1990-2001	G
Sulphur Hexafluoride	SF_6	1990-2001	G
Nitrogen Oxides	NO_x (NO_2 + NO)	1970-2001	NAQS, AC, IG, O
Sulphur Dioxide	SO_2	1970-2001	NAQS, AC, IG
Carbon Monoxide	CO	1970-2001	NAQS, O
Non-Methane Volatile Organic Compounds	NMVOC	1970-2001	NAQS, O, IG
Black Smoke	BS	1970-2001	NAQS
Particulates < 10 µm	PM_{10}	1970-2001	NAQS
Ammonia	NH_3	1990-2001	AC
Hydrogen Chloride	HCl	1970-2001	AC
Hydrogen Fluoride	HF	1970-2001	AC
Lead	Pb	1970-2001	NAQS, TP
Cadmium	Cd	1970-2001	TP
Mercury	Hg	1970-2001	TP
Copper	Cu	1970-2001	TP
Zinc	Zn	1970-2001	TP
Nickel	Ni	1970-2001	TP
Chromium	Cr	1970-2001	TP
Arsenic	As	1970-2001	TP
Selenium	Se	1970-2001	TP
Vanadium	V	1970-2001	TP
Beryllium	Be	2000-2001	TP
Manganese	Mn	2000-2001	TP
Tin	Sn	2000-2001	TP
Polycyclic Aromatic Hydrocarbons	PAH	1990-2001	TP
Dioxins and Furans	PCDD/F	1990-2001	TP
Polychlorinated Biphenyls	PCB	1990-2001	TP
Lindane (gamma-HCH)	HCH	1990-2001	TP
Pentachlorophenol	PCP	1990-2001	TP
Hexachlorobenzene	HCB	1990-2001	TP
Short-chain chlorinated paraffins	SCCP	1990-2001	TP
Polychlorinated Napthalenes	PCN	NE	TP
Polybrominated diphenyl ethers	PBDE	SE	TP
Sodium	Na	1990-2001	BC
Potassium	K	1990-2001	BC
Calcium	Ca	1990-2001	BC
Magnesium	Mg	1990-2001	BC

1 An explanation of the codes used for time series:

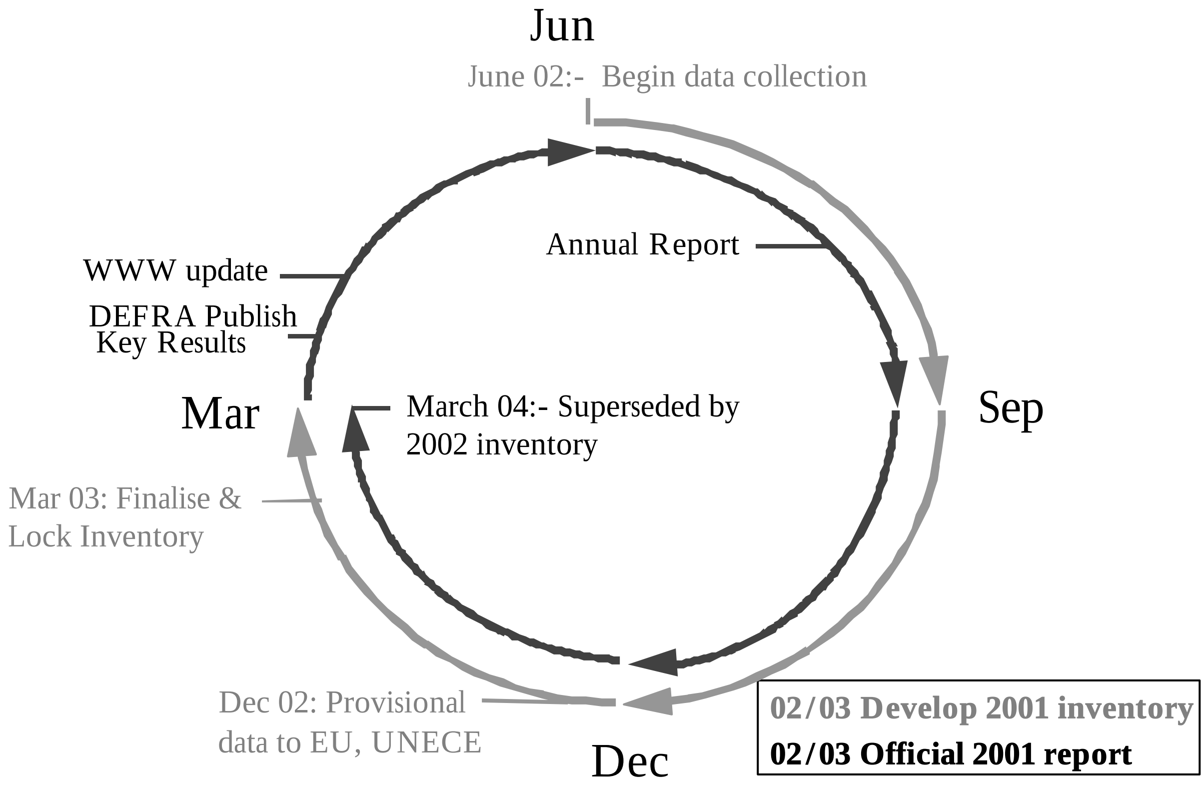
SE	A "Single Emission" estimate not attributed to a specific year
NE	"Not Estimated" due to lack of information currently available

2 An explanation of the codes used for pollutant types:

G	Greenhouse gas	**IG**	Indirect greenhouse gas
O	Ozone precursor	**AC**	Acid gas
NAQS	National Air Quality Standard/Local Air Quality Management pollutant		
TP	Heavy metals and POPs are generally referred to as "Toxic Pollutants" (although other pollutants also have toxic properties)		
BC	Base cation		

The NAEI is compiled on an annual basis, each year the latest set of data are added to the inventory and the full time series are updated to take account of improved data and any advances in the methodology used to estimate the emissions. Updating the full time series is an important process as it ensures that the entire dataset uses the methodology that is the most current, and hence considered to give the most accurate results and the most accurate indication of temporal trends. The new data are then reported to UN/ECE, UNFCCC and other international fora. This annual cycle of activity is represented schematically in Figure 1.2.

Figure 1.2 The Annual NAEI Cycle



This report presents the definitive 2001 data from the NAEI and is the latest in a series of annual reports published by the NAEI (Eggleston, 1988; Eggleston and Munday, 1989; Munday, 1990; Leech, 1991; Gillham *et al* 1992; Gillham *et al* 1994; Salway *et al* 1996, 1996a, 1997, Salway 2000, Salway *et al* 2000, Goodwin *et al* 2000, Goodwin *et al* 2000, Goodwin *et al* 2001, Salway *et al* 2002).

This report discusses trends in pollutant emissions, the accuracy of the emission estimates and in many cases the pattern of their spatial disaggregation within the UK. A detailed description of the methodology used in the compilation of the data is given in Appendix 1 and recent methodological improvements to the inventory, and planned developments are both included in Appendix 2. Mapping methodologies, NMVOC speciation and a full listing of pollutant emissions at a high detail level are also included in the Appendices. The appendices are now not included with this hard copy of the report, but can be accessed from the NAEI webpage (http://www.naei.org.uk).

1.2.3 Information Dissemination

Data from the NAEI is made available to national and international bodies in a number of different formats- as explained in Sections 1.2.1 and 1.2.2. An annual report is produced, giving the most recent emissions data and other information such as: temporal trends, new pollutants and methodology changes. The NAEI team also hold seminars with representatives from industry, trade associations, UK Government and the devolved administrations.

In addition there is a continuous drive to make information available and accessible to the public. A large amount of information is made available on the internet. The NAEI web pages may be found at:
http://www.naei.org.uk

These web pages are arranged into a number of different categories which fall under the following headings:

- **Annual Report:-** The most recent NAEI annual report is made available in electronic format.

- **Methodology:-** The methods used for the compilation of the NAEI are given.

- **Datasets:-** Various datasets are made available, the most comprehensive being a queriable database of the NAEI emission estimates.

- **Emissions Maps:-** Emissions of pollutants are given in the form of UK maps. These maps give emissions of various pollutants on a 1 x 1 km resolution. It is possible to zoom in to areas of interest, and access the source data for the maps.

- **Post Code Search:-** This search facility enables visitors to the site to enter their post code, and obtain emissions data concerning the major sources in the vicinity.

The web site is constructed so that the air emissions are placed in context. In addition there are numerous links to locations explaining technical terms, pages giving airborne pollutant concentrations and why there is an interest in particular pollutants. In particular there are links to the various Defra pages containing comprehensive measurement data on ambient concentrations of various pollutants. The Defra air quality sites can be found at:

http://www.defra.gov.uk/environment/airquality/index.htm

and

http://www.defra.gov.uk/environment/climatechange/index.htm

1.2.4 Continuous Improvement and Basic Methodology

Throughout the compilation of the inventory, considerable effort has been made to ensure both consistency with other national statistics and that all available data sources are considered. Hence, the source data are drawn from a wide range of sources. One source is the provision by the Environment Agency of emissions data, since 1988, on SO_2 and NO_x emissions from large combustion plant, and more recently the emissions data for Part A Processes in the Pollution Inventory. Where specific point source emission data are unavailable, emissions are estimated from other activity data such as fuel consumption, distance travelled, production or some other statistical data that is directly related to the emissions. 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 assumed to be representative of a particular source sector. The resulting emission factor may then be applied to similar sources within the sector. However, as mentioned above, some sectors are particularly well characterised and individual point sources within the sector may report a specific emission, which is regarded as being more reliable. This is often the case with sectors incorporating large point sources (an example being the Power Station sector). The inventories presented here are generated using a combination of reported point source emissions, and emissions calculated using emission factors. Methodology improvements are applied to all years (where appropriate).

For many of the pollutants, the major source of emission is generated from fossil fuel combustion. As a result fuel consumption statistics feature prominently in the calculation of these emission estimates. It is important to consider the difference between consumption and deliveries when making use of fuel statistics. Most readily available statistics refer to deliveries which for many source categories relate closely to actual consumption of fuel. However, where fuel can be stockpiled, deliveries and consumption may differ significantly. This is just one example of having to ensure that the available data is correctly interpreted, and used in the most appropriate way to arrive at representative emission estimates.

Emissions from sources such as industrial processes, farm animals and motor fuel evaporation require different statistics; in these cases data on process output, population and motor fuel sales are appropriate.

In other cases, where emissions are more complex, further refinements or an alternative methodology is required. For example, consider the emissions from road vehicles. An obvious activity indicator would be distance travelled, but emissions per unit distance travelled will depend on: vehicle type, vehicle age, engine size, average speed and several other parameters. Clearly the methodology rapidly becomes complicated. A separate road transport model is used for calculating the emissions given in the NAEI.

For the 1970-2001 emissions dataset, particular emphasis has been placed on improving several areas of the emission inventory. In particular, emissions of PM_{10} and heavy metals have been improved. In addition, a considerable amount of work has been conducted on generating emission projections. The emissions estimates for base cations were reported for the first time in 2000, and have been substantially revised for the 2001 time series reported here.

Under several international protocols, emissions from UK dependent territories (and some other locations) are allotted to the UK. Consequently it has been necessary to estimate the emissions from a number of new geographical locations. Emission estimates for: Gibraltar, Jersey, Guernsey, the Isle of Man have been made, and were included for the first time in the 2000 report. Preliminary emission estimates have been made for the two Sovereign base areas of Cyprus. There is on-going work to revise and extend the work being conducted for these Overseas Dependencies, Crown Dependencies and Sovereign Bases.

At a more general level there is also a continued drive to use data which most accurately represents the source. Emission factors and activity data are assessed each year to identify whether more appropriate information has become available. The methodology used for compiling the inventory is given in Appendix 1, and the most significant changes from the 2000 inventory methodology are given in Appendix 2. The current methodology used for generating emission maps is also included in this report as Appendix 3. It should be noted that this methodology is for mapping only, and does not generate total emission estimates- merely spatially disaggregates them in the most appropriate way. These appendices are no longer included with this hard copy of the report, and can be found on the NAEI website (http://www.naei.org.uk).

Chapters 1 to 7 present the NAEI emission estimates for the UK. They have been divided into five groups, reflecting the national and international activity relating to atmospheric pollution, namely greenhouse gases, National Air Quality Strategy pollutants, stratospheric ozone depletors, acidifying gases and tropospheric ozone and other hazardous air pollutants. Each of these chapters include a discussion of the importance of the pollutants concerned, present time series emission data, and discuss the data trends and the accuracy of the emission estimates. Chapter 8 contains emissions estimates for the UK, divided into the Country Regions. This allows comparisons to be made on the different industrial profiles in the Regions and the resulting emissions per capita to be considered. The emissions data summarised in this report is available to differing detail levels by accessing the NAEI website (see http://www.naei.org.uk).

Chapter 9 gives emission estimates arising from animal pyres occurring during the foot and mouth outbreak. These emissions are specific to 2001.

1.2.5 Mapping Emissions

The sources contributing to the UK emissions can be represented as one of three categories: points, lines or areas. Sectors such as power stations, refineries and large industrial plant can be represented by points. Their locations are known and data to estimate emission contributions are available. Major roads and railways are sectors that can be represented by lines if data are available. Other diverse and numerous source sectors such as agriculture, domestic and commercial are represented by areas.

The method used to map emissions in the UK is shaped by the data that are available. The technique employs a combination of reported emissions (for emission sources at regulated sites) and surrogate geographical statistics to distribute emissions from line and area sources.

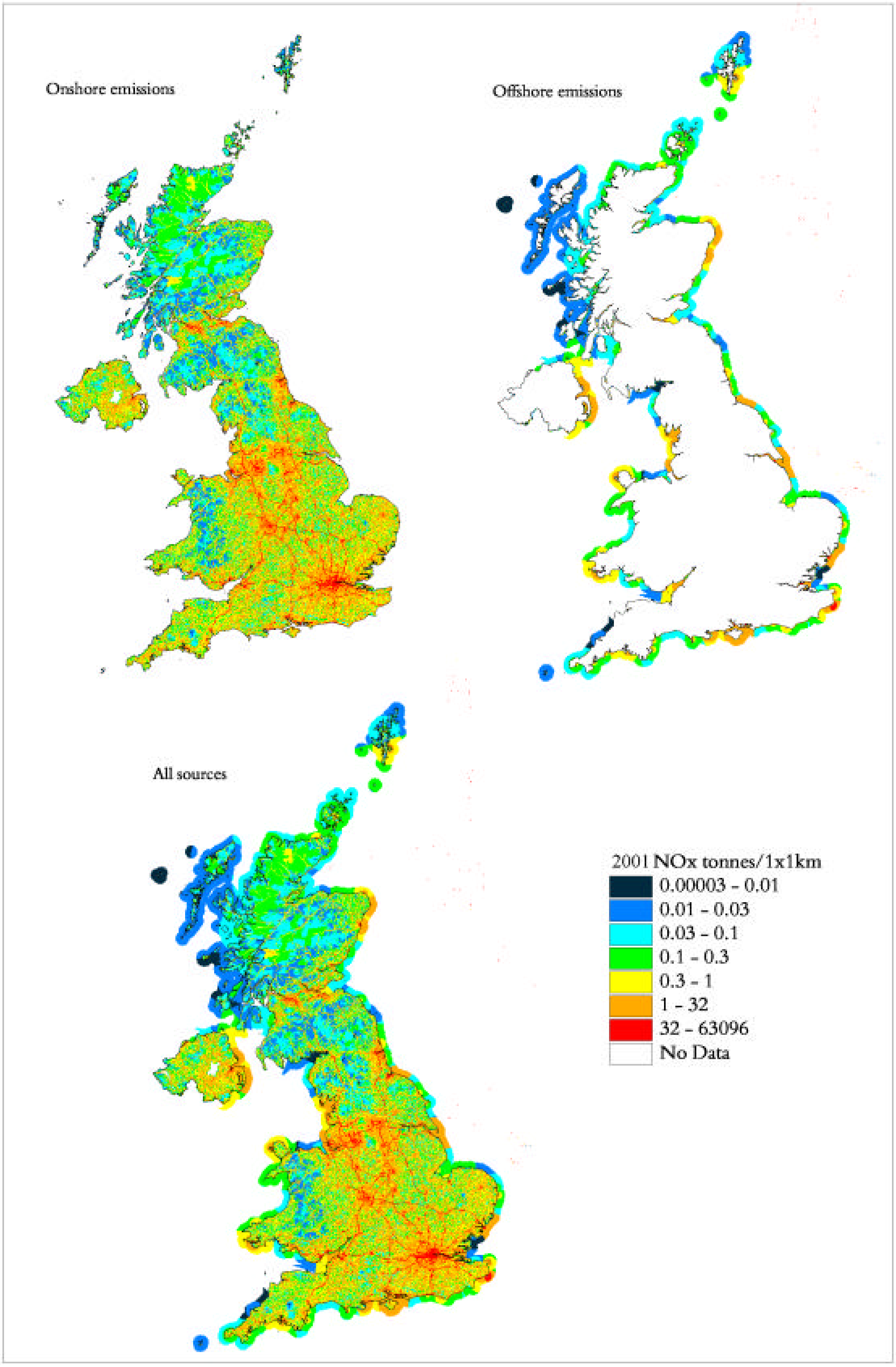
The emission maps combine a number of different source sectors represented by the point, line and area sources. In order to map this combination, the UK is divided into a grid of 1km squares. Emissions are then represented in terms of tonnes per 1km grid square.

Maps of emissions for various pollutants have been included in the main body of this report. These maps show emissions from all sources including some offshore sources. The offshore component is made up of shipping and fishing related emissions within a 12km coastal zone and also offshore oil and gas extraction further afield. The onshore and offshore components of the maps are shown separately for NOx below in Figure 1.3.

It is difficult to identify an offshore total for many of the pollutants as the emissions occur from a number of different sectors under reporting formats. For example, CH_4 emissions from offshore platforms will arise from a number of activities. Emissions may be included under “Extraction and Distribution of Fossil Fuels”, however other emissions may fall within the “Waste Treatment and Disposal” category (e.g. venting of the CH_4). Emissions from fuel combustion in shipping fall into the “Other Mobile Sources and Machinery” sector. Annex 1 gives an explanation of the UN/ECE reporting framework and indicates which source category the emissions are reported under.

These maps meet the needs of a wide range of users. For example, they are used to provide input into air quality modelling, which allows Local Authorities to generate action plans as part of their air quality management role. The maps are also used in research projects investigating pollutant transport and atmospheric chemistry, and by the general public who are interested in understanding the air quality climate in their area.

Figure 1.3 NO_x Emissions Maps- Onshore, Offshore and Total Emissions



1.3 THE ENVIRONMENT AGENCY’S POLLUTION INVENTORY

The Environment Agency (EA) compile a Pollution Inventory (PI) of emissions from around 2,000 major point sources in England and Wales. This requires the extensive compilation of data from a large number of different source sectors. This valuable source of information is incorporated into the NAEI wherever possible, either as emissions data, or surrogate data for particular source sectors. The information held in the PI is also extensively used in the generation of the NAEI maps, as the locations of individual point sources are known. The NAEI and the EA work closely to maximise the exchange of useful information. The PI allows access to air emissions through post code interrogation, and may be found at:-

http://www.environment-agency.gov.uk/business/444255/446867/255244/

2. Greenhouse Gas Emissions

2.1 INTRODUCTION

Increasing atmospheric concentrations of greenhouse gases (GHGs) originating from anthropogenic activities are leading to enhanced warming of the atmosphere and global climate change. The major greenhouse gases are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) all of which have both natural and anthropogenic sources. In contrast, the three industrial gases: hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF_6), are potent greenhouse gases but do not occur in nature, and hence only originate from anthropogenic sources.

These six greenhouse gases comprise the ‘basket of emissions’ against which reduction targets were agreed at the Third Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto, Japan in December 1997. The target for the UK is to achieve a reduction of the global warming potential of the six greenhouse gases of 12.5% by 2008-2012 (based on 1990 emissions estimates). Consequently the UK is required to compile annual emission inventories of these greenhouse gases and report the emissions to international bodies, such as the UNFCCC to demonstrate progress against its target under the Kyoto Protocol. The UK Greenhouse Gas Inventory is submitted to UNFCCC in the Common Reporting Format (CRF). The Common Reporting Format gives net carbon emissions, that is emissions minus removals. The data in this report is presented here in a UN/ECE reporting format (see Annex 1) and quotes land use change and forestry emissions and removals separately. More detailed information may be found in the annual report on UK GHG emissions produced by the NAEI (Salway et al, 2002).

The 2001 emissions for each of these six greenhouse gases are summarised in Table 2.1, and their inventories are discussed in the following sections. Inventories for the three indirect greenhouse gases (carbon monoxide, nitrogen oxides and non-methane volatile organic compounds) are included in subsequent chapters (Chapters 4, 5 and 5 respectively).

The total global warming potential of UK greenhouse gas emissions has been calculated using their global warming potentials (GWPs), which measures their effectiveness in global warming relative to CO_2, agreed by IPCC for a 100 year time horizon (IPCC, 1996).

Table 2.1 GWP for UK Emissions of Greenhouse Gases in 2001

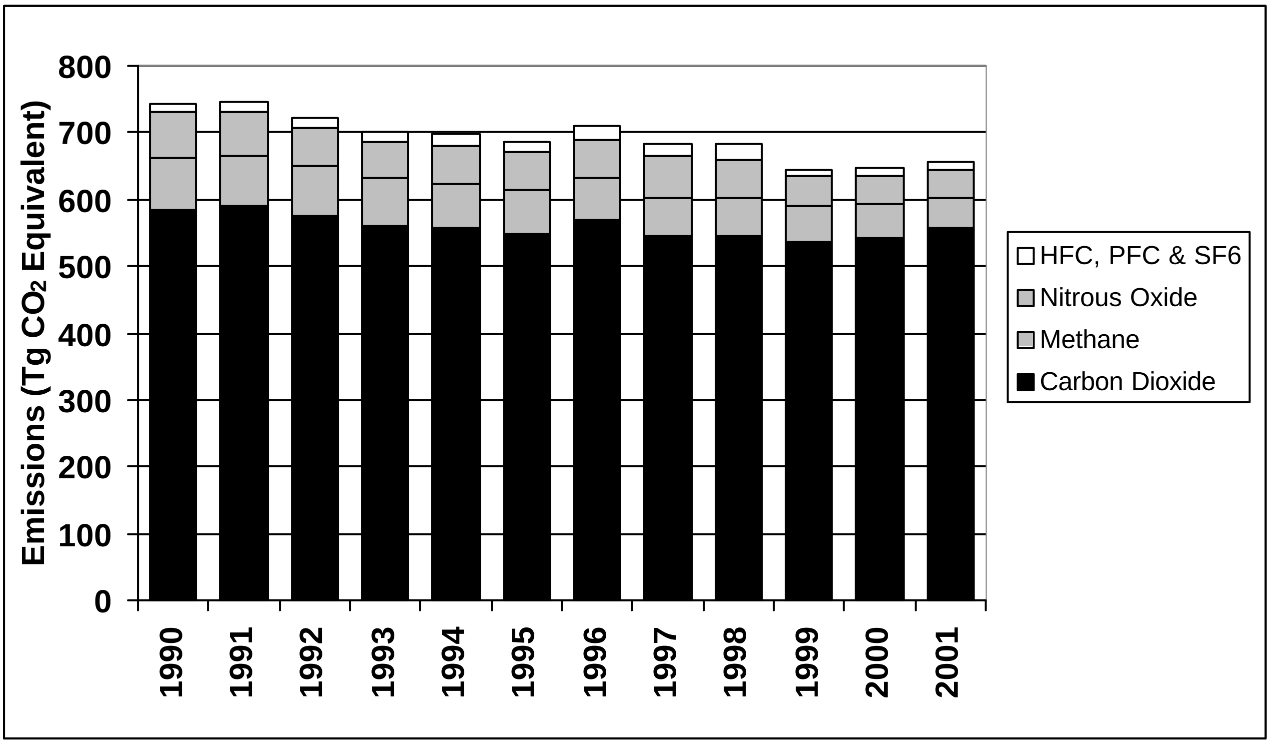
Direct GHG	Emissions (ktonnes) in 2001	GWP (100 years)	Global Warming Equivalence (equivalent kt of CO_2)
CO_2 (as carbon)[1]	151,732	3.7	556,352
CH_4	2,195	21	46,105
N_2O	136	310	42,155
HFCs	2366	560-12100[2]	8,674
PFCs	192	6000-7400[2]	706
SF_6	522	23900	1,913

1 The emissions given here are on a UNECE basis and hence do not include land-use change emissions.

2 A number of GWPs are used as this refers to a group of compounds.

During the period 1990-2001 there has been a decrease in UK emissions of CO_2, CH_4, N_2O, HFC and PFC but considerable increases in SF_6 emissions. The overall effect has been a decrease in global warming potential from UK emissions. Figure 2.1 shows greenhouse gas emissions (comprising CO_2 , CH_4 , N_2O , HFCs, PFCs and SF_6) as CO_2 equivalent[1] for 1990 to 2001. Reliable emission estimates of HFCs, PFCs, SF_6 and N_2O (from adipic acid production) are not available prior to 1990.

Figure 2.1 Total Global Warming Potential Associated with UK Emissions of GHGs



CO_2 is the major contributor to greenhouse gas emissions in the UK and arises predominately from the combustion of fossil fuels. Non-fossil fuel sources are more difficult to assess and include the emission and uptake of CO_2 from the global carbon cycle. Following internationally agreed conventions, the NAEI excludes emissions of CO_2 originating from recently photosynthesised carbon as these will be part of the carbon cycle. Hence emissions from biomass combustion, non fossil-fuel derived components of waste incineration, landfill and sewage treatment are not included in the total. Emissions of other pollutants from biomass combustion are included in the appropriate inventories. The NAEI also currently excludes CO_2 emissions from the effect of changing land use although these emissions are estimated in the UK Greenhouse Gas Inventory (Salway, 2002) and are discussed below.

Methane, like carbon dioxide, is naturally occurring and is part of the global carbon cycle. However, the magnitudes of sinks and sources of methane are not well known. Methane in the atmosphere is eventually oxidised to CO_2 and the most recent IPCC estimate of its lifetime in the atmosphere is 12±3 years (IPCC, 1996). Methane has a much greater warming effect on the climate than carbon dioxide (Table 2.1). The major anthropogenic sources of methane are waste disposal, agriculture, coal mining and leakage from the gas distribution system. Due to the nature of these sources the estimation of methane emissions is very uncertain although the methodologies are continuously being improved. Early estimates of methane emissions by sector were based on the findings of the Watt Committee on

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[1] Different pollutants can be expressed as a carbon equivalent emission by taking their global warming potential relative to CO_2 into account. This then allows comparisons across different pollutant species on a like for like basis.

Energy (Williams, 1994), however many have now been revised to take into account new information and to ensure consistency with the methodologies recommended by the IPCC 1996 Revised Guidelines (IPCC, 1997).
The third direct greenhouse gas, nitrous oxide (N_2O), is emitted from natural and anthropogenic sources (agriculture, biomass burning, coal combustion and some industrial processes). As N_2O has a GWP of 310, it is a powerful greenhouse gas. However, emissions from the UK are low, so the overall contribution to global warming is relatively small. A full set of detailed emission factors for man-made sources, e.g. combustion, are not yet available. However, emissions are estimated using the default values given in the guidelines and more detailed data on coal combustion based on UK literature.

The three industrial greenhouse gases included in the ‘basket of emissions’ agreed at Kyoto, namely hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6), have very high GWPs but the quantities emitted to the atmosphere are far smaller than the emissions of CO_2. Hence the contribution of these gases to global warming was equivalent to just 3% of the total contribution from CO_2 emissions in 1995 (MCG, 2000). These are gases with particular industrial applications; HFCs and PFCs are substitutes for chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC) which are being phased out under the Montreal Protocol due to their role in the depletion of ozone in the stratosphere. A more detailed description of the usage, emissions and methodology for calculating emissions of these gases is given by MCG (2000).

The following sections present the inventories for each of the six greenhouse gases. To date, most international attention has focused on carbon dioxide and methane. Hence estimates of these pollutants were included in the UK inventory a number of years before the other four pollutants. This is reflected in the longer time series of data available for carbon dioxide and methane. The overall accuracy of the inventories is also discussed. Full details of the methodology used to compile the inventory and the changes which have been made since the publication of the inventory for 1999 are included in Appendices 1 and 2, respectively which can be accessed from the methodology section of the NAEI website (http://www.naei.org.uk)

2.2 CO_2 EMISSION ESTIMATES

2.2.1 Total CO_2 Emissions

Carbon dioxide emissions in 2001 have reduced by 18% since 1970, as shown in Figure 2.2. However, this decline has not been steady, and peaks were observed in 1973 and 1979 which were due to the state of the economy, high oil prices and severe winters in these years. Emissions fell again during the early eighties reflecting the recession during this period and the coal miners strike of 1984. Since the mid-1980s the emissions profile has been much smoother showing an overall reduction in emissions. There are small increases in several sectors. The elevated emission from the domestic sector in 1996 is considered to be due to the colder than average winter (indicated by lower than average mean air temperatures).

The major emissions of carbon dioxide arise from the combustion of fossil fuels in power generation, and the transport, domestic and industrial sectors (Figure 2.2, Table 2.2). The level of emissions depends on the fuel mix and the fuel consumption data. Details of UK fuel consumption are given annually in the Department of Trade and Industry's Digest of United Kingdom Energy Statistics (DTI, 2001). The fuel consumption data used to calculate the pollutant emission totals in the NAEI are given in Table 2.3; fuels which are used as feedstocks are omitted (principally natural gas used for the production of ammonia, methanol and acetic acid and some use of LPG and OPG in petrochemical plants).

Figure 2.3 gives the CO_2 emissions mapped across the UK on a 1km x 1km grid. Fuel combustion sources are clearly dominant and occur in urban centres and across the road network. The mapping concept, and methodology, is outlined in Section 1.2.5.

Table 2.2 UK Emissions of CO_2 as Carbon by UN/ECE[1] Source Category and Fuel (Mtonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[2]											
Combustion in Energy Prod											
Public Power	57.0	58.3	54.1	44.1	43.5	39.6	40.6	38.8	41.9	44.4	29%
Petroleum Refining Plants	5.6	5.5	4.8	5.4	5.6	5.5	5.6	5.1	4.4	4.4	3%
Other Combustion & Trans.	8.2	2.9	3.8	4.8	5.3	5.4	5.8	5.9	5.8	6.0	4%
Combustion in Comm/Res											
Residential Plant	26.5	23.2	21.5	21.7	24.7	22.7	23.2	23.1	23.4	24.4	16%
Comm/Agricul Combustion	12.3	9.9	8.5	8.8	9.3	8.6	8.5	8.5	8.2	8.2	5%
Combustion in Industry											
Iron & Steel Combustion	1.5	0.4	0.7	1.9	2.0	2.0	1.9	1.9	1.8	1.6	1%
Other Ind. Combustion	46.8	29.8	23.8	22.0	22.2	22.4	21.8	21.6	21.0	21.9	14%
Production Processes	4.8	3.9	4.0	3.5	3.8	3.6	3.5	3.7	3.7	3.3	2%
Extr./Distrib. of Fossil Fuels	0.1	0.1	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0%
Road Transport	16.3	21.2	29.8	30.2	31.4	31.8	31.6	31.8	32.0	31.8	21%
Other Trans/Machinery											
Off-Road Sources	3.1	3.0	3.2	2.7	2.8	2.6	2.4	2.3	2.2	2.0	1%
Other[3]	2.3	2.0	1.7	1.7	1.7	1.7	1.7	1.6	1.6	1.5	1%
Waste	0.6	3.8	2.6	2.3	2.3	2.0	1.9	1.8	1.7	1.7	1%
Agricul & Land Use Change	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.2	0%
By FUEL TYPE											
Solid	90.3	70.6	61.4	42.7	39.6	34.4	34.4	30.5	31.9	35.9	24%
Petroleum	67.7	54.5	52.9	50.3	51.6	49.5	48.3	47.1	46.2	46.8	31%
Gas	22.7	32.2	38.8	50.7	57.8	58.7	60.7	63.7	65.0	64.1	42%
Non-Fuel	4.9	7.3	6.5	5.8	5.9	5.7	5.7	5.3	5.0	4.9	3%
TOTAL	**185.6**	**164.5**	**159.5**	**149.6**	**155.0**	**148.3**	**149.0**	**146.6**	**148.1**	**151.7**	**100%**

[1] UK emissions reported in IPCC format (Salway, 2002) differ slightly due to the different source categories used.

[2] See Annex 1 for definition of UN/ECE Categories

[3] Railways, civil aircraft, shipping, naval vessels and military aircraft.

Figure 2.2 Time Series of CO_2 Emissions (Mtonnes)

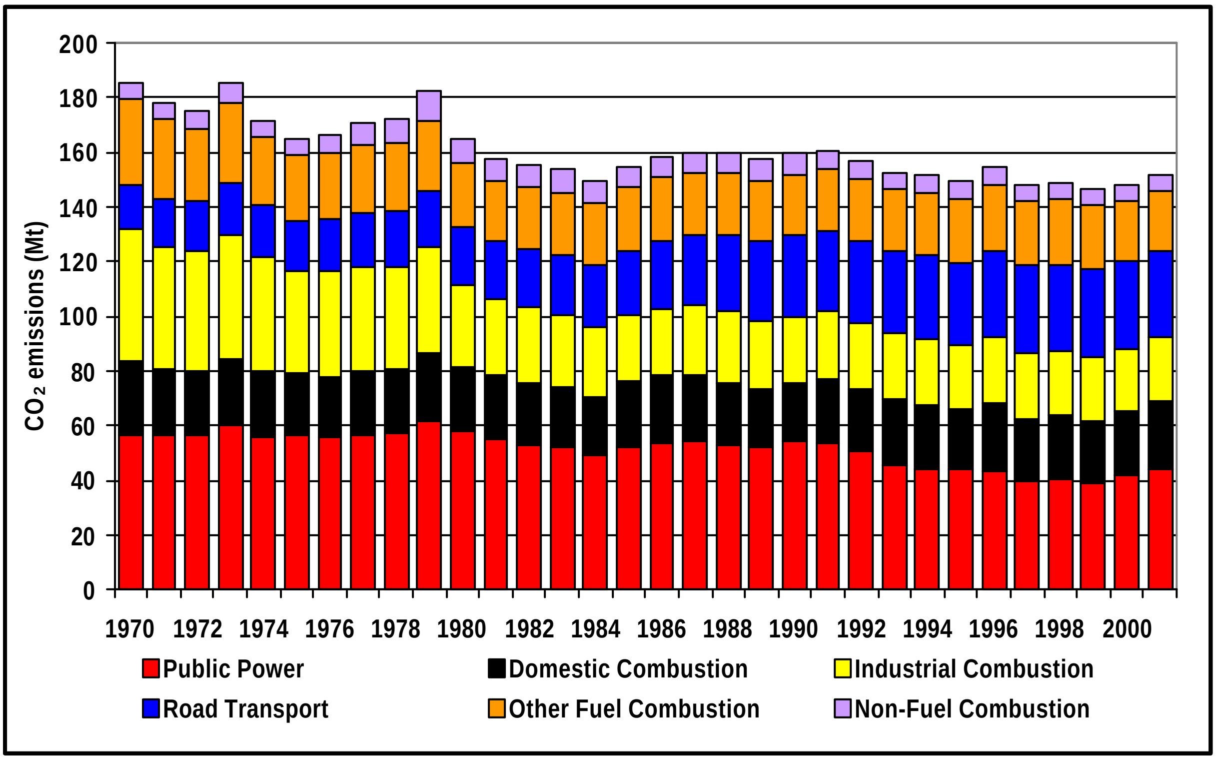
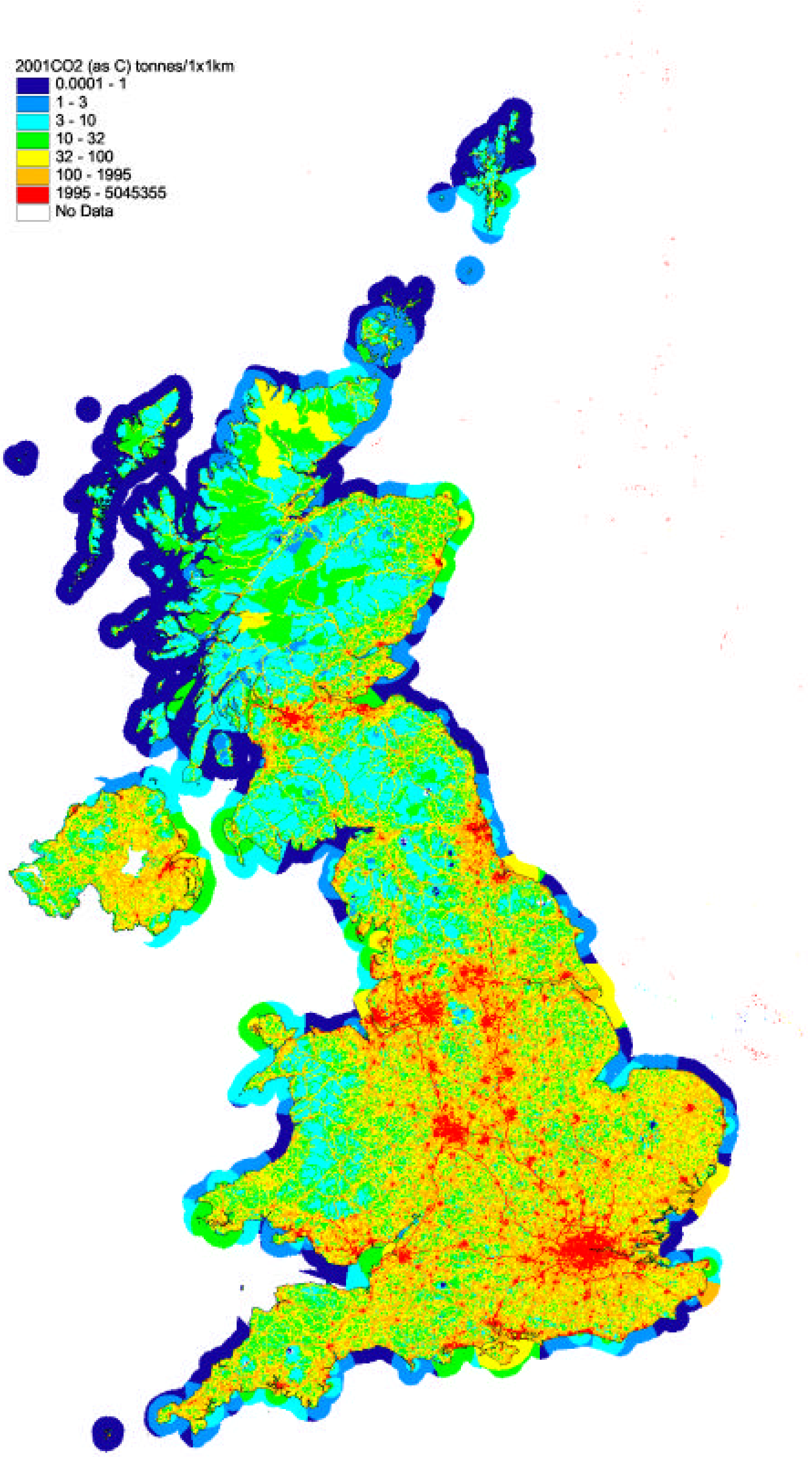


Figure 2.3 Spatially Disaggregated UK Emissions of CO_2



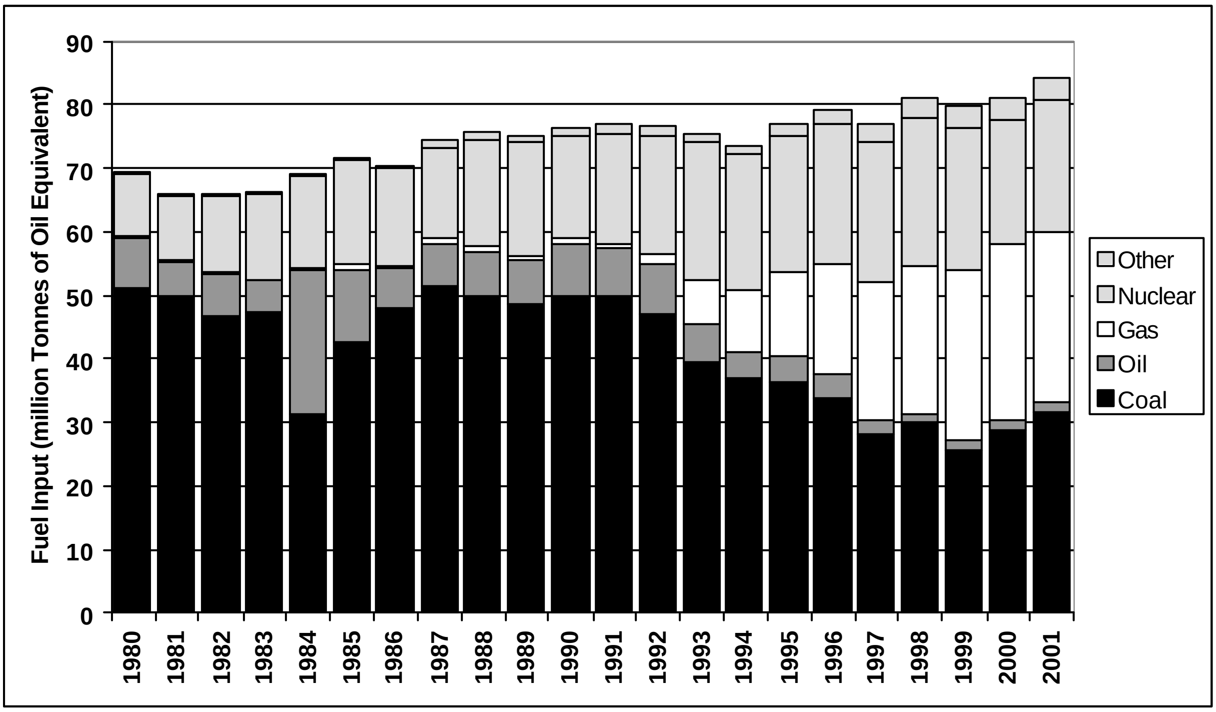
2.2.2 Electricity Supply Industry

The electricity supply industry is the major consumer of fossil fuels, and hence the major source of carbon dioxide emissions in the UK (Tables 2.2 and 2.3). There have been significant changes in the generating mix between 1980 and 2001, as shown in Figure 2.4. The level of CO_2 emissions is determined by both the fuel mix and the generating technology used. During the 1970s the electricity supply industry was dominated by coal and fuel oil fired thermal power stations, and coal and oil consumption increased to meet the rising demand for electricity. The use of coal for power generation peaked in 1980 at 89.6 Mt and has subsequently declined. The fall has not been steady, showing minima in 1982 and 1984 due to recession in the early 1980s and the miners strike of 1984. During the late 1980s and early 1990s, the closure of inefficient plants led to an overall increase in the thermal efficiency of the conventional thermal power plants, and the contribution of nuclear power generation increased with the greater utilisation of existing nuclear plants and the commissioning of Sizewell B in 1995. The use of oil generation peaked in 1972 and apart from increased consumption during the miners strike of 1984 has been in decline ever since. Two oil-fired stations were converted to burn Orimulsion® (an emulsion of bitumen and water) although this practice has been discontinued, largely on environmental grounds. More recently, the privatisation of the power industry has resulted in a move away from coal and oil generation towards combined cycle gas turbines (CCGT). Since 1970 the use of gas in power generation has increased by 99%, and further increases may be expected as and when more CCGT stations come on line.

Table 2.3 UK Fuel Consumption

Fuel	Consumer		1970	1980	1990	1995	1996	1997	1998	1999	2000	2001
Coal	Major Power Prod	Mtonnes	77	90	83	58	53	45	47	40	45	49
Coal	Industry	Mtonnes	22	9	8	6	5	5	4	4	3	4
Coal	Domestic	Mtonnes	20	9	4	3	3	3	2	3	2	3
Coal	Others	Mtonnes	38	16	14	10	10	10	10	9	10	9
Other Solid Fuels	All Consumers	Mtonnes	26	10	10	10	10	10	9	9	9	8
Motor Spirit	Road Transport	Mtonnes	14	19	24	22	22	22	22	22	22	21
Gas Oil	Road Transport	Mtonnes	5	6	11	14	14	15	15	16	16	16
Gas Oil	Industry	Mtonnes	5	5	3	3	3	3	3	3	3	4
Gas Oil	Others	Mtonnes	7	8	6	5	5	5	5	4	4	3
Fuel Oil	Major Power Prod	Mtonnes	12	6	6	2	2	1	1	1	1	1
Fuel Oil	Refineries	Mtonnes	4	4	2	2	2	2	2	2	1	2
Fuel Oil	Industry	Mtonnes	21	10	4	3	3	2	2	1	1	1
Fuel Oil	Others	Mtonnes	5	2	1	1	1	1	1	1	0	0
Orimulsion	Major Power Prod	Mtonnes	0	0	0	1	1	0	0	0	0	0
Burning Oil	Domestic	Mtonnes	2	2	2	2	3	3	3	2	2	3
Burning Oil	Others	Mtonnes	4	0	0	1	1	1	1	1	1	2
Aviation Turb. Fuel	Air Transport	Mtonnes	1	1	7	8	8	9	10	10	11	11
Other Pet. Products	All Consumers	Mtonnes	1	1	1	2	2	2	2	2	2	1
Petroleum Gases	Refineries	Mtherms	1011	987	1303	1382	1460	1378	1318	1279	1308	1194
Petroleum Gases	Others	Mtherms	700	717	680	858	858	760	742	728	687	755
Natural Gas	Major Power Prod	Mtherms	60	55	3	4540	6029	7633	8063	9622	9683	9454
Natural Gas	Industry	Mtherms	710	6616	7016	7967	8783	9152	9698	10185	10717	10726
Natural Gas	Domestic	Mtherms	627	8420	10250	11124	12824	11790	12144	12218	12622	12938
Natural Gas	Others	Mtherms	2206	2188	3021	3945	4375	4172	4382	4570	4659	4747
Other Gases	All Consumers	Mtherms	7009	1126	1371	1268	1339	1394	1397	1409	1433	1310

Figure 2.4 Generating Mix (1980-2001) Million Tonnes Oil Equivalent (Mtoe).

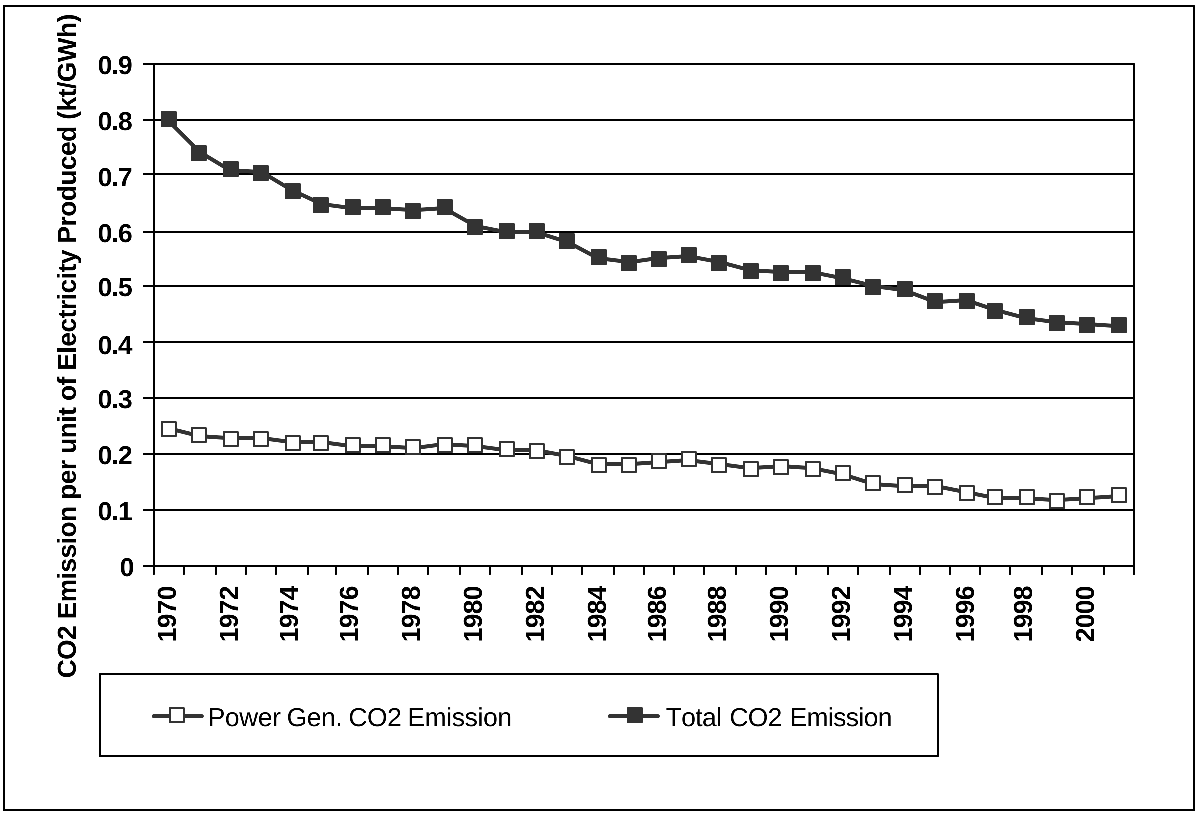


The effect of these changes in the power sector are clearly reflected in the carbon dioxide emissions. Since 1970 electricity generation has substantially increased but emissions have decreased by around 22%. Despite a slight increase in coal consumption between 1999 and 2001, emissions have fallen by 42% between 1990 and 2001. This is due specifically to:

- The greater efficiency of the CCGT stations compared with conventional coal fired stations - around 47% as opposed to 36%.
- The calorific value of natural gas (per unit mass carbon) being higher than that of coal and oil (the inventory takes account of unrefined gas or sour gas used by some plant).
- and to a lesser extent, the proportion of nuclear generated electricity increasing to 25%.

The overall effect of the fuel and technology changes are also clearly illustrated in Figure 2.5 which shows that the average CO_2 emission (from power generation) per kWh electricity generated decreases from 245 tonnes/GWh in 1970 to 125 tonnes/GWh in 2001. This trend is likely to continue into the future through the use of more advanced technology and abatement equipment. However, the extent to which nuclear power is used in the future is expected to have a large impact on air emissions. A decreased use of nuclear power for electricity production is expected to give rise to increased consumption of fossil fuels, and the increased use of coal between 1999 and 2001 is evident.

Figure 2.5 Average CO_2 Emission per unit of Electricity Generated (ktonne/GWh)



2.2.3 Domestic

The domestic use of coal (including anthracite) shows an overall decline between 1970 and 2001, falling by 85%; domestic use of smokeless solid fuels (including coke) has also fallen significantly. This reflects a trend away from solid fuels towards alternatives such as electricity and gas in the domestic sector. Over the same period the domestic use of natural gas has increased by a factor of over 20.

2.2.4 Industrial

The 2001 industrial emissions show a decrease of 52% since 1970. The curve exhibits peaks in 1973, 1979, and 1988 which are due in part to the cold winters in these years but mainly to the various levels of economic activity. The reduction in the industrial energy consumption since 1970 reflects the decline in a number of the energy intensive industries conducted in the UK and improvements in energy efficiency. Over this period, there has also been a marked move away from coal and oil consumption to gas and to a lesser extent electricity.

2.2.5 Transport

Total emissions from the transport sector have steadily increased since 1970. Of these, road transport emissions have risen by 100% and currently account for 94% of the total transport/mobile machinery emissions in 2001. This also equates to 21% of the total UK carbon dioxide emissions. Emissions fell a little during 1974-75 reflecting the increase in motor fuel prices after the oil crisis. The steady increase in fuel use by most forms of transport reflects the increased demand for transport in the UK between 1970 and 2001. The increased use of private motor vehicles has resulted in a 50% increase in the consumption of petrol from 1970 to 2001. However, petrol consumption has declined by 13% since 1990, which is a result of the increase in popularity of diesel cars, and the increased fuel efficiency of petrol driven cars. Increased use of goods vehicles is reflected in the increase in DERV consumption by a factor of more than 3 since 1970.

2.2.6 Agriculture/Forests/Land Use Change

The effect of changing land-use can result in either net emission or net absorption of CO_2 , particularly on a global scale. For example, forest clearing for agricultural use could be a net source of CO_2. Recently the Intergovernmental Panel on Climate Change agreed new guidelines for preparing national inventories (IPCC, 1997). Land use change and forestry estimates are included in the UK Greenhouse Gas Inventory (Salway et al, 2002) for the years 1990-2001. The estimates have yet to be included in the NAEI which covers the longer period 1970-2001 (the entry under "Agricul. & Land use change" in Table 2.2 corresponds to the CO_2 emissions arising from the application of lime to soils). For comparative purposes the land use change estimates of carbon emissions and *removals* are summarised in Table 2.4 (Milne, 2000). The new guidelines for Land Use Change and Forestry include emissions from liming of soils under 'D CO_2 Emissions and Removals from Soils'. These are already included in the NAEI under Agricultural Soils.

Table 2.4 Emissions & Removals of CO_2[1] (as CO_2) from Land Use Change & Forestry (2001)

Sources	**Emissions (ktonnes)**	**Removals (ktonnes)**
A. Changes in Forest and Other Woody Biomass Stocks [1]	-	10,516
B. Forest and Grassland conversion	-	-
C. Abandonment of Managed Lands	-	-
D. CO_2 Emissions and Removals from Soil [2]	11,254	-
E. Other [3]	3,583	1,100
Total	**14,836**	**11,616**

[1] Removals include removals to forest and soil litter, and to forest products.

[2] Emissions include removals to soil due to set aside of arable land

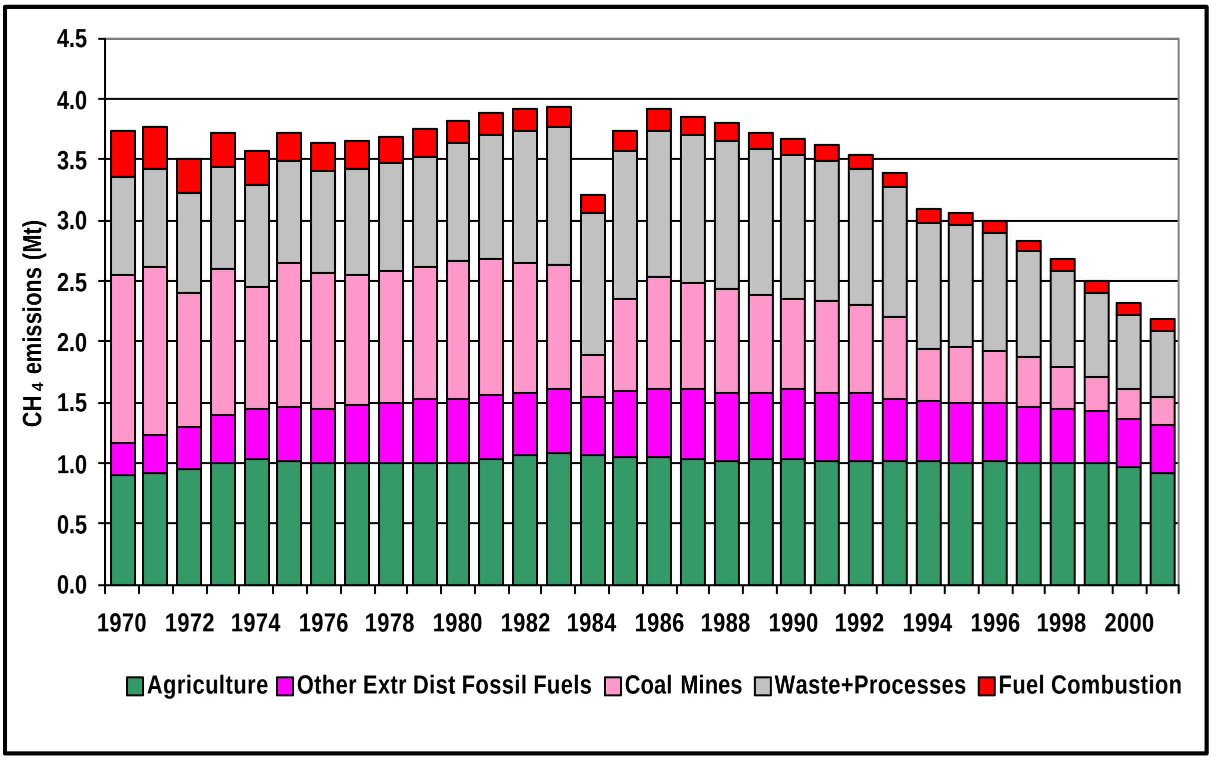
[3] Emissions include emissions from soil due to upland drainage, lowland drainage and peat extraction. Removals are increases in crop biomass.

2.3 CH_4 EMISSION ESTIMATES

2.3.1 Total CH_4 Emissions

Since 1970, the total methane emission in the UK has declined by 41%, although this has not been a steady decrease with emissions actually increasing throughout the seventies, reaching a peak in 1983 (Figure 2.6). There was a temporary fall in emissions in 1984 as a result of the miners strike reducing emissions from coal mines. The major sources of methane are landfill sites, livestock in the agricultural sector, leakage during the transmission and distribution of natural gas and coal mines (Table 2.5). The patterns of emissions from each of these sectors are discussed in the following sections.

Figure 2.6 Time Series of CH_4 Emissions (Mtonnes)



2.3.2 Landfill

Landfills are estimated to account for 22% of the UK's methane emissions in 2001. However, the estimation is relatively complex as it needs to take account of the wide range of different types of landfill sites in the UK and the variation in methane emissions during the lifetime of a landfill site. Methane emissions are derived from estimates of the amount of putrescible waste disposed of to landfill. Based on a model of the kinetics of anaerobic digestion the rate of methane production is estimated. Corrections are then applied for methane recovery, utilisation, flaring and oxidation by capping soil on the different landfill sites.

The methane emission from landfill shows a gradual increase to a peak in the mid 1980's followed by a decline because of the implementation of methane recovery systems. This trend is likely to continue since all new landfill sites after 1994 must collect and utilise (or flare) the methane emissions. Similarly, since 1994 the combustion of landfill gas has been required at all existing sites in the UK which have significant remaining capacity and where significant gas production is likely. The uncertainties associated with the estimation of methane from landfills are large and it is likely that these estimates will be further refined in the future as more information becomes available.

2.3.3 Agriculture

The largest source of methane emissions is the agricultural sector where the emissions arise from enteric fermentation in the guts of ruminant animals and from animal wastes. Emissions increased in the early seventies and have declined extremely slowly since 1974. The methane emission is dependent on the numbers and types of farm animals-with dairy cattle being the most significant source. The recent decline results from the reduction in dairy cattle numbers in line with the 1992 CAP reforms and gradual increases in animal productivity. It is expected that there will be further reductions in animal numbers leading to a continued reduction in the emission of methane from this sector.

Table 2.5 UK Emissions of Methane by UN/ECE[1] Source Category and Fuel (ktonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[2]											
Combustion in Energy Prod											
Public Power	2	2	6	12	14	16	19	24	28	31	1%
Petroleum Refining Plants	1	1	1	1	1	1	1	1	1	1	0%
Other Combustion & Trans.	1	1	1	3	3	4	3	8	7	8	0%
Combustion in Comm/Res											
Residential Plant	326	139	65	35	37	34	36	39	29	35	2%
Comm/Agricul Combustion	2	2	4	4	5	4	4	4	4	4	0%
Combustion in Industry	25	13	13	13	14	14	14	13	12	11	0%
Production Processes	9	8	8	7	8	7	5	4	4	3	0%
Extr./Distrib. of Fossil Fuels											
Coal Mines	1540	1269	818	504	473	445	378	310	264	243	11%
Gas Leakage	88	354	398	374	368	352	349	349	336	343	16%
Offshore Oil & Gas	13	42	92	71	66	66	60	43	39	42	2%
Gasoline Distribution	0	1	1	2	0	0	2	1	1	1	0%
Road Transport	22	25	30	23	22	21	19	17	15	14	1%
Other Trans/Machinery [3]	3	2	2	2	2	2	2	2	2	2	0%
Waste											
Landfill	764	889	1131	938	892	806	729	626	552	487	22%
Non Landfill Waste	32	66	55	65	65	59	60	56	58	56	3%
Agricul. & Land Use Change											
Animal Wastes	107	113	111	110	111	111	112	110	105	101	5%
Enteric Fermentation	782	872	911	899	907	895	895	895	865	813	37%
Non Livestock Agriculture	14	21	13	0	0	0	0	0	0	0	0%
By FUEL TYPE											
Solid	332	140	67	35	37	34	35	38	28	34	2%
Petroleum	30	31	34	27	27	25	23	21	19	17	1%
Gas	18	11	21	31	34	37	39	49	52	54	2%
Non-Fuel	3351	3636	3539	2968	2891	2740	2589	2395	2225	2090	95%
TOTAL	**3730**	**3819**	**3661**	**3062**	**2988**	**2836**	**2686**	**2503**	**2323**	**2195**	**100%**

1 UK emissions reported in IPCC format (Salway, 2002) differ slightly due to the different source categories used.

2 See Annex 1 for definition of UN/ECE Categories

3 Railways, civil aircraft, shipping, naval vessels, military aircraft and off-road sources.

2.3.4 Coal mining

Methane emissions from coal mining have reduced significantly during the past 20 years reflecting the reduction in UK coal production. In 1970 the emission accounted for 41% of total UK emissions but by 2001 this had reduced to just 11%. The strong correlation between coal production and methane emission is clearly illustrated in Figure 2.6 by the large fall in emissions during the 1984 miners strike. The reduction in mining emissions is the most important contributor to the overall fall in methane emissions.

2.3.5 Leakage from the Gas Distribution System

Methane leakage from the gas distribution system increased substantially between 1970 and 1990 reflecting the growth in gas sales for domestic use, and currently accounts for 16% of UK methane emissions. Emissions are estimated based on the throughput of gas and hence are rather uncertain. However, since 1990, emission estimates are based on actual leakage measurements made by British Gas (and successor companies) together with data on their gas main replacement programme. Emissions have declined as old mains are replaced by new ones.

2.3.6 Offshore Oil and Gas

Methane emissions from offshore activities only account for 2% of total UK emissions but have declined in recent years (despite the increase in the number of installations). Emissions are estimated on the basis of data provided by the operating companies to the UK Offshore Operators Association. Methane emissions from cold venting, natural gas use, well testing, fugitive emissions and flaring from offshore platforms are now all estimated separately. Of these, venting is the main source of methane. Other sources are fuel oil and gas combustion and emissions from tanker loading and unloading.

2.3.7 Sewage Disposal

Methane emissions from sewage disposal are fairly uncertain but are likely to be quite small. They depend on the mode of disposal: sea dumping; land spreading or incineration. The proportion disposed of in landfills is allocated to the landfill estimate. Emissions are likely to rise as a result of the EC Urban Waste Water Treatment Directive but the rate of increase will depend on the disposal routes adopted. The UK stopped dumping sewage at sea in 1998.

2.4 N_2O EMISSION ESTIMATES

The major source of nitrous oxide emissions in the UK are from agricultural activities. Lower levels of emissions arise from industrial processes, combustion processes in the power generation sector and from road transport (Table 2.6 and Figure 2.7).

Table 2.6 UK Emissions of Nitrous Oxide (N_2O) by UN/ECE[1] Category and Fuel (ktonnes)

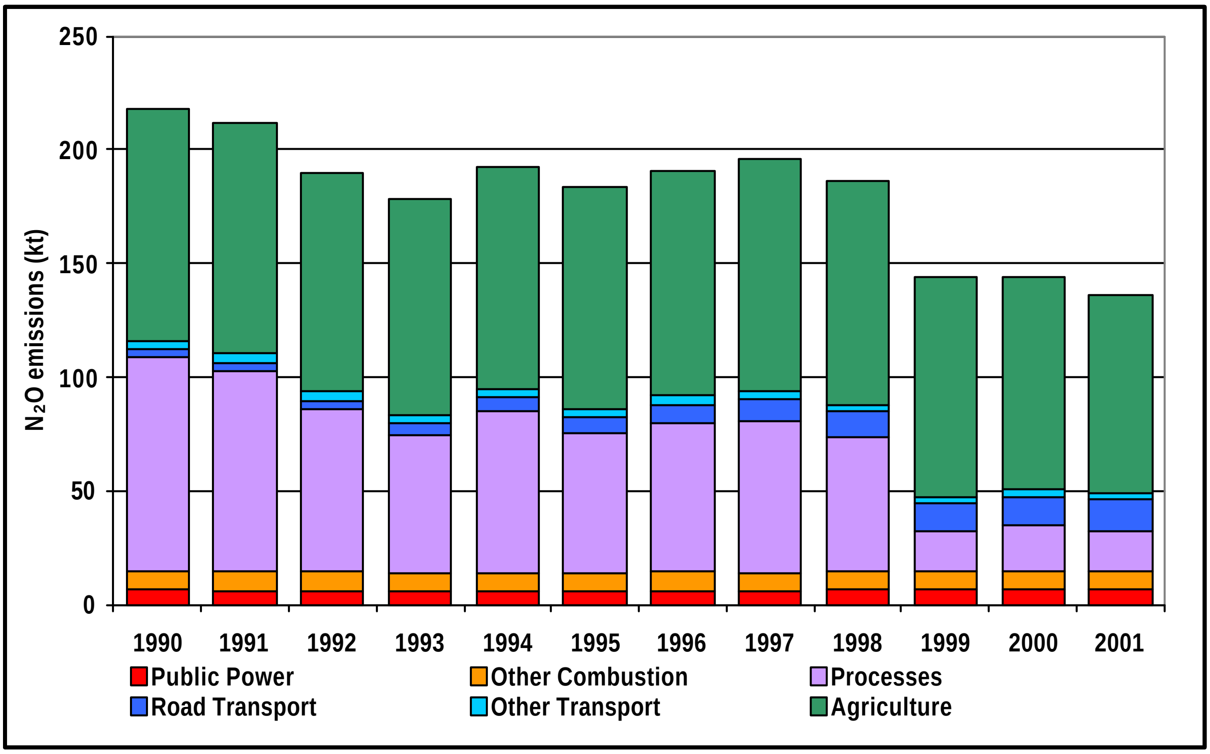
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001 %
BY UN/ECE CATEGORY[2]													
Combustion in Energy Prod													
Public Power	6.2	6.1	5.8	5.4	5.5	5.7	5.8	5.8	6.2	6.3	6.7	7.0	5%
Petroleum Refining Plants	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.2	0%
Other Combustion & Trans.	0.8	0.8	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.3	1.4	1.4	1%
Combustion in Comm/Res	1.2	1.3	1.2	1.2	1.1	0.9	0.9	0.8	0.8	0.8	0.7	0.8	1%
Combustion in Industry	2.0	2.1	2.3	2.1	2.0	2.0	1.9	1.8	1.7	1.7	1.5	1.6	1%
Production Processes	94.5	88.5	71.6	61.1	71.5	61.3	65.5	67.0	59.5	18.2	20.2	17.4	13%
Extract/Distrib Fossil Fuels	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Road Transport	3.3	3.4	3.8	4.7	5.9	7.1	8.5	9.7	10.8	11.9	12.8	13.6	10%
Other Trans/Machinery[3]	3.7	3.8	3.8	3.7	3.6	3.5	3.6	3.4	3.4	3.2	3.1	3.0	2%
Waste	3.7	3.7	3.7	3.7	3.7	3.7	3.8	3.8	3.8	3.8	4.0	3.7	3%
Land Use Change													
Animal Wastes	4.3	4.3	4.3	4.4	4.4	4.4	4.4	4.4	4.4	4.3	4.1	3.9	3%
Non Livestock Agriculture	98.2	97.7	92.4	90.7	93.1	93.6	94.2	97.1	94.3	92.4	88.9	83.2	61%
By FUEL TYPE													
Solid	8.6	8.6	8.3	7.1	6.6	6.1	5.6	4.9	4.9	4.3	4.3	4.9	4%
Petroleum	7.8	8.0	8.5	9.3	10.4	11.5	13.0	13.9	15.0	15.8	16.5	17.2	13%
Gas	1.2	1.2	1.3	1.9	2.5	2.9	3.6	4.3	4.6	5.3	5.6	5.5	4%
Non-Fuel	200.7	194.2	172.1	159.8	172.8	163.1	168.0	172.4	162.1	118.8	117.3	108.4	80%
TOTAL	**218.3**	**212.1**	**190.1**	**178.2**	**192.3**	**183.6**	**190.2**	**195.5**	**186.6**	**144.2**	**143.7**	**136.0**	100%

1 UK emissions reported in IPCC format (Salway, 2002) differ slightly due to the different source categories used.

2 See Annex 1 for definition of UN/ECE Categories

3 Including railways, shipping, naval vessels, military aircraft and off-road sources

Figure 2.7 Time Series of N_2O Emissions (ktonnes)



2.4.1 Agriculture

The calculation of emissions from agricultural soils and animal wastes have been considerably extended in recent years. In particular, the publication of the Revised 1996 IPCC Guidelines (IPCC, 1997) has enabled a greater number of sources to be considered.

The emissions from agricultural soils currently account for around 61% of total UK emissions. The most significant sources are fertiliser application and emissions indirectly from leaching.

2.4.2 Production Processes

The production processes sector is comprised of emissions from adipic acid manufacture (a feedstock for nylon) and nitric acid manufacture. This sector accounts for 13% of the total nitrous oxide emissions in 2001. The extent of the emission depends on the production of these acids, hence the time series reflects production levels. However, the UK manufacturer of adipic acid commissioned an abatement unit in 1998 which has significantly reduced the UK total emission.

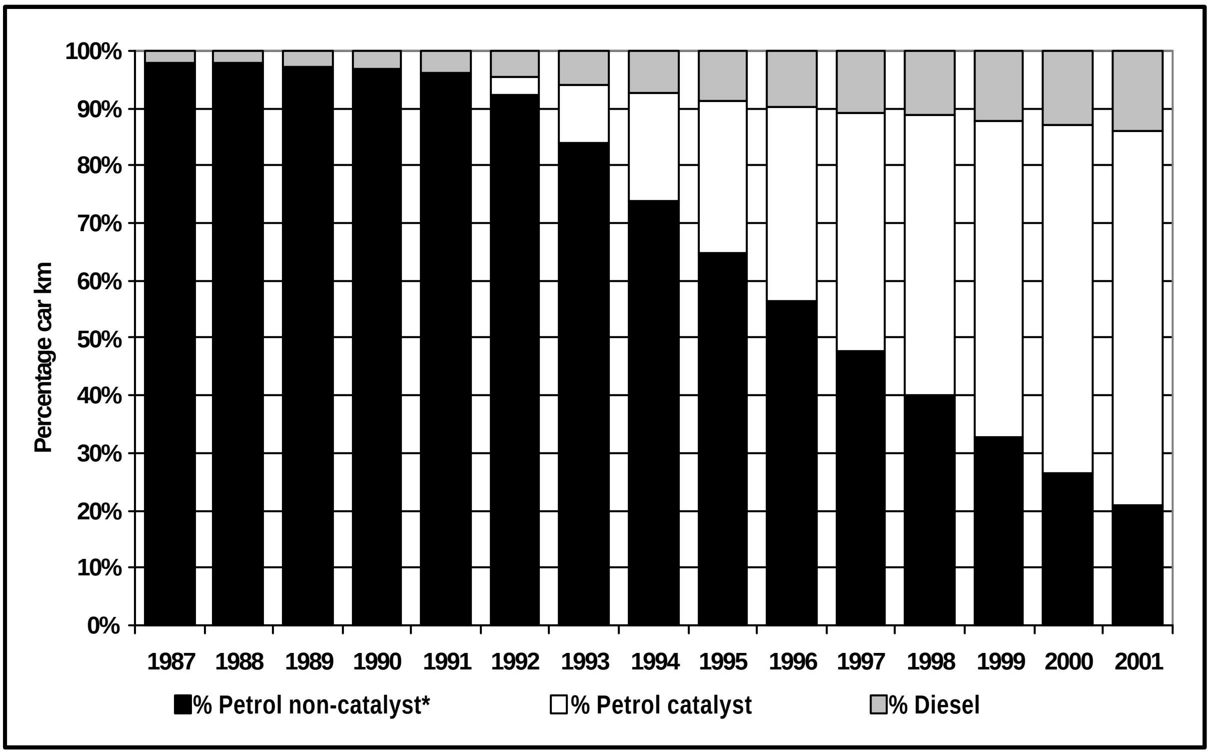
2.4.3 Power Generation

The contribution from public power generation has been relatively constant between 1990 and 2001 in spite of the trend away from coal towards natural gas combustion.

2.4.4 Road Transport

Emissions from the road transport sector have increased significantly since 1992. This is as a direct result of the introduction of three way catalytic converters which produce significantly larger emissions of nitrous oxide than cars not equipped with abatement technology. Between 1990 and 2001 the proportion of the car kilometres with converters has increased from <1% to 65% (Figure 2.8) and emissions of N_2O have increased by 76%. The contribution of road transport to the total N_2O emission is small, but is one of the few sources expected to consistently increasing with time. Conversely emissions of N_2O from the other significant sectors are expected to decrease with time.

Figure 2.8 The Growth in the Number of Car Kilometres from Cars with Catalytic Converters



*Includes cars with failed catalysts

2.5 HFCS, PFCS AND SF_6 EMISSION ESTIMATES

2.5.1 Hydrofluorocarbons

The UK emissions of HFCs are shown in Table 2.7. The emissions are reported in terms of their global warming potential (GWP). The HFC emissions comprise many species each with its own GWP, hence it is more helpful to express emissions in terms of GWP as Carbon equivalent. It is not currently possible to give emission estimates for individual HFCs because some of these are considered commercially sensitive data within the industries involved.

HFCs had limited usage primarily as refrigerants blended with CFCs. However, CFCs and HCFCs are being phased out under the Montreal protocol, and hence HFCs are now being used increasingly as:

- substitutes for CFCs and HCFCs in domestic, commercial and industrial refrigeration and air conditioning
- substitutes for CFCs in plastic foam blowing
- substitutes for CFCs for some medical aerosols
- substitutes for CFCs for industrial and specialist aerosols
- fire fighting fluids

Salway (2002) reports the emissions, estimation methodology and ongoing improvements in some detail. The UK reports both actual and potential emissions of HFCs, although here only the actual emissions are presented.

Refrigeration is the largest source and contributed 41% of the total in 2001. Here emissions arise due to leakage from refrigeration and air conditioning equipment during its life time and from losses during manufacture and the recovery of the refrigerants on decommissioning.

There has been a large decrease in emissions from “Halocarbon production” from 1998 to 1999. This is a result of an abatement system fitted to a plant producing HCFCs.

In the case of closed foams where the fluid is retained within the foam there will be some leakage from the foam during its lifetime and on disposal but with open foams all losses occur during manufacture. Since 1990, the use of HFCs in aerosols has greatly increased, and this source sector now accounts for 20% of the total emission.

The total 2001 HFC UK emission has decreased by 24% compared with the 1990 emission and is characterised by the increasing use of HFCs offset by the large reduction in emissions from halocarbon production between 1998 and 2001.

Table 2.7 UK Emissions of HFCs (ktonnes C equivalent)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
Halocarbon production	3102	3229	3357	3485	3614	3807	3898	4267	4510	1179	1025	866	37%
Foams & Firefighting	0	0	0	0	0	1	5	9	11	15	37	57	2%
Refrigeration	0	2	6	26	121	228	331	477	618	756	880	958	41%
Aerosols[1]	0	3	4	8	32	111	234	259	304	282	474	484	20%
Total	**3102**	**3234**	**3367**	**3519**	**3767**	**4147**	**4468**	**5012**	**5443**	**2233**	**2417**	**2366**	**100%**

[1] Includes metered dose inhalers.

2.5.2 Perfluorocarbons

Table 2.8 shows the UK emissions of PFCs reported as Ktonnes C equivalent. It is not currently possible to give emission estimates for individual PFCs because some of these are considered commercially sensitive data within the industries involved. PFCs had limited usage prior to the phase out of CFCs in the electronics and electrical industry. PFCs are now used in:

- etching processes in the semiconductor industry
- chemical vapour deposition in the electronics industry
- soldering processes
- leak testing of electrical components
- cooling electrical components , for example in supercomputers and radar systems.

Other uses include
- refrigerant blended with HFC
- firefighting in specialist applications
- cushioning in the soles of training shoes

Other minor uses of CFCs, which now use PFCs, were in cosmetics and as a tracer gas.

The largest source of PFCs for 2001, representing over half of the total, is from the electronics sector, where emissions arise from the manufacture of semiconductors. PFCs are also formed as a by-product of aluminium smelting. Emission from this sector account for 32% of the UK total in 2001. The emissions are caused by the anode effect which occurs when alumina concentrations become too low in the smelter. This can cause very high electrical current and decomposition of the salt - fluorine bath.

The fluorine released reacts with the carbon anode, creating PFC compounds CF_4 and C_2F_6 . Total emissions have declined by 69% since 1990 reflecting steps taken by the industry to reduce emissions.

Table 2.8 UK Emissions of PFCs (ktonnes C equivalent)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
Fire-fighting	0	0	0	0	0	0	0	1	1	1	1	1	1%
Aluminium Production	554	425	203	129	111	102	81	65	61	52	72	61	32%
Refrigeration	0	0	0	0	1	2	4	5	7	8	9	9	5%
Electronics & Training Shoes	68	64	58	92	155	194	194	123	103	119	120	121	63%
Total	**622**	**488**	**262**	**221**	**267**	**298**	**279**	**194**	**172**	**180**	**201**	**192**	**100%**

2.5.3 Sulphur Hexafluoride

SF_6 is used in the following applications:

- insulation medium in high voltage applications such as switchgear and circuit breakers
- cover gas in magnesium foundries to protect the molten magnesium from re-oxidising when it is cast
- degasser in aluminium casting applications, though its use in the UK is rather limited
- insulating gas in double glazing applications, replacing vacuum as an insulation technique
- plasma etching of polysilicon and nitrite surfaces
- atmospheric tracer for scientific studies
- cushioning in soles of training shoes

Table 2.9 shows the UK emissions of SF_6. The largest source is from magnesium manufacture, where SF_6 is used as a cover gas. It is not possible to recover the SF_6, and hence the total consumption of SF_6 is released to atmosphere- emissions from this sector account for 40% of the UK total in 2001. Emissions in 2001 are higher than those in 1990 because SF_6 has been increasingly used in place of SO_2.

The other main sources are from the manufacture of trainers, and electrical/electronic equipment. The use of SF_6 as a cushioning in trainers will be phased out in the near future. Emissions from the electrical insulation arise during the manufacture and filling of electrical switchgear and from leakage and maintenance during the equipment's lifetime. This application has only been in use for the last 20 to 30 years and little of the equipment has been decommissioned. It is expected that users will take great care over future fluid recovery so that emissions will be minimised. SF_6 emissions have increased by 164% since 1990.

Table 2.9 UK Emissions of Sulphur Hexafluoride (ktonnes C equivalent)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001 %
SF_6 Cover Gas	130	130	130	130	163	163	196	196	163	163	189	209	40%
Electrical Insulation	35	37	39	41	42	55	58	53	144	148	167	203	39%
Electronics & Trainers	0	12	25	39	52	65	71	76	81	87	92	98	19%
Electrical equipment	33	33	33	33	33	26	22	20	17	12	12	12	2%
Total	**198**	**212**	**227**	**242**	**289**	**309**	**346**	**344**	**405**	**409**	**461**	**522**	**100%**

2.6 ACCURACY OF EMISSION ESTIMATES OF GREENHOUSE GASES

Quantitative estimates of the uncertainties in the greenhouse gas emissions were calculated using direct simulation, a technique similar to Monte Carlo Simulation. This corresponds to the IPCC Tier 2 approach. This work is described in detail by Eggleston et al (1998) though the estimates reported here have been revised to reflect changes in the 2001 Inventory. (Salway et al, 1991)

Table 2.10 Uncertainty of the Emission Inventories

Pollutant	Estimated Uncertainty %
Carbon Dioxide	± 2
Methane	± 19
Nitrous Oxide [a]	-75% to +254%
HFCs	± 25
PFCs	± 19
SF_6	± 13

a - Skewed uncertainty distribution.

It should be noted that these uncertainties primarily arise from emission factor uncertainties. Activity data is considered to be more reliable and better characterised. As a result it can be assumed that the trends identified from time series plots are considerably more reliable than an absolute emission total.

3. Stratospheric Ozone Depletors

Ozone, ozone depletors and ozone forming compounds (ozone precursors) are all important atmospheric pollutants for differing reasons. Ozone itself is a gas which has an irritant effect on the surface tissues of the body, such as eyes, nose and lungs. Consequently at tropospheric levels (i.e. near the surface) ozone and ozone precursors are important pollutants. Ozone emissions are not estimated by the NAEI as the direct emissions are not significant compared with photochemical formation of ozone from ozone precursors. Estimating ozone concentrations in the troposphere requires modelling, and the input of information on ozone precursors. Consequently there is a need for emission estimates of ozone precursors, and these are given in this report (for location see Table 3.1 below).

Ozone naturally occurs in the stratosphere (higher layers of the earth's atmosphere) formed by the action of ultraviolet light from the sun on oxygen molecules. At this level, ozone is beneficial to health, filtering out harmful ultraviolet rays that can cause skin cancers. Chemicals which cause stratospheric ozone depletion must therefore be estimated.

Table 3.1 Location of Ozone Depletors and Precursors in this Report

Nitrous Oxide (N_2O)	Ozone Precursor	Chapter 5:Tropospheric Ozone
NMVOCs	Ozone Precursor	Chapter 5:Tropospheric Ozone
HFCs	Stratospheric Ozone Depletor	Chapter 2: Greenhouse Gases
PFCs	Stratospheric Ozone Depletor	Chapter 2: Greenhouse Gases

Evidence suggests that stratospheric ozone depletion is being caused by anthropogenic emissions of chlorine and bromine-containing substances (halocarbons) such as: CFCs, halons, and HCFCs. HCFCs are similar to CFCs but have a lower potential for depleting ozone and in some cases are being used as transitional replacements (for example in refrigeration equipment). Emissions of methyl chloroform, carbon tetrachloride and methyl bromide also contribute to the effect.

International agreement to limit the production and consumption (and hence emission) of ozone depleting substances and phase out use of these substances was reached in 1987 through the Montreal Protocol on Substances that Deplete the Ozone Layer. This has subsequently been strengthened by a number of Amendments. In addition, the EU introduced EC Regulation 3093/94 which in some cases adopted a faster timescale for the reductions. Overall this has led to substantial reductions in the production and consumption of these substances over the last 10 years.

The NAEI does not contain emissions inventories for all of these substances individually, although some of them, such as HCFCs, are included within the emissions for non-methane volatile organic compounds (see Section 5.5 and Appendix 6).

4. Air Quality Strategy Pollutants

4.1 INTRODUCTION

The original National Air Quality Strategy (NAQS) published in 1997 (DOE 1997) set out a framework of standards and objectives for the air pollutants of most concern (SO_2, PM_{10}, NO_x, CO, lead, benzene, 1,3-butadiene and tropospheric ozone). The aim of the strategy was to reduce the air pollutant impact on human health by reducing airborne concentrations. Different pollutants have differing timescales associated with human health impacts. Therefore concentrations during episodes (both Winter and Summer) are important for some pollutants, but less so for others.

The NAQS identified air quality standards for 8 priority pollutants based on the recommendations of the Expert Panel on Air Quality Standards (EPAQS) or WHO guidance where no EPAQS recommendation existed. EPAQS was set up by the Secretary of State for the Environment in 1991, and is a panel created to “advise, as required, on the establishment and application of air quality standards in the UK… taking account of the best available evidence of the effects of air pollution on human health…”. The NAQS has been subject to periodic review, with consultation documents being published in 1998 and 2000 (DETR 1998a, 2000).

The NAQS then evolved into the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (AQS for ESWNI), with the same goals. A second edition of the strategy was published in 2000 (DETR 2000), identifying further revisions and focused on the incorporation of air quality limit values in European Directives, and the impacts of devolution.

In 2002, following consultation, new objectives were announced for particles, benzene, carbon monoxide and polycyclic aromatic hydrocarbons. More details can be found at the Defra website (Defra news release 323/02). The situation for Scotland differs slightly- the Air Quality (Scotland) Amendment Regulations came into force on 12 June 2002. More detailed information can be found on the Scottish Executive website (Scottish Executive News Release SEen057/2002 on www.scotland.gov.uk). For Wales, the consultation paper on the same subject is available from the Welsh assembly web pages (http://www.wales.gov.uk).

In addition to the above, Local Authorities in the UK have a duty, under the 1995 Environment Act: Part IV, to review and assess air quality in their areas. The Air Quality Regulations 2000 define a staged process of review and assessment on the basis of guidance provided by Defra and the Devolved Administrations. The first stage primarily involves the collection of existing data on air quality measurements and emission sources for the 8 pollutants of interest in the AQS for ESWNI. These data are then used to define whether there is likely to be an air quality problem in a specific future year (depending on pollutant). The second and third stages require the use of increasingly sophisticated monitoring and modelling tools to identify hotspots of pollution and to determine whether or not the relevant air quality objectives will be met in each area.

The NAEI is being used as an important source of data for the compilation of appropriate local inventories. Table 4.1 summarises the total 2001 emissions of the 9 priority pollutants covered by the AQS for ESWNI.

Table 4.1 Total UK Emissions of AQS Pollutants

Pollutant	**Total 2001 emission (ktonnes)**
PM_{10}	182
Carbon Monoxide	3737
Benzene	15.4
1,3 Butadiene	4.5
Nitrogen oxides	1680
Sulphur dioxide	1125
Tropospheric Ozone	NS[1]
Lead	0.19
PAH[2]	2.19

[1] No significant ozone emissions from anthropogenic sources

[2] Benzo[a]pyrene is used as an indicator for PAH, but the emission total given here corresponds to the USEPA 16 (see Section 6.2).

The following sections provide a discussion of the UK emissions for particulate matter, carbon monoxide, benzene and 1,3-butadiene whilst a full discussion of the other pollutants is included in other chapters of this report as indicated in Table 4.2.

Table 4.2 Location of Emissions and Discussion of AQS Pollutants

Pollutant	**Location**
PM_{10}	Chapter 4: AQS Pollutants
Carbon Monoxide	Chapter 4: AQS Pollutants
Benzene	Chapter 4: AQS Pollutants
1,3 Butadiene	Chapter 4: AQS Pollutants
Nitrogen oxides	Chapter 5: Acidifying Gases & Ozone Precursors
Sulphur dioxide	Chapter 5: Acidifying Gases & Ozone Precursors
Tropospheric Ozone	Chapter 5: Acidifying Gases & Ozone Precursors
Lead	Section 6.3: Heavy Metals
PAH	Section 6.2: Persistent Organic Pollutants

4.2 PARTICULATE MATTER

4.2.1 Introduction

Historically, interest in particulate matter focused mainly on smoke which can cause health problems especially in combination with other pollutants. The classic example was emissions of smoke and sulphur dioxide leading to the London smogs in the 1950s and early 1960s when several thousand excess deaths were recorded. Smoke emissions have fallen significantly as a result of the Clean Air Act eliminating domestic coal combustion in many urban areas. However, there is increasing interest in the measurement of fine particles, such as those arising from the combustion of diesel fuel in the transport sector, and aerosol concentrations in the atmosphere from other sources which may have harmful effects. Recent epidemiological evidence is linking concentrations of particles in the atmosphere with human health effects. Indeed, current ambient mass concentrations are thought to be sufficient to lead to increased mortality and morbidity (EPAQS, 1995).

Particles can vary widely in size and composition. Particles larger than about 30 μm (a m is a "micrometre", or one thousandth of a millimetre) fall rapidly under gravity and those larger than about 100 μm fall out of the atmosphere so rapidly they are not usually considered. At the other end of the size scale are particles less than a tenth of a µm which are so small they do not fall under gravity appreciably, but coagulate to form larger particles that are then removed from the atmosphere.

The US PM_{10} standard was a monitoring standard designed to measure the mass of particles less than 10 µm in size (more strictly, particles that pass through a size selective inlet with a 50% efficiency cut-off at 10 µm aerodynamic diameter). This corresponds to the International Standards Organisation thoracic convention for classifying those particles likely to be inhaled into the thoracic region of the respiratory tract. The epidemiological evidence of the effects of particulates shows good correlation in the UK between PM_{10} concentrations and mortality or morbidity (EPAQS 1995, 2001). Therefore PM_{10} has become the generally accepted measure of particulate material in the atmosphere in the UK and in Europe. There is also an increasing interest in the correlation between $PM_{2.5}$ and health indicators. PM_{10} measurements have been made in the UK for a number of years (see http://www.airquality.co.uk/archive/index.php) and their emissions have been included in the NAEI since 1995.

For many years the monitoring of particulate levels was based on the measurement of “Black Smoke”. Levels were estimated using a simple non-gravimetric reflectance method in which air is sampled through a filter and the resulting blackening measured. The method was calibrated for domestic coal smoke. When most of the emissions come from coal combustion the blackening should be approximately proportional to the mass concentrations. In the 50s and 60s, domestic coal combustion was the dominant source of black smoke and hence this method gave an indication of the concentration. The NAEI estimates of black smoke emissions were extended in 1988 to include emissions from all fuel combustion. Prior to 1988 only emissions from coal combustion had been estimated and published in the DOE Digest of Environmental Statistics.

Smoke from different sources has a different blackening effect and so there is no simple relationship between black smoke and the mass of particulate emissions. For example, typically diesel emissions have a blackening effect three times greater, mass for mass, than coal emissions, while petrol emissions are effectively an order of magnitude less. Black smoke is a poor indicator of the concentrations of particulates in the atmosphere. Current interest and the AQS is focused on PM_{10} (particulate matter less than 10 m i.e. 10 millionths of a metre) and smaller size fractions (EPAQS, 1995). However, black smoke has been shown to have relationships with health effects and is still used as an indicator.

For completeness the following sections present emission estimates and discussion for PM_{10} , $PM_{2.5}$, $PM_{1.0}$, $PM_{0.1}$. Black Smoke is included in a summarised format.

4.2.2 PM_{10}

4.2.2.1 Sources of emissions

PM_{10} in the atmosphere arises from two sources. The first is the direct emission of particulate matter into the atmosphere from a wide range of sources such as fuel combustion, surface erosion and wind blown dusts and mechanical break-up in, for example, quarrying and construction sites. These are called 'primary' particulates. The second source is the formation of particulate matter in the atmosphere through the reactions of other pollutants such as sulphur dioxide, nitrogen oxides and ammonia to form solid sulphates and nitrates, as well as organic aerosols formed from the oxidation of NMVOCs. These are called 'secondary' particulates. This inventory only considers primary sources. For further information on secondary particulate see the third Quality of Urban Air Review Group report (QUARG, 1996) and the report from the Airborne Particles Expert Group (APEG, 1999)- see http://www.airquality.co.uk/archive/index.php and http://www.defra.gov.uk/environment/airquality/airbornepm/index.htm respectively.

There is currently a programme sponsored by Defra and the Society of Motor Manufacturers and Traders (SMMT) to measure PM_{10} emissions from road transport. This programme has developed measurement techniques and aims to produce improved PM_{10} emission factors, particulate characterisation and particle size distribution.

The main sources of primary PM_{10} are briefly described below:

- Road Transport. All road transport emits PM_{10}. However diesel vehicles emit a greater mass of particulate per vehicle kilometre than petrol-engined vehicles. Emissions also arise from brake and tyre wear and from the re-entrainment of dust on the road surface. Emission estimates for the resuspension (or "re-entrainment") of dust have been made. However this does not fall within the UN/ECE reporting format and consequently has been reported separately.

- Stationary Combustion. Domestic coal combustion has traditionally been the major source of particulate emissions in the UK. However, the use of coal for domestic combustion has been restricted in the UK by the Clean Air Acts, and as a result other sources are more important nationally. Domestic coal can still be a significant source in some smaller towns and villages, in Northern Ireland and in areas associated with the coal industry. Other fossil fuels emit PM_{10}, but emissions from gas use are small. In general, particles emitted from combustion are of a smaller size than from other sources.

- Industrial Processes. These include the production of metals, cement, lime, coke, and chemicals, bulk handling of dusty materials, construction, mining and quarrying. Emissions from these sources are difficult to quantify due to the contribution of fugitive emissions (i.e. those diffuse emissions which are released directly into the atmosphere from a process rather than being collected in a controlled manner and then vented to atmosphere). Few UK measurements are available for these fugitive releases. Nonetheless, there have been substantial improvements in the estimation of PM_{10} emissions from industrial processes in recent years. Usually a substantial fraction of the particles from these sources is larger than 10 µm but the large quantities emitted ensure that the fraction less than 10 µm is still substantial.

4.2.2.2 PM_{10} Emission estimates

Emissions of PM_{10} are shown in Table 4.3 and Figure 4.1. Emissions of PM_{10} from the UK have declined since 1970. This is due mainly to the reduction in coal use. Domestic emissions have fallen from 222 ktonnes (41% of the total emission) in 1970 to 33 ktonnes (18%) in 2001.

Emission estimates for the resuspension of dust from roads is not included in the standard UN/ECE reporting format (and hence not included in Table 4.3). However for completeness it is given in Table 4.4 below. Estimates for resuspension are based on the deposition of primary particles from all UK sources (including vehicle tailpipes and from brake and tyre wear) that are returned to the air from the turbulence of passing vehicles. As such, resuspension to some extent double counts the emissions, but is important in reconciling road side concentration measurements.

Table 4.3 UK Emissions of PM_{10} by UN/ECE Source Category and Fuel (ktonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[1]											
Combustion in Energy Prod											
Public Power	67	76	70	38	35	24	25	20	21	18	10%
Petroleum Refining Plants	5	5	3	4	4	4	4	3	3	2	1%
Other Combustion & Trans.	16	2	0	0	0	0	0	0	0	0	0%
Combustion in Comm/Res											
Residential Plant	222	102	52	33	35	33	33	34	28	33	18%
Comm/Agricul Combustion	22	11	8	6	6	7	6	5	5	5	3%
Combustion in Industry											
Iron & Steel Combustion	17	8	8	7	6	6	5	4	4	3	2%
Other Ind. Combustion	79	38	31	29	27	25	24	22	18	20	11%
Production Processes											
Processes in Industry	17	14	17	16	16	16	16	15	13	13	7%
Construction	8	3	4	4	4	4	4	4	4	4	2%
Quarrying	22	21	29	26	23	24	23	21	21	21	11%
Road Transport											
Combustion	38	45	53	46	45	41	37	36	31	30	16%
Brake & Tyre Wear	2	3	4	4	4	4	4	4	4	5	2%
Other Trans/Machinery	15	13	13	11	12	11	11	10	10	9	5%
Waste[2]	2	4	3	2	2	2	2	2	2	1	3%
Agricul & Land Use Change	11	12	12	12	13	13	14	14	14	14	8%
By FUEL TYPE											
Solid	358	198	138	84	80	68	66	62	52	57	31%
Petroleum	89	79	76	67	66	59	55	52	46	44	24%
Gas	5	6	7	8	9	9	10	10	10	10	6%
Non-Fuel	91	76	89	80	77	77	77	72	69	87	39%
TOTAL	**542**	**358**	**309**	**239**	**233**	**213**	**207**	**196**	**178**	**178**	100%

1 See Annex 1 for definition of UN/ECE Categories

2 Excludes emissions of 3.8 ktonnes from foot and mouth animal pyres. See Chapter 9.

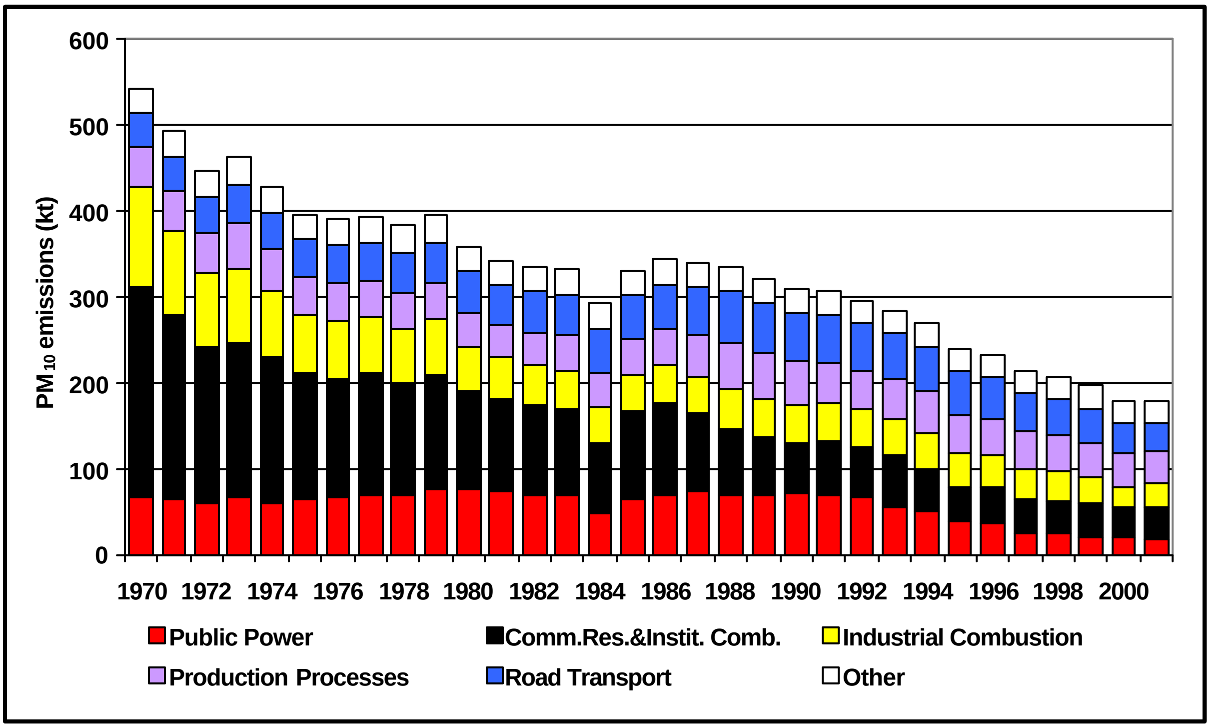
Table 4.4 PM_{10} Emission Estimates from Resuspension (ktonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001
Resuspension from Road Trans	8.2	11.2	16.9	17.8	18.3	18.7	19.0	19.3	19.4	19.6

The geographical disaggregation of emissions is shown in Figure 4.2. There is a clear distinction between the important sources in rural and urban areas. Indeed, many of the sources do not occur inside towns and cities. While road transport accounts for only 20% of national emissions, it can account for up to 80% of primary emissions in urban areas such as London (Buckingham *et. al.*, 1997).

Emissions from electricity generation have also recently been declining (since 1991) despite a significant growth in the electricity generated between 1970 and 2001. This is due to the move away from coal to natural gas and nuclear power for electricity generation and to improvements in the performance of electrostatic precipitators at coal-fired power stations. Also the installation of flue gas desulphurisation at two power stations have reduced particulate emissions further.

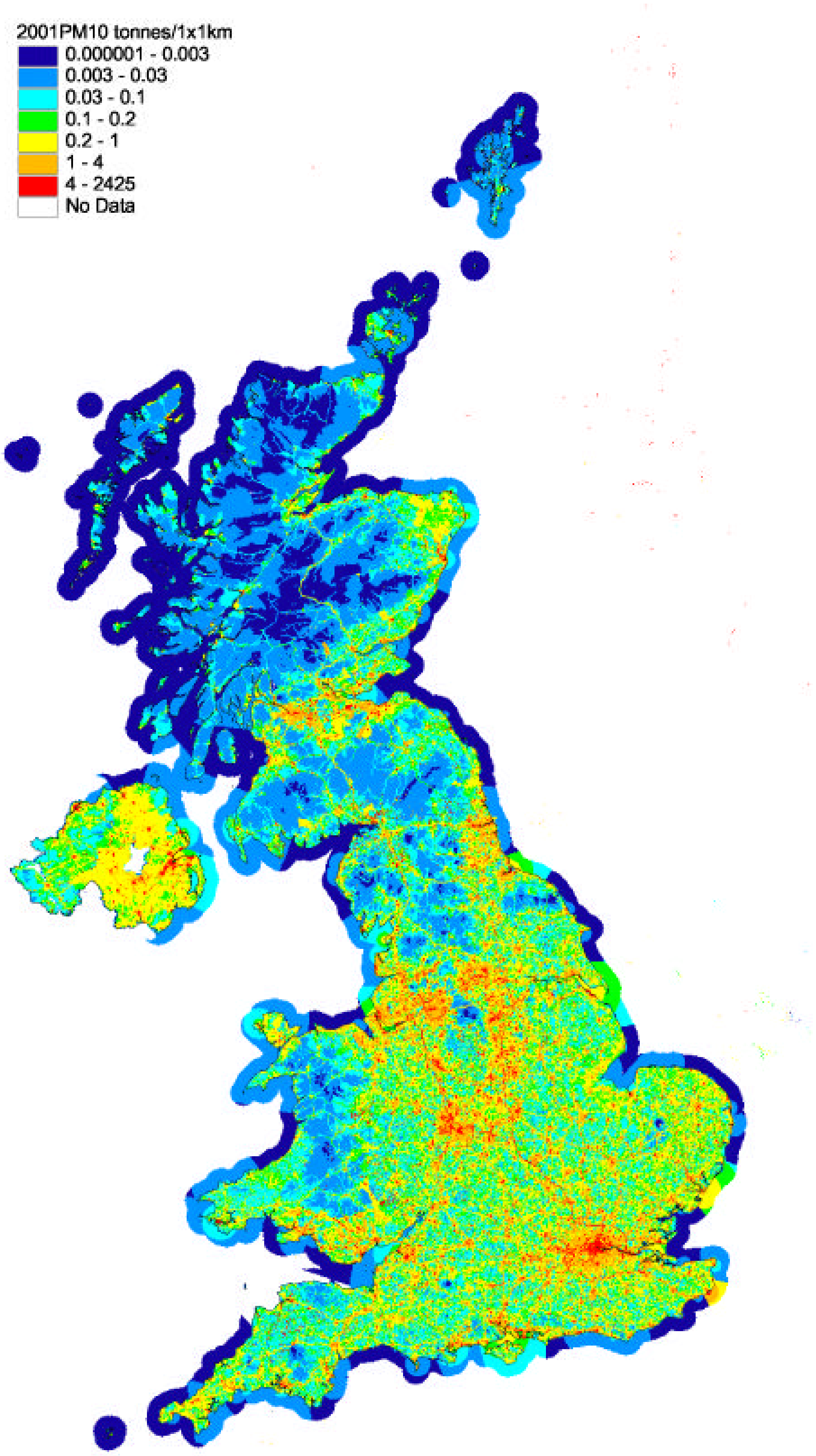
Figure 4.1 Time Series of PM_{10} Emissions (ktonnes)



Emissions from road transport have not increased, but the contribution to the total emission has increased with time due to other sectors decreasing. The contribution to the total UK emission has risen from 7% in 1970 to 19% in 2001. In urban areas with little industrial activity, where public power and industrial processes do not make a significant contribution, the contribution of road transport to emissions will be even higher; for example as much as 80% of primary emissions in London. The main source of road transport emissions is exhaust from diesel engine vehicles. Emissions from diesel vehicles have been growing due to the growth in heavy duty vehicle traffic and the move towards more diesel cars, (which diesel cars have increased from 3% to 14% of the UK car fleet between 1990 and 2001). Since around 1992, however, emissions from diesel vehicles have been decreasing due to the penetration of new vehicles meeting tighter PM_{10} emission regulations ("Euro standards" for diesel vehicles were first introduced in 1992).

Among the non-combustion and non-transport sources, the major emissions are from industrial processes, the most important of which is quarrying whose emission rates have remained fairly constant. Other industrial processes, including the manufacture of steel, cement, lime, coke, and primary and secondary non-ferrous metals, are collectively important sources of particulate matter although emissions from individual sectors are relatively insignificant.

Figure 4.2 Spatially Disaggregated UK Emissions of PM_{10}



4.2.3 Finer Particulates: $PM_{2.5}$, $PM_{1.0}$ and $PM_{0.1}$

Inventories for $PM_{2.5}$, $PM_{1.0}$ and $PM_{0.1}$ have been estimated from the PM_{10} inventory and the mass fractions in these size ranges available for different emission sources and fuel types. A total of 33 different size distributions covering $PM_{2.5}$ and $PM_{1.0}$ emissions from different source sectors were taken from the USEPA (1995) as being applicable to sources in the UK; a fewer number of sectors with size fractions in the $PM_{0.1}$ range were available from the study by the TNO Institute of Environmental Sciences, Energy Research and Process Innovation in the Netherlands for the Dutch National Institute of Public Health and Environment (RIVM) (TNO, 1997) which produced a particulates emissions inventory for Europe. In general, combustion processes emit a higher proportion of fine particles (<2.5 μm) than mechanical sources such as quarrying and construction. Gaseous fuels also tend to emit finer particles than petroleum and solid fuels.

Each of the detailed source sectors for which a PM_{10} emission is estimated (a total of 236 individual sectors and sub-sectors) were allocated an appropriate size distribution and used to calculate emission inventories for $PM_{2.5}$, $PM_{1.0}$ and $PM_{0.1}$. The results are shown in Tables 4.5-4.7 in the same format as for the PM_{10} inventory.

Figures 4.3-4.5 show trends in emissions of each particle size by source sector. The results show a comparable decline in emissions of each particle size since 1990, although the $PM_{0.1}$ size fractions indicate a larger decrease. Between 1990 and 2000, UK emissions of PM_{10} fell by 40%, whereas emissions of $PM_{2.5}$ fell by 28%, $PM_{1.0}$ by 28% and $PM_{0.1}$ by 40%. There is a gradual change in the relative source contribution with particle size. This is illustrated in Figures 4.2 to 4.5 which show the contribution of each sector to PM_{10}, $PM_{2.5}$, $PM_{1.0}$ and $PM_{0.1}$ emissions from 1990 to 2000. Road transport becomes an increasingly important sector as the particle size decreases. In 2000, it accounted for 18% of PM_{10} emissions, but 43% of $PM_{0.1}$ emissions.

Table 4.5 UK emissions of PM$_{2.5}$ by sector (ktonnes) estimated for the mass fraction of particles below 2.5 μm in each sector in the PM$_{10}$ inventory

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
Comb. in Energy Prod/Trans	34	34	32	27	25	20	19	14	14	12	12	10	10%
Combustion in Comm/Resid	27	28	27	27	24	20	22	20	20	21	18	20	20%
Combustion in Industry	28	28	29	28	27	25	24	22	20	18	15	16	16%
Production Processes	19	18	17	17	18	17	17	17	16	15	15	14	14%
Road Transport	47	47	46	45	45	43	41	38	35	34	30	29	29%
Other Transport	10	11	10	10	9	9	9	9	9	8	8	7	7%
Waste Treatment & Disposal	3	3	3	3	3	2	2	2	2	2	2	2	2%
Agriculture/Forestry	2	2	2	2	2	2	2	2	2	2	2	2	2%
TOTAL	171	171	167	159	153	138	136	123	119	112	101	101	100%

Table 4.6 UK Emissions of PM$_{1.0}$ by Sector (ktonnes) Estimated for the Mass Fraction of Particles below 1 μm in each Sector in the PM$_{10}$ Inventory

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
Comb in Energy Prod/Trans	16	15	15	13	12	10	10	7	8	7	7	6	8%
Combustion in Comm/Resid	19	20	19	19	16	13	15	14	14	15	12	14	19%
Combustion in Industry	18	17	18	17	17	16	15	14	12	11	9	10	14%
Production Processes	9	9	9	9	9	8	8	8	8	8	7	7	10%
Road Transport	42	42	41	40	40	38	36	33	31	30	26	26	35%
Other Transport	9	10	9	9	8	8	9	8	8	8	7	7	9%
Waste Treatment & Disposal	3	3	3	3	3	2	2	2	2	2	2	2	2%
Agriculture/Forestry	2	2	2	2	2	2	2	2	2	2	2	2	3%
TOTAL	**118**	**118**	**115**	**110**	**107**	**97**	**96**	**88**	**85**	**81**	**73**	**73**	100%

Table 4.7 UK Emissions of PM$_{0.1}$ by Sector (ktonnes) Estimated for the Mass Fraction of Particles below 0.1 μm in each Sector in the PM$_{10}$ Inventory

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001 %
Comb. in Energy Prod/Trans	6	6	6	5	5	4	4	3	3	3	3	3	8%
Combustion in Comm/Resid	3	3	3	3	3	3	3	3	3	3	3	3	9%
Combustion in Industry	8	8	8	8	8	7	7	7	6	6	5	5	16%
Production Processes	2	2	2	2	2	2	2	2	2	2	2	2	6%
Road Transport	22	22	22	22	22	21	20	19	17	17	15	15	49%
Other Transport	2	2	2	2	2	2	2	2	2	2	2	1	5%
Waste Treatment & Disposal	0	0	0	0	0	0	0	0	0	0	0	0	1%
Agriculture/Forestry	2	2	2	2	2	2	2	2	2	2	2	2	7%
TOTAL	**46**	**46**	**45**	**44**	**44**	**41**	**40**	**37**	**35**	**34**	**31**	**30**	100%

Figure 4.3 Time Series of PM$_{2.5}$ Emissions (ktonnes)

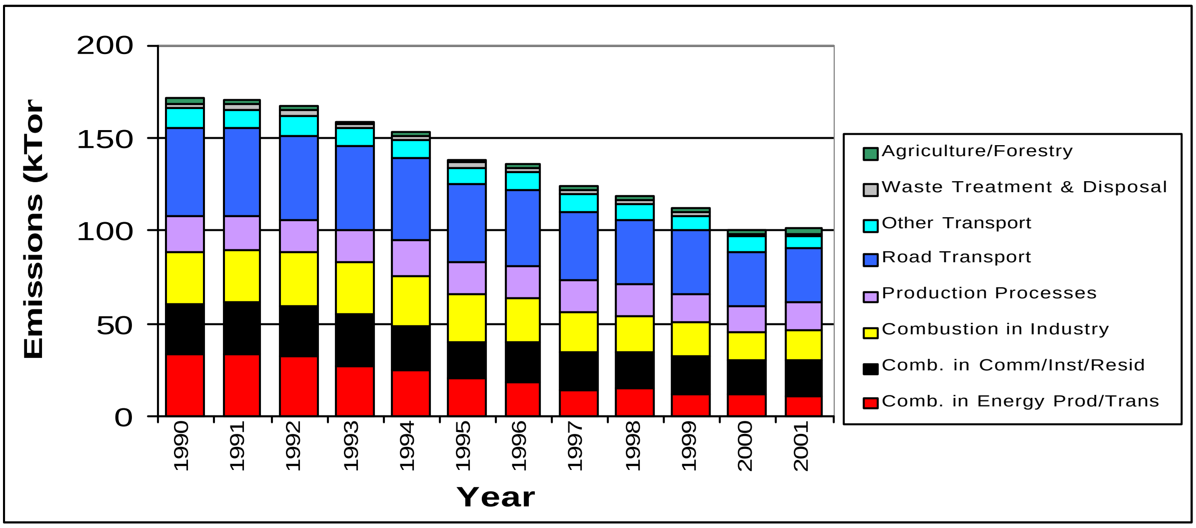


Figure 4.4 Time Series of PM$_{1.0}$ Emissions (ktonnes)

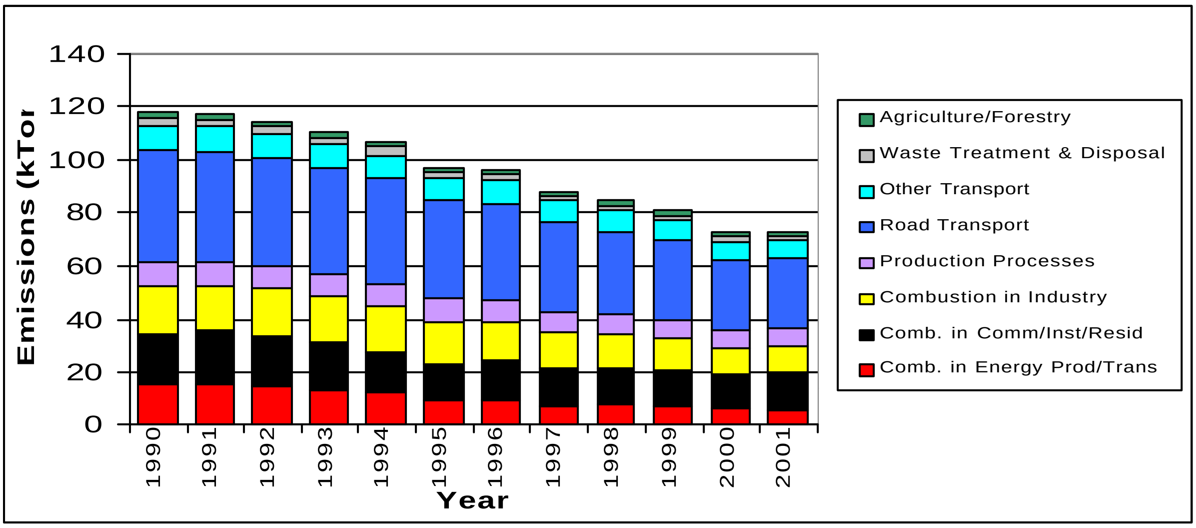
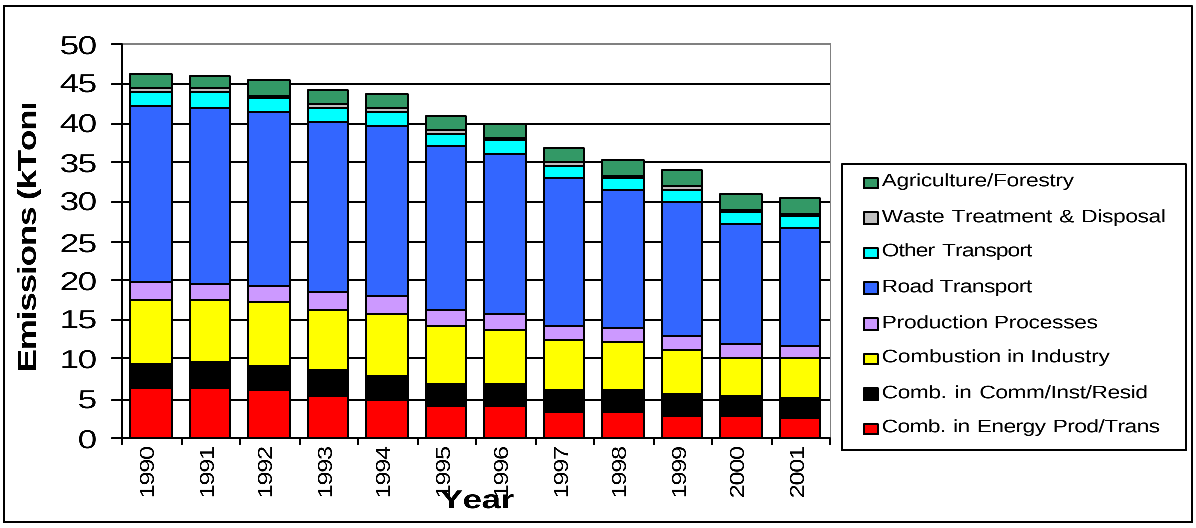


Figure 4.5 Time Series of PM$_{0.1}$ Emissions (ktonnes)



4.2.4 Black Smoke

There has been less interest in the emissions of black smoke in recent years. This is because PM_{10} has superseded black smoke as an indicator of particulate material in the air. As a result, black smoke emission estimates are presented here in less detail than previous years. The total emissions are included below in Table 4.8

Table 4.8 UK Emissions of Black Smoke by UN/ECE Source Category (ktonnes)

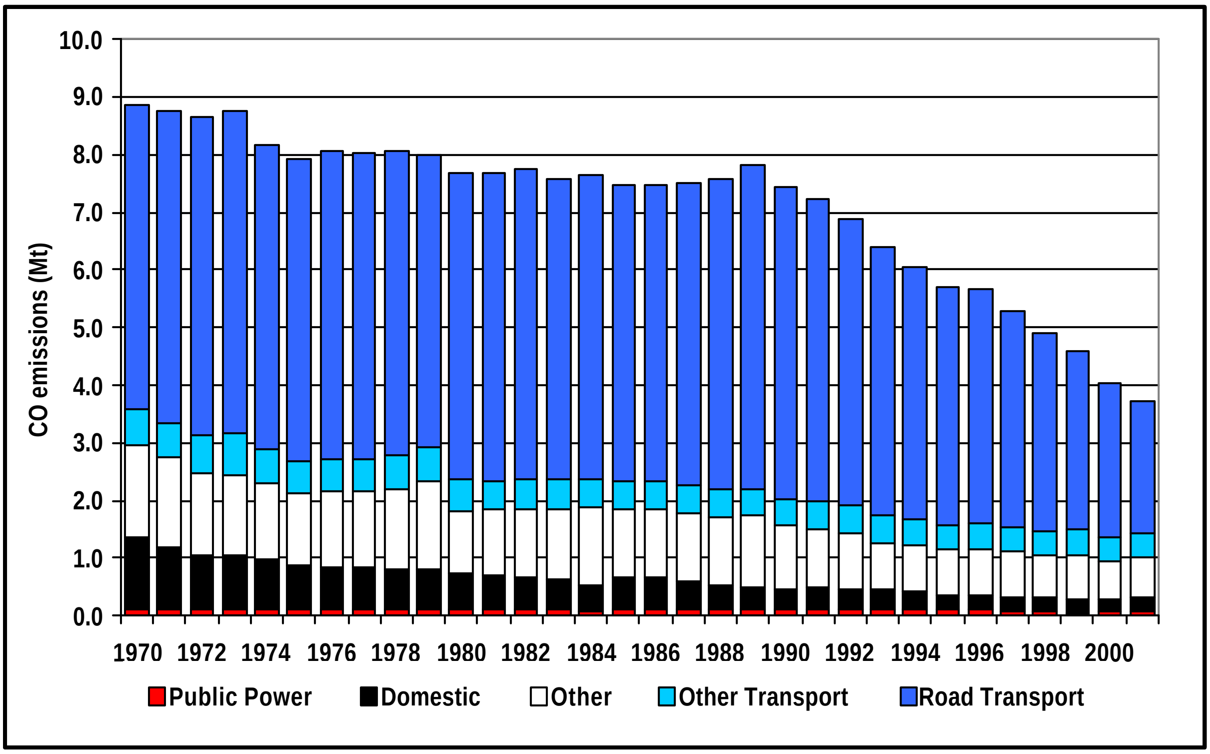
	1970	1980	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
TOTAL	1073	599	480	486	474	450	410	370	359	324	284	268	244	268

4.3 CARBON MONOXIDE EMISSION ESTIMATES

Carbon monoxide arises from incomplete fuel-combustion and is of concern mainly because of its effect on human health and its role in tropospheric ozone formation. It leads to a decreased uptake of oxygen by the lungs and can lead to a range of symptoms as the concentration increases.

The UK emissions of carbon monoxide are shown in Figure 4.6 and Table 4.9 disaggregated by source and fuel. Over the period 1970-2001 emissions decreased by 58% reflecting significant reduction in emissions from road transport, agricultural field burning and the domestic sector.

Figure 4.6 Time Series CO Emissions (Mtonnes)



The spatial disaggregation of CO emissions is shown in Figure 4.7. The observed pattern of emissions is clearly dominated by road transport emissions. A large proportion of road transport emissions are from vehicles travelling at slow speeds on urban or minor roads, hence the map shows high emissions in urban conurbations.

Table 4.9 UK Emissions of CO by UN/ECE[1] Source Category and Fuel (ktonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[2]											
Combustion in Energy Prod.											
Public Power	117	121	114	104	102	71	73	61	70	72	2%
Petroleum Refining Plants	8	8	7	8	8	8	8	7	6	4	0%
Other Combustion & Trans.	45	24	22	22	23	23	26	27	28	27	1%
Combustion in Comm/Inst/Res											0%
Residential Plant	1237	608	345	260	268	246	239	244	215	238	6%
Comm/Pub/Agri Combustion	46	26	23	19	19	19	18	18	18	18	0%
Combustion in Industry											
Iron & Steel Combustion	757	215	385	348	347	353	339	343	241	281	8%
Other Ind. Combustion	240	141	133	128	125	122	108	141	136	143	4%
Production Processes	217	182	238	231	235	239	216	199	213	211	6%
Extr./Distrib. of Fossil Fuels	2	2	7	3	3	3	3	1	1	1	0%
Road Transport	5267	5304	5411	4112	4075	3740	3417	3101	2651	2303	62%
Other Trans/Machinery											
Off-Road Sources	30	28	32	26	26	25	23	22	21	20	1%
Other[3]	584	512	428	407	408	407	407	406	405	403	11%
Waste[4]	6	48	34	28	28	23	24	20	19	16	0%
Land Use Change	288	449	266	0	0	0	0	0	0	0	0%
By FUEL TYPE											
Solid	2243	994	884	738	743	697	673	659	525	596	16%
Petroleum	5919	5867	5889	4559	4523	4184	3858	3539	3085	2734	73%
Gas	44	36	41	58	61	59	61	67	70	65	2%
Non-Fuel	637	772	631	340	339	341	311	326	345	342	9%
TOTAL	**8843**	**7669**	**7445**	**5695**	**5666**	**5280**	**4902**	**4591**	**4025**	**3737**	**100%**

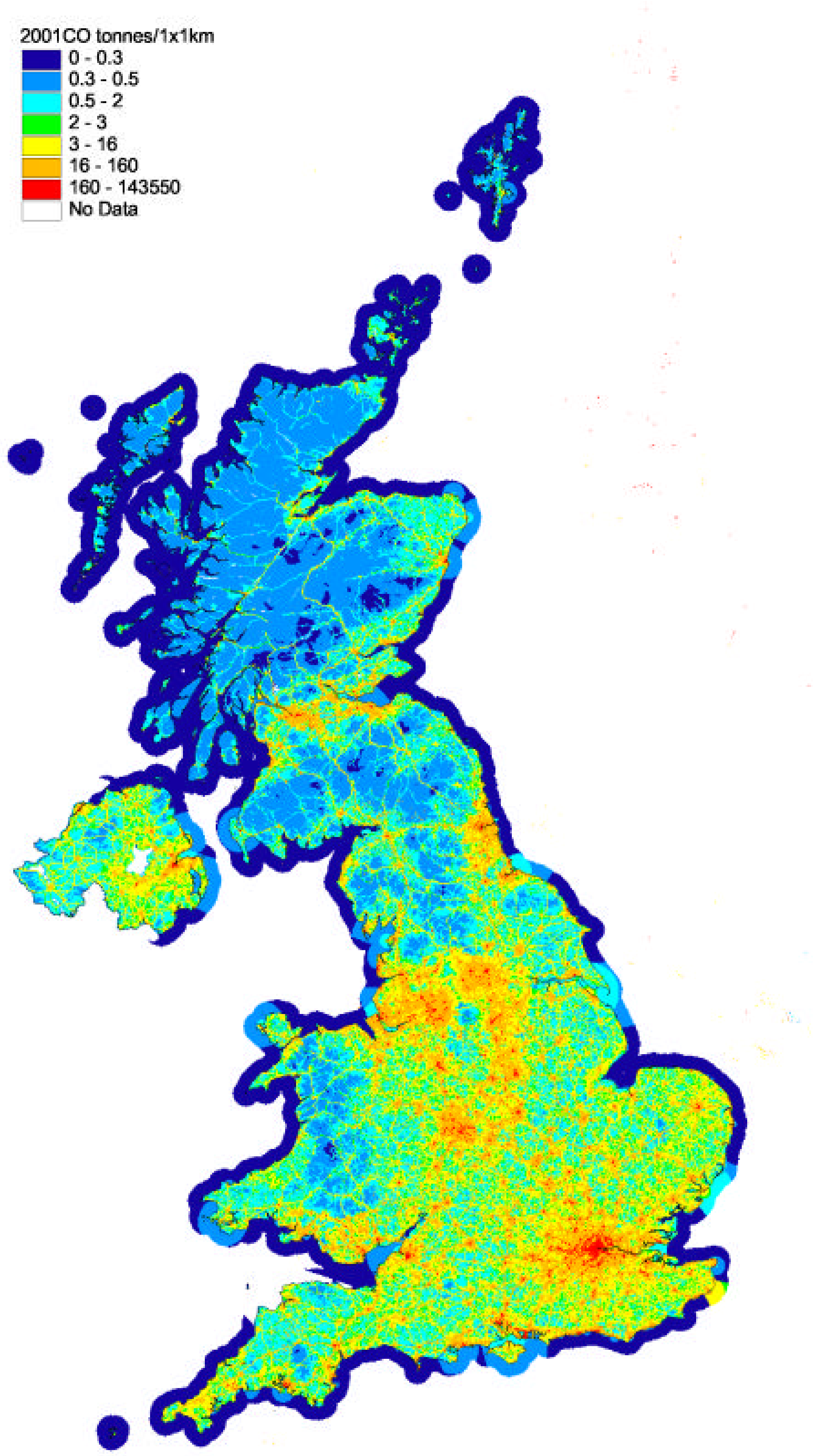
1 UK emissions reported in IPCC format (Salway, 2002) differ slightly due to the different source categories used.

2 See Annex 1 for definition of UN/ECE Categories

3 Including railways, shipping, naval vessels, military aircraft

4 Excludes emissions of 21.2 ktonnes from foot and mouth animal pyres. See Chapter 9.

Figure 4.7 Spatially Disaggregated UK Emissions of CO



4.3.1 Transport

The most important source of CO is road transport and in particular petrol driven vehicles. Emissions from road transport fell only slightly between 1970 and 1990 but in recent years have declined more significantly. This is due primarily to the increased use of catalytic converters and to a lesser extent to fuel switching from petrol cars to diesel cars. The emissions from off-road sources includes portable generators, fork lift trucks, lawnmowers and cement mixers. The estimation of emissions from such machinery is very uncertain since it is based on estimates of equipment population and annual usage time.

4.3.2 Other Sources

Other emission sources of CO are small compared with transport and off-road sources. Combustion-related emissions from the domestic and industrial sectors have decreased by 81% and 57% respectively since 1970 due to the decline in the use of solid fuels in favour of gas and electricity. The sudden decline in emissions from the agricultural sector reflects the banning of stubble burning in 1993 in England and Wales. Currently energy production accounts for only 2% of UK emissions.

4.4 BENZENE

Studies have shown that exposure to benzene gives rise to an increase in the risk of developing leukaemia, and that benzene exerts its effect by damaging the genetic make-up of cells i.e. it is a genotoxic carcinogen. Consequently it is important to understand sources of benzene and their relative strengths, and ensure that emissions do not give rise to unacceptably high concentrations of benzene.

Benzene emissions arise predominately from the evaporation and combustion of petroleum products. Emissions of benzene are dominated by the road transport sector, accounting for 36% of the 2001 emission estimate total. As benzene is a constituent of petrol, emissions arise from both evaporation and combustion of petrol. Benzene emissions for 1990 to 2001 are given in Table 4.10 and Figure 4.8 below.

Benzene emissions also arise as stack emissions and, more importantly, fugitive emissions from its manufacture and use in the chemical industry. Benzene is a major chemical intermediate, being used in the manufacture of many important chemicals including those used for the production of foams, fibres, coatings, detergents, solvents and pesticides.

Benzene emissions have been steadily decreasing since 1990. These decreases are primarily due to the introduction of cars equipped with catalytic converters since 1991. Emissions from the domestic and industrial sectors are also falling, but the impact is relatively small compared with the changes in the emissions from transport.

The most noticeable decrease between 1999 and 2001 arises from the road transport sector. This is because the benzene content of petrol was substantially decreased between 1999 and 2001 resulting in a corresponding decrease in emissions.

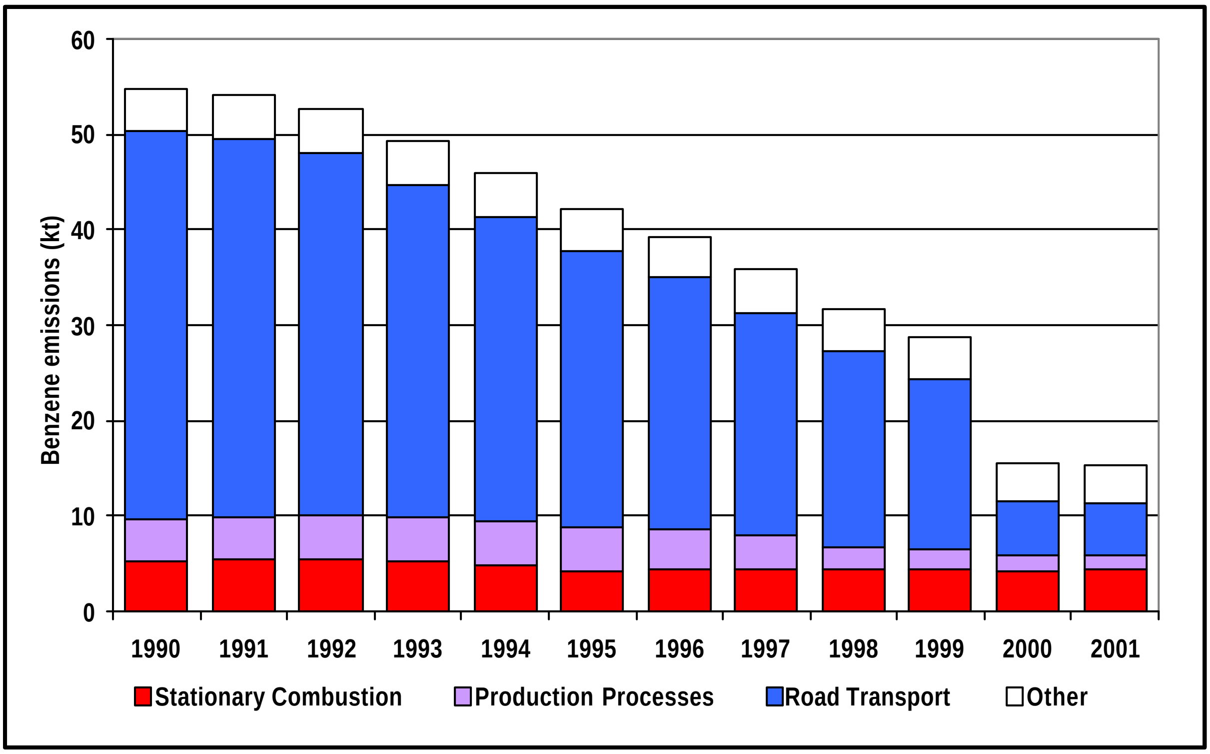
Table 4.10 UK emissions of Benzene by UN/ECE[1] Source Category and Fuel (ktonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[1]													

Combustion in Energy Prod.													
Petroleum Refining Plants	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0%
Other Combustion & Trans.	0.29	0.29	0.29	0.29	0.33	0.14	0.16	0.18	0.18	0.19	0.19	0.18	1%
Combustion in Comm/Res													
Residential Plant	4.16	4.32	4.28	4.26	3.70	3.19	3.37	3.21	3.29	3.40	3.03	3.31	22%
Comm/Pub/Agri Combustion	0.11	0.13	0.13	0.12	0.13	0.14	0.15	0.14	0.14	0.15	0.15	0.16	1%
Combustion in Industry													
Iron & Steel Combustion	0.01	0.01	0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0%
Other Ind. Combustion	0.72	0.71	0.67	0.67	0.75	0.78	0.81	0.84	0.79	0.74	0.79	0.72	5%
Production Processes	4.31	4.39	4.62	4.49	4.60	4.55	4.07	3.50	2.38	2.01	1.61	1.47	10%
Extr./Distrib. of Fossil Fuels	1.11	1.16	1.21	1.23	1.24	1.18	1.01	1.36	1.34	1.15	1.08	1.06	7%
Road Transport													
Combustion	38.35	37.38	35.72	32.67	29.97	27.17	24.79	21.91	19.20	16.76	5.44	5.27	34%
Evaporation	2.31	2.28	2.23	2.07	1.91	1.74	1.60	1.46	1.22	1.09	0.25	0.26	2%
Other Trans/Machinery	2.44	2.52	2.51	2.44	2.36	2.27	2.31	2.30	2.22	2.19	2.17	2.09	14%
Waste	0.94	0.93	0.93	0.94	0.93	0.91	0.93	0.89	0.92	0.92	0.91	0.84	5%
By FUEL TYPE													
Solid	3.7	3.8	3.8	3.7	3.3	2.8	2.9	2.8	2.8	2.9	2.5	2.7	17%
Petroleum	43.1	42.2	40.5	37.2	34.3	31.2	28.7	25.7	22.7	20.1	7.9	7.6	50%
Gas	1.5	1.6	1.5	1.6	1.5	1.4	1.5	1.5	1.5	1.5	1.5	1.5	10%
Non-Fuel	6.4	6.5	6.8	6.7	6.9	6.7	6.1	5.9	4.7	4.2	3.8	3.5	23%
TOTAL	**54.76**	**54.13**	**52.60**	**49.21**	**45.95**	**42.09**	**39.24**	**35.83**	**31.71**	**28.65**	**15.65**	**15.39**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

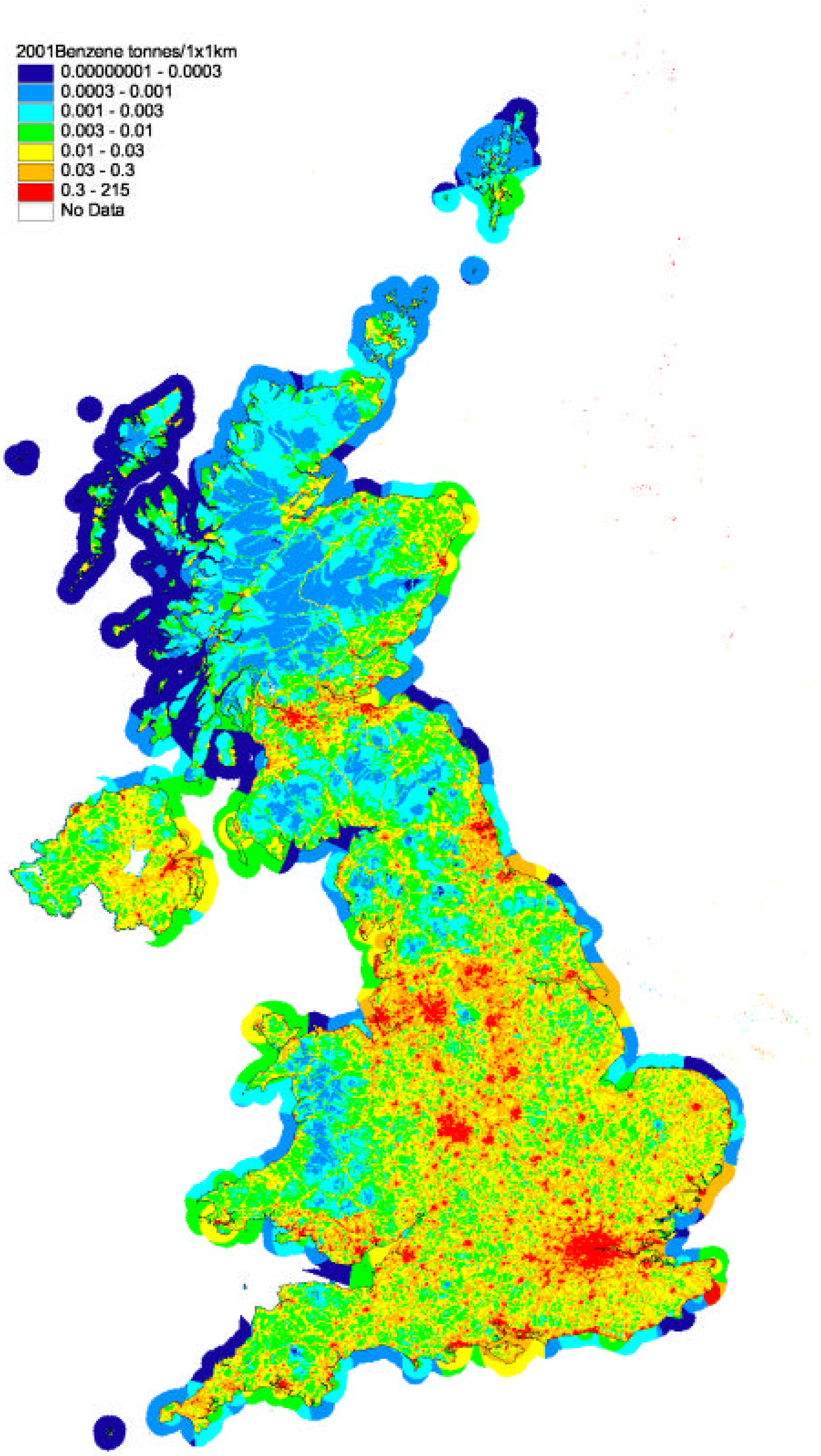
Figure 4.8 Time Series of Benzene Emissions (ktonnes)



Spatially disaggregated emissions of benzene are shown in Figure 4.9. A high percentage of the total benzene emission arises from the road transport sector, and this is evident in the spatially disaggregated UK map. High emission densities (i.e. emission per 1x1 km grid square) may be found in areas of high population density, and it is apparent that the dominant emissions are arising from the road transport activities in these areas, although other urban sources do also make a significant contribution.

Road transport emissions of benzene fall with increasing speed (and then start rising at higher speeds). This results in relatively high emissions per km in urban areas, as can be seen in Figure 4.9. Although evident, motorways and other major roads are not associated with particularly high emissions evident from urban roads.

Figure 4.9 Spatially Disaggregated UK Emissions of Benzene



4.5 1,3-BUTADIENE

Studies have indicated that elevated concentrations of 1,3-butadiene give rise to a variety of cancers, and damages the genetic structures of cells i.e. 1,3-butadiene is a genotoxic carcinogen. Atmospheric concentrations have been determined at which the risk of adverse impacts is considered acceptably small, and it is therefore important to be able to understand the major sources of 1,3-butadiene which contribute to the ambient concentration.

Emissions of 1,3 butadiene arise from the combustion of petroleum products and its manufacture and use in the chemical industry. 1,3-Butadiene is not present in petrol but is formed as a by-product of combustion- hence it is not present in road transport evaporative emissions. The road transport sector dominates the UK emissions in 2001, contributing 78% of the total. Emissions of 1,3-butadiene for 1990 to 2001 are given in Table 4.11 and Figure 4.10 below.

As with benzene, the introduction of catalytic converters in 1991 has had a significant impact on the emissions from the road transport sector, causing a reduction in emissions of 68% from 1990 to 2001. Emissions from other significant combustion sources, such as other transportation and machinery, have not significantly decreased.

1,3-Butadiene emissions also arise as stack and, more importantly, fugitive emissions from its manufacture and extensive use in the chemical industry. 1,3- Butadiene is used in the production of various forms of synthetic rubber. Reported emission estimates for the chemical industry sectors (Environment Agency, 2001) have been incorporated into the inventory.

Spatially disaggregated emissions of 1,3-butadiene are shown in Figure 4.11. Emissions of 1,3-butadiene arise almost exclusively from road transport activities, and an interesting comparison may be drawn with the UK emissions map for benzene (Figure 4.9), where other sources make a significant contribution to the total emissions. As with benzene, emissions of 1,3-butadiene per km from road transport decrease with increasing speed (but then increase at higher speeds). Consequently the emissions density is high in urban areas, and the major roads (such as motorways) are not particularly highlighted.

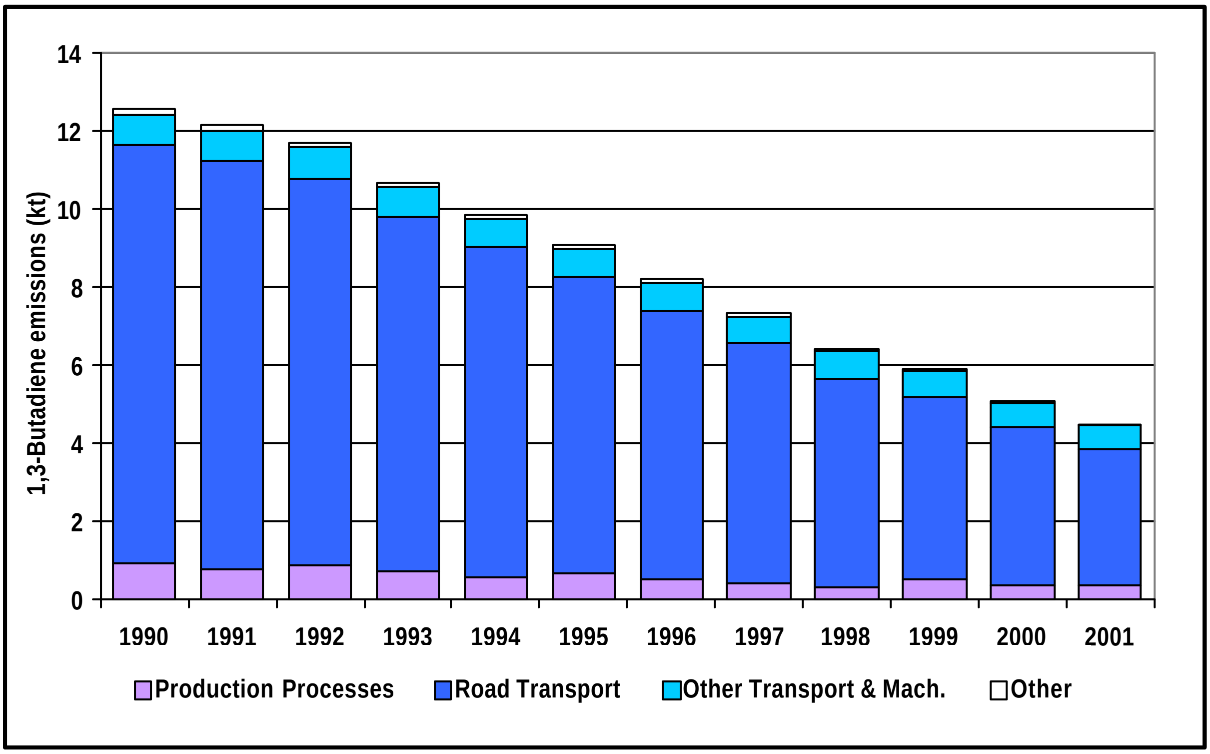
Benzene and 1,3-butadiene emission maps (Figures 4.9 and 4.11) may be contrasted with mapped NO_x emissions (Figure 5.2) as the emissions of NO_X at higher speeds are more significant than those for benzene or 1,3-butadiene.

Table 4.11 UK Emissions of 1,3-butadiene by UN/ECE[1] Category and Fuel (ktonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[1]													
Combustion in Energy Prod.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0%
Combustion in Comm/Res	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0%
Combustion in Industry	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0%
Production Processes	0.91	0.79	0.90	0.70	0.58	0.70	0.52	0.42	0.33	0.52	0.38	0.35	8%
Extr./Distrib. of Fossil Fuels	0.12	0.11	0.10	0.09	0.08	0.07	0.06	0.05	0.04	0.02	0.01	0.01	0%
Road Transport	10.75	10.46	9.90	9.11	8.46	7.59	6.89	6.14	5.33	4.69	4.03	3.48	78%
Other Trans/Machinery	0.77	0.78	0.79	0.77	0.73	0.69	0.71	0.69	0.70	0.67	0.65	0.63	14%
Waste	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0%
By FUEL TYPE													
Solid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Petroleum	11.5	11.2	10.7	9.9	9.2	8.3	7.6	6.8	6.0	5.4	4.7	4.1	92%
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Non-fuel	1.1	0.9	1.0	0.8	0.7	0.8	0.6	0.5	0.4	0.6	0.4	0.4	8%
TOTAL	**12.58**	**12.16**	**11.72**	**10.70**	**9.88**	**9.07**	**8.21**	**7.32**	**6.41**	**5.91**	**5.09**	**4.48**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

Figure 4.10 Time Series of 1,3-Butadiene Emissions (ktonnes)



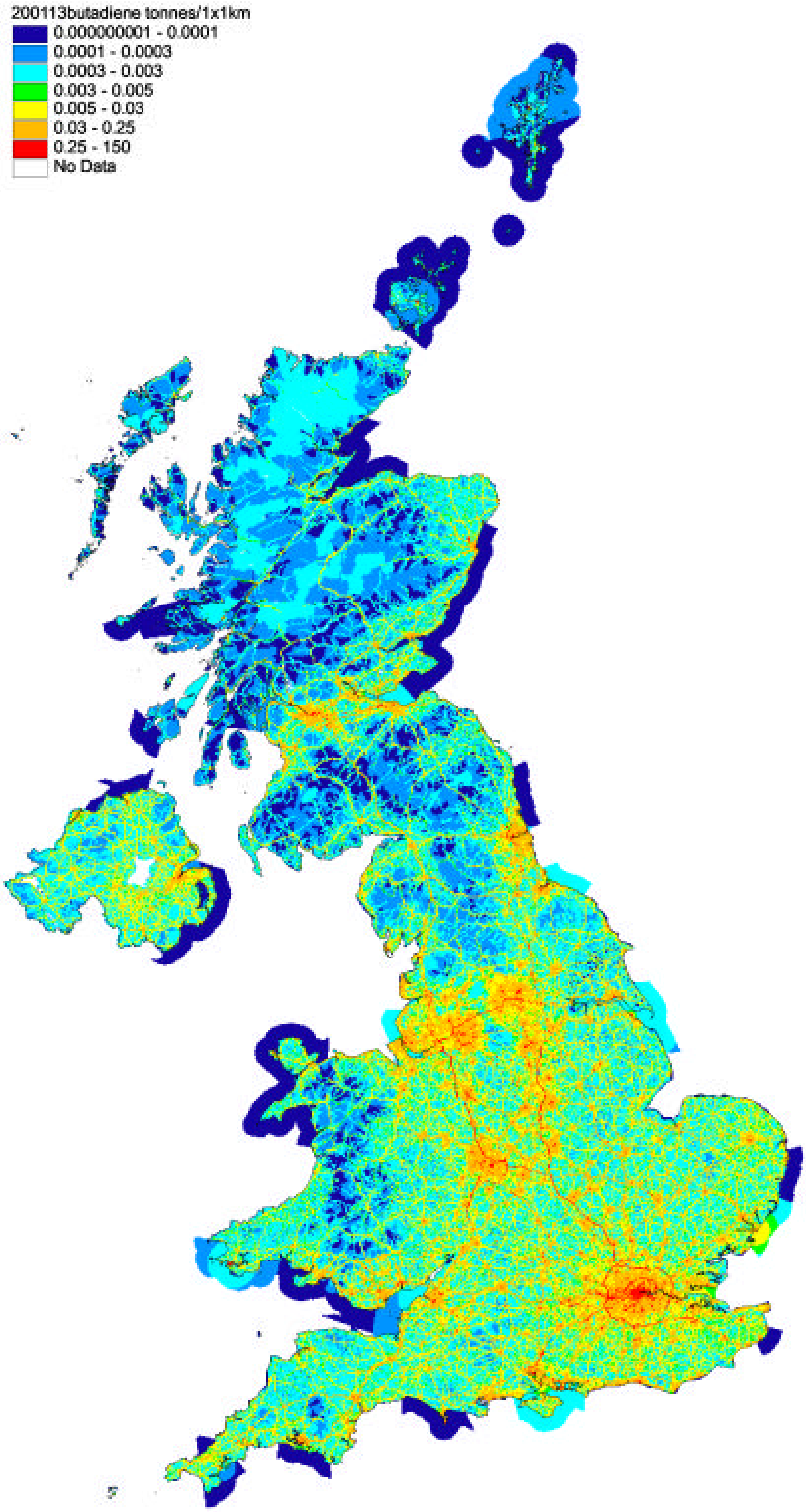


Figure 4.11 Spatially Disaggregated UK Emissions of 1,3- Butadiene

4.6 ACCURACY OF EMISSION ESTIMATES OF AIR QUALITY STRATEGY POLLUTANTS

Quantitative estimates of the uncertainties in emission inventories are based on calculations made using a direct simulation technique, which corresponds to the IPCC Tier 2 approach recommended for greenhouse gases and also the methodology proposed in draft guidance produced by the UN/ECE Taskforce on Emission Inventories. This work is described in more detail by Passant (2002). Uncertainty estimates are shown in Table 4.12.

Table 4.12 Uncertainty of the Emission Inventories for Air Quality Strategy Pollutants

Pollutant	**Estimated Uncertainty %**
Carbon Monoxide	+/- 20
Benzene	-20 to + 30
1,3-butadiene	+/- 20
PM_{10}	-20 to +50
$PM_{2.5}$	+/- 20
$PM_{1.0}$	+/- 20
$PM_{0.1}$	+/- 20
Black smoke	-50 to +80

4.6.1 Carbon Monoxide Estimates

Carbon monoxide emissions occur almost exclusively from combustion of fuels, particularly by road transport. Emission estimates for road transport are highly uncertain, due to the relatively small number of measurements made of emissions which appear to be highly variable. Emissions from stationary combustion processes are also variable and depend on the technology employed and the specific combustion conditions. The emission factors used in the inventory have been derived from relatively few measurements of emissions from different types of boiler. As a result of the high uncertainty in major sources, emission estimates for CO are much more uncertain than other pollutants such as NOx, CO_2 and SO_2 which are also emitted mainly from combustion processes.

4.6.2 Benzene and 1,3-Butadiene Estimates

There has been much improvement in the benzene and 1,3-butadiene emission estimates in recent years. Information gained in speciating the emissions of NMVOC (see Section 5.5) has helped the generation of more robust emission inventories for both benzene and 1,3-butadiene. However, due in particular to the uncertainty in the levels of both pollutants in NMVOC emissions from road transport and other combustion processes, the uncertainty in these inventories is much higher than the uncertainty in the NMVOC inventory.

4.6.3 Particulate Matter Estimates

The emission inventory for PM_{10} has undergone considerable revision over the last three versions of the NAEI and must be considered significantly more robust now than, say, in 1997. Nonetheless, the uncertainties in the emission estimates must still be considered high. These uncertainties stem from uncertainties in the emission factors themselves, the activity data with which they are combined to quantify the emissions and the size distribution of particle emissions from the different sources.

Emission factors are generally based on a few measurements on an emitting source which is assumed to be representative of the behaviour of all similar sources. Emission estimates for PM_{10} are based whenever possible on measurements of PM_{10} emissions from the source, but sometimes measurements have only been made on the mass of total particulate matter and it has been necessary to convert this to PM_{10} based either on the size distribution of the sample collected or, more usually, on size distributions given in the literature. Many sources of particulate matter are diffuse or fugitive in nature e.g. emissions from coke ovens, metal processing, or quarries. These emissions are difficult to measure and in some cases it is likely that no entirely satisfactory measurements have ever been made.

Emission estimates for combustion of fuels are generally considered more reliable than those for industrial processes, quarrying and construction. All parts of the inventory would need to be improved before the overall uncertainty could be reduced to the levels seen in the inventories for CO_2, SO_2, NOx, or NMVOC.

The approach adopted for estimating emissions of the smaller particle sizes, while it is currently the only one available, includes a number of assumptions and uncertainties. The approach depends on the PM_{10} emission rates estimated for each sector which themselves have great uncertainties. The emission estimates for the smaller particles will be even more uncertain for a given source as there are additional uncertainties in the size fractions and their applicability to individual emission source sectors. The relevance of US and Dutch size fraction data to UK emission sources can also be questioned. Perhaps surprisingly, the inventories for the smaller particles are less uncertain overall than the PM_{10} inventory. This is because the most uncertain PM_{10} emissions are those from industrial processes, quarrying and construction and these sources emit very little of the finer particles, road transport dominating instead.

4.6.4 Black Smoke Estimates

Black smoke emissions are less accurate than those for PM_{10} due to the fact that, since its importance as a policy tool has declined, the black smoke inventory methodology has not been revised for many years and the relevance of the emission factors used in the inventory to current industrial technology is in doubt.

5. Acidifying Gases and Tropospheric Ozone Precursors

5.1 INTRODUCTION

The deposition of acidifying species can have adverse effects on buildings and vegetation, as well as acidifying streams and lakes and damaging the aquatic environment. Sulphur dioxide and nitrogen oxides from fuel combustion are major contributors to acidification (Review Group on Acid Rain-RGAR, 1997). Ammonia plays an important part in the long range transport of the acidifying pollutants by the formation of relatively stable particles of ammonium sulphate and ammonium nitrate. Although ammonia is a basic gas, deposition to soil surfaces and has an indirect effect on acidification. The biological transformation of NH_4^+ to NO_3^- in soils (nitrification) and plant uptake both release acidity into the soil contributing to acidification. NH_3 deposition can also give rise to terrestrial eutrophication- where nutrient enrichment gives rise to changes in ecosystems.

Tropospheric, or ground level, ozone occurs naturally and there are no significant ozone emissions from anthropogenic activities. Atmospheric levels can be increased *in-situ* by the photochemical reaction of precursor pollutants such as carbon monoxide, nitrogen oxides and volatile organic compounds. Specific non-methane volatile organic compounds (NMVOC) and groups of compounds play a key role in ozone formation. Ozone episodes in which concentrations rise substantially above background levels occur in summer months when there are long periods of bright sunshine, temperatures above 20^{o} C and light winds. Ozone can affect human health and can damage plants and crops. The total 2001 UK emissions of acidifying gases and ozone precursors are summarised in Table 5.1.

Table 5.1 Total UK Emissions of Acidifying and Ozone Precursors

Pollutant	**Total 2001 emission (ktonnes)**[1]
Nitrogen oxides (as NO_2)	1680
Sulphur dioxide	1125
Hydrogen chloride	80
Non-methane volatile organic compounds (NMVOC)	1514
Ammonia	290
Hydrogen fluoride	4.2

[1] Emission totals exclude animal pyres during the foot and mouth outbreak.

The UK is committed to reducing acidifying gas and ozone precursor emissions and is a party to several protocols under the UN/ECE's Convention on Long-Range Transboundary Air Pollution.

Under the Second Sulphur Protocol, the UK must reduce its total SO_2 emissions by 50% by 2000, 70% by 2005 and 80% by 2010 (all from a 1980 baseline). The UK is well on track to meet these targets, and by the end of 2000 had achieved a 76% reduction from 1980 baseline levels, 26% ahead of the UN/ECE target level for the year 2000.

The NMVOC Protocol requires the UK to achieve a 30% reduction of anthropogenic NMVOC emissions by 1999 from a 1988 baseline. The emission estimates given in the 1999 version of the emissions inventory indicated that this was achieved. Emissions excluding those from forests fell from 2475 ktonnes in 1988 to 1577 ktonnes in 1999 - a reduction of 36%**.** This reduction was achieved largely as a result of emission controls for road vehicles and industrial processes, introduced by European Directives and the Environmental Protection Act 1990 respectively. Other factors also had an impact:

- prohibition of the burning of crop residues in England and Wales since 1993, except in limited cases of exemption.
- a decline in the use of coal as a fuel by electricity generators, industry and domestic users in favour of gas;
- a decline in the use of petrol as a fuel for cars in favour of diesel;
- improvements in technology introduced for economic reasons, or in response to health & safety legislation (e.g. the introduction of more efficient dry cleaning machines with lower emission levels);
- measures introduced either voluntarily, or in response to pressure from end-users for improved environmental or health and safety performance (e.g. the formulations of many consumer products have been changed, resulting in lower levels of solvent in those products and therefore lower emissions of NMVOC during their use).

The NO_x Protocol required that the total emissions of NO_x in 1994 should be no higher than they were in 1987; UK emissions were 17% lower in 1994 than in 1987 and have fallen substantially since 1994.

In 1996, the UN/ECE started negotiating a new multieffect, multipollutant protocol on nitrogen oxides and related substances. This was aimed at addressing photochemical pollution, acidification and eutrophication. The Protocol to Abate Acidification, Eutrophication and Ground-level Ozone was adopted in Gothenburg in December 2000, where it was signed by the UK. The multipollutant protocol incorporates several measures to facilitate the reduction of emissions:-

- Emission ceilings are specified for sulphur, nitrogen oxides, NH_3 and NMVOCs. These are summarised in the following table.

Table 5.2 Emissions Ceilings for 2010 (ktonnes) in the NECD

Country	Sulphur (as SO_2)	NO_x (as NO_2)	NH_3	VOC
Armenia	73	46	25	81
Austria	39	107	66	159
Belarus	480	255	158	309
Belgium	106	181	74	144
Bulgaria	856	266	108	185
Croatia	70	87	30	90
Czech Rep.	283	286	101	220
Denmark	55	127	69	85
Finland	116	170	31	130
France	400	860	780	1100
Germany	550	1081	550	995
Greece	546	344	73	261
Hungary	550	198	90	137
Ireland	42	65	116	55
Italy	500	1000	419	1159
Latvia	107	84	44	136
Liechtenstein	0.11	0.37	0.15	0.86
Lithuania	145	110	84	92
Luxembourg	4	11	7	9
Netherlands	50	266	128	191
Norway	22	156	23	195
Poland	1397	879	468	800
Portugal	170	260	108	202
Rep. of Moldova	135	90	42	100
Romania	918	437	210	523
Slovakia	110	130	39	140
Slovenia	27	45	20	40
Spain	774	847	353	669
Sweden	67	148	57	241
Switzerland	26	79	63	144
Ukraine	1457	1222	592	797
United Kingdom	**625**	**1181**	**297**	**1200**

- The protocol gives emission limits for sulphur, nitrogen oxides and NMVOCs from stationary sources.
- The protocol indicates limits for CO, hydrocarbons, nitrogen oxides and particulates from new mobile sources
- Environmental specifications for petrol and diesel fuels are given.
- Several measures to reduce NH_3 emissions from the agriculture sector are required.

The Gothenburg protocol forms a part of the Convention on Long-range Transboundary Air Pollution. More detailed information on both of the Gothenburg protocol and the Convention may be found at the UN/ECE web site:- http://www.unece.org/env/lrtap/

Within the EU, the National Emission Ceilings Directive was agreed in 2001. It sets emission ceilings to be achieved from 2010 onwards for each Member State for the same 4 pollutants as in the Gothenburg Protocol. A number of Member States reduced their ceilings somewhat below the levels included in the Protocol. The UK reduced its SO_2 ceiling to 585 ktonnes and its NO_x ceiling to 1167 ktonnes. Ceilings for NH_3 and NMVOCs were the same as in the Gothenburg Protocol. The ceilings for the EU 15 are summarised above in Table 5.2.

Sulphur dioxide has long been recognised as a pollutant because of its role, along with particulate matter, in forming winter-time smogs. Estimates of sulphur dioxide emissions have been produced since the inception of the NAEI. Fuel combustion accounts for more than 95% of UK SO_2 emissions with the sulphur arising from the fuel itself. The SO_2 emission can be calculated from knowledge of the sulphur content of the fuel and from information on the amount of sulphur retained in the ash. Published fuel consumption data (DTI, 1998), published sulphur contents of liquid fuels (Institute of Petroleum, 1996) and data from coal producers regarding sulphur contents of coals enable reliable estimates to be produced.

The main sources of NO_x in the UK are also combustion processes. However, such emissions are complex since the nitrogen can be derived from both the fuel and atmospheric nitrogen. The emission is dependent on the conditions of combustion, in particular temperature and excess air ratio, which can vary considerably. Thus combustion conditions, load and even state of maintenance are important. The estimation of NO_x emissions is often based on relatively few measurements and, in view of the possible variation in emissions from apparently similar combustion plant, there is greater uncertainty in the estimates than for SO_2 .

Within the UK, the implementation of the EC's Large Combustion Plant Directive and other associated policy measures has led to substantial reductions in acidifying pollutants from power plants and industrial sources. Emissions of NO_x from road traffic peaked in 1989 but by 2000 had substantially declined.

The inventories for SO_2, NO_x , HCl, NMVOC, NH_3 and HF are discussed in the following sections. Full details of the methodologies used to compile the inventories, changes to the methodology since the 1999 inventory and detailed time series for these pollutants are presented in the Appendices (see the NAEI website: http://www.naei.org.uk).

5.2 NO_X EMISSION ESTIMATES

Since 1990 there has been a reduction in total NO_x emissions of 39%, however this decrease in emissions has not been constant (Figure 5.1). Up to 1984 the NO_x emission profile was relatively flat with small peaks in 1973 and 1979, as seen previously for CO_2, which were due largely to the cold winters in those years. However, from 1984, emissions rose markedly as a result of the growth in road traffic reaching a peak in 1989 (Table 5.3). Since 1989, total emissions have declined by 40% as a result of a 51% reduction from power stations and 40% decrease from road transport.

The spatially disaggregated emission inventory for the UK based on a 1x1 km grid is shown in Figure 5.2 and data files are also available from the NAEI's internet site (http://www.naei.org.uk). A large fraction (the order of 30%) of the total emission is concentrated in approximately 50 grid squares, which contain point sources. For NO_x road transport dominates with approximately one third of the UK NO_x emission deriving from major sections of road. Vehicles travelling at high speeds contribute most. As a result the major route-ways (e.g. Motorways and primary routes) are clearly defined on the map. Conurbations and city centres show high emissions resulting from large volumes of road transport, residential and commercial combustion. A combination of high national shipping emission and relatively few large ports result in significant localised emissions from shipping in port areas.

Table 5.3 UK Emissions of Nitrogen Oxides (as NO_2) by UN/ECE[1] Category & Fuel (ktonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001 %
BY UN/ECE CATEGORY[2]											
Combustion in Energy Prod											
Public Power	812	861	781	495	449	372	365	338	365	379	23%
Petroleum Refining Plants	43	42	40	35	35	33	39	31	28	28	2%
Other Combustion & Trans.	56	42	61	47	47	47	50	53	53	53	3%
Combustion in Comm/Res											
Residential Plant	62	64	64	66	75	69	71	71	72	75	4%
Comm/Agri Combustion	74	46	38	38	39	36	34	34	32	32	2%
Combustion in Industry											
Iron & Steel Combustion	20	6	10	13	13	14	13	14	13	13	1%
Other Ind. Combustion	400	278	226	206	222	210	192	168	148	158	9%
Production Processes	13	14	11	4	4	4	4	4	4	3	0%
Extr./Distrib. of Fossil Fuels	0	0	1	1	1	1	1	1	1	1	0%
Road Transport	764	981	1290	1067	1067	1024	958	915	848	781	46%
Other Trans/Machinery											
Off-Road Sources	121	116	131	110	114	110	99	94	91	80	5%
Other[3]	120	104	89	85	89	87	88	81	78	73	4%
Waste[4]	6	12	9	8	7	5	5	4	4	4	0%
Land Use Change	10	15	9	0	0	0	0	0	0	0	0%
By FUEL TYPE											
Solid	912	886	800	503	471	379	357	320	317	347	21%
Petroleum	1381	1413	1646	1359	1364	1292	1211	1146	1067	990	59%
Gas	99	171	216	243	267	270	281	289	303	297	18%
Non-Fuel	110	112	97	68	62	70	68	55	50	46	3%
TOTAL	**2501**	**2581**	**2759**	**2174**	**2164**	**2012**	**1918**	**1810**	**1737**	**1680**	**100%**

1 UK emissions reported in IPCC format (Salway, 2002) differ slightly due to the different source categories used.

2 See Annex 1 for definition of UN/ECE Categories.

3 Including railways, shipping, naval vessels, military aircraft.

4 Excludes emissions of 0.6 ktonnes from foot and mouth animal pyres. See Chapter 9.

Figure 5.1 Time Series of NO$_x$ Emissions (Mtonnes)

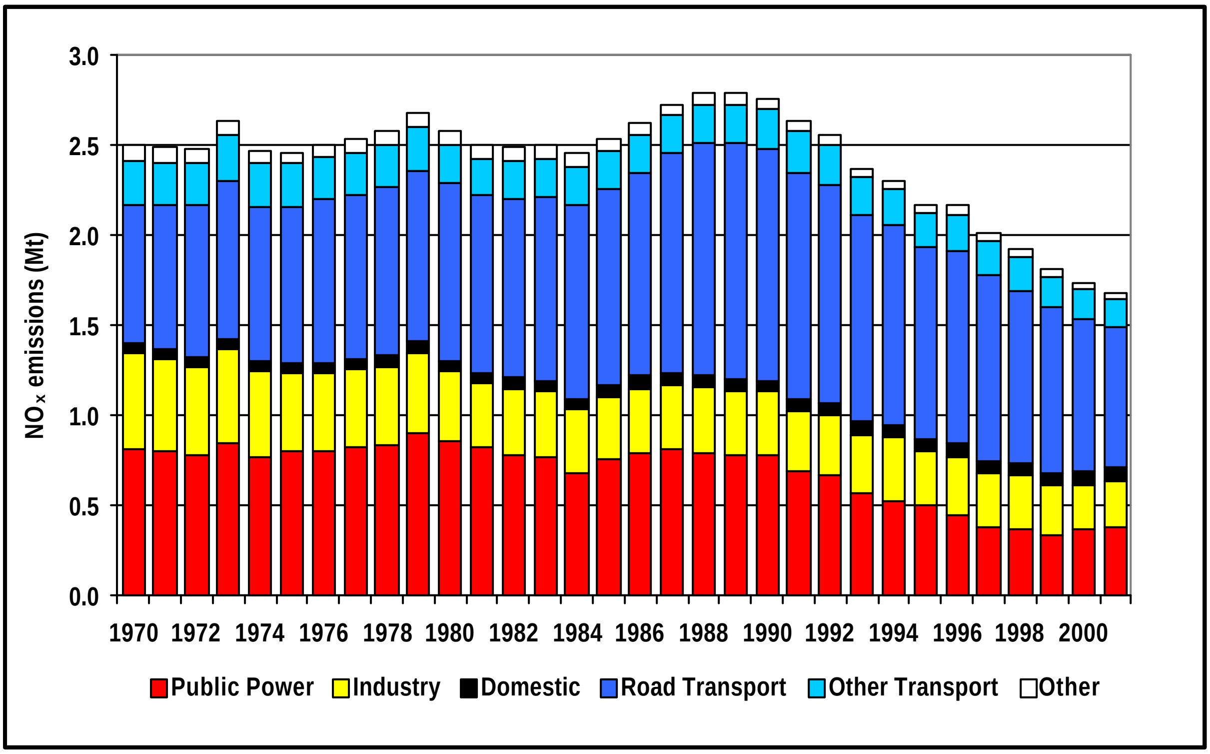
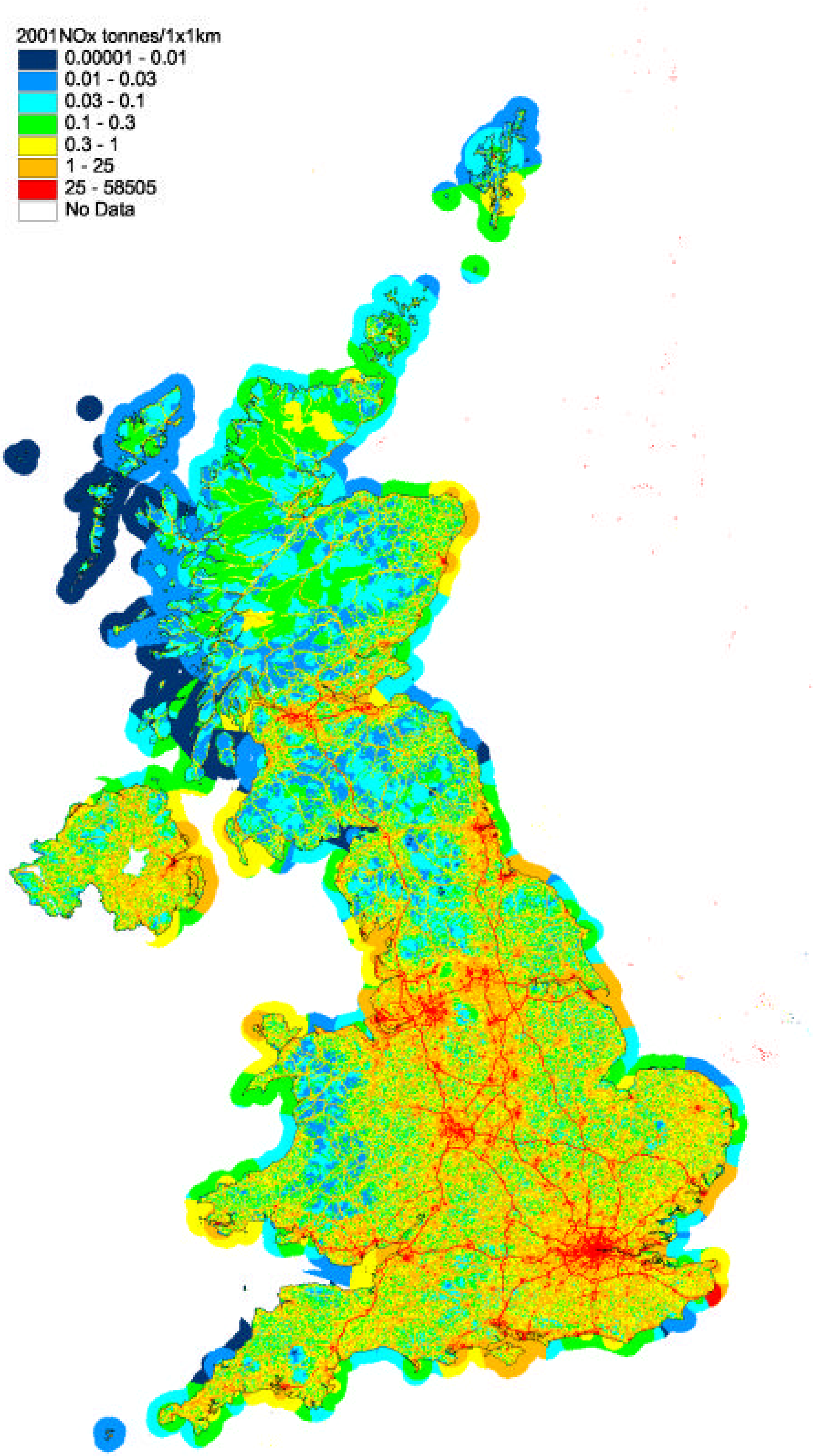


Figure 5.2 Spatially Disaggregated UK Emissions of NO_x



5.2.1 Transport

In 2001 the major source of NO_x emissions in the UK is the transport sector with road vehicles and off-road vehicles contributing 46% and 5%, respectively, to the total emission. Road emissions rose steadily between 1970 and 1989 reflecting the overall growth in road traffic in the UK. During this period emissions from total petrol consumption, predominantly cars, rose by 102% compared to the 1970 level and emissions from diesel consumption rose by 40%. Figure 5.3 clearly shows the growth in the vehicle fleet and vehicle mileage during this period. Since 1989 there has been a steady decline in emissions due to the introduction of catalytic converters on cars and stricter regulations on truck emissions.

Figure 5.3 Emissions of NO_x from Road Transport by Vehicle Type (ktonnes)

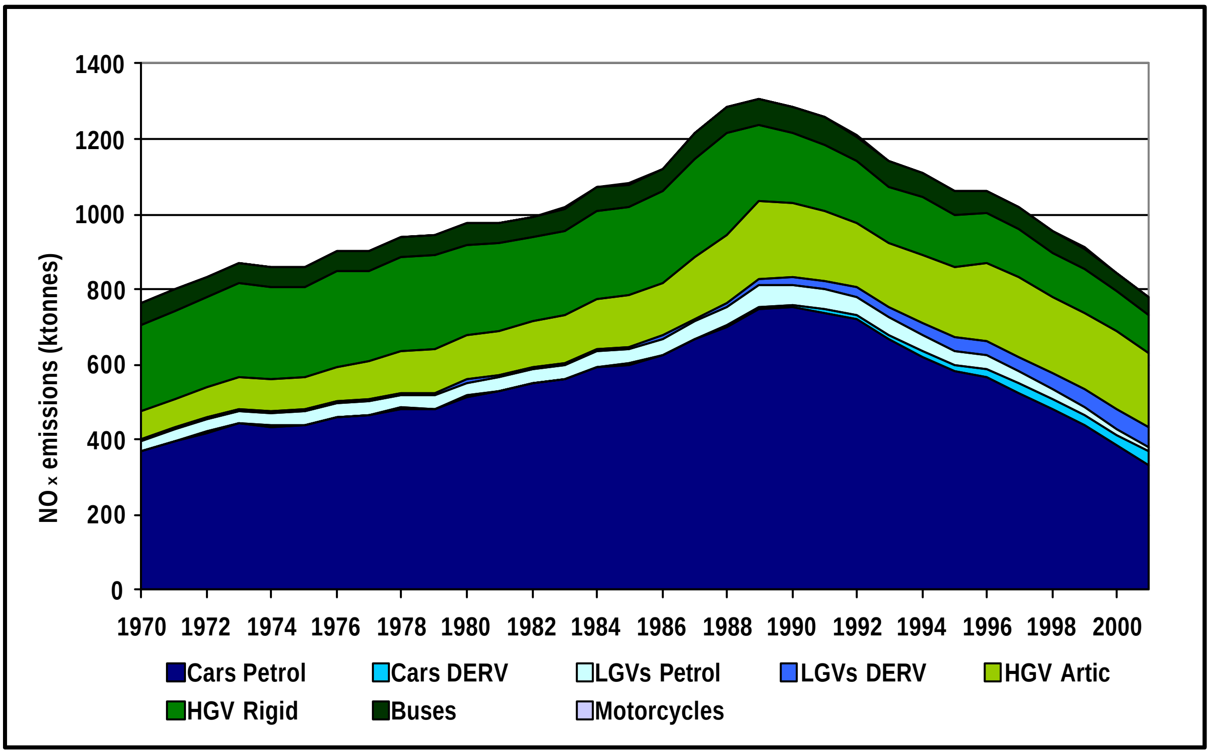


Figure 5.4 shows the average NO_x emissions per vehicle kilometre for different vehicle types (NOTE: two different vertical scales are used). Various emission regulations on new petrol cars which have come into effect in stages since 1976 have led to the gradual reduction in emission rates from petrol cars. The more rapid decline in emissions from 1992 is due to the penetration of cars fitted with three-way catalysts. Limits on emissions from diesel cars and Light Goods Vehicles (LGVs) did not come into effect until 1993/94. Overall emissions per kilometre from Heavy Goods Vehicles (HGVs) showed a small rise from 1970-1987 due to the increasing usage of larger HGVs for freight movement. Limits on emissions from HGVs first came into effect in 1988 leading to a gradual reduction in emission rates as new HGVs penetrated the fleet, accelerated by tighter limits on emissions from new HGVs in 1993/94.

Figure 5.4 NO_X Emissions per Vehicle km by Vehicle Type

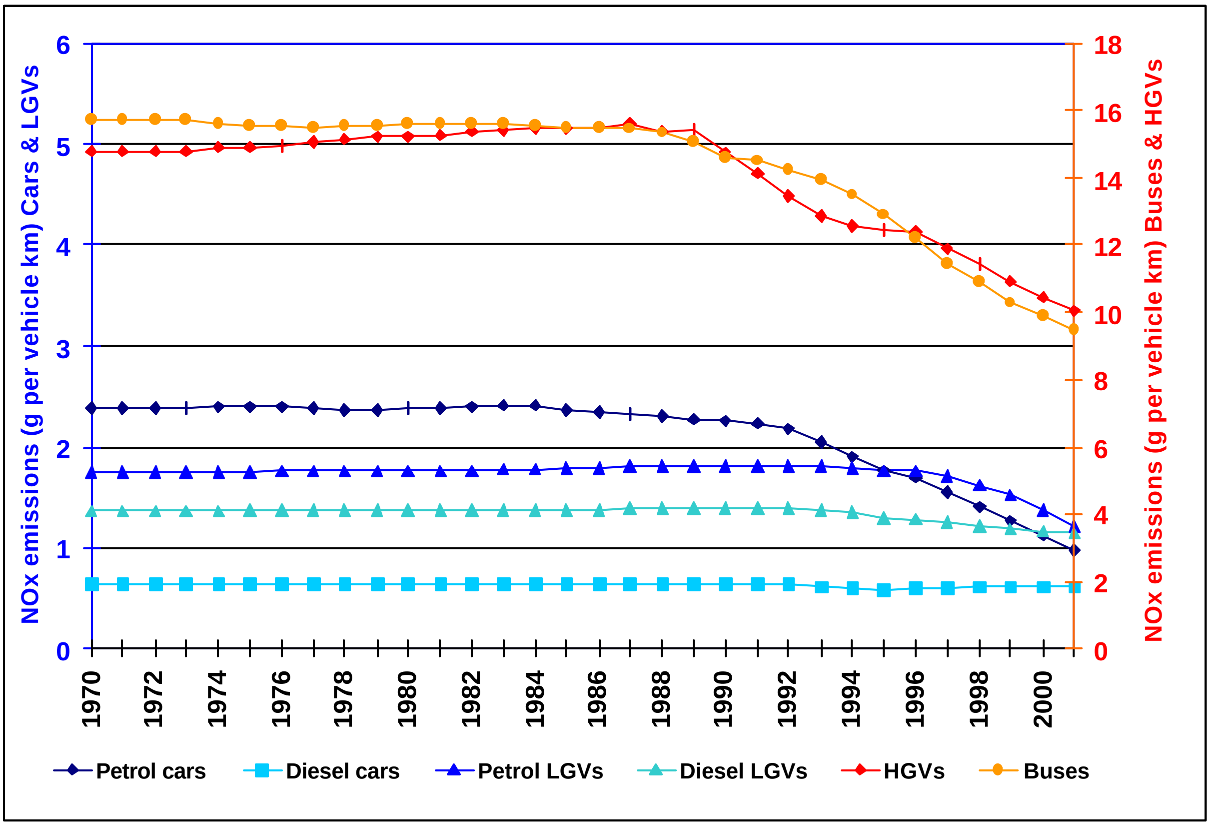
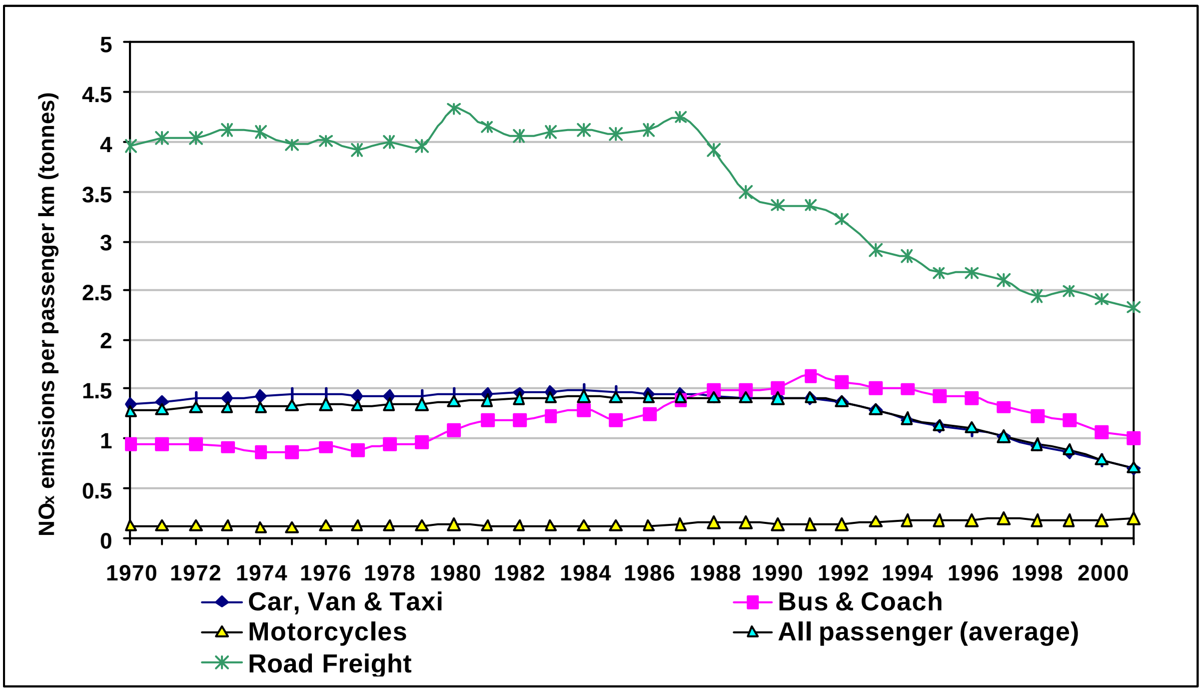


Figure 5.5 shows emissions per passenger km and by tonne km of freight. Technological improvements to HGVs give rise to approximately half the emissions per tonne of freight moved in 1998 compared with 1970. Emissions per passenger km from cars, vans and taxies have significantly decreased since 1970 due mainly to the introduction of catalytic convertors in 1992 now penetrating the car fleet. Per passenger km emissions from buses and coaches have increased from 1970 to 1993. This was due to the gradual decrease in occupancy rate of buses and their under utilisation over this period. Since 1993, this rise in per passenger km emissions has been halted by the penetration of buses meeting tighter emission standards into the fleet.

Figure 5.5 Emissions of NO_x (grammes) by Mode for Passenger and Freight Transport (tonnes)



In 2001 other transport and machinery contributed a further 9% to total UK NO_x emissions. Of these only those from civil aircraft have grown steadily over the period 1970 to 2001 (take-off and landing cycles up to an altitude of 1000 m only are considered here in accordance with UN/ECE guidelines). However, these emissions contribute only a small percentage of the total emission.

5.2.2 Power Generation

Emissions from power stations have declined over the period 1970-2001 by 53%. Emissions in the seventies were fairly constant from year to year, with peaks in severe winters. Since 1979 emissions have declined with a significant decrease at the time of the miners strike in 1984. Prior to 1989 this decline was due to the increased use of nuclear power and an increase in the average efficiency of the thermal power stations. Since 1988 the electricity generators have adopted a programme of progressively fitting low NO_x burners to their 500 MWe (megawatt electric) coal fired units. More recently the increased use of nuclear generation and the introduction of CCGT (Combined Cycle Gas Turbine) plant burning natural gas (See Section 2.2.2) have further reduced NO_x emissions. The emissions from the low NO_x turbines used are much lower than those of pulverised coal fired plant even when low NO_x burners are fitted. Given that these trends continue, power station emissions are expected to fall further.

5.2.3 Industry

The emissions from industrial combustion have declined by 52% since 1970 and they currently contribute 15% to total UK emissions. This is due to the decline in coal use in favour of gas and electricity.

5.3 SO_2 EMISSION ESTIMATES

Since 1970 there has been a substantial overall reduction of more than 83% in SO_2 emissions (Figure 5.6). The emission profile exhibits a steady decline between 1970 and 2001 with the exception of small peaks in 1973 and 1979 corresponding to the harsh winters in those years, and a short period at the end of the 1980s when emissions were relatively constant from year to year. It is also evident that there is little decrease between total SO_2 emissions in 1997 and 1998. This occurs because the large reductions in emissions from the power generation sector are not as substantial between 1997 and 1998. However the downward trend resumes between 1998 and 2001.

Table 5.4 shows emissions broken down by fuel categories. The two main contributors are solid fuel and petroleum products. Emissions from solid fuel use have declined by 77% since 1970 and those from petroleum by 93%. The most important factors in the fall in emissions from petroleum use are the decline in fuel oil use and the reduction in the sulphur content of gas oil and DERV. The reduction in the sulphur content of gas oil is particularly significant in sectors such as domestic heating, commercial heating and off-road sources where gas oil is used extensively. The sulphur content of DERV has steadily reduced across recent years, giving rise to a significant reduction in SO_2 emissions. SO_2 emissions from DERV in the early 1990's were relatively constant, however between 1994 and 2001 there has been a 97% reduction in emissions.

Figure 5.6 Time Series of SO_2 Emissions (Mtonnes)

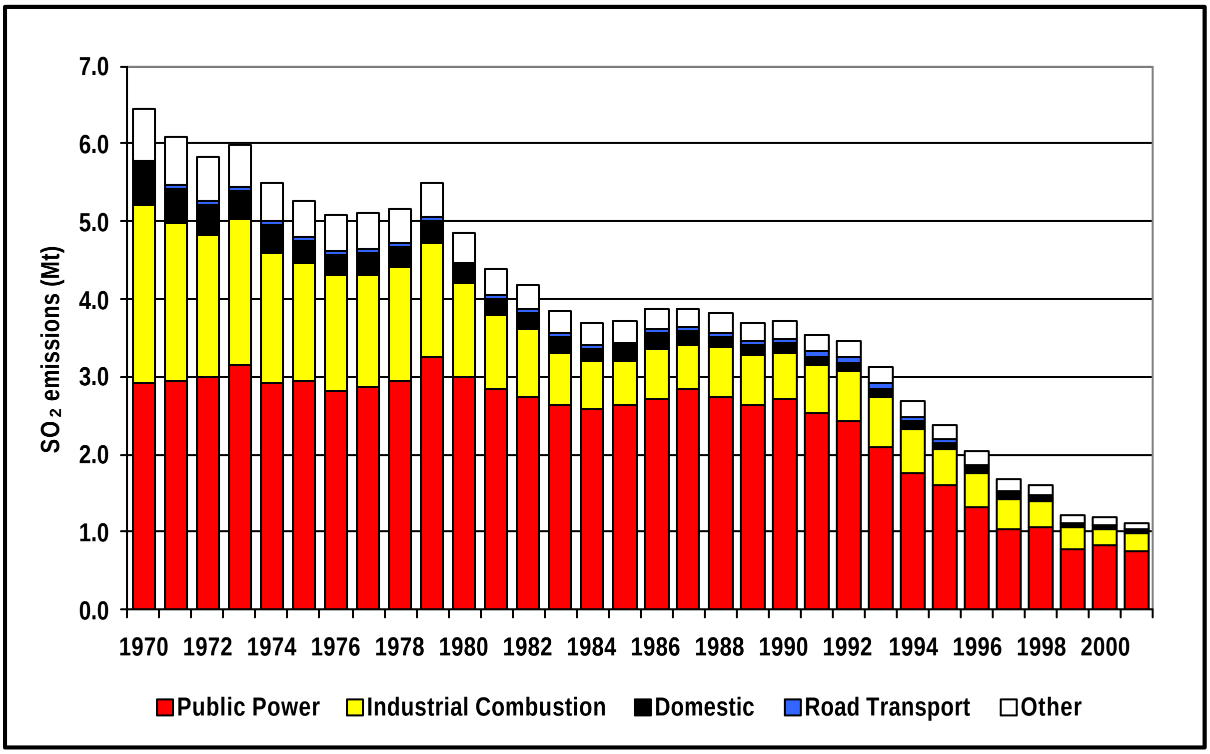


Table 5.4 UK Emissions of SO_2 by UN/ECE[1] Source Category and Fuel (ktonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[2]											
Combustion in Energy Prod.											
Public Power	2913	3007	2723	1591	1320	1025	1072	776	821	743	66%
Petroleum Refining Plants	242	262	153	142	144	134	98	93	72	72	6%
Other Combustion & Trans.	231	25	8	3	3	6	7	9	10	8	1%
Combustion in Comm/Inst/Res											
Residential Plant	522	226	108	67	71	63	53	52	45	49	4%
Comm/Pub/Agri Combustion	451	218	93	60	57	47	34	27	17	16	1%
Combustion in Industry											
Iron & Steel Combustion	35	10	18	17	17	17	15	15	11	12	1%
Other Ind. Combustion	1799	898	414	324	270	249	208	158	131	148	13%
Production Processes	120	95	71	57	56	51	52	46	38	42	4%
Extr./Distrib. of Fossil Fuels	5	5	16	6	7	6	6	1	1	1	0%
Road Transport	44	42	63	51	38	28	23	14	6	3	0%
Other Trans/Machinery[3]	93	61	47	44	44	42	38	34	32	27	2%
Waste[4]	5	6	5	3	2	2	2	5	3	3	0%
By FUEL TYPE											
Solid	3672	3140	2769	1637	1357	1155	1189	888	903	857	76%
Petroleum	2546	1548	811	605	558	395	295	229	185	170	15%
Gas	60	11	10	11	12	19	19	19	20	14	1%
Non-Fuel	182	155	128	112	102	102	106	93	81	84	7%
TOTAL	**6460**	**4854**	**3719**	**2365**	**2029**	**1670**	**1608**	**1229**	**1188**	**1125**	**100%**

1 UK emissions reported in IPCC format (Salway, 2002) differ slightly due to the different source categories used.

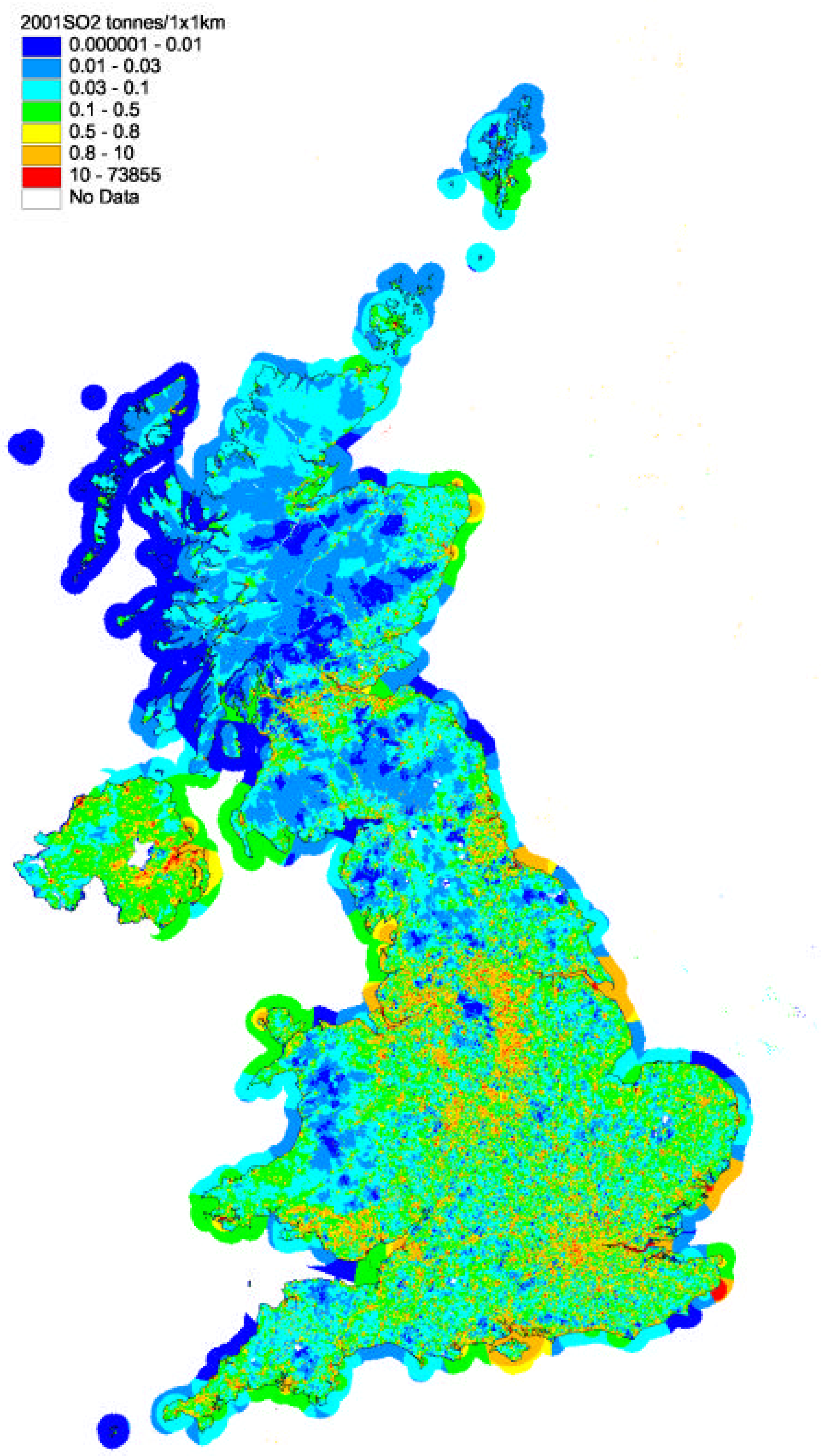
2 See Annex 1 for definition of UN/ECE Categories

3 Including railways, shipping, naval vessels, military aircraft and off-road sources

4 Excludes emissions of 1.4 ktonnes from foot and mouth animal pyres. See Chapter 9.

The geographical distribution of SO_2 emissions are shown in Figure 5.7. A large fraction (of the order of 80%) of the SO_2 emissions are concentrated into relatively few 1x1 km grid squares containing the major point sources such as refineries and power stations and large industrial plant. The resulting map highlights the main conurbations. High emissions in Plymouth and Newport result from a combination of shipping and industry. London and Birmingham, which are covered by Smoke Control Areas, show relatively low SO_2 emission levels. High emission densities are noted in Belfast where there is substantial consumption of solid fuels in the domestic sector for heating etc.

Figure 5.7 Spatially Disaggregated UK Emissions of SO_2



5.3.1 Power Generation

The largest contribution to SO_2 emissions is from power stations which accounts for 66% of the total in 2001. Historically coal combustion has been the most important source- the sulphur content of the coal being directly proportional to the emission estimate. Since 1970 there has been a gradual decline in power station emissions of around 74%. This reflects the changes in fuel mix and in the types of power plant which have taken place during the period. From 1970 to 1990 the reduction was due to a gradual increase in the use of nuclear plant and improvements in efficiency (See Section 2.2.2). Since 1990, this decline has accelerated because of the increase in the proportion of electricity generated in nuclear plant and the use of Combined Cycle Gas Turbine (CCGT) stations and other gas fired plant. CCGTs are more efficient than conventional coal and oil stations and have negligible SO_2 emissions. It is expected that these reductions will continue in the near future as more CCGT stations are built. Most recently the flue gas desulphurisation plants, constructed at Drax and Ratcliffe power stations, have had a significant effect on emissions.

5.3.2 Industry

Emissions of SO_2 from industry result from the combustion of coal and oil, some refinery processes and the production of sulphuric acid and other chemicals. Between 1970 and 2001 industrial emissions from combustion sources have fallen by 90% though most of the fall took place between 1970-1985 reflecting the decline in the energy intensive iron and steel industry and other heavy industries. There has been also been a decline in the use of coal and oil in favour of natural gas.

5.3.3 Transport

Road transport emissions account for less than 1% of the total SO_2 emissions. Between 1970 and the early 1990s, road transport emissions grew with the increase in road vehicles, however more recently emissions have declined with the reduction in the sulphur content of DERV. Similarly the reduction in sulphur content of gas oil is reflected in the emissions from off-road vehicles.

5.3.4 Other

Emissions from the remaining categories are low compared with those discussed above. Emissions from domestic and other commercial/institutional sectors have declined substantially during the period 1970-2001, reflecting the major changes in fuel mix from oil and coal to gas. The decrease in emissions from waste reflects the closure of a number of old incinerators due to the introduction of new emission standards and their replacement with modern equipment.

5.4 HYDROGEN CHLORIDE EMISSION ESTIMATES

HCl is an acidic gas primarily released to air from combustion of fuels which contain trace amounts of chloride. This results in the emissions of HCl being dominated by the combustion of solid fuel.

Table 5.5 and Figure 5.8 summarise the UK emissions of hydrogen chloride. Emissions have fallen by 76% since 1970. The main source of these emissions is coal combustion so the fall is a result of the decline in coal use and also the installation of flue gas desulphurisation at Drax and Ratcliffe since 1993, and the impact of the miners strike of 1984 is clearly visible. The other significant source of hydrogen chloride is waste incineration. Here the commissioning of new incinerators and the closure or upgrading of old plant has resulted in a large decrease for all years since 1996.

Table 5.5 UK Emissions of HCl by UN/ECE Source Category and Fuel (ktonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%

BY UN/ECE CATEGORY[1]											
Combustion in Energy Prod											
Public Power	222.3	257.8	239.4	134.1	110.3	74.5	76.7	82.2	74.7	62.7	79%
Petroleum Refining Plants	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Other Combustion & Trans.	4.5	1.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Combustion in Comm/Res											
Residential Plant	47.3	21.0	10.0	6.3	6.4	6.1	5.6	5.9	4.5	6.0	7%
Comm/Agricul Combustion	9.9	4.3	3.6	2.0	2.1	1.5	1.0	0.9	0.7	0.7	1%
Combustion in Industry											
Iron & Steel Combustion	1.1	0.4	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.6	1%
Other Ind. Combustion	40.5	13.5	13.5	13.4	11.6	10.7	9.6	9.4	6.4	9.3	12%
Production Processes	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0%
Road Transport	0.4	0.4	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0%
Other Trans/Machinery[2]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Waste[3]	10.6	10.6	8.1	3.6	3.3	0.1	0.1	0.1	0.1	0.1	0%
By FUEL TYPE											
Solid	323.9	297.8	263.9	148.1	122.7	91.9	91.8	97.5	85.5	77.9	98%
Petroleum	0.7	0.6	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0%
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Non-Fuel	12.3	11.6	12.0	12.5	12.0	2.2	2.3	2.0	1.8	1.7	2%
TOTAL	**337**	**310**	**276**	**161**	**135**	**94**	**94**	**100**	**87**	**80**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

2 Including railways, shipping, naval vessels, military aircraft and off-road sources

3 Excludes emissions of 0.3 ktonnes from foot and mouth animal pyres. See Chapter 9.

Figure 5.8 Time Series of HCl Emissions (ktonnes)

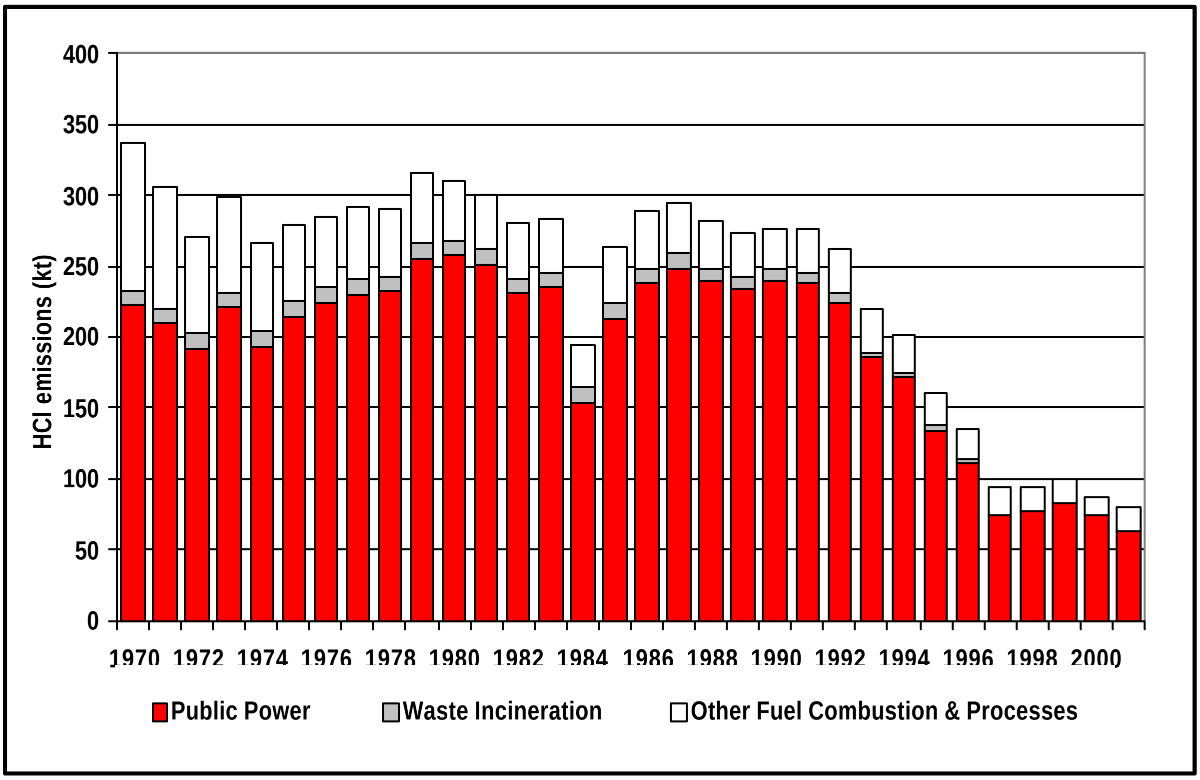
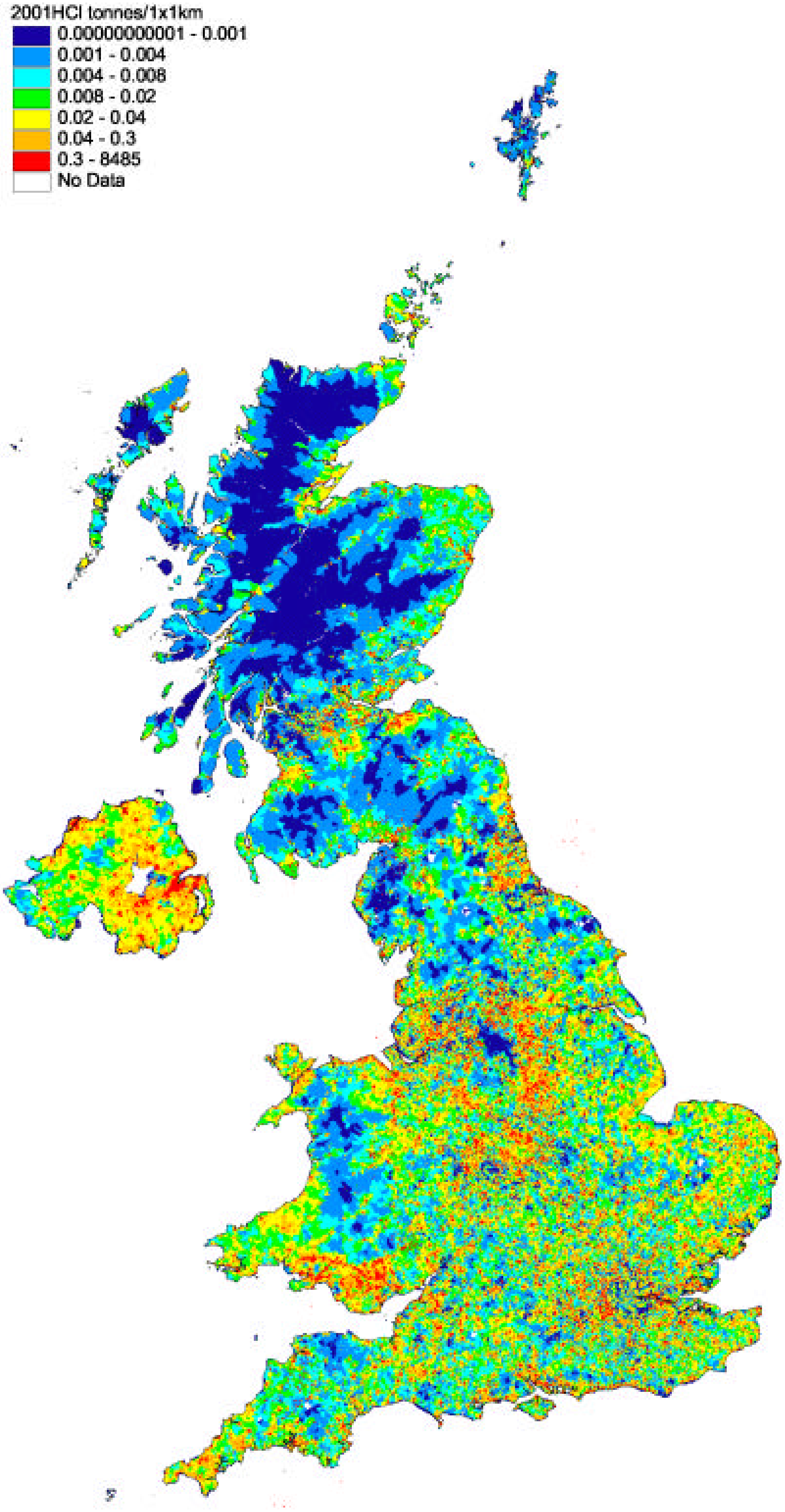


Figure 5.9 Spatially Disaggregated UK Emissions of HCl



5.5 NON-METHANE VOLATILE ORGANIC COMPOUNDS

NMVOCs are organic compounds which may differ widely in their chemical composition. These organic compounds are often grouped under the NMVOC label as the majority display similar behaviour in the atmosphere. NMVOCs are emitted to air as combustion products, as vapour arising from handling or use of petroleum distillates, solvents or chemicals, and from numerous other sources.

Interest in NMVOC emissions has grown as their role in the photochemical production of ozone has been appreciated. The diversity of processes which emit NMVOCs is huge, covering not only many branches of industry, but also transport, agriculture and domestic sources.

The NMVOC inventory is summarised in Table 5.6. Only 29% of the NMVOC emissions arise from combustion sources (unlike SO_2 and NO_x where the contribution from combustion sources is much higher). Of these emissions from combustion sources, it is the transport sector which dominates. Other major sources of NMVOC emissions are the use of solvents and industrial processes. Natural emissions of NMVOCs are included here as per UN/ECE guidelines. The NMVOC emission profile, presented in Figure 5.10, shows a small overall increase in emissions between 1970 and 1989 with minor peaks in 1973 and 1979, followed by a steady reduction in emissions during the 1990s. The latter is largely a reflection of the increasingly stringent emission limits across a range of sectors.

Figure 5.10 Time Series of NMVOC Emissions (Mtonnes)

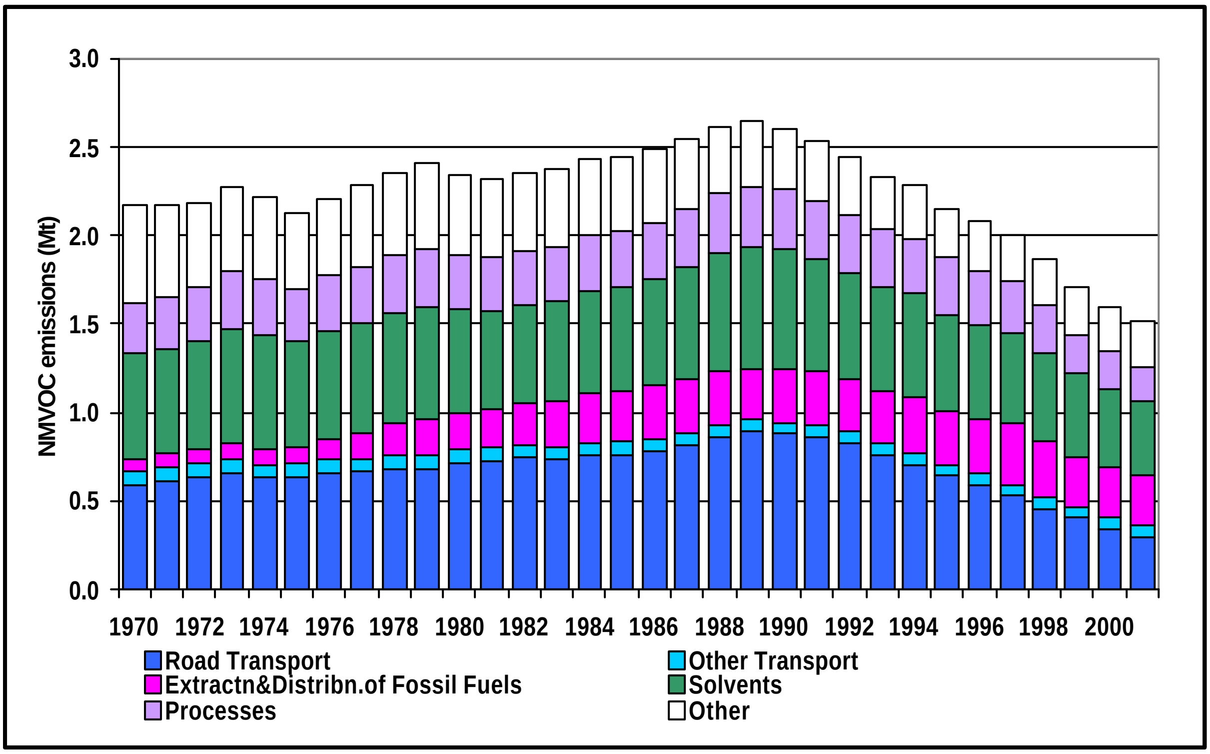


Table 5.6 UK Emissions of NMVOCs by UN/ECE[1] Source Category and Fuel (ktonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[2]											
Combustion in Energy Prod											
Public Power	7	8	7	8	9	8	6	8	8	9	1%
Petroleum Refining Plants	1	1	1	1	1	1	1	1	1	1	0%
Other Combustion & Trans.	2	2	2	1	1	1	1	1	1	1	0%
Combustion in Comm/Res	296	131	67	40	43	40	42	45	36	42	3%
Combustion in Industry	19	14	9	9	9	9	9	7	9	8	1%
Production Processes											
Petroleum Refining Plants	107	99	100	87	74	66	59	46	45	37	2%
Chemicals manufacture	94	113	149	141	140	126	114	79	73	59	4%
Food & Drink Manufacture	74	82	73	76	77	78	79	80	78	78	5%
Other processes	16	14	18	17	16	13	10	10	10	10	1%
Extr./Distrib. of Fossil Fuels											
Gas Leakage	12	38	42	40	39	67	66	66	63	65	4%
Offshore Oil&Gas	5	98	147	168	180	182	160	155	163	168	11%
Gasoline Distribution	47	72	109	98	93	95	87	61	58	51	3%
Solvent Use											
Industrial solvent use	512	485	522	402	392	379	367	333	302	281	19%
Domestic solvent use	83	97	152	141	138	138	138	138	141	144	10%
Road Transport											
Combustion	477	554	648	467	430	384	338	300	255	219	14%
Evaporation	116	164	231	174	160	146	122	109	91	81	5%
Other Trans/Machinery[3]	78	72	66	63	64	63	62	61	61	60	4%
Waste	12	58	45	39	38	33	31	26	22	22	1%
Land Use Change	37	58	35	0	0	0	0	0	0	0	0%
Nature	178	178	178	178	178	178	178	178	178	178	12%
By FUEL TYPE											
Solid	300	132	66	38	39	35	34	37	27	33	2%
Petroleum	677	793	947	706	655	594	524	471	408	360	24%
Gas	7	12	15	17	19	19	20	22	23	23	2%
Non-Fuel	1188	1401	1575	1389	1369	1359	1293	1174	1137	1097	72%
TOTAL	**2172**	**2338**	**2603**	**2149**	**2082**	**2007**	**1871**	**1704**	**1596**	**1514**	**100%**

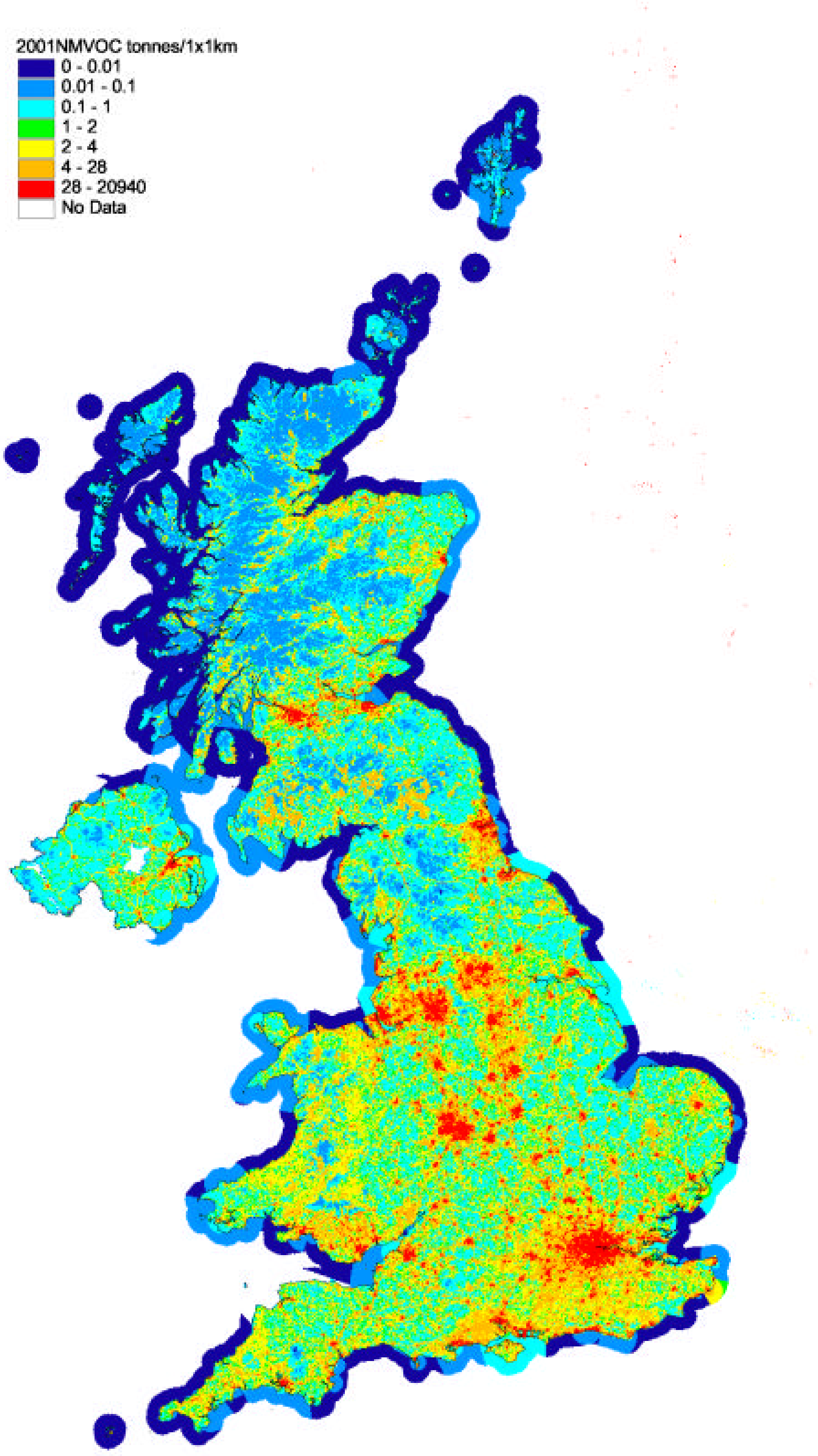
1 UK emissions reported in IPCC format (Salway, 2002) differ slightly due to the different source categories used.
2 See Annex 1 for definition of UN/ECE Categories
3 Including railways, shipping, naval vessels, military aircraft and off-road sources

The spatial disaggregation of NMVOC emissions in the UK is shown in Figure 5.11. A large proportion of emissions are caused either as a result of the activities of people in and around their homes (e.g. domestic solvent use or domestic combustion), or by widespread industrial activities such as small-scale industrial coating processes, dry cleaning shops, and small bakeries, which are present in towns and cities throughout the UK. Consequently the resulting emissions map is well correlated with population density.

The NMVOC map includes a large number of point sources, including oil refineries, crude oil terminals, large combustion plant, chemicals manufacture, iron and steel processes, whisky manufacture, large bread bakeries, and industrial solvent using processes. The domestic sources are distributed using population density statistics, and the sources arising from other industrial processes are mapped using information on the size and locations of industrial installations.

Unlike the map presented previously for NO_x, the NMVOC map has little major road definition except where the major roads go through rural areas. This reflects the fact that NMVOC emissions are dependent on vehicle speed and are higher on minor and urban major roads than on the high speed motorways and major roads.

Figure 5.11 Spatially Disaggregated UK Emissions of NMVOC



5.5.1 Solvent Use and Production Processes

Solvent use and production processes are responsible for 29% and 12%, respectively, of the 2001 emission total. The estimates are derived either based on plant specific data provided by process operators or regulators or by use of appropriate emission factors combined with solvent consumption data or industrial production data. The NMVOC inventory has been subject to a continuous programme of review and improvement over the past decade and estimates, especially those for the period 1988 – 2001, can be considered reasonably reliable.

The solvent use sector comprises both industrial and domestic applications, both being significant sources. Emissions from industrial solvent use reached their peak in 1973, then dipped to a low in 1982, before increasing again until 1989. Since 1989 emissions have fallen as a result of emission controls, technological changes, and reduced manufacturing output in some sectors. In comparison, domestic solvent emissions showed little trend until the mid 1980s when they increased sharply. Since 1991 however, emissions have fallen back by 8% due to a trend towards formulating products such as paints and aerosols with lower solvent contents.

The production processes sector includes emissions from the chemical industry, petroleum refining, and food and drink manufacture as well as minor sources such as iron and steel production and road construction. Emissions from the chemical industry grew steadily until 1989, since when tightening emission controls have led to a reduction in emissions of 61%. The emissions from the petroleum refining sector show little trend over the period from 1970 until 1994, but since then emission controls and, latterly, refinery closures have led to emissions falling by 62% since 1994.

Emissions from the food and drink industry comprised 5% (78.4 ktonnes) of the total NMVOC emission in 2001. The largest source is whisky maturation although bread baking, animal feed manufacture, fat and oil processing and barley malting are also important. Emissions from the sector peaked in 1980 before falling again. Since 1987 emissions increased by an average of 1% per year until 2000 when they dropped slightly. The trends with time are primarily driven by production in these sectors.

5.5.2 Transport

Total transport emissions are currently responsible for 23% of NMVOC emissions of which 19% are a result of road transport. From 1970 the emission rose by 18% with increasing car numbers, to a peak of 2.64 Mtonnes in 1989. Since then it has declined by 43% owing to the increased use of catalytic converters and fuel switching from petrol to diesel cars. Emissions from the road transport sector for 2001 are now 30% lower than in 1970.

5.5.3 Other Sectors

Offshore oil and gas emissions have increased substantially since 1970 with the growth of the UK's offshore industry and now constitute 11% of the 2001 emissions total. The most important sources of NMVOC emissions are tanker loading, flaring and fugitive emissions.

Emissions from gas leakage currently comprise around 4% of the total NMVOC emission. This estimate has been significantly revised upwards in light of new data. Even though the mass of mains gas being released has decreased (due to pipe replacement), there is an upward temporal trend of NMVOC emission. This is caused by the increasing NMVOC content of mains gas.

The evaporative losses from the distribution and marketing of petrol rose between 1970 and the early 1990s reflecting the growth in road transport. Since then they have decreased, partly as a result of fuel switching to diesel, and partly as a result of increasing usage of petrol vapour recovery systems to prevent emissions from petrol terminals and service stations. They currently account for 3% of national NMVOC emissions.

The contribution from domestic heating has fallen by more than a factor of 6 over the period 1970-2001 as the use of coal for domestic heating has declined. It now accounts for just 3% of the UK emission.

NMVOC emissions from waste treatment and disposal contribute 1% to national emissions. Data from the Environment Agency (2001) shows emissions from municipal waste incinerators to be very small.

NMVOCs, in particular isoprene and mono-terpenes, are emitted from several natural and agricultural sources- such as forests. The entries under Land Use Change and Nature in Table 5.6 represent emissions from forests and forestry, heathland, pastures and crops.

5.5.4 Speciation of NMVOCs

As mentioned previously, the term NMVOC covers a wide range of compounds and although a total NMVOC inventory is sufficient for some purposes, in other cases greater detail is required concerning the nature and concentration of individual compounds. For example, when assessing the photochemical production of ozone, individual species have different ozone creation potentials hence information is required on the concentration of individual species (QUARG, 1993). Table 5.7 shows the emissions of the 50 most important NMVOC species disaggregated as far as possible by source. "Unspeciated" emissions are those where no suitable speciation profile is available. In some cases the speciation profile that is available includes groups of compounds (e.g. C6's- representing all hydrocarbons with six carbon atoms). These are reported in the table as "other grouped species".

A more detailed speciation of all NMVOCs estimated by the NAEI (currently over 600) is given on the NAEI website (http://www.naei.org.uk).

Table 5.7 The 50 Most Significant NMVOC Species in Terms of Mass Emission (ktonnes)

	Stationary Combustion (Energy Production)	Stationary Combustion (Commercial & Residn)	Stationary Combustion (Industrial)	Production Processes	Extraction & Distribution of Fossil Fuels	Solvent Use	Road Transport	Other Transport & Machinery	Waste Treatment & Disposal	Nature (Forests)	TOTAL
butane	0.51	3.86	0.63	5.01	71.01	23.93	23.32	0.47	0.03		**129**
ethanol		1.25	0.15	53.09		38.96			0.32		**94**
ethane	1.39	5.70	0.21	1.37	50.80		4.17	0.57	5.99		**70**
propane	0.50	3.06	0.27	2.50	37.96	4.58	1.85	0.38	5.66		**57**
pentane	0.21	1.93	0.65	2.08	29.48	0.54	15.75	0.29	0.02		**51**
2-methylbutane	0.09	3.74	0.23	1.12	11.19	0.06	30.69	0.77	0.02		**48**
toluene	0.12	2.01	0.15	3.19	0.24	14.32	23.01	3.13	0.18		**46**
hexane	0.15	0.32	0.10	4.52	15.43	2.91	14.80	0.20	0.12		**39**
ethene (ethylene)	0.23	3.31	0.46	6.28	0.04		18.21	3.63	1.07		**33**
methanol			0.03	2.03	0.00	25.65			0.08		**28**
2-methylpropane	0.08	1.28	0.02	0.25	13.21	0.88	10.76	0.22	0.01		**27**
m-xylene	0.49	0.31	0.04	1.20	0.09	15.02	6.80	0.71	0.08		**25**
trichloroethene			0.00	0.86		23.23			0.07		**24**
propanone (acetone)	0.09	0.03	0.08	1.59		19.53	0.96	0.07	0.00		**22**
methanal (formaldehyde)	5.69	1.94	1.29	0.37	0.16	0.04	7.38	1.55	3.77		**22**
heptane	0.02	0.82	0.00	0.09	15.27	1.88	2.67	0.09			**21**
propene (propylene)	0.30	1.79	0.06	6.78	0.02		8.92	1.39	0.06		**19**
octane	0.00	0.08		0.05	13.45	1.55	1.03	0.09			**16**
benzene	0.19	3.47	0.75	1.47	1.06		6.14	1.48	0.84		**15**
ethylbenzene	0.14	0.11	0.03	1.43	0.03	5.74	6.68	0.77	0.14		**15**
1,2,4-trimethylbenzene	0.00	0.00	0.00	0.25	0.01	7.32	6.17	0.52			**14**
2-butanone			0.01	0.08		13.13	0.28	0.02	0.02		**14**
dichloromethane			0.00	3.42	0.08	9.82			0.07		**13**
o-xylene	0.11	0.18	0.02	0.55	0.05	3.70	6.79	0.81	0.05		**12**
decane	0.00	0.05		0.76	0.03	8.75	1.07	0.53			**11**
ethyne (acetylene)	0.04	0.02	0.07	0.58	0.03		8.68	1.64			**11**
p-xylene	0.00	0.24	0.02	0.67	0.03	4.04	5.26	0.55	0.07		**11**
2-propanol		0.01		0.46		8.90			0.02		**9**
2-methylpropene	0.00	0.18	0.00	0.72	0.26		6.91	1.07	0.01		**9**
4-methyl-2-pentanone				0.04		8.62					**9**
ethyl ethanoate				1.10		7.44			0.03		**9**
butyl ethanoate				0.01		7.72			0.02		**8**
tetrachloroethene				0.22		6.24			0.14		**7**
1-butanol				0.06		6.43			0.01		**6**
nonane	0.00	0.07		0.44	0.08	5.32	0.25	0.12			**6**
2-butene	0.01	0.70	0.00	0.15	0.81		4.11	0.21	0.02		**6**
methyl acetate				5.35							**5**
1,3,5-trimethylbenzene	0.00	0.00	0.00	0.12	0.00	2.38	2.43	0.25			**5**
undecane ($C_{11}H_{24}$)	0.00	0.00		0.40		4.55		0.22			**5**
2-pentene	0.01	0.44	0.00	0.01	1.40		2.94	0.04	0.00		**5**
acetaldehyde	0.00	0.00	0.00	0.79			3.28	0.70			**5**
2-methylpentane	0.00	0.01	0.02	0.90	2.32	1.40		0.01	0.06		**5**
1,3-butadiene	0.00		0.00	0.35	0.01		3.48	0.63	0.01		**4**
methylethylbenzene						4.28					**4**
1,2,3-trimethylbenzene	0.00	0.00	0.00	0.10	0.00	2.38	1.39	0.16			**4**
2-butoxyethanol						3.96					**4**
2-methylhexane				0.01	0.15	1.03	2.20	0.20			**4**
1-propanol						3.45					**3**
1-butene	0.01	0.33	0.05	0.70	0.24		1.89	0.12	0.01		**3**
dipentene						3.10					**3**
Sub Total	**10.40**	**37.26**	**5.34**	**113.55**	**264.94**	**302.90**	**240.24**	**23.62**	**19.02**	**0.00**	**1017**
unspeciated	0.01	1.84	2.71	27.06	4.83	6.81	1.38	0.39	0.01		**45**
isoprene + BVOC [1]										178.0	**178**

other grouped species [2]	0.01	0.79	0.01	24.23	11.08	7.93	41.47	32.92	1.31		**120**
other speciated NMVOC	0.25	2.07	0.18	19.34	3.36	107.67	16.33	2.77	1.89		**154**
Total NMVOC	**11**	**42**	**8**	**184**	**284**	**425**	**299**	**60**	**22**	**178**	**1514**

[1] biogenic NMVOCs. [2] Some speciation profiles give disaggregation into groups of compounds (e.g. C6's)
An entry of "0.00" represents a value of <0.005 ktonnes (i.e. <5 tonnes)

5.5.5 Photochemical Ozone Creation Potential

Table 5.7 (and Appendix 5) is a useful reference for finding the emission of a particular NMVOC compound. However, species specific emissions do not reflect the fact that NMVOC compounds have different efficiencies in generating ozone through photochemical reactions. To resolve this, the concept of a photochemical ozone creation potential (POCP) was created. This POCP identifies, on a relative basis, the ozone creation potential for each NMVOC compound through modelling studies. The creation potentials are then normalised by defining ethene as a creation potential of 1.

It is therefore possible to determine which NMVOCs are the most important for the photochemical formation of ozone in the atmosphere. This is achieved by scaling the emissions of each NMVOC by the corresponding POCP to determine a weighted total.

Table 5.8 POCP Weighted NMVOC Emissions

		POCP Weighted Emissions										
	POCP	**Stationary Combustion**	**Production Processes**	**Extraction and Distribution of Fossil Fuels**	**Solvent Use**	**Road Transport**	**Other Transport & Machinery**	**Waste Treatment & Disposal**	**Nature (Forests)**	**TOTAL (Mass Emission)**	**TOTAL (POCP Weighted)**	**TOTAL (POCP Weighted %)**
butane	35.2	1.76	1.76	24.99	8.42	8.21	0.17	0.01		**128.8**	**45.3**	**5.2%**
ethanol	39.9	0.56	21.18		15.55			0.13		**93.8**	**37.4**	**4.3%**
ethene (ethylene)	100.0	4.01	6.28	0.04		18.21	3.63	1.07		**33.2**	**33.2**	**3.8%**
toluene	63.7	1.45	2.03	0.15	9.12	14.66	2.00	0.12		**46.4**	**29.5**	**3.4%**
m-xylene	110.8	0.94	1.33	0.10	16.64	7.54	0.79	0.09		**24.8**	**27.4**	**3.2%**
propene (propylene)	112.3	2.42	7.62	0.03		10.01	1.56	0.07		**19.3**	**21.7**	**2.5%**
pentane	39.5	1.10	0.82	11.65	0.21	6.22	0.11	0.01		**51.0**	**20.1**	**2.3%**
2-methylbutane	40.5	1.64	0.45	4.53	0.02	12.43	0.31	0.01		**47.9**	**19.4**	**2.2%**
hexane	48.2	0.27	2.18	7.44	1.40	7.13	0.10	0.06		**38.5**	**18.6**	**2.1%**
1,2,4-trimethylbenzene	127.8	0.00	0.32	0.01	9.36	7.88	0.67			**14.3**	**18.2**	**2.1%**
o-xylene	105.3	0.32	0.58	0.05	3.90	7.14	0.85	0.05		**12.2**	**12.9**	**1.5%**
methanal (formaldehyde)	51.9	4.63	0.19	0.09	0.02	3.83	0.81	1.96		**22.2**	**11.5**	**1.3%**
ethylbenzene	73.0	0.20	1.05	0.02	4.19	4.88	0.56	0.10		**15.1**	**11.0**	**1.3%**
p-xylene	101.0	0.27	0.68	0.03	4.08	5.31	0.55	0.07		**10.9**	**11.0**	**1.3%**
heptane	49.4	0.42	0.04	7.54	0.93	1.32	0.05			**20.8**	**10.3**	**1.2%**
propane	17.6	0.67	0.44	6.68	0.81	0.32	0.07	1.00		**56.7**	**10.0**	**1.1%**
ethane	12.3	0.90	0.17	6.25		0.51	0.07	0.74		**70.2**	**8.6**	**1.0%**
2-methylpropane	30.7	0.42	0.08	4.06	0.27	3.30	0.07	0.00		**26.7**	**8.2**	**0.9%**
trichloroethene	32.5	0.00	0.28		7.58			0.02		**24.3**	**7.9**	**0.9%**
octane	45.3	0.04	0.02	6.09	0.70	0.46	0.04			**16.2**	**7.4**	**0.8%**
1,3,5-trimethylbenzene	138.1	0.00	0.16	0.00	3.29	3.35	0.35			**5.18**	**7.2**	**0.8%**
2-butene	113.9	0.81	0.17	0.93		4.68	0.24	0.02		**6.02**	**6.9**	**0.8%**
2-methylpropene	62.7	0.11	0.45	0.16		4.33	0.67	0.00		**9.15**	**5.7**	**0.7%**
2-pentene	111.9	0.51	0.01	1.56		3.29	0.05	0.00		**4.85**	**5.4**	**0.6%**
1,2,3-trimethylbenzene	126.7	0.00	0.13	0.00	3.02	1.77	0.20			**4.04**	**5.1**	**0.6%**
2-butanone	37.3	0.00	0.03		4.90	0.10	0.01	0.01		**13.5**	**5.0**	**0.6%**
decane	38.4	0.02	0.29	0.01	3.36	0.41	0.20			**11.2**	**4.3**	**0.5%**
4-methyl-2-pentanone	49.0		0.02		4.22					**8.7**	**4.2**	**0.5%**
methylethylbenzene	94.1				4.03					**4.3**	**4.0**	**0.5%**
1-butanol	62.0		0.04		3.98			0.00		**6.5**	**4.0**	**0.5%**
methanol	14.0	0.00	0.28	0.00	3.59			0.01		**27.8**	**3.9**	**0.4%**
1,3-butadiene	85.1	0.01	0.30	0.01		2.96	0.53	0.01		**4.5**	**3.8**	**0.4%**
1-butene	107.9	0.42	0.75	0.26		2.04	0.13	0.01		**3.3**	**3.6**	**0.4%**
ethyldimethylbenzene	132.0				3.38					**2.6**	**3.4**	**0.4%**
benzene	21.8	0.96	0.32	0.23		1.34	0.32	0.18		**15.4**	**3.4**	**0.4%**
ethanal (acetaldehyde)	64.1	0.00	0.51			2.10	0.45			**4.8**	**3.1**	**0.4%**
nonane	41.4	0.03	0.18	0.04	2.20	0.10	0.05			**6.3**	**2.6**	**0.3%**
1-pentene	97.7	0.19	0.07	0.28		1.76	0.04	0.00		**2.4**	**2.3**	**0.3%**
dipentene	74.5				2.31					**3.1**	**2.3**	**0.3%**
propanone (acetone)	9.4	0.02	0.15		1.84	0.09	0.01	0.00		**22.4**	**2.1**	**0.2%**
butyl ethanoate	26.9		0.00		2.08		0.00	0.01		**7.8**	**2.1**	**0.2%**
naphthalene	97.7	0.60	0.00		1.44		0.01			**2.1**	**2.0**	**0.2%**
undecane ($C_{11}H_{24}$)	38.4	0.00	0.15		1.75		0.08			**5.2**	**2.0**	**0.2%**
2-methylpentane	42.0	0.01	0.38	0.98	0.59		0.00	0.02		**4.7**	**2.0**	**0.2%**
1-propanol	56.1				1.94			0.02		**3.5**	**2.0**	**0.2%**
2-butoxyethanol	48.3				1.91					**4.0**	**1.9**	**0.2%**
ethyl ethanoate	20.9		0.23		1.56			0.01		**8.6**	**1.8**	**0.2%**
2-propanol	18.8	0.00	0.09		1.67			0.00		**9.4**	**1.8**	**0.2%**
2-methylhexane	41.1		0.01	0.06	0.42	0.90	0.08			**3.6**	**1.5**	**0.2%**
3-methylpentane	47.9	0.01	0.29	0.63	0.51			0.02		**3.1**	**1.5**	**0.2%**
Sub Total										**1017**	**540**	**62.1%**
unspeciated	51.3	2.34	13.88	2.48	3.50	0.71	0.20	0.00		45.0	23.1	2.7%
isoprene + BVOC[1]	90								160.2	178.0	160.2	18.4%
Other grouped species [2]		0.70	11.97	4.91	4.06	36.72	18.03	0.69		119.8	77.1	8.9%

Other speciated NMVOCs		0.98	7.91	0.91	49.67	7.63	1.37	0.73		153.9	69.2	8.0%
unspeciated	51.3	2.34	13.88	2.48	3.50	0.71	0.20	0.00		45.0	23.1	2.7%
Total		**31**	**94**	**94**	**244**	**201**	**37**	**8**	**160**	**1514**	**869**	**100%**

[1] biogenic NMVOCs. [2] Some speciation profiles give disaggregation into groups of compounds (e.g. C6's)

An entry of "0.00" represents a value of <0.005 ktonnes (i.e. <5 tonnes)

5.5.6 Temporal Disaggregation of NMVOC Emission Estimates

The emission of NMVOC plays a key role in the formation of ground level ozone. The representation of the emissions therefore has an important influence on the results of emission-driven ozone modelling studies. In addition to the overall magnitude and speciation of the emissions, it is also important to define their temporal variation.

Broadly speaking, the emissions can vary on three timescales, namely (i) with season, (ii) with day of week, and (iii) with hour of day. Clearly, a correct description of the seasonal dependence is important, because the photochemical conditions required for ozone formation are more prevalent during the summer months (April – September). The hour of day dependence is also important, particularly for very reactive NMVOC which are rapidly oxidised during daylight hours. The variation of emissions with day of week, in conjunction with the multi-day timescale for ozone formation and transport to occur, is believed to provide an explanation for the observed prevalence of photochemical ozone episodes on particular days of the week (Jenkin *et al* 2000).

Variations in emissions of NMVOC have been estimated over the following timescales:

- **Diurnal**: the portion of daily emissions which occur during each hour of a typical 24 hour period have been estimated.
- **Weekly**: the portion of weekly emissions which occur on each day of a typical week have been estimated.
- **Annual**: the portion of annual emissions which occur during each month of a typical year have been estimated.

A single representative profile has therefore been defined for the diurnal, weekly and annual variations for each NMVOC source category. Currently, no attempt has been made to identify differences in the diurnal pattern of emissions on different days of the week or at different times of year. Similarly, no attempt has been made to distinguish differences in the weekly pattern of emissions at different times of year. Such differences could well exist: for example, it is conceivable that emissions from decorative paint use and lawn mowers could exhibit a different pattern on a weekend compared with a week-day. In the former case, the emission might be expected to occur throughout the day whereas, in the latter case, emissions might be expected to peak during the early evening, after many people return home from work. Clearly, a fully rigorous temporal profile should therefore define the portion of emissions occurring in each hour of a given year, with the precise profile also changing from one year to the next. However, such a methodology would be impractical, and the resultant information would be difficult to use in modelling applications. The present approach is therefore designed to provide a practical method of defining the temporal variations in emissions.

Two approaches have been used to define the temporal profiles – the use of 'real' data or the use of 'default' profiles. In the first case, we have used data such as fuel consumption, electricity generated, or traffic volumes, which can be related to emissions, and which are themselves temporally resolved. In the second case, we have assumed that emissions follow one of a small set of default profiles. This second approach is used for most emission sources since no 'real' data are available. The default profiles have been applied, based on our knowledge of the emitting processes. Real data were used to define the typical temporal variations for a series of categories, namely road transport, natural emissions (forests), paint sectors and power generation. Further details of both the default profiles and real data used for temporal disaggregation of NMVOC emissions are given in Goodwin *et al*, 2001. All graphs are based on data from 1998.

5.5.6.1 Total NMVOC temporal profiles

The applied temporal codes allow emissions estimates to be made for a given hour for either total NMVOC, or for specific sectors or sectoral combinations. Some examples of data for total NMVOC emissions are presented in Figures 5.12-5.14. Figure 5.12 shows a comparison of the emissions of total NMVOC on a typical Friday for each month of the year, both for the hour ending at midday and the hour ending at midnight. Whereas the night-time emissions estimates show little variation with month, the daytime emissions maximise in the summer, owing partially to increased emissions from road transport.

Figure 5.12 Emissions of NMVOC for the Hours Ending at Midday and Midnight on a Typical Friday in Each Month of the Year.

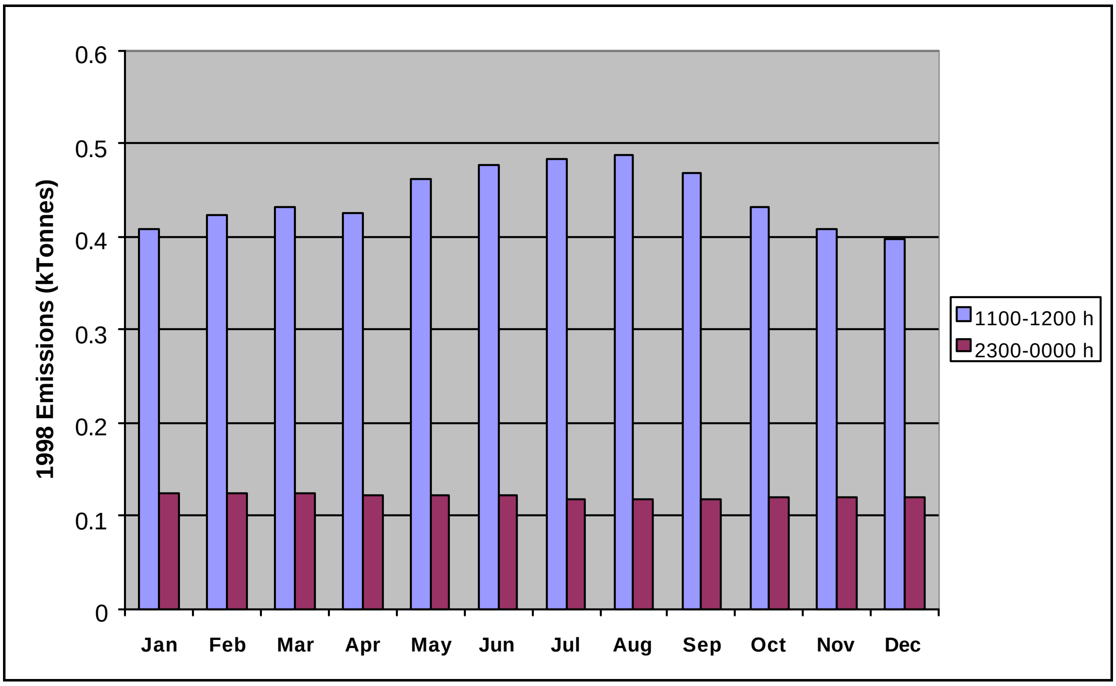


Figure 5.13: Emissions of NMVOC for the Hours Ending at Midday and Midnight for Each Day of the Week in July.

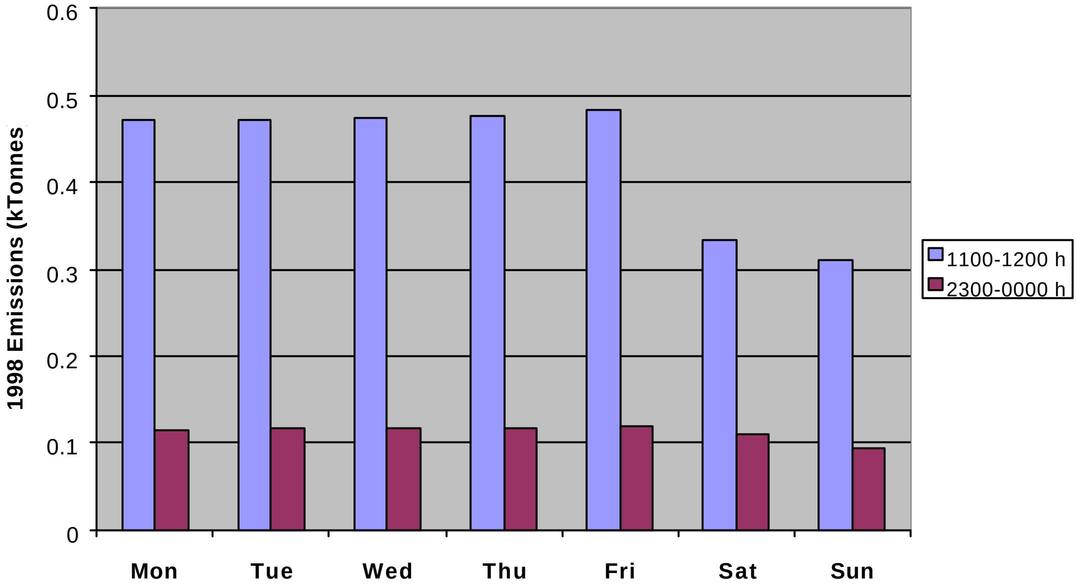


Figure 5.14 Emissions of NMVOC for Each Hour of the Day for a Typical Friday in January and July.

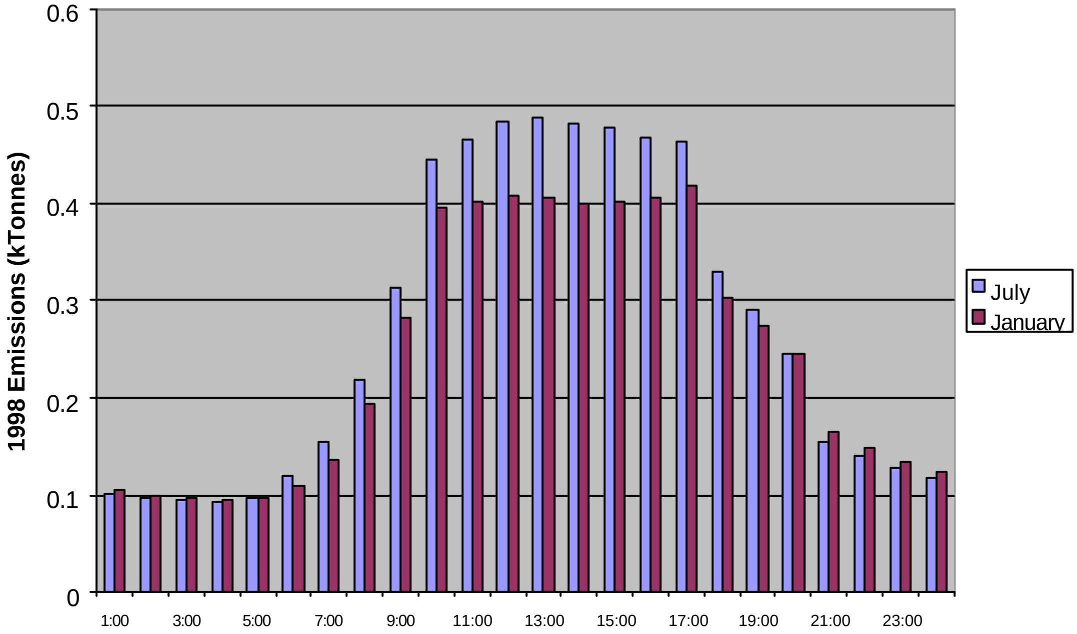


Figure 5.13 demonstrates that NMVOC emissions are substantially greater on weekdays than they are on weekends. This information has been applied in ozone modelling studies to explain the possible link between the day-of-week variation in ozone precursor emissions and the observed prevalence of episodes of health-related ozone threshold concentration exceedances at the end of the week (Jenkin *et al* 2000).

A typical diurnal dependence of total NMVOC emissions is presented in Figure 5.14 for midsummer and midwinter. The calculated profiles are reasonably similar, which partially reflects that only a single representative diurnal profile is assigned to each source with no allowance made for possible variations with time of year. Also, the diurnal dependence of the major contributions from road transport and many solvent subcategories are strongly correlated with the working day. So the similarity in the summer and winter profiles is considered reasonable.

5.6 AMMONIA EMISSION ESTIMATES

Emissions from the agricultural sector are taken directly from the agricultural ammonia (NH_3) inventory compiled for Defra each year by a consortium of organisations. There is on-going work to improve the NH_3 emission estimates from both agricultural and non-agricultural sources.

Table 5.11 UK Emissions of NH_3 by UN/ECE Source Category and Fuel (ktonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001 %
BY UN/ECE CATEGORY[1]													
Combustion in Energy Prod													
Public Power	0	0	0	0	0	0	0	0	0	0	0	0	0%
Other Combustion & Trans.	0	0	0	0	0	0	0	0	0	0	0	0	0%
Combustion in Comm/Res													
Residential Plant	5	6	5	6	5	4	4	4	3	4	3	3	1%
Commercial/Agricul Comb	0	0	0	0	0	0	0	0	0	0	0	0	0%
Combustion in Industry	1	1	1	1	1	1	1	1	1	1	1	1	0%
Production Processes	8	8	8	8	8	8	9	7	9	6	4	4	2%
Solvent Use	1	1	1	1	1	1	1	1	1	1	1	1	0%
Road Transport	1	1	2	4	6	9	12	12	12	12	12	12	4%
Off road sources	0	0	0	0	0	0	0	0	0	0	0	0	0%
Waste													
Landfill	8	8	8	7	7	7	7	6	5	5	4	4	1%
Non Landfill Waste	6	6	5	6	6	6	6	6	6	6	6	6	2%
Agriculture													
Animal Wastes	257	255	254	256	258	252	257	259	253	250	237	224	77%
Non Livestock Agriculture	54	58	44	39	37	32	26	31	29	33	29	35	12%
By FUEL TYPE													
Solid	5	6	5	6	5	4	4	4	3	4	3	4	1%
Petroleum	1	1	2	4	6	9	12	12	12	12	12	12	4%
Gas	0	0	0	0	0	0	0	0	0	0	0	0	0%
Non-Fuel	335	337	321	318	317	307	307	311	305	301	282	275	95%
TOTAL	**341**	**343**	**328**	**328**	**329**	**319**	**322**	**326**	**320**	**316**	**297**	**290**	**100%**

[1] See Annex 1 for definition of UN/ECE Categories

Table 5.11a UK Emissions of NH_3 from other sources (ktonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Domestic and Wild Animals	21.9	21.8	21.9	21.6	21.4	21.3	21.4	21.4	21.7	21.5	21.5	21
Humans	1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.5	1
TOTAL	23.6	23.5	23.5	23.2	23.0	23.0	23.1	23.1	23.3	23.1	23.0	22

Ammonia emissions n 2001 are dominated by agricultural sources with emissions from livestock and their wastes comprising 77% of the total emission. These emissions derive mainly from the decomposition of urea in animal wastes and uric acid in poultry wastes. Emissions depend on animal species, age, weight, diet, housing systems, waste management and storage techniques. Hence emissions are affected by a large number of factors which make the interpretation of experimental data difficult and emission estimates uncertain (DOE, 1994). The other agricultural sources included are emissions from fertiliser use, crops and decomposition of agricultural vegetation. These are particularly uncertain owing to the complexity of the processes involved.

Sutton *et al* (2000a, 2000b) and Handley *et al* (2001) give estimates of a number of non-agricultural emission estimates, some of which have been incorporated here. The non-agricultural sources comprise a number of diverse sources and equal 11% of the total. However, emission estimates for these sources are very uncertain due to a lack of data. Emissions of ammonia from road transport although relatively small are increasing as a result of the increasing number of three way catalysts in the vehicle fleet. Emission estimates from domestic/wild animals and humans are not included in the standard UN/ECE reporting format and (and hence not included in Table 5.11 or Figure 5.18). However for completeness the emission estimates from these sources are included in Table 5.11a.

NH_3 emissions from agricultural livestock are decreasing with time. This is driven by decreasing animal numbers. In addition, there is a decline in fertiliser use, which also gives rise to decreasing emissions. During 2001 the foot and mouth outbreak had a significant impact on the animal livestock numbers. However, a degree of restocking occurred after the outbreak had finished. As a result, across an annual period, the impact of the foot and mouth outbreak does not stand out as being a particularly strong feature in the time series (See Figure 5.18 below).

Figure 5.18 Time Series of NH_3 Emissions (ktonnes)

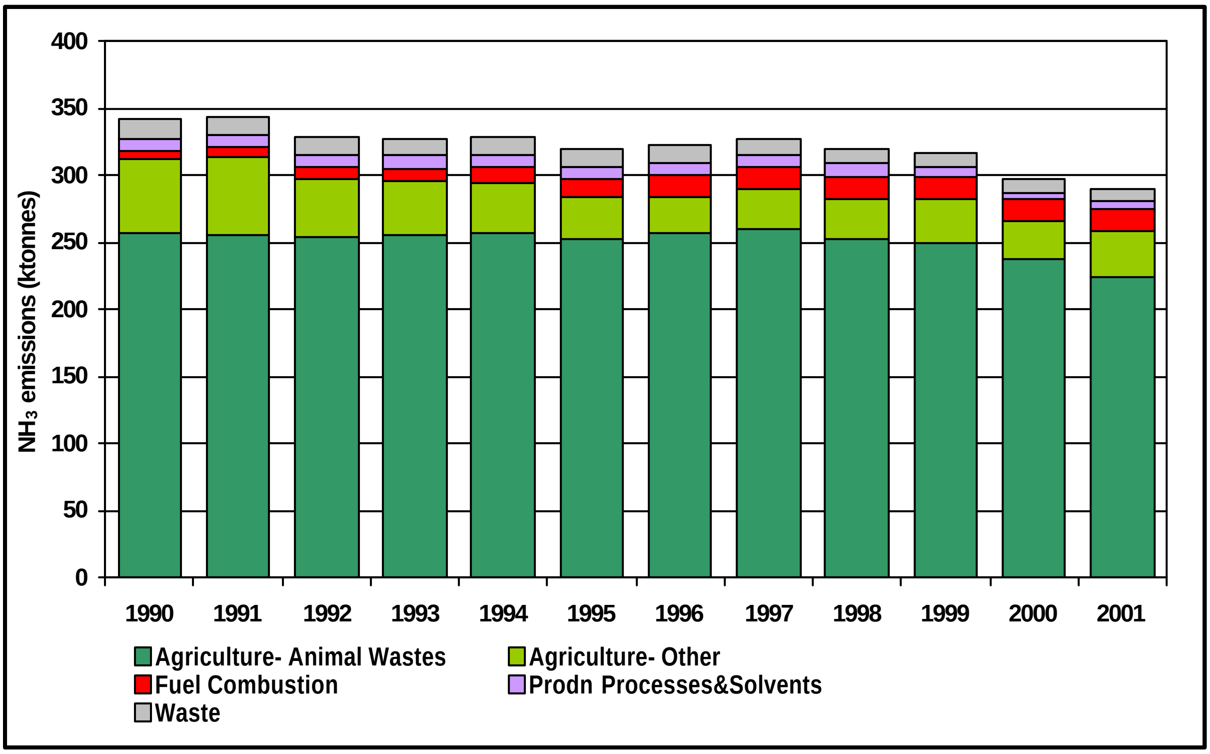
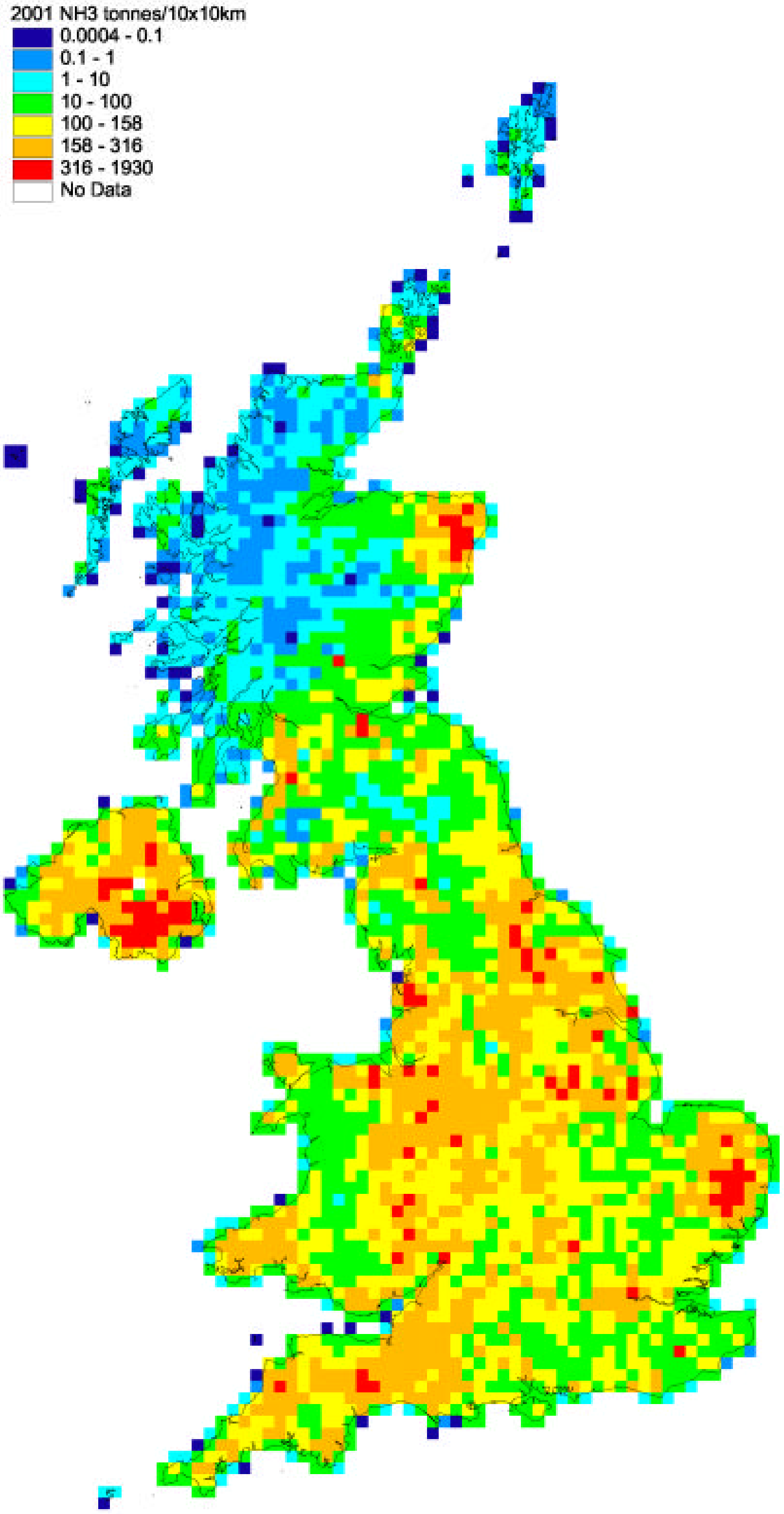


Figure 5.19 shows mapped NH_3 emissions. High emission densities are observed in agricultural areas, for example East Anglia, the South West and the North of England and Northern Ireland. Non-agricultural emissions are also noted to give rise to high emission densities in major urban areas such as London.

Figure 5.19 Spatially Disaggregated UK Emissions of NH_3



5.7 HYDROGEN FLUORIDE EMISSION ESTIMATES

Hydrogen fluoride (HF) is an acidic gas released to air from combustion of fuels which contain trace amounts of fluoride. Some industrial processes use HF as a an acidic reagent (or produce HF), giving rise to emissions. HF is chemically very similar to HCl.

Hydrogen fluoride emissions for the UK are presented here for the first time. As expected, the emissions of HF displays a similar source pattern to HCl (see Section 5.4). However, the emissions of HF from the power generation sector do not account for such a high percentage of the total (see Table 5.12). The reduction of the emissions from this sector with time is an indication of the increased use of emission abatement equipment in power stations. Emissions of HF from the residential sector have decreased with time. This is due to the decreasing use of coal in domestic heating. These trends with time are highlighted in Figure 5.20, and the impact of the miners strike in 1984 is apparent.

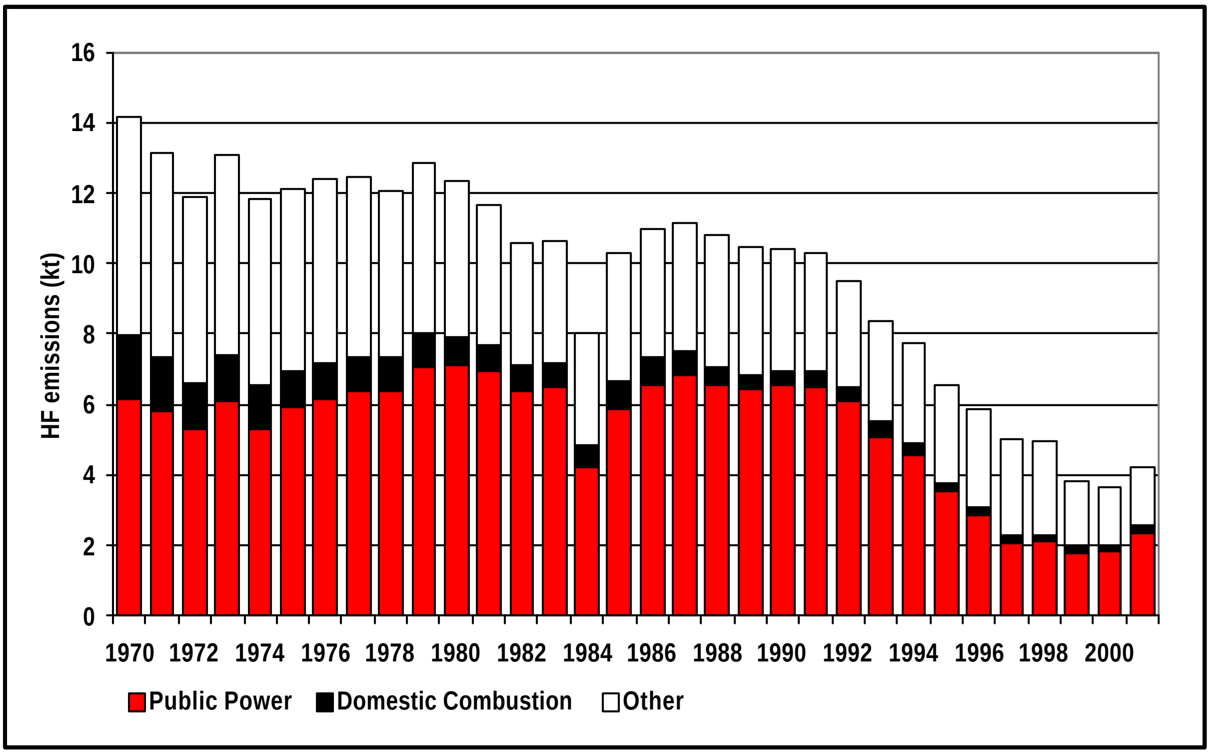
The increase of 10% in HF emission between 1999 and 2001 is caused by the increased coal consumption in electricity generation. Interestingly this trend is not noted for HCl (which exhibits a decrease of 20% from 1999 to 2001). This is because the HCl emission per unit of coal consumed decreased between 1999 and 2001, whereas that for HF remained reasonably constant.

Table 5.12 UK Emissions of HF by UN/ECE Source Category and Fuel (ktonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[1]											
Combustion in Energy Prod											
Public Power	6.1	7.1	6.6	3.5	2.9	2.0	2.1	1.8	1.8	2.3	55%
Other Combustion & Trans.	2.8	1.1	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.7	17%
Combustion in Comm/Res											
Residential Plant	1.8	0.8	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	5%
Commercial/Agricul Comb	0.4	0.2	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	1%
Combustion in Industry											
Iron & Steel Combustion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Other Ind. Combustion	2.4	1.2	0.9	0.8	0.7	0.7	0.6	0.5	0.4	0.4	10%
Production Processes	0.6	1.9	1.4	1.2	1.2	1.2	1.2	0.5	0.4	0.5	11%
Waste	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0%
By FUEL TYPE											
Solid	13.3	10.2	8.9	5.2	4.5	3.6	3.6	3.2	3.1	3.7	88%
Petroleum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Non-Fuel	0.9	2.2	1.5	1.3	1.4	1.4	1.4	0.6	0.6	0.5	12%
TOTAL	**14.2**	**12.3**	**10.4**	**6.6**	**5.9**	**5.0**	**5.0**	**3.8**	**3.7**	**4.2**	**100%**

[1] See Annex 1 for definition of UN/ECE Categories

Figure 5.20 Time Series of Hydrogen Fluoride Emissions (ktonnes)



5.8 ACCURACY OF EMISSION ESTIMATES OF ACIDIFYING GASES AND TROPOSPHERIC OZONE PRECURSORS

Quantitative estimates of the uncertainties in emission inventories have been based on calculations made using a direct simulation technique, which corresponds to the IPCC Tier 2 approach recommended for greenhouse gases and also the methodology proposed in draft guidance produced by the UN/ECE Taskforce on Emission Inventories. This work is described in detail by Passant (2002). Uncertainty estimates are shown in Table 5.13.

Table 5.13 Uncertainty of the Emission Inventories

Pollutant	Estimated Uncertainty %
Sulphur Dioxide	± 3
Oxides of Nitrogen	± 8
Non-Methane Volatile Organic Compounds	± 8
Ammonia	± 20
Hydrogen Chloride	± 20
Hydrogen Fluoride	± 20 [1]

[1] Assumed to be same as for hydrogen chloride (see text below for discussion)

Sulphur Dioxide
Sulphur dioxide emissions can be estimated with most confidence as they depend largely on the level of sulphur in fuels. Hence the inventory, being based upon comprehensive analysis of coals and fuel oils consumed by power stations and the agriculture, industry and domestic sectors, contains accurate emission estimates for the most important sources.

Oxides of Nitrogen

NO_x emission estimates are less accurate than SO_2 because they are calculated using measured emission factors, however these emission factors can vary widely with combustion conditions. Hence, emission factors given in the literature for combustion sources show large variations. In the case of road transport emissions, while the inventory methodology takes into account variations in the amount of NO_x emitted as a function of speed and vehicle type, significant variations in measured emission factors have been found even when keeping these parameters constant.

From the above, one might expect the NO_x inventory to be very uncertain, however the overall uncertainty is in fact lower than any pollutant other than SO_2. This is probably largely as a result of two factors. First, while emission factors are uncertain, activity data used in the NO_x inventory is very much less uncertain. This contrasts with inventories for pollutants such as volatile organic compounds, PM_{10}, metals, and persistent organic pollutants, where some of the activity data are very uncertain. Second, the NO_x inventory is made up of a large number of emission sources with many of similar size and with none dominating (the largest source category contributes just 18% of emissions, and a further 42 sources must be included to cover 90% of the emission). This leads to a large potential for error compensation, where an underestimate in emissions in one sector is very likely to be compensated by an overestimate in emissions in another sector. The other extreme is shown by the inventories for PCP, HCH and HCB (see Section 6.2.4) where one or two sources dominate and the inventories are highly uncertain.

Non-Methane Volatile Organic Compounds

The NMVOC inventory is less uncertain than those for SO_2 and NO_x. This is due in part to the difficulty in obtaining good emission factors or emission estimates for some sectors (e.g. fugitive sources of NMVOC emissions from industrial processes, and natural sources) and partly due to the absence of good activity data for some sources.

As with NO_x, there is a high potential for error compensation, and this is responsible for the relatively low level of uncertainty compared with most other pollutants in the NAEI.

Ammonia

Ammonia emission estimates are more uncertain than those for SO_2, NO_x and NMVOC due largely to the nature of the major agricultural sources. Emissions depend on animal species, age, weight, diet, housing systems, waste management and storage techniques. Hence emissions are affected by a large number of factors which make the interpretation of experimental data difficult and emission estimates uncertain (DOE, 1994). Emission estimates for non-agricultural sources such as wild animals are also highly uncertain. Unlike the case of NO_x and NMVOC, a few sources dominate the inventory and there is limited potential for error compensation.

Hydrogen Chloride

The hydrogen chloride inventory is equally uncertain as the ammonia inventory. As with ammonia, a few sources dominate the inventory and the levels of uncertainty in these sources is generally quite high.

Hydrogen Fluoride

Uncertainty analysis has not been performed on the hydrogen fluoride inventory as this is not a core part of the NAEI. However, the sources of hydrogen fluoride are very similar to those for hydrogen chloride and the level of uncertainty in emission factors might also be expected to be similar. As a result it seems reasonable to assume the same level of overall uncertainty as for hydrogen chloride.

6 Hazardous Air Pollutants

6.1 INTRODUCTION

This section includes pollutants singled out for control under recent international protocols of the UN/ECE under the Convention on Long-range Transboundary Air Pollution- namely Persistent Organic Pollutants (POPs) and Heavy Metals (HMs).

6.1.1 UN/ECE Heavy Metals and POPs Protocols

The Convention on Long-range Transboundary Air Pollution was signed in 1979 and entered into force in 1983. Since its entry into force the Convention has been extended by a number of protocols, including the 1998 Protocol on Heavy Metals and the 1998 Protocol on POPs. These two Protocols are given in outline below; more information may be found at the UN/ECE web site, located at:- http://www.unece.org/env/lrtap/. The UK has signed both of these protocols.

6.1.1.1 Persistent Organic Pollutants (POPs)

The UN/ECE Protocol on Persistent Organic Pollutants focuses on a list of 16 substances (or groups of substances), that have been identified according to certain risk criteria. In brief, these 16 pollutants may be classified in three source sectors as follows:

1. **Pesticides**: aldrin, chlordane, chlordecone, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), mirex, toxaphene, hexachlorocyclohexane (HCH) (incl. lindane);

2. **Industrial Chemicals**: hexabromobiphenyl, polychlorinated biphenyls (PCBs);

3. **By-products or Contaminants**: dioxins, furans, polycyclic aromatic hydrocarbons (PAHs).

The ultimate objective of the protocol is to eliminate any losses, discharges and emissions of POPs to the environment. This is achieved through several different legislative mechanisms. First, the production and use of several compounds is banned (aldrin, chlordane, chlordecone, dieldrin, endrin, hexabromobiphenyl, mirex and toxaphene). Second, several compounds are scheduled for elimination at a later date (DDT, heptachlor, hexachlorobenzene, PCBs). Finally, the protocol severely restricts the use of selected compounds (DDT, HCH- including lindane and PCBs). Limited uses which are thought to be essential and for which there are no adequate substitutes, can be exempted. For instance, the use of substances like DDT would be allowed under the protocol for public health emergencies. The protocol includes provisions for dealing with the surplus of products that will be banned.

Under the protocol, countries are also required to reduce their emissions of dioxins, furans, PAHs and HCB below their levels in 1990 (or an alternative year between 1985 and 1995). The protocol requires the best available techniques (BAT) to be applied to cut emissions of these POPs. For the incineration of municipal, hazardous and medical waste, it lays down specific limit values. The protocol allows for the addition of further compounds into control, depending on the development of the scientific basis for such an action.

In 1999, EPAQS (Expert Panel on Air Quality Standards) published a report on PAHs which recommended an Air Quality Standard of 0.25 ng m^{-3} benzo[a]pyrene as an annual average. As a result, further work assessing the concentrations of PAHs in the atmosphere has been commissioned by Defra and the results compared with the spatially disaggregated emissions inventory.

In August 2002 PAHs were added to the list of pollutants covered by the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (see Chapter 6.2), and an objective was set relating to the PAH concentrations in the air. As a consequence there is a continued drive to decrease PAH emissions from the major sources.

Continued improvements have been made in compiling the 2001 UK emission estimates for POPs. This has been instigated in a response to the increasing interest in hazardous air pollutants and their impact on the environment over the last several years. The level of data available for many of these pollutants is relatively limited and hence several areas of the current emission inventory have been targeted for improvements which will be included in future emission estimates as a part of the NAEI continuous improvement process.

Table 6.1 lists the toxic pollutants (i.e. POPs and heavy metals) included in the current inventory together with their total UK emissions in 2001. Each of the pollutant classes are considered in more detail in the following sections.

6.1.1.2 Heavy Metals

The UN/ECE Protocol on Heavy Metals targets three particularly harmful substances: lead, cadmium and mercury. Countries are obliged to reduce their emissions of these three metals below their levels in 1990 (or an alternative year between 1985 and 1995). The protocol aims to cut emissions from industrial sources (iron and steel industry, non-ferrous metal industry), combustion processes (power generation, road transport) and waste incineration.

The protocol specifies limit values for emissions from stationary sources and requires BAT for obtaining emission reductions from these sources, such as special filters or scrubbers for combustion sources or mercury-free processes. The protocol also requires countries to phase out leaded petrol.

Under the protocol, measures are introduced to lower heavy metal emissions from other products e.g. mercury in batteries, and examples are given of management measures for other mercury-containing products, such as electrical components (thermostats, switches), measuring devices (thermometers, manometers, barometers), fluorescent lamps, dental amalgam, pesticides and paint.

Further metals may be added to the protocol, and further measures may be introduced for lead, cadmium and mercury, depending on the development of the scientific basis for action.

The best known effects of heavy metals are those on humans and animals. Of these, the most important effects are deterioration of the immune system, the metabolic system and the nervous system. They lead to disturbances in behaviour and some heavy metals are suspected to be or have been proven to be carcinogenic.

The impact of heavy metals on the environment due to long-range transport can be summarized as:

1. Impact on aquatic ecosystems. Atmospheric deposition of metals may influence the quality of surface waters and ground water. In addition to the effects on the uses of water (e.g. restricted use of water for human consumption, livestock, recreation etc) accumulation in aquatic organisms may have adverse effects on the food web.
2. Impact on terrestrial systems. Metal uptake by plants is a key route for the entry of metals into the food chain. Contaminants may be toxic to plants and can alter the structure or diversity of

a habitat. When plants accumulate metals, these can be ingested by animals creating the potential for toxic effects at higher trophic levels.

3. Mesofauna and macrofauna. The accumulation of cadmium and lead in birds and mammals in remote areas is attributable to long range atmospheric transport.
4. Agricultural products. Airborne heavy metals account for significant fractions of the total heavy metal input to arable soils.

Major environmental problems due to long range transport have been reported, relating to the:

- Accumulation of Pb, Cd and Hg in forest top soils, implying disturbed nutrient recirculation in forest ecosystems and increased stress on tree vitality in central Europe, reinforced by the acidification of soils
- Highly increased content of Hg in fish from lakes, especially in Scandinavia.

Table 6.1 Total UK Emissions of Toxic Pollutants

Pollutant	**Total 2001 UK emission**	
Persistent organic compounds (POPs)		
• Polycyclic aromatic hydrocarbons (PAHs)	2193	tonnes (USEPA16)[1]
• Dioxins and Furans (PCDD/F)	357	TEQ grammes[2]
• Polychlorinated biphenyls (PCBs)	1.56	tonnes
• Pesticides		**tonnes**
- lindane (γ-HCH)	27	
- pentachlorophenol (PCP)	443	
- hexachlorobenzene (HCB)	0.59	
• Short Chain Chlorinated Paraffins (SCCPs)	1	tonnes
• Polychlorinated Napthalenes (PCNs)	NE[3]	
• Polybrominated Diphenyl Ethers (PBDEs)	13.8	tonnes
Heavy metals		**tonnes**
• Arsenic	41	
• Beryllium	16	
• Cadmium	5.1	
• Chromium	75	
• Copper	43	
• Lead	194	
• Manganese	343	
• Mercury	8.8	
• Nickel	138	
• Selenium	31	
• Tin	85	
• Vanadium	214	
• Zinc	393	

[1] See Table 6.3 for different PAHs included under different groupings.

[2] TEQ is a way of weighting emissions according to their toxicity. See Table 6.4

[3] NE- Not Estimated. It has not been possible to make an emission estimate

6.2 PERSISTENT ORGANIC POLLUTANTS

Persistent organic pollutants (POPs) are organic compounds of anthropogenic origin that do not readily break down in the environment. Their long lifetime means that they can be transported over long distances, resulting in widespread distribution across the earth, including remote regions. They accumulate in the food chain, and their toxicity poses a threat to humans and the environment.

Over recent years there has been a growing interest in these pollutants and in particular their potential chronic toxicity and impacts on human health. This is reflected by the recent international agreement to reduce releases of these chemicals under the UN/ECE Persistent Organic Pollutants Protocol (detailed in Section 6.1) and their consideration for air quality standards by the Expert Panel on Air Quality Standards (EPAQS). The detailed methodology for the compilation of these inventories depends on the combination of emission factors gathered from a range of sources and production statistics used elsewhere in the emission inventory or developed for the specific sector concerned.

The UK NAEI does not include emission estimates for a number of POPs that have been banned in the UK for several years. Table 6.2 below indicates the years in which the use of particular POPs were banned or their use severely restricted, and whether the listed POPs are included in the NAEI.

Table 6.2 POPs Included/Not Included in the NAEI and Corresponding Year of Ban on Use

Compound or Compound Group	Banned in UK	Included in NAEI
Polycyclic aromatic hydrocarbons (PAHs)	-	**Yes**
Dioxins and Furans (PCDD/Fs)	-	**Yes**
Polychlorinated biphenyls (PCBs)	-	**Yes**
Hexabromobiphenyl	Never Used	No
Pesticides		
γ-Hexachlorocyclohexane	-	**Yes**
Pentachlorophenol[1]	1995[2]	**Yes**
Hexachlorobenzene[1]	1975	**Yes**
Aldrin	1989	No
Chlordane	1992	No
Dichlorodiphenyl-trichloroethane (DDT)	1984	No
Chlordecone	1977	No
Dieldrin	1989	No
Endrin	1984	No
Heptachlor	1981	No
Mirex	Never Used	No
Toxaphene	Never Used	No

[1] Hexachlorobenzene and pentachlorophenol are also emitted from other sources as well as being or having been active ingredients in pesticides.

[2] Use of pentachlorophenol is severely restricted rather than banned absolutely.

6.2.1 Polycyclic aromatic hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons are a large group of chemical compounds with a similar structure comprising two or more joined aromatic carbon rings. Different PAHs vary both in their chemical characteristics and in their environmental sources and they are found in the environment both as gases and associated with particulate material. They may be altered after absorption into the body into substances that are able to damage the genetic material in cells and initiate the development of cancer, although individual PAHs differ in their capacity to damage cells in this way.

The speciated PAH inventory was first compiled for the 1996 emissions inventory (see “Speciated PAH Inventory for the UK” Wenborn MJ 1999) and has allowed a more detailed understanding of the PAH emissions in the UK.

There have been several pollutant classifications relating to PAHs. Although there are a vast number of PAHs, the NAEI inventory focuses on sixteen. These 16 PAHs have been designated by the United States Environmental Protection Agency (USEPA) as compounds of interest using a suggested procedure for reporting test measurement results (USEPA 1988). The estimated emissions for individual compounds are given in Appendix 5 (for the appendices of this report see http://www.naei.org.uk/). A subset of this includes six of the PAHs identified by the International Agency for Research on Cancer (IARC) as probable or possible human carcinogens (IARC 1987). In addition, the Borneff 6 PAHs (another subset focussing on the health impacts of the PAHs) have been used in some EC emission inventory compilations. A further subset of PAHs are those to be used as indicators for the purposes of emissions inventories under the UN/ECE's Persistent Organic Pollutants Protocol. These classifications are given in the following table.

Table 6.3 The USEPA 16 PAH Primary Pollutants, and other PAH Subsets.

	Included in the NAEI	**USEPA** Priority pollutants (16 PAH)	**IARC** Probable or possible Human carcinogens (6 PAH)	**Borneff** (6 PAH)	**UN/ECE POPs Protocol** Indicators for purpose of emission inventories
Naphthalene	✔	✓			
Acenapthene	✔	✓			
Acenapthylene	✔	✓			
Fluorene	✔	✓			
Anthracene	✔	✓			
Phenanthrene	✔	✓			
Fluoranthene	✔	✓		✓	
Pyrene	✔	✓			
Benz[a]anthracene	✔	✓	✓		
Chrysene	✔	✓			
Benzo[b]fluoranthene	✔	✓	✓	✓	✓
Benzo[k]fluoranthene	✔	✓	✓	✓	✓
Benzo[a]pyrene	✔	✓	✓	✓	✓
Dibenz[ah]anthracene	✔	✓	✓		
Indeno[1,2,3-cd]pyrene	✔	✓	✓	✓	✓
Benzo[ghi]perylene	✔	✓		✓	

The main environmental impact of PAHs relate to their health effects, focusing on their carcinogenic properties. The most potent carcinogens have been shown to be benzo[a]anthracene, benzo[a]pyrene and dibenz[ah]anthracene (APARG 1996). The semi-volatile property of PAHs makes them highly mobile throughout the environment via deposition and re-volatilisation between air, soil and water bodies. It is possible that a proportion of PAHs released in the UK are deposited in the oceans and/or subject to long range transport making them a widespread environmental problem.

In 1999 the Expert Panel on Air Quality Standards (EPAQS) published a recommendation for an air quality standard for PAHs. This standard was based on the use of benzo[a]pyrene as an indicator of the overall carcinogenicity of the PAHs present in the atmosphere. In August 2002 PAHs were included in the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (see Section 4.1) through the introduction of an objective relating to concentrations in ambient air.

Emissions of the total amount of the 16 PAHs and benzo[a]pyrene (BaP) are summarised in Tables 6.4a and 6.4b. Whilst BaP emissions are included in the 16 PAHs, it is also considered here individually due to its importance.

Aluminium production and anode baking (carried out for the aluminium industry) was the largest source of PAH emissions in the UK until 1996 (contributing nearly half of the total PAH emission). Emissions since then have declined and in 2001 these sources accounted for only 5% of the emissions. This is a consequence of investment in abatement equipment following from the authorisation regime implementing the Environmental Protection Act 1990. One of the anode baking plants has dramatically reduced its emissions and the other is timetabled to follow shortly.

Road transport combustion is currently the largest source of PAH emissions contributing 49% of the emissions in 2001. These figures have been substantially revised since the 1999 NAEI Report. This is primarily a result of revisions to the emissions of napthalene from road transport combustion. Further detail on the methodology changes can be found in Appendix 1 (See http://www.naei.org.uk/). The next largest sources of emissions in 2001 were domestic combustion and other forms of industrial combustion.

Emissions of PAH and BaP from domestic combustion increased between 1997 and 1999 but started to declined in 2000. This reflects the increased consumption of coal in the domestic sector during 1997 to 1999 and the subsequent decline from 2000.

There are several source sectors relevant to PAHs which have been targeted for improvement:

- Wood treatment may be a significant source of some of the lighter PAHs such as acenapthene, fluorene and anthracene. Currently this source is not included due to a lack of available data. However, data is being sought, and the feasibility of including emission estimates from this source will be determined.
- Emissions from bitumen production and use have not been estimated due to a lack of emission data. It is possible that bitumen use is a significant source of benzo[a]pyrene and other PAHs.

The BaP inventory was updated in the 2000 report (Goodwin *et al* 2002) to incorporate new information regarding emission factors and activity data on sources of BaP.

The most notable changes to the BaP inventory include significantly reduced emissions from some industrial sources and smaller road transport emissions. Further details can be found in Coleman *et al* (2001). Increased measurement of PAHs by both industry and regulators, particularly in the aluminium sector, has allowed improvements in the precision of the emission estimates. The uncertainties associated with the emissions estimates of PAHs are considered in Section 6.4.

Tables 6.4a/b UK emissions of PAHs (emissions of individual PAHs are given in Appendix 5- see http://www.naei.org.uk/)

Table 6.4a UK Emissions of 16 PAHs[1] by UN/ECE Source Category (tonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY													
Combustion in Energy Prod													
Public Power	6	6	5	4	4	4	4	3	4	3	4	4	0%
Petroleum Refining Plants	4	4	4	4	4	4	4	5	5	5	4	2	0%
Other Combustion & Trans.	10	10	7	4	2	1	1	1	1	1	1	1	0%
Combustion in Comm/Res													
Residential Plant	765	786	760	739	591	464	485	471	488	523	411	486	22%
Comm/Agricul Combustion	32	29	19	21	19	16	17	18	10	4	2	2	0%
Combustion in Industry													
Iron & Steel Combustion	22	22	21	21	21	22	22	23	22	21	19	17	1%
Other Ind. Combustion	363	409	489	392	370	348	294	224	186	196	99	189	9%
Production Processes													
Non-Ferrous Metals	3490	3354	3219	3083	2947	2307	735	432	143	98	104	117	5%
Processes in Industry	107	99	91	86	87	87	87	87	86	82	86	77	4%

Solvent Use	104	100	97	94	90	87	83	80	76	73	69	69	3%
Road Transport													
Combustion	2139	2119	2027	1980	1964	1790	1674	1545	1367	1277	1159	1064	49%
Other Trans/Machinery	9	9	9	9	8	6	6	5	4	4	4	4	0%
Waste[2]	66	66	66	66	65	65	65	65	65	65	65	65	3%
Agriculture	933	800	582	12	0	0	0	0	0	0	0	0	0%
Nature (Natural Fires)	95	95	95	95	95	95	95	95	95	95	95	95	4%
TOTAL	**8145**	**7908**	**7491**	**6609**	**6268**	**5296**	**3573**	**3051**	**2551**	**2447**	**2122**	**2193**	**100%**

1 The PAHs selected are listed above in Table 6.3

2 Excludes emissions of 12607kg from foot and mouth animal pyres. See Chapter 9.

Emissions of BaP are included in the 16 PAH emissions, but it is an important pollutant, and is therefore also reported in its own right in the following table.

Table 6.4b UK Emissions of BaP[3] by UN/ECE Source Category (tonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY													
Combustion in Energy Prod													
Public Power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Petroleum Refining Plants	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Other Combustion & Trans.	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Combustion in Comm/Res													
Residential Plant	6.1	6.3	6.0	5.8	4.5	3.4	3.6	3.4	3.6	3.9	2.9	3.6	35%
Comm/Agricul Combustion	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0%
Combustion in Industry													
Iron & Steel Combustion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Other Ind. Combustion	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0%
Production Processes													
Non-Ferrous Metals	24.6	23.7	22.7	21.8	20.8	16.3	5.2	3.9	2.6	1.5	0.7	0.7	7%
Processes in Industry	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2%
Solvent Use	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0%
Road Transport													
Combustion	5.3	4.5	3.9	3.2	2.6	2.1	1.6	1.3	1.0	0.8	0.7	0.6	6%
Other Trans/Machinery	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0%
Waste[4]	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	19%
Agriculture	28.3	24.3	17.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Nature	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	29%
TOTAL	**70**	**65**	**56**	**37**	**33**	**27**	**16**	**14**	**13**	**11**	**10**	**10**	**100%**

[3] Benzo[a]pyrene

[4] Excludes emissions of 382.5kg from foot and mouth animal pyres. See Chapter 9.

Figure 6.1 Time Series of 16 PAHs Emissions (tonnes)

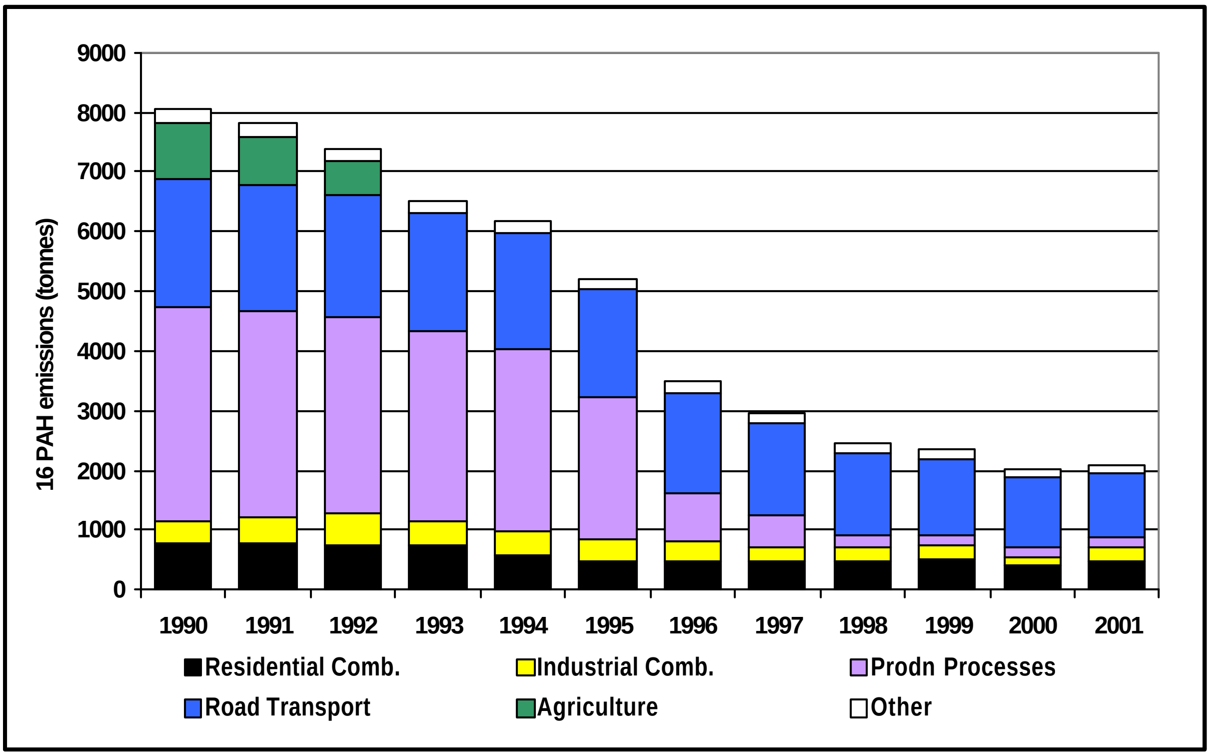


Figure 6.2 Time Series of Benzo[a]Pyrene Emissions (tonnes)

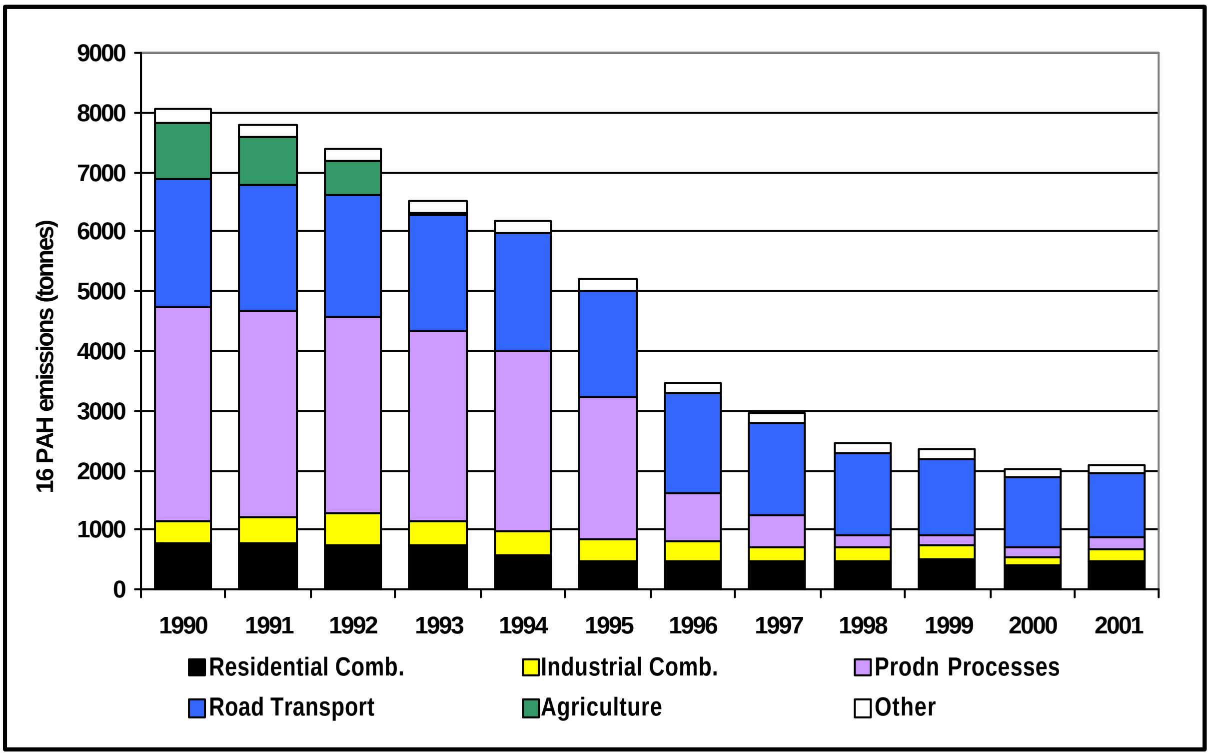
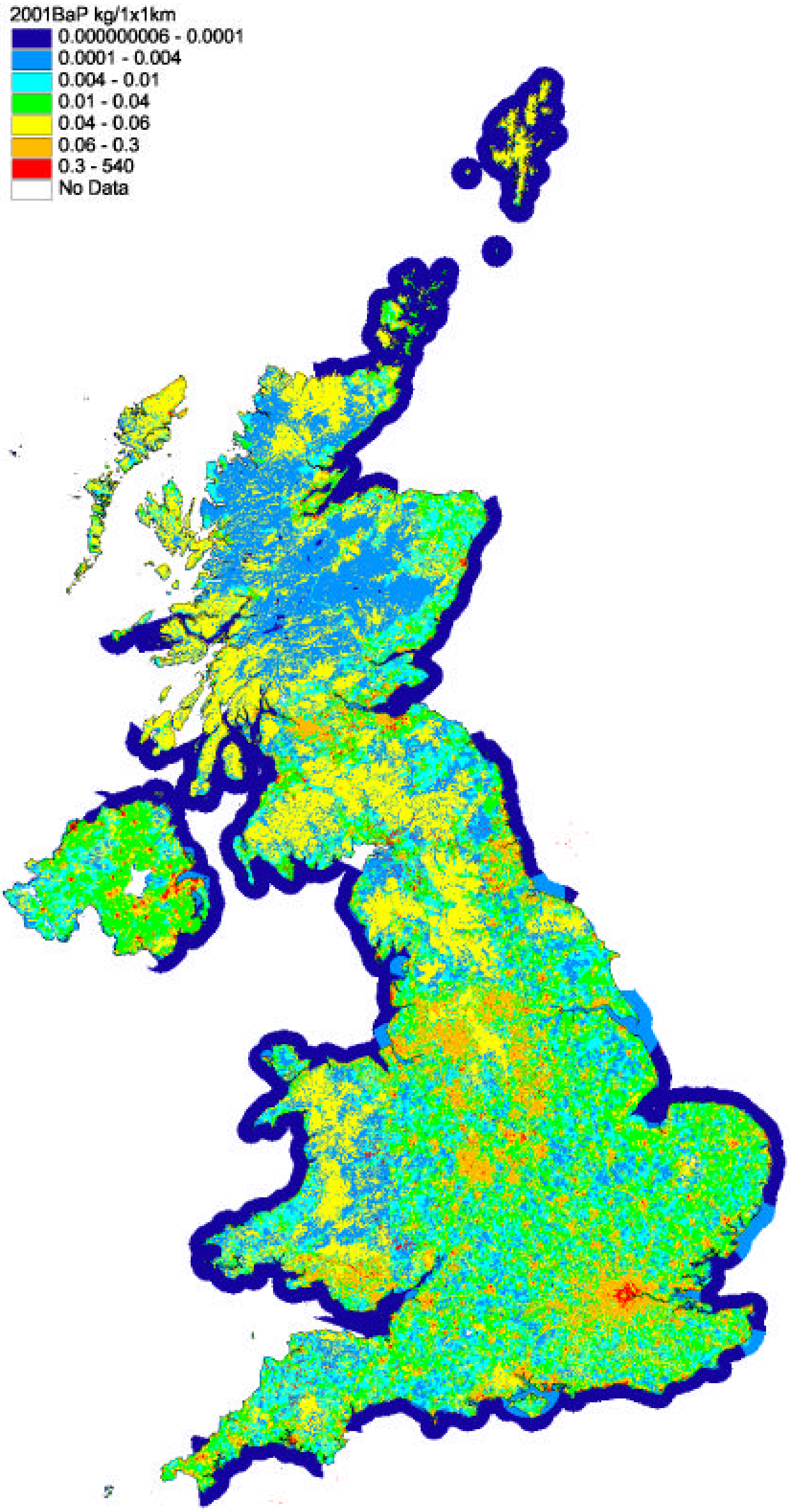


Figure 6.3 Spatially Disaggregated UK Emissions of Benzo[a]pyrene



6.2.2 Dioxins and Furans (PCDD/F)

The term “dioxin” is used to refer to the polychlorinated dibenzo-*p*-dioxins (PCDD) and “furan” is used for polychlorinated dibenzofurans (PCDF). There are 210 PCDD/F compounds in total, which can be described as "congeners"- i.e. different compounds within a family or group having a similar structure. Of these 210 compounds the emissions of importance are those of the 17 PCDD/Fs (7 PCDDs and 10 PCDFs) as defined by the NATO/CCMS (Committee on the Challenges of Modern Society 1988) international toxic equivalent (I-TEQ) scheme. TEQ schemes weight the toxicity of the less toxic congeners as fractions of the toxicity of 2,3,7,8-TCDD, the most toxic congener.

The inventory presented here is in terms of the sum of the weighted emissions expressed as ‘I-TEQs’ which are widely used in UK and European legislation. However, more recently the World Health Organisation (WHO) has suggested a modification to the values used to calculate the toxic equivalents for some of the PCDDs and PCDFs. They have also suggested that there is value in using a similar approach for the PCBs which have dioxin-like toxicity and combining the PCDD/F and PCB TEQs together. The International and the WHO toxic equivalence factors (TEFs) for PCDD/Fs are shown in Table 6.5

Table 6.5 The International and the WHO Toxic Equivalence Factors for PCDD/Fs (the differences are highlighted)

Dioxins	**International TEFs** [1]	**WHO TEFs** [2]
2,3,7,8 tetraetrachlorodibenzo-p-dioxin	1	1
1,2,3,7,8 pentachlorodibenzo-p-dioxin	**0.5**	**1**
1,2,3,4,7,8 hexachlorodibenzo-p-dioxin	0.1	0.1
1,2,3,6,7,8 hexachlorodibenzo-p-dioxin	0.1	0.1
1,2,3,7,8,9 hexachlorodibenzo-p-dioxin	0.1	0.1
1,2,3,4,6,7,8 heptachlorodibenzo-p-dioxin	0.01	0.01
Octachlorodibenzo-p-dioxin	**0.001**	**0.0001**
Furans		
2,3,7,8 tetra4chlorodibenzofuran	0.1	0.1
1,2,3,7,8 pentachlorodibenzofuran	0.05	0.05
2,3,4,7,8 pentachlorodibenzofuran	0.5	0.5
1,2,3,4,7,8 hexachlorodibenzofuran	0.1	0.1
1,2,3,6,7,8 hexachlorodibenzofuran	0.1	0.1
1,2,3,7,8,9 hexachlorodibenzofuran	0.1	0.1
2,3,4,6,7,8 hexachlorodibenzofuran	0.1	0.1
1,2,3,4,6,7,8 heptachlorodibenzofuran	0.01	0.01
1,2,3,4,7,8,9 heptachlorodibenzofuran	0.01	0.01
Octachlorodibenzofuran	**0.001**	**0.0001**

[1] NATO/CCMS (1988) [2] WHO (1998)

PCDD/Fs have been shown to possess a number of toxicological properties. The major concern is centred on their possible role in immunological and reproductive effects. The main sources of PCDD/Fs are thermal processes, but they can also be released to the environment from some chemical processes.

PCDD/Fs can arise from any thermal process where chlorine is present. For example, coal and other solid fuels contain trace amounts of chlorine compounds which can under certain combustion conditions result in PCDD/F formation. In addition PCDD/Fs can be present in the feed stock material, or chlorinated impurities may be introduced into the feed stock of some thermal processes. The amount of chlorine required for PCDD/F formation may be small and consequently many processes have the potential to emit these pollutants. PCDD/Fs can also be emitted from the chemical production and use of polychlorinated aromatic pesticides and herbicides, many of which are now controlled. However, some chlorinated organic chemicals such as the wood preservative pentachlorophenol are still used in the UK and these have the potential to be sources of PCDD/Fs e.g. from the combustion of treated wood.

Estimated PCDD/F emissions for 1990-2001 are summarised in Table 6.6 below.

Table 6.6 UK emissions of PCDD/Fs by UN/ECE Source Category (grams TEQ/year)

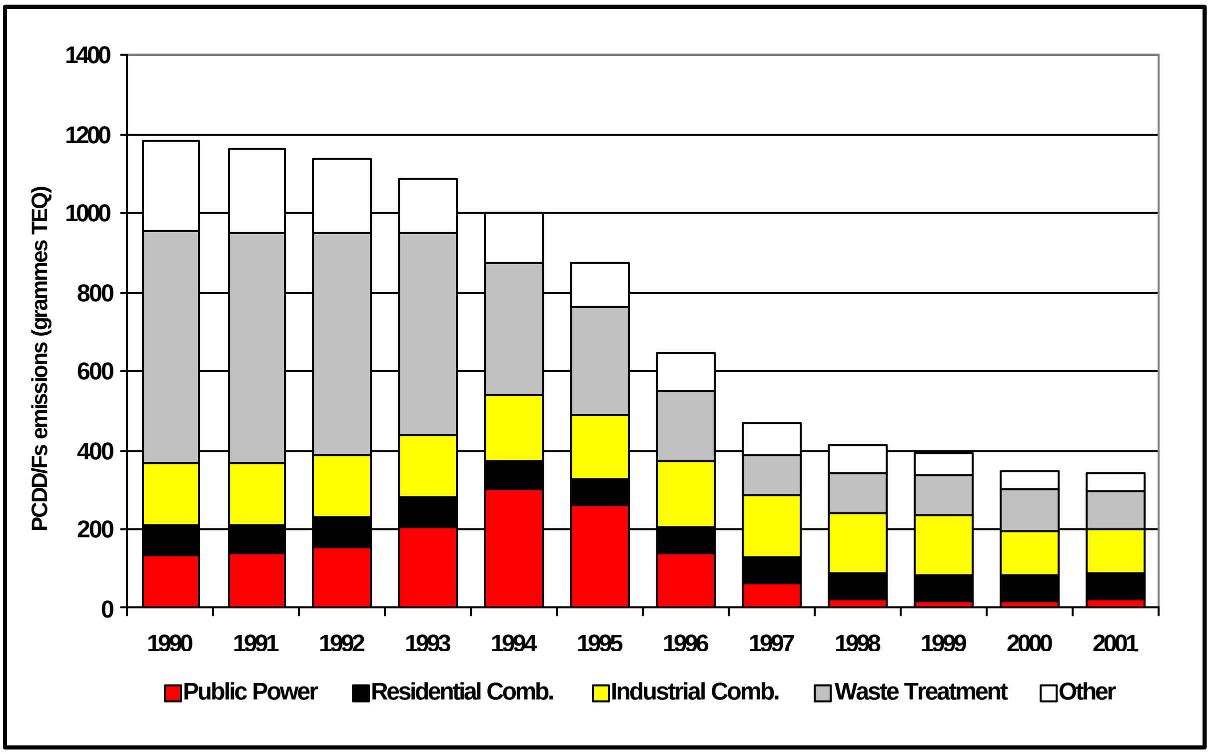
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2001 %**
BY UN/ECE CATEGORY													
Combustion in Energy Prod													
Public Power	137	137	157	206	302	262	139	63	23	19	19	20	6%
Petroleum Refining Plants	12	13	13	14	14	14	14	14	14	12	9	11	3%
Other Combustion & Trans.	0	0	0	0	0	0	0	0	0	0	0	0	0%
Combustion in Comm/Res													
Residential Plant	74	75	73	74	71	67	68	66	66	67	65	66	19%
Comm/Agricul Combustion	98	100	91	80	71	56	43	33	24	24	21	21	6%
Combustion in Industry													
Iron & Steel Combustion	46	45	44	44	44	44	45	46	45	43	36	31	9%
Non-Ferrous Metals	32	28	28	31	34	33	34	31	32	33	17	16	4%
Other Ind. Combustion	68	70	72	69	73	71	71	66	60	61	50	57	16%
Production Processes													
Iron & Steel	31	26	28	29	29	30	28	30	26	17	10	9	3%
Non-Ferrous Metals	6	6	5	5	5	5	5	5	5	5	6	6	2%
Processes in Industry	6	5	5	4	4	4	4	3	3	3	3	3	1%
Solvent Use	0	0	0	0	0	0	0	0	0	0	0	0	0%
Road Transport													
Combustion	29	26	23	21	19	16	15	11	9	6	5	4	1%
Vehicle Fires	6	7	7	7	6	7	7	7	7	8	9	10	3%
Other Trans/Machinery	1	1	1	1	1	1	1	1	1	0	0	0	0%
Waste[1]													
Landfill	1	1	1	1	1	1	1	1	1	1	1	1	0%
Waste Incineration	584	578	560	510	335	268	177	100	103	104	104	97	27%
Other Waste Treat. & Disp.													
Agriculture	57	49	36	1	0	0	0	0	0	0	0	0	0%
Nature	6	6	6	6	6	6	6	6	6	6	6	6	2%
TOTAL	**1193**	**1174**	**1149**	**1102**	**1014**	**886**	**657**	**484**	**424**	**409**	**360**	**357**	**100%**

1 Excludes emissions of 0.7grammes TEQ from foot and mouth animal pyres. See Chapter 9.

The largest sources of PCDD/F emission has been, and still is, waste incineration. However emissions from waste incineration have fallen rapidly from 1993 to 2001. This significant trend has been driven by the introduction of control measures. Municipal Solid Waste (MSW) incinerators not meeting the new standards closed in the period leading up to December 1996. New designs of MSW incinerator result in significantly lower levels of PCDD/F emissions.

The relatively low emissions from chemical incinerators reflects the use of rotary kilns and the incorporation of a secondary combustion chamber in the process to destroy organic contaminants together with the relatively low waste throughput and advanced pollution abatement equipment. However, clinical waste incineration remains a significant source. This is due to the fact that emissions from clinical waste incinerators (although showing significant reductions) have not been reducing as rapidly as the total PCDD/F total.

Figure 6.4 Time Series of PCDD/Fs Emissions (grams TEQ)



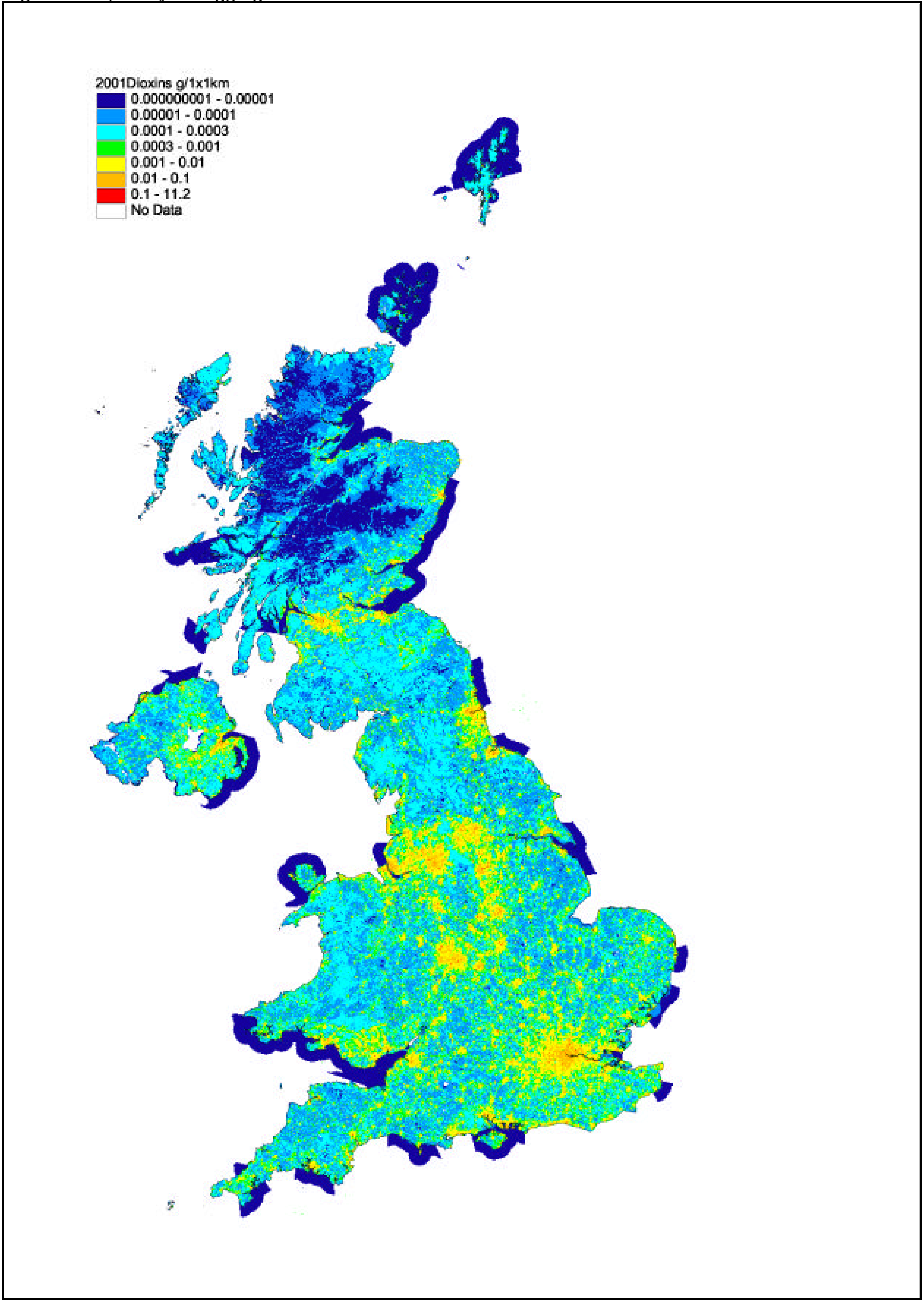
Emissions from power stations are fairly low because the combustion is efficient and the post-combustion fly ash temperatures are rapidly reduced. The emission factors associated with industrial and domestic coal combustion are significantly higher and sum to give a similar contribution, even though the coal consumption is smaller. However, emissions from all three sectors have decreased with the reduction in the quantity of coal burned.

Emissions from open agricultural burning and accidental fires are included in the agricultural and nature sectors. The former has declined to near zero since the cessation of most agricultural burning. Accidental fires are currently treated as a source of constant magnitude, and consequently, the percentage contribution from this sector to the total PCDD/F emission has risen as emissions from other significant sectors have decreased.

There are significant emissions from sinter plants owing more to the large gas volumes emitted than to high concentrations. Emissions from iron and steel plants are probably underestimated since only electric arc furnaces are considered. Scrap used in electric arc furnaces and secondary non-ferrous metal production will contain chlorinated impurities such as plastics and cutting oil which contribute to PCDD/F formation.

It is generally accepted that the source of PCDD/F emissions from road transport are the 1,2-dichloroethane scavengers added to leaded petrol. Over recent years both the consumption of leaded petrol, and the lead content of leaded petrol has decreased. Consequently the emissions of PCDD/F from this sector have decreased. Unleaded petrol and diesel is likely to contain only trace quantities of chlorinated impurities. For 2001, the contribution to the PCDD/F emission total from road transport was 1%.

Figure 6.5 Spatially Disaggregated UK Emissions of PCDD/F



6.2.3 Polychlorinated biphenyls (PCBs)

PCBs are synthetic organic compounds that have mainly been used in electrical equipment as dielectric insulating media.

PCBs have been linked with effects such as reduced male fertility and long-term behavioural and learning impairment. They are classified as probably carcinogenic to humans. Certain PCBs have been assessed as having dioxin-like effects. PCBs are extremely persistent in the environment and possess the ability to accumulate in the food chain. These compounds are highly insoluble in water but accumulate in body fat. Present human exposure is probably dominated by the accumulation through the food chain of the PCBs present in environmental reservoirs such as soils and sediments as a result of previous releases to the environment.

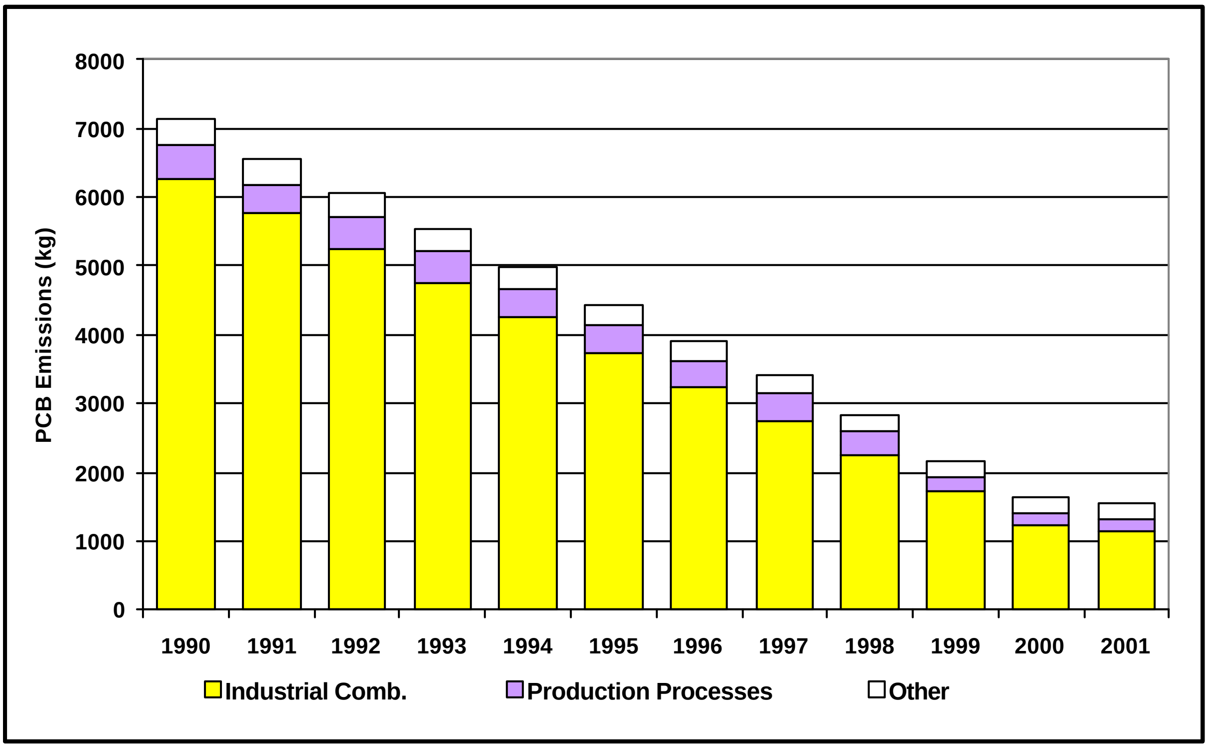
PCBs have not been manufactured and used in the UK for many years, but old PCB-containing equipment still exist. It is estimated that in 2001, 71% of primary PCB emissions to the atmosphere are associated with such appliances. These emissions primarily arise from in-service appliances; however emissions during disposal are also considered to be significant. Large quantities of PCBs are thought to have been disposed of to landfill in the past, mainly in the form of electrical components or fragmentiser residues, but now such equipment containing PCBs are disposed of by chemical incineration. This process ensures significant reduction in the amount of PCBs being released into the environment. PCBs are also emitted from the soil having previously been deposited there from the air.

PCB speciation has been incorporated into the emission estimates since the 1998 inventory report. A summary of the total PCB emission estimates for 1990 to 2001 is given below in Table 6.7 (detailed emission estimates and TEQs may be found in Appendix 8, see http://www.naei.org.uk/).

Table 6.7 – UK Emissions of PCB Emissions by UN/ECE Source Category (kg)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY													
Combustion in Energy Prod													
Public Power	91	90	84	72	61	58	53	51	50	44	49	54	3%
Other Combustion & Trans.	4	1	4	4	4	4	3	4	4	4	4	4	0%
Combustion in Comm/Res													
Residential Plant	23	25	22	24	20	15	15	16	16	16	10	14	1%
Comm/Agri Combustion	2	2	2	2	2	1	1	1	1	1	1	1	0%
Combustion in Industry													
Iron & Steel Combustion	38	37	37	36	37	37	38	39	39	40	36	32	2%
Other Ind. Combustion	6231	5727	5223	4719	4215	3710	3205	2701	2196	1692	1187	1117	72%
Production Processes													
Iron & Steel	495	422	440	458	425	395	374	397	346	192	187	169	11%
Processes in Industry	1	1	1	1	1	0	0	0	0	0	0	0	0%
Waste													
Landfill	1	1	1	1	1	1	1	1	1	0	0	0	0%
Waste Incineration	159	159	158	157	154	153	152	149	149	149	149	149	10%
Other Waste Treat. & Disp.	80	81	78	81	73	64	55	46	38	29	20	20	1%
Agriculture	1	1	1	0	0	0	0	0	0	0	0	0	0%
TOTAL	**7127**	**6546**	**6051**	**5554**	**4991**	**4440**	**3899**	**3404**	**2840**	**2166**	**1643**	**1561**	**100%**

Figure 6.6 Time Series of PCBs Emissions (kg)



Sales of PCBs in the UK were stopped in 1986. It is thought that they are still manufactured in some countries. The total PCB emission in 1990 was dominated by leaks from capacitors (87% of total emission), and this is the case for 2001 (72% contribution). However, not all electrical equipment containing PCBs is readily identifiable. Emissions from electrical equipment will probably continue, and will only start to fall significantly as the relevant electrical equipment is either destroyed or reaches the end of its working life.

In 1997 an Action Plan was published by DETR (now Defra) which laid out the commitments made by the UK at the Third International North Sea Conference at the Hague in 1991 in accordance with the requirements of Directive 96/59/EC. These regulations require all PCB holders in the UK to report their stocks to the relevant regulatory bodies. These stocks (except for certain exemptions) were destroyed before the end of December 2000.

PCBs can be formed in trace amounts from chlorinated precursors in thermal processes such as scrap metal recycling. As a result, there are significant emissions from the iron and steel industrial sector, as with PCDD/Fs.

PCBs occur in sewage sludge due to their persistent nature, and may occur in significant quantities. Not all the PCBs spread on land will volatilise but the potential for emissions to air is greater than that of landfill. The emission estimate comprises only 1% of the total and is highly uncertain. Emissions arise from waste incineration and refuse-derived fuel production resulting from the PCB content of the waste.

6.2.4 Pesticide Emissions

Although there is little available information to enable accurate estimates of pesticide emissions to air, the emission estimates presented here follow from significant improvements to the earlier emission estimates first made in 1996.
Despite these improvements, the confidence in the accuracy of these estimates is low. Relevant data is currently scarce with the majority of emission factors coming from the USA or Europe. The emission factors used here have been derived for a particular method of pesticide application (during specific atmospheric conditions), which may not be representative of the situation in the UK. Until further data become available it is difficult to reduce the uncertainty associated with these estimates. At present no relevant measurement programmes are known of, and therefore the possibility of acquiring additional data is considered to be poor.

Pesticide emissions to the air occur predominately through three pathways: during manufacture, during application and volatilisation after application. Tables 6.8, 6.9 and 6.10 show the estimated emissions of lindane (γ-HCH), pentachlorophenol (PCP) and hexachlorobenzene (HCB) respectively.

6.2.4.1 Lindane (g HCH)

Acute (short-term) effects caused by the inhalation of lindane consist of irritation of the nose and throat, as well as effects on the blood. Chronic (long-term) effects through inhalation have been associated with effects on the liver, blood, immune and cardiovascular systems.

Lindane is applied as an insecticide, fungicide and used as a wood preservation treatment. Lindane is used in the agriculture, domestic and veterinary sectors. Until 1990 lindane was also used as a remedial wood treatment i.e. in a curative role rather than a preservative/preventative. However, data on quantities used for a remedial wood treatment prior to 1990 are not available.

HCH exists in several isomers, however as a result of regulation in the UK, γ-HCH accounts for more than 99% of the total HCH use. Consequently only the γ isomer has been considered in any detail here. The emission estimates presented in Table 6.8a were made assuming that emissions arise from: the application of γ-HCH, treated wood and agricultural and domestic use. γ-HCH emissions are dominated by emissions from treated wood and wood preserving sources, contributing 74% and 3% to the 2001 total emission respectively. Emissions from wood preserving have fallen since 1990.

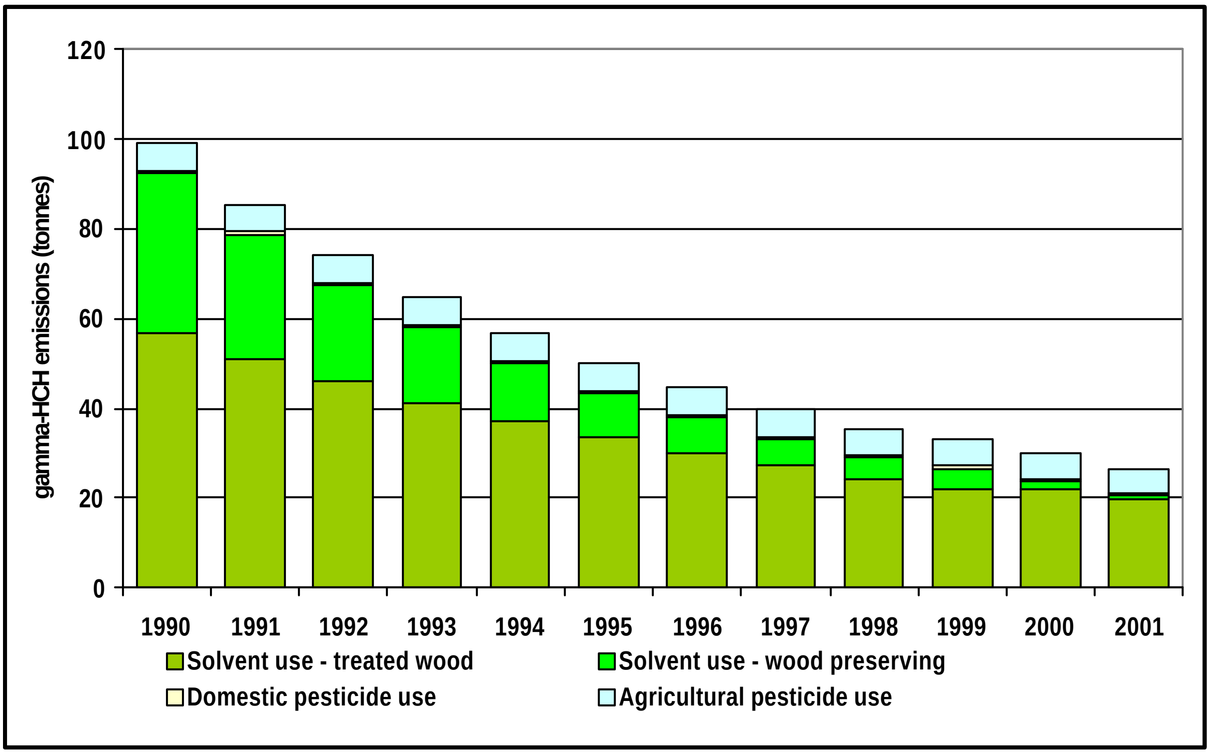
Emissions from agricultural activities are also significant, accounting for around 21% of total 2001 γ-HCH emissions. These emissions are based on statistics on the use of pesticides containing lindane, obtained from the Pesticide Usage Survey Group (MAFF, 1991a,b,c; 1992a,b,c,d) The emission factors used are taken from van der Most *et al* (1989).

Emissions of γ-HCH arising from domestic applications are thought to be comparatively small. However, usage statistics are scarce and were only available for 1988 (DOE, 1989). Emission factors are taken from van der Most *et al* (1989).

Table 6.8a – UK Emissions of γ-HCH by UN/ECE Source Category (tonnes).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY													
Solvent Use													
Treated Wood	57	51	46	41	37	33	30	27	24	22	22	20	74%
Wood Preserving	36	28	21	17	13	10	8	6	5	5	2	1	3%
Agriculture													
Domestic Pesticide Use	1	1	1	1	1	1	1	1	1	1	1	1	2%
Agriculture Pesticide	6	6	6	6	6	6	6	6	6	6	6	6	21%
TOTAL	**99**	**85**	**74**	**65**	**57**	**50**	**45**	**40**	**36**	**33**	**30**	**27**	100%

Figure 6.7 Times Series of γ-HCH Emissions (tonnes)



For completeness, the total emissions of HCH are also included here (see Table 6.8b below), although the differences are obscured due to rounding. These total HCH emissions estimates assume the worst case scenario of 1% contribution from non γ isomers to the HCH total.

Table 6.8b – UK Emissions of Total HCH by UN/ECE Source Category (tonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY													
Solvent use	57	52	46	42	38	34	30	27	25	22	22	20	74%
Processes in Industry	36	28	22	17	13	10	8	6	5	5	2	1	3%
Agriculture													
Domestic Pesticide Use	1	1	1	1	1	1	1	1	1	1	1	1	2%
Agricultural Pesticide Use	6	6	6	6	6	6	6	6	6	6	6	6	21%
TOTAL	**100**	**86**	**75**	**65**	**57**	**51**	**45**	**40**	**36**	**33**	**30**	**1**	**100%**

6.2.4.2 Pentachlorophenol (PCP)

Pentachlorophenol is associated with both acute and chronic effects on humans through inhalation. Acute effects can lead to eye irritation as well as liver, blood and neurological effects. Chronic exposure can result in effects on the respiratory tract, immune system, liver, kidneys, blood as well as the eyes and nose.

Pentachlorophenol is used as a biocide, and is effective in destroying insect eggs. It is used in the timber and textile industries. The emission estimates given here also include emissions of sodium pentachlorophenoxide (NaPCP) and pentachlorophenyl laureate (PCPL) as well as PCP since these are also included in the proprietary formulations.

The estimated PCP emissions for 1990 to 2001 are given in Table 6.9. The largest percentage contribution to the total PCP emission arises from wood that has been treated within the last 15 years. This accounts for some 94% of the 2001 total PCP emission.

Once again it is very difficult to be certain of these estimates due to the lack of research into emission rates and limited knowledge of quantities used both in the year of the estimate and in previous years. An emission factor of 3% of the wood content per year has been used.

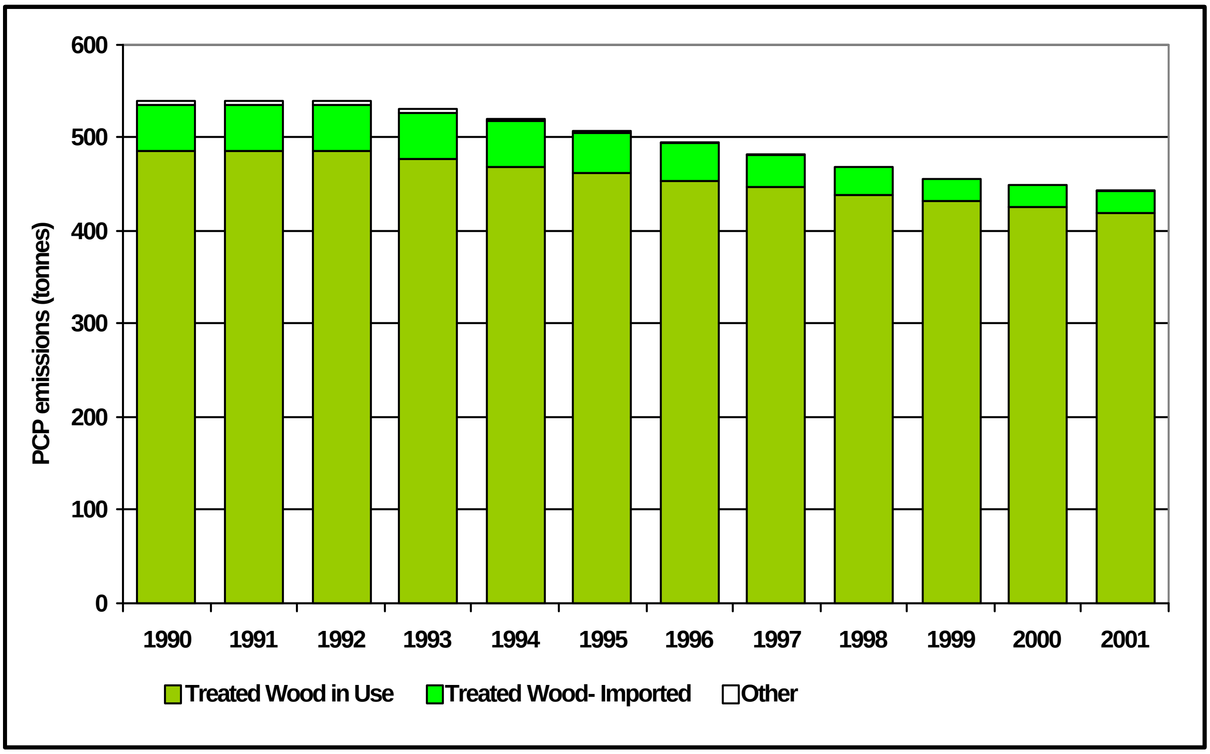
PCP emissions from the textile industry primarily arise from volatilisation during application as a cotton preservative. Emission factors used were based on a study of PCP emissions in the UK (Wild, 1992) reporting that approximately 30% of the applied PCP is lost through volatilisation. Emissions from this sector are comparatively small.

PCP is used in the agricultural sector as the active ingredient in disinfecting wooden trays used in mushroom farming (classified as solvent use). Usage statistics are reliable coming from the Pesticide Usage Survey Group (MAFF, 1991a,b,c; 1992a,b,c,d). The emission factor assumes 30% loss due to volatilisation (Wild, 1992). Emissions from this sector are comparatively small.

Table 6.9 – UK Emissions of PCP by UN/ECE Source Category (tonnes)

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2001%**
BY UN/ECE CATEGORY													
Combustion in Energy Prod	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0%
Combustion in Comm/Res	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Combustion in Industry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Production Processes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Solvent Use													
Textile Coating	3.0	3.0	3.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
NaPCP Wood Treatment	4.0	4.0	4.0	2.0	2.0	2.0	2.0	2.0	0.0	0.0	0.0	0.0	0%
PCP Treated Wood in Use	474.5	474.5	474.5	474.5	466.6	458.9	451.5	444.3	437.3	430.6	424.1	417.8	94%
PCP Wood Treatment	6.2	6.2	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
PCP in Imported Wood	50	50	50	50	50	45	40	35	30	25	25	25	6%
Road Transport	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Other Trans/Machinery	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Waste	0.3	0.3	0.3	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0%
Agriculture	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
TOTAL	**538**	**538**	**538**	**530**	**519**	**506**	**494**	**481**	**467**	**456**	**449**	**443**	**100%**

Figure 6.8 Times Series of PCP Emissions (tonnes)



The emission inventory for PCP is very uncertain as only limited emission factors are available on the release of PCP during agricultural activities and statistics are not actively collected on the extent of its usage. There is some data on release of PCP from combustion processes, but the available studies are not consistent with each other suggesting that the uncertainty may be considerable. Without new data becoming available, significant improvements are not expected in the near future.

6.2.4.3 Hexachlorobenzene (HCB)

Very little information is available on the health effects of HCB via inhalation. However, the lungs may be affected by repeated or prolonged exposure. It is also considered to be a possible carcinogen if long term exposure occurs.

Studies in the USA have identified two main industrial sources of HCB (Mumma *et al*, 1975) (Jacoff *et al*, 1986). These are the manufacture of chlorinated solvents (e.g. trichloroethylene, tetrachloroethylene and carbon tetrachloride) and the manufacture of specific pesticides where HCB remains as an impurity. HCB emissions may also arise from combustion sources, but other than waste incineration these could not be estimated, although they are believed to be small.

Statistics for chlorinated solvent production in the UK are commercially confidential, hence estimates were made based on UK solvent usage data from the Solvent Industries Association and import and export statistics.

Although there is no UK manufacture of pesticides that results in the production of HCB, pesticides with HCB as an impurity are still imported and used in the UK for agricultural pest control. Statistics for the use of these pesticides is provided by the Pesticide Usage Survey Group (MAFF, 1991a,b,c; 1992a,b,c,d).

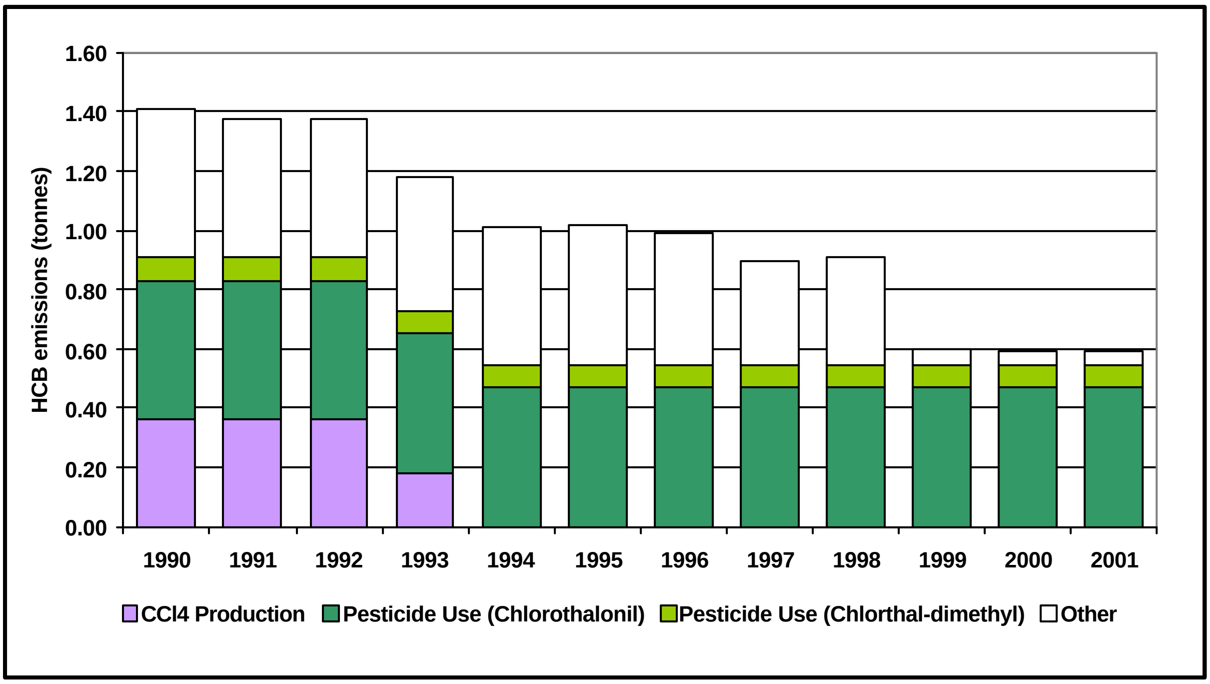
HCB emissions in secondary aluminium smelting result from the use of hexachloroethane (HCE) tablets as a degassing agent (van der Most *et al*, 1992). Regulations now control the use of HCE and so since 1999, very little secondary aluminium is now melted using HCE. Data on the quantity of degassing agent supplied and the quantity of HCE used per tonne of aluminium melted were obtained from industrial experts and van der Most *et al* (1989).

Emissions from pesticide application and chlorinated solvent production now account for virtually all of the UK HCB emissions (Table 6.10). For 2001, these two sources are estimated to account for 92% and 7%, respectively, of the total HCB emissions. This represents a change in the relative contributions to the total for 1990 where the same sectors contributed 39% and 43% respectively. This change is a direct result of the reduced emissions from the production of chlorinated solvents, but only very small changes are noted between more recent years.

Table 6.10 – UK Emissions of HCB (kg)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY													
Combustion In Energy Prod.	1	1	1	2	3	2	2	1	1	1	1	1	0%
Comm., Public & Agri. Com	0	0	0	0	0	0	0	0	0	0	0	0	0%
Secondary aluminium prod	252	236	255	290	313	311	300	290	310	0	0	0	0%
Production Processes													
Pentachlorophenol Production	31	31	31	6	6	6	6	0	0	0	0	0	0%
Picloram Production	0	0	0	0	0	0	0	0	0	0	0	0	0%
Carbon Tetrachloride Producn.	360	360	360	180	0	0	0	0	0	0	0	0	0%
Tetrachloroethylene Producn.	95	90	83	65	57	57	53	24	20	20	21	20	3%
Trichloroethylene Production	114	102	88	82	82	90	82	30	27	26	24	21	4%
Waste	6	6	5	5	3	3	2	0	0	0	0	0	0%
Agriculture													
Pesticides (Chlorothalonil)	470	470	470	470	470	470	470	470	470	470	470	470	79%
Pesticides (Chlorthal-dimethyl)	77	77	77	77	77	77	77	77	77	77	77	77	13%
Pesticides (Quintozine)	2	2	2	2	2	2	2	2	2	2	2	2	0%
TOTAL	**1408**	**1375**	**1373**	**1178**	**1013**	**1018**	**992**	**894**	**908**	**596**	**595**	**591**	**100%**

Figure 6.9 Time Series of HCB Emissions (tonnes)



6.2.5 Short Chain Chlorinated Paraffins (SCCP)

6.2.5.1 Introduction

Short chain chlorinated paraffins (SCCPs) are a range of commercially available chlorinated paraffins with 10-13 carbon atoms. The commercial products are usually mixtures of different carbon chain paraffins with a range of different degrees of chlorination. SCCPs are considered persistent organic pollutants- they do not occur naturally and due to their bioaccumulative and toxicological properties they are of concern to the environment.

6.2.5.2 Production and Emissions to Air

SCCPs are currently manufactured in the EU and are marketed under a variety of trade names with an average chlorine content of 40-74%. Current consumption in the UK is estimated to be approximately 1000 tonnes per year.

The main uses of SCCPs are in metal working fluids. It has been reported that there are negligible emissions to air of SCCP from production sources, and releases from the majority of industrial consumption results in emissions primarily to water (with very low emissions to air). Emissions from waste water to the atmosphere are unlikely to be large due to the physical properties of SCCPs.

6.2.5.3 Emission Estimates

Emission estimates have been revised since last years NAEI Report (Goodwin et al., 2002), but this had had little impact on the resulting emission estimates. Current estimates are based on information provided in the European Union Risk Assessment Report (1999) and other data. Emissions of SCCPs have declined considerably since 1990 due to the decrease in consumption generally and the switching to alternatives.

Table 6.11 UK Emissions of SCCPs (tonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
TOTAL	48	45	43	41	30	24	18	13	8	6	3	1

6.2.6 Polychlorinated Napthalenes (PCN)

6.2.6.1 Introduction

Polychlorinated Napthalenes (PCNs) are a group of 75 theoretically possible chlorinated naphthalenes containing between one and eight chlorine atoms. Their chemical structure is similar to that of PCBs. PCNs are widely considered be associated with cancer and chronic liver disease.

PCNs have been used in a variety of industries. The most important uses are cable insulation, wood preservation, engine oil additives, electroplating masking compounds, feedstock for dye production, dye carriers, capacitors and refractive testing oils.

PCNs have been produced in a number of countries including the UK, USA and France, their synonyms and trade names include Halowax, Nibren waxes, Seekay Waxes, Cerifal Materials and N-Oil. The majority of production generates a standard mixture of the different PCN congeners.

6.2.6.2 Production and Consumption

A number of assumptions give an estimate of the world-wide PCN production as 150,000 tonnes. Similar assumptions can be made to estimate the UK production as 6,650 tonnes.

Emission Estimates

There is very little information concerning the production of PCNs for commercial purposes. Commercially produced PCNs are thought to be the most important source of PCNs in the atmosphere with the other source sectors being thermal sources, other industrial processes and contamination in PCB industrially produced mixtures.

PCNs have not been produced in the UK for over 30 years and therefore the major releases that were present during their extensive use have decreased. The potential sources are expected to be dominated by the disposal routes of capacitors and engine oil (this is where the majority of the PCNs produced are thought to have been used). Another potential source of PCNs may be the incineration industry, PCNs have been found in fly ash and flue gas in waste incinerators. Landfills are also expected to be a source of PCN emissions.

PCNs have been found in emissions from incinerators and are thought to be produced from the combustion of PAHs. Therefore PCNs could in theory be produced from other high temperature combustion processes. A full review of emission measurements from such processes would be required prior to ascertaining the scale of the emissions of PCNs from such a potentially large array of sources.

As the information regarding the emission of PCNs in the UK is relatively sparse, it is not currently realistic to quote an emission estimate for PCNs. It is hoped that data will become available to resolve this in the future. However, at this time, no programmes are known of which would provide the data required to help with the generation of PCN emissions.

6.2.7 Polybrominated Diphenyl Ethers (PBDEs)

6.2.7.1 Introduction

There are 209 possible congeners of polybrominated diphenyl ethers (PBDEs). Concern about potential risks to human health and the environment has centred on the potential toxicity, persistence and the tendency for bioaccumulation of some brominated diphenyls.

Since the 1960s, PBDEs have been added as flame-retardants. They are used in a variety of materials (Strandman et al. 2000), including thermoplastics (e.g. high-impact polystyrene) that are used in electrical equipment, computer circuit boards, casings, upholstery, furnishings; interiors in cars, buses, trucks and aeroplanes, rugs, drapery and building materials.

6.2.7.2 Production and Releases to Air

The annual EU production of polybrominated diphenyl ethers has been estimated to be 11,000 tonnes per year. It has been reported (EU 2000) that the UK used up to 2,000 tonnes of polybrominated biphenyl in 1994. Production of the three commercial mixtures (penta-, octa- and deca-dibrominated diphenyl) has virtually ceased in the EU.

The possible routes of release of PBDEs vary from production to the disposal of the materials for which they are used. There is limited information concerning the releases and it is difficult to attempt to estimate an emission inventory without any measurements of releases from sources or potential sources. Attempts have been made to gather UK usage information. However, information is not easily accessible, particularly as PBDEs are a material used in such a wide variety of industries.

6.2.7.3 Emission Estimate

It has not been possible to obtain UK specific emission data for PBDEs, but an estimate of the UK emission of PBDEs has been made using the total EU estimate. This is done by scaling with population. Without further assessment of the potential emissions from materials such as plastic and upholstery during production use and disposal it is not possible to make a more accurate estimate. The resulting unspeciated UK emission estimate for PBDE's is 13.8 tonnes per year.

There are a number of improvements that can be made to the UK emission estimate. Resources will be focussed on the following aspects of production and use of secondary products that contain PBDEs.

- Emission from manufacturing sites
- Releases from materials during use
- Release from materials during and following disposal

Improvements arising from this work will be incorporated in the next annual dataset.

6.3 ACCURACY OF EMISSION ESTIMATES OF POPS

Quantitative estimates of the uncertainties in emission inventories have been based on calculations made using a direct simulation technique, which corresponds to the IPCC Tier 2 approach recommended for greenhouse gases and also the methodology proposed in draft guidance produced by the UN/ECE Taskforce on Emission Inventories and Projections. This work is described in detail by Passant (2002b). The uncertainty estimates are shown below in Table 6.12.

Table 6.12 Uncertainty of the Emission Inventories for persistent organic pollutants

Pollutant	**Estimated Uncertainty %**
Benzo[a]pyrene	-70 to +200
Dioxins and furans	-50 to +100
Polychlorinated biphenyls	-40 to + 60
Pentachlorophenol	-80 to +200
Hexachlorohexane	-80 to +300
Hexachlorobenzene	-70 to +200
Short-chain chlorinated paraffins	-90 to +1000
Pentabromodiphenyl ether	-90 to +1000
Polychlorinated naphthalenes	not estimated

Inventories for persistent organic pollutants are more uncertain than those for gaseous pollutants, PM_{10}, and metals. This is largely due to the paucity of emission factor measurements on which to base emission estimates, coupled with a lack of good activity data for some important sources. The inventories for polychlorinated biphenyls and short chain chlorinated paraffins are less uncertain than those for other persistent organic pollutants due to the fact that these pollutants are released to air during their use as products and that reasonably robust data are available on the levels of usage. The uncertainty in emission estimates for polychlorinated naphthalenes has not been estimated since no emission estimates are made.

6.4 HEAVY METAL EMISSION ESTIMATES

6.4.1 Introduction

The NAEI currently reports emissions of thirteen metals. These are:

- Arsenic
- Beryllium
- Cadmium
- Chromium
- Copper
- Lead
- Manganese
- Mercury
- Nickel
- Selenium
- Tin
- Vanadium
- Zinc

Emissions inventories for all of the above except beryllium, manganese, selenium, tin, and vanadium were reported by Leech (1993), Gillham *et al* (1994) and Couling *et al* (1994). Emissions of all metals except beryllium, manganese and tin were reported by Salway *et al* (1996, 1996a, 1997, 1999) and Goodwin *et al* (1999, 2000, 2001). Emission estimates for beryllium, manganese, and tin were reported for the first time in the 2000 version of the NAEI (Goodwin *et al* 2002).

Heavy metal emissions arise from a number of different sources, but in general fuel combustion and certain industrial processes that produce dust are the main contributors. Metal emissions arise from the trace concentrations in the fuels or in the case of industrial processes, the raw materials. In the case of combustion, metals are emitted either as vapour or particulate matter or both. Volatile metals such as mercury and selenium are mostly emitted as vapour. Metals such as cadmium and lead are emitted as both with some of the vapour condensing onto the ash particles. Other metals such as chromium do not vaporise and may be emitted in the ash particles.

Emission estimates for combustion sources are generally based on emission factors developed from fuel composition data, applied to fuel consumption statistics (DTI, 2000). Emission estimates for industrial processes are generally based on data taken from the Pollution Inventory or based on the use of emission factors and activity data taken from the literature. The methodology for industrial process emissions has recently been reviewed (Passant *et al,* 2002) and numerous changes have been made. The emissions estimates presented here are based on a recent review of the methodology used for the combustion related sources.

UK data is used for the metal contents of coal and fuel oils where available. Emissions from the combustion of liquid fuels are based on data reported by Wood (1996) and other sources in the literature (Sullivan, 1992; Lloyds 1995). Lead emissions from petrol combustion are based on detailed data on the lead content of petrol published by the Institute of Petroleum (1999). The emissions from coal and oil fired power stations are based on estimates reported in the Pollution Inventory (Environment Agency, 2001) or the operators' annual reports. Emissions from other coal combustion sources follow the PARCOM methodology (van der Most, 1992) but use data based on UK coal (Smith, 1987). Many of the emission factors for industrial processes such as iron & steel, primary lead/zinc manufacture, secondary copper and cement manufacture are based on data given in the Pollution Inventory, although literature-based emission factors are also used (sources include Clayton *et al*, 1991, EMEP/CORINAIR(1996), van der Most (1992), Jockel and Hartje (1991), and Smyllie, 1996). Details of the methodology are given in Passant *et al*, 2002. Emissions from the chloralkali industry are based on manufacturers estimates (Ratcliffe, 1999).

Heavy metal emissions can be reduced using gas cleaning equipment which removes particulates from waste gases. This abatement equipment can be fitted to large coal-fired industrial boilers and power station boilers and also industrial processes which produce large amounts of dust. Hence, when estimating emission factors it is often necessary to assume some efficiency of abatement.

The majority of the emission factors used in generating emission estimates are based on the mass of metal emitted per unit mass of fuel burnt, or mass of metal emitted per unit mass of product for processes. These emission factors are assumed not to vary with time for many of the sources considered. This is assumed as there is usually insufficient information to estimate any temporal variation of the emission factor. However, for sources such as road transport, chlorine production, waste incineration and public power generation, there is sufficient information to allow time dependent emission factors to be estimated.

At the end of 1996 all municipal solid waste and clinical incinerators had to comply with new emission standards (see also Section 6.2.2). As a result, a number of old incinerators have closed, whilst some have been renovated and some new ones opened. Hence there have been significant reductions in emissions from waste incineration. Data is available for most metals for the new plant (Environment Agency, 2001).

In 1984 the miners strike lead to a significant decrease in the use of coal for combustion in electricity generation, industry and the domestic sector. During this period there was an increased use of petroleum products. This fuel switching had a significant impact on the emissions of numerous pollutants, which can be seen in the following time series plots.

6.4.2 Emissions of Arsenic

Acute exposure to high levels of arsenic via the inhalation of dust or fumes leads to gastrointestinal effects such as nausea, diarrhoea and abdominal pain. Chronic inhalation exposure to inorganic arsenic is associated with irritation of the mucous membranes as well as being strongly associated with lung cancer.

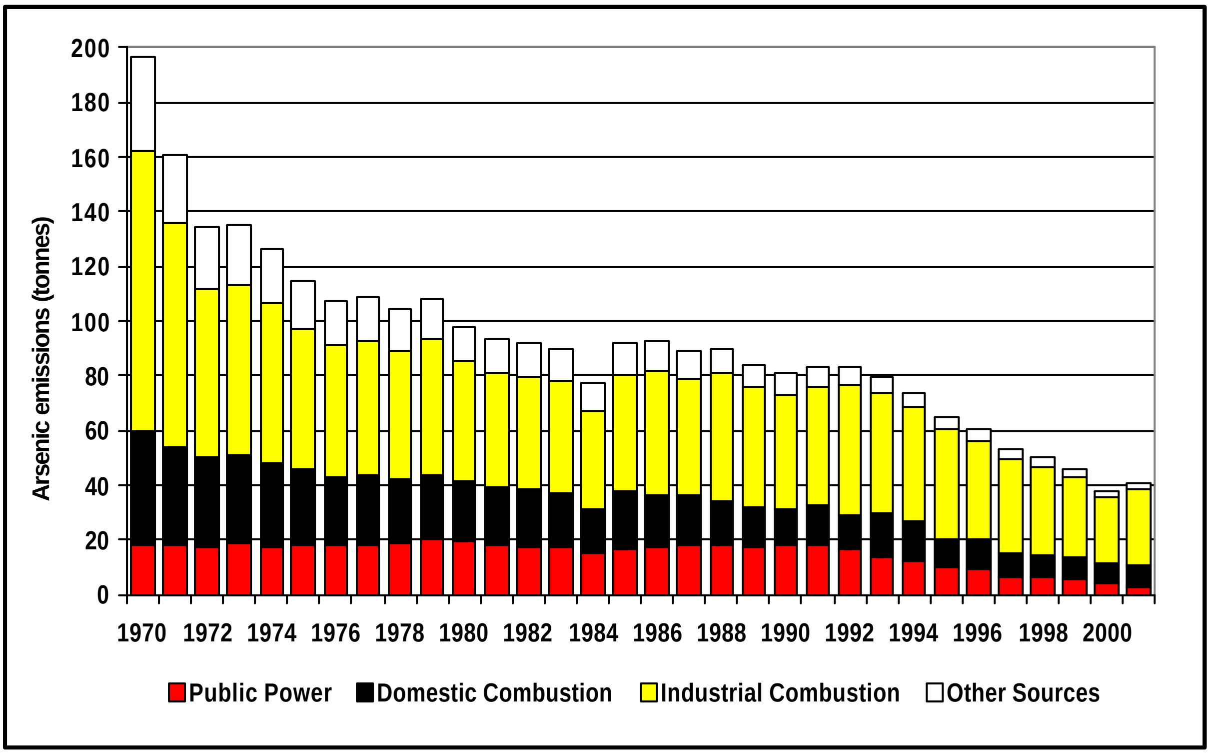
Table 6.13 and Figure 6.10 summarise the UK emissions of arsenic. Emissions have declined by 79% since 1970. The largest source of emission arises from coal combustion with other sources being very small by comparison. Coal use has declined over the period considered, in favour of natural gas use. The emissions from the industrial sector are large compared with the emissions from public power generation; this is due to the different levels of abatement efficiency that are assumed.

Table 6.13 UK Emissions of Arsenic by UN/ECE Category and Fuel (tonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[1]											
Combustion in Energy Prod											
Public Power	18.1	19.1	18.0	9.6	9.0	6.1	6.7	5.7	4.4	2.8	7%
Petroleum Refining Plants	0.7	0.7	0.5	0.6	0.6	0.6	0.6	0.5	0.4	0.4	1%
Other Combustion & Trans.	8.9	3.1	0.5	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0%
Combustion in Comm./Res											
Residential Plant	41.6	22.7	13.3	10.8	11.0	9.1	8.0	7.7	7.3	7.8	19%
Comm/Agricul Combustion	21.3	6.1	4.4	1.4	1.5	1.5	0.9	0.7	0.5	0.5	1%
Combustion in Industry											
Iron & Steel Combustion	0.5	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0%
Non-Ferrous Metals	2.2	1.6	1.5	1.2	1.2	1.1	1.0	0.9	1.6	0.4	1%
Other Ind. Combustion	99.9	41.9	39.6	38.6	34.7	32.8	30.8	28.8	22.1	27.6	67%
Production Processes											
Iron & Steel	2.0	0.9	1.5	1.5	1.5	1.6	1.5	1.4	1.2	1.1	3%
Non-Ferrous Metals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Processes in Industry	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.3	1%
Other Trans/Machinery	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Waste	1.3	1.3	1.0	0.6	0.5	0.2	0.2	0.2	0.2	0.0	0%
By FUEL TYPE											
Solid	172.3	77.5	60.5	46.0	41.9	35.9	32.8	30.9	23.6	27.9	68%
Petroleum	4.2	2.5	2.1	1.1	1.1	0.7	0.7	0.6	0.5	0.5	1%
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Non-Fuel	20.2	17.7	18.2	17.7	17.3	16.6	16.4	14.6	14.0	12.6	31%
TOTAL	**196.6**	**97.8**	**80.9**	**64.7**	**60.4**	**53.2**	**49.9**	**46.1**	**38.0**	**40.9**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

Figure 6.10 Time Series of Arsenic Emission (tonnes)



6.4.3 Emissions of Cadmium

Effects of acute inhalation exposure to cadmium consist mainly of effects on the lung, such as pulmonary irritation. Chronic effects via inhalation can cause a build-up of cadmium in the kidneys that can lead to kidney disease.

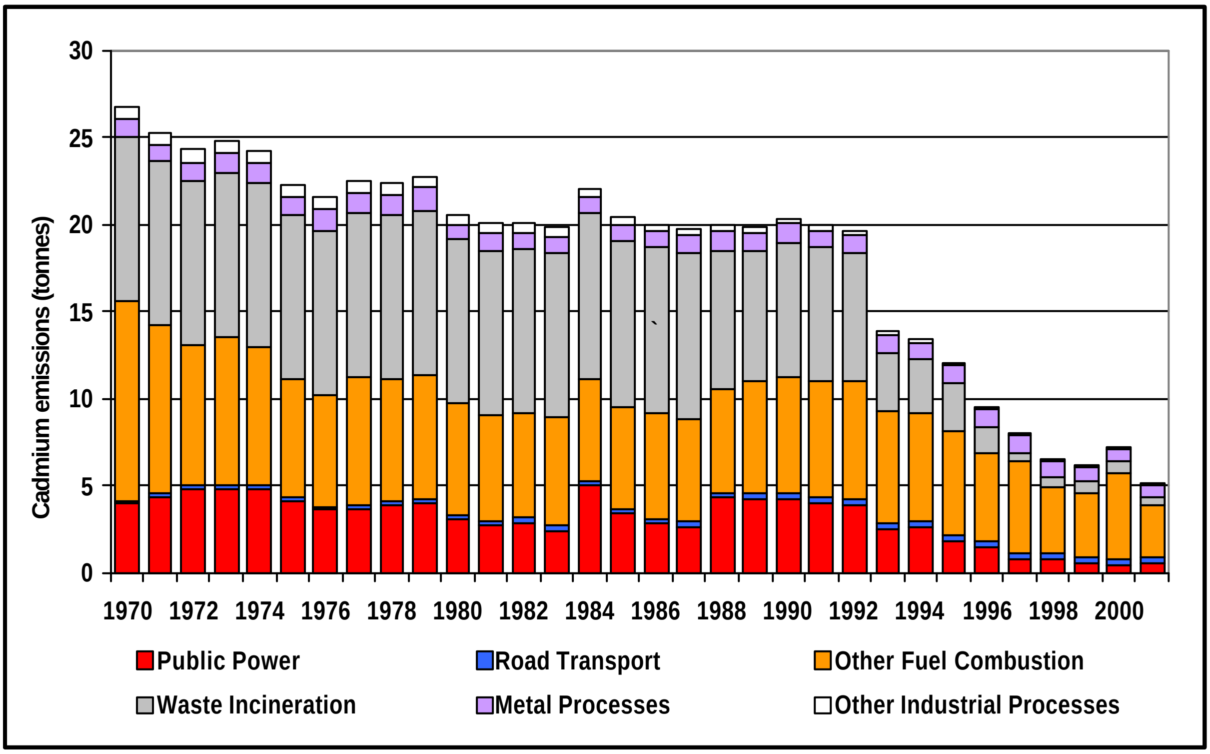
Table 6.14 and Figure 6.11 summarise the UK emissions of cadmium. Emissions have declined by 81% since 1970. The main sources are non-ferrous metal production and iron and steel manufacture and other forms of industrial combustion. The former includes a lead-zinc smelting plant and a number of lead battery recycling plants. The estimate for energy production includes a significant proportion from waste combustion and fuel oil combustion for electricity generation. The decline in emissions is a result of the general fall in coal combustion and the decline in fuel oil combustion in power generation. The large reduction in waste emissions is due to improved controls on Municipal Solid Waste (MSW) incinerators from 1993 onwards and their conversion to power generating plant.

Table 6.14 UK Emissions of Cadmium by UN/ECE Category and Fuel (tonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[1]											
Combustion in Energy Prod											
Public Power	4.0	3.1	4.2	1.8	1.5	0.8	0.7	0.5	0.4	0.5	10%
Petroleum Refining Plants	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	3%
Other Combustion & Trans.	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Combustion in Comm/Res											
Residential Plant	1.4	0.7	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	6%
Comm/Agricul Combustion	0.6	0.2	0.7	0.1	0.1	0.1	0.0	0.0	0.0	0.0	1%
Combustion in Industry											
Iron & Steel Combustion	2.0	0.9	1.0	0.7	0.7	0.6	0.5	0.5	0.5	0.4	9%
Non-Ferrous Metals	4.0	2.6	3.0	3.0	2.3	2.8	1.6	1.7	3.3	1.3	25%
Other Ind. Combustion	3.1	1.7	1.5	1.5	1.3	1.2	1.0	0.9	0.7	0.8	16%
Production Processes											
Iron & Steel	1.1	0.7	1.0	1.0	1.0	1.0	0.9	0.8	0.7	0.6	12%
Non-Ferrous Metals	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1%
Processes in Industry	0.7	0.6	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	2%
Road Transport											
Combustion	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	7%
Brake & Tyre Wear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Other Trans/Machinery	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1%
Waste	9.4	9.5	7.7	2.7	1.5	0.5	0.6	0.7	0.7	0.4	7%
By FUEL TYPE											
Solid	5.6	3.5	2.9	2.0	1.8	1.5	1.4	1.2	0.9	1.2	23%
Petroleum	3.1	2.0	1.9	1.0	1.1	0.7	0.7	0.7	0.7	0.7	14%
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Non-Fuel	18.0	15.1	15.6	9.1	6.7	5.8	4.4	4.3	5.7	3.2	63%
TOTAL	**26.8**	**20.6**	**20.3**	**12.0**	**9.5**	**8.0**	**6.6**	**6.1**	**7.2**	**5.1**	**100%**

[1] See Annex 1 for definition of UN/ECE Categories

Figure 6.11 Time Series of Cadmium Emissions (tonnes)



6.4.4 Emissions of Chromium

Inhaled chromium is a carcinogen, leading to an increased risk of lung cancer. Acute exposure effects can result in shortness of breath, coughing and wheezing, whilst chronic exposure effects lead to perforation and ulceration of the septum, bronchitis, pneumonia, and decreased pulmonary function.

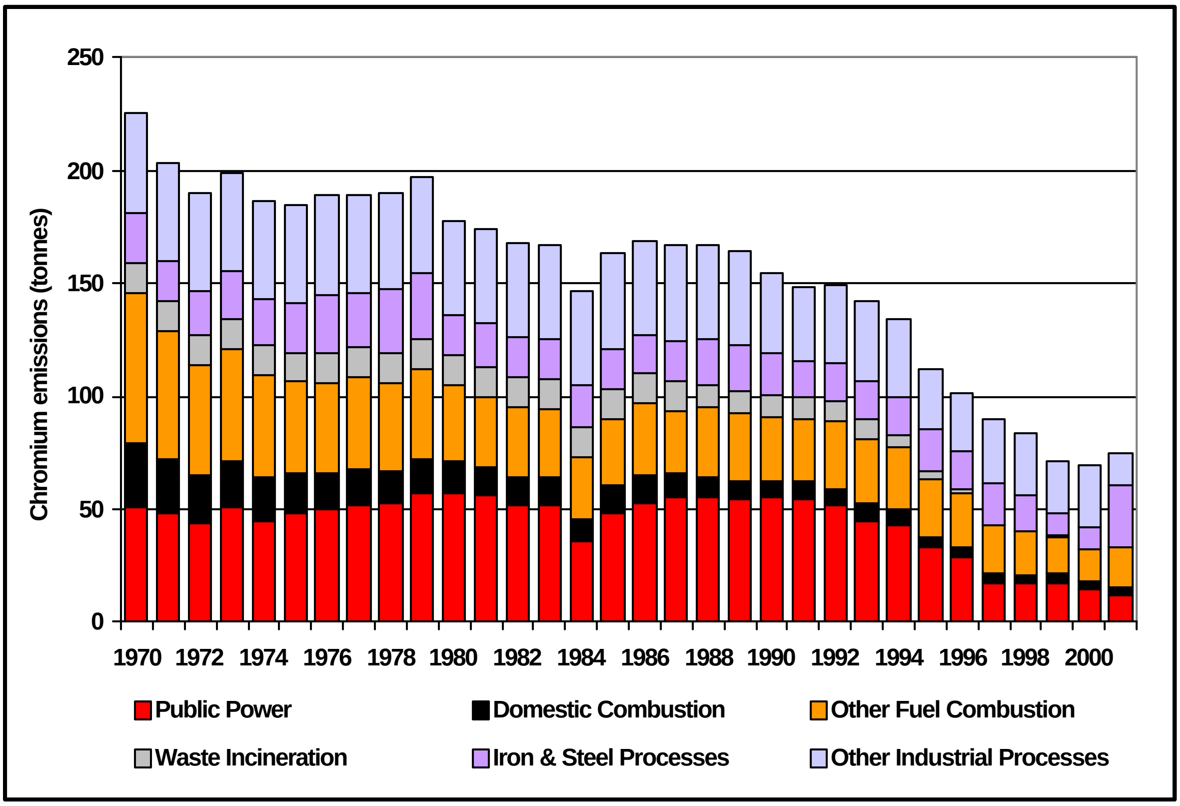
Table 6.15a and Figure 6.12 summarise the UK emissions of chromium. Emissions have fallen by 67% since 1970. The largest sources are various forms of coal combustion, iron and steel production in integrated works and in electric arc furnaces and the production of chromium-based chemicals.

Table 6.15a UK Emissions of Chromium by UN/ECE Category and Fuel (tonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[1]											
Combustion in Energy Prod											
Public Power	50.6	57.5	55.2	32.8	28.3	17.3	17.1	17.4	14.9	12.1	16%
Petroleum Refining Plants	0.5	0.5	0.3	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0%
Other Combustion & Trans.	3.1	1.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Combustion in Comm/Res											
Residential Plant	28.3	13.4	7.0	4.7	4.8	4.2	3.9	3.9	3.3	3.8	5%
Comm/Agricul Combustion	8.3	2.5	2.6	1.4	1.1	0.7	0.5	0.4	0.2	0.2	0%
Combustion in Industry											
Iron & Steel Combustion	1.5	0.7	0.6	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0%
Non-Ferrous Metals	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0%
Other Ind. Combustion	53.1	29.0	24.1	23.2	21.3	19.4	17.4	15.2	13.1	16.1	21%
Production Processes											
Iron & Steel	22.0	17.5	18.7	18.2	17.2	18.2	15.8	10.5	9.4	26.9	36%
Non-Ferrous Metals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Processes in Industry	44.4	41.7	35.0	26.8	25.9	28.4	27.8	22.3	27.2	14.6	19%
Road Transport	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0%
Other Trans/Machinery	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0%
Waste	13.2	13.2	10.0	3.4	1.7	0.1	0.1	0.1	0.1	0.1	0%
By FUEL TYPE											
Solid	116.6	82.6	68.2	39.5	36.3	26.4	25.2	25.6	20.7	19.9	27%
Petroleum	10.9	6.1	3.4	2.6	2.5	1.9	1.7	1.4	1.1	1.2	2%
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Non-Fuel	98.1	88.8	82.7	69.9	62.8	61.3	57.1	44.0	47.6	53.8	72%
TOTAL	**225.6**	**177.5**	**154.4**	**112.0**	**101.6**	**89.6**	**83.9**	**71.0**	**69.4**	**75.0**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

Figure 6.12 Time Series of Chromium Emissions (tonnes)



6.4.4.1 Speciation of Chromium

Chromium may be emitted to air in two oxidised forms - hexavalent (Cr^{6+}) and trivalent (Cr^{3+}). The proportion of each form emitted by each source has been estimated and the overall split between the two forms is shown in Table 6.15b

Table 6.15b. Speciated Emissions of Chromium (tonnes)

	Cr^{6+}	Cr^{3+}	Total (2001)
BY UN/ECE CATEGORY[1]			
Combustion in Energy Prod.	1.39	11	12.39
Combustion in Comm/Inst/Res	0.42	3.61	4.03
Combustion in Industry	2.23	14.25	16.47
Production Processes	5.06	36.49	41.55
Road Transport	0.07	0.29	0.37
Other Trans/Machinery	0.01	0.04	0.05
Waste	0.01	0.09	0.1
TOTAL	**9.19**	**65.77**	**74.96**

The profiles used for the speciation are based on the recommendations given in Passant *et al* (2002). In general, these profiles are subject to great uncertainty and further measurement data are required, particularly for major sources such as coal combustion, glass production, electric arc furnaces and chemical processes (other than chromium chemicals for which good data are available).

6.4.5 Emissions of Copper

Acute effects of copper fumes can lead to irritation of the eyes, nose and throat, resulting in coughing, wheezing and nosebleeds. It may also cause 'metal fume fever', which is a flu-like illness that has symptoms of a metallic taste, fever, chill, aches and chest tightness. Chronic exposure may lead to decreased fertility in both men and women. Severe irritation and ulcers in the nose may also occur.

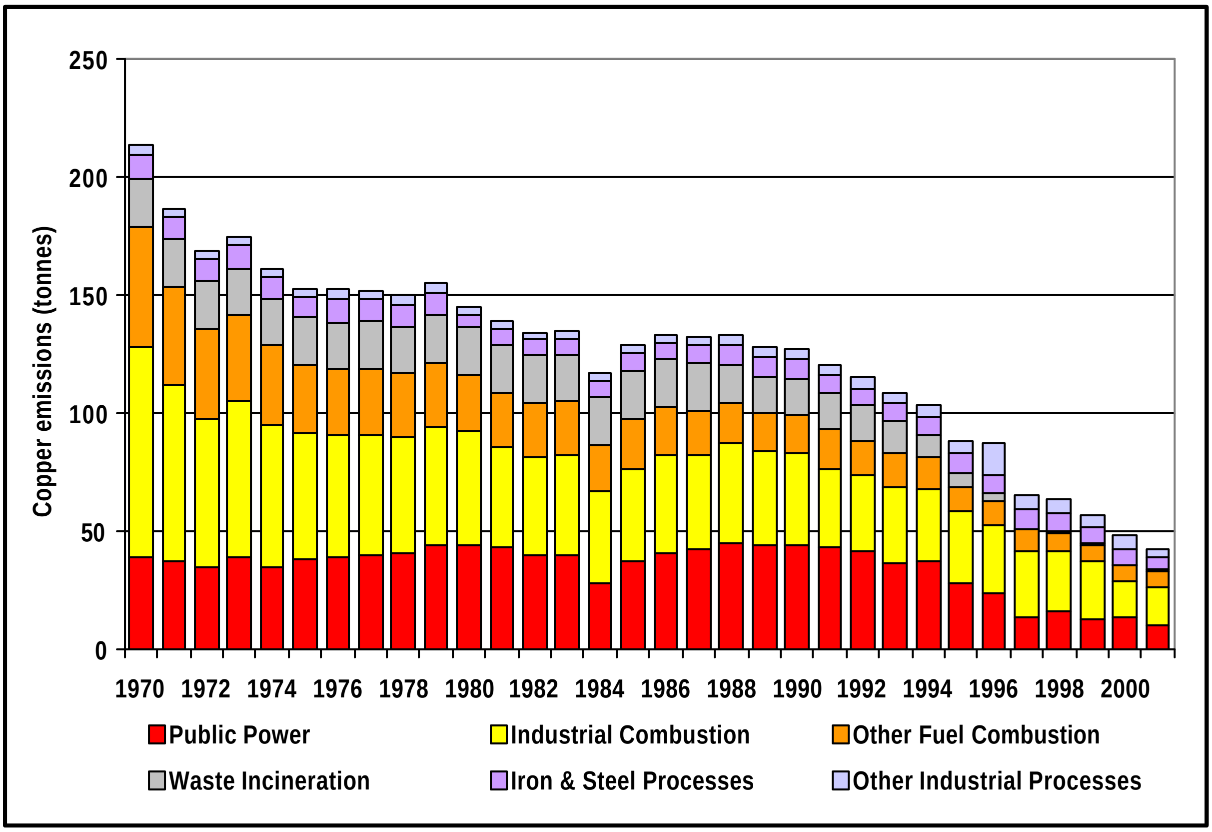
Table 6.16 and Figure 6.13 summarise the UK emissions of copper. Emissions have declined by 80% since 1970. The main sources are coal combustion, iron and steel manufacture and non-ferrous metals production. Emissions have declined over the period due to the decline in coal combustion and to a lesser extent the combustion of heavy fuel oil. The large reduction in waste emissions is due to improved controls on MSW waste incinerators from 1997 and their conversion to power generating plant.

Table 6.16 UK Emissions of Copper by UN/ECE Category and Fuel (tonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[1]											
Combustion in Energy Prod											
Public Power	39.5	44.5	44.1	28.4	23.7	13.8	16.6	13.1	14.0	10.8	25%
Petroleum Refining Plants	1.0	1.0	0.7	0.8	0.8	0.8	0.8	0.7	0.5	0.6	1%
Other Combustion & Trans.	4.0	1.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Combustion in Comm/Res											
Residential Plant	18.9	10.3	6.1	5.0	5.1	4.3	3.8	3.6	3.4	3.7	9%
Comm/Agricul Combustion	26.9	11.1	8.1	3.8	3.6	3.3	2.3	2.2	1.8	1.7	4%
Combustion in Industry											
Iron & Steel Combustion	5.6	2.2	3.3	3.3	3.4	3.4	3.4	3.2	3.0	2.8	6%
Non-Ferrous Metals	32.8	25.6	20.1	12.3	12.8	13.5	12.2	10.9	5.1	4.5	11%
Other Ind. Combustion	49.9	19.9	15.6	14.4	12.4	11.2	10.0	10.1	7.1	8.7	20%
Production Processes											
Iron & Steel	10.7	5.5	8.2	8.0	8.1	8.4	7.8	7.0	6.5	5.4	13%
Non-Ferrous Metals	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0%
Processes in Industry	3.2	3.1	4.0	4.6	12.8	5.2	5.2	5.2	5.4	3.2	7%
Road Transport	0.3	0.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1%
Other Trans/Machinery	0.3	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0%
Waste	19.9	19.9	15.5	6.4	3.4	0.5	0.5	0.6	0.6	0.4	1%
By FUEL TYPE											
Solid	122.7	77.8	64.4	39.7	36.7	29.2	29.6	25.8	23.7	23.2	54%
Petroleum	16.5	9.3	5.2	4.1	3.8	3.1	2.8	2.3	1.9	2.1	5%
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Non-Fuel	74.0	58.2	57.3	44.1	46.5	33.0	31.1	29.3	22.6	17.3	41%
TOTAL	**213.2**	**145.3**	**126.9**	**87.9**	**87.1**	**65.2**	**63.4**	**57.4**	**48.2**	**42.6**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

Figure 6.13 Time Series of Copper Emissions (tonnes)



6.4.6 Emissions of Lead

Lead is a very toxic element and can cause a variety of symptoms at low dose levels. Lead dust or fumes can irritate the eyes on contact, as well as causing irritation to the nose and throat on inhalation. Acute exposure can lead to loss of appetite, weight loss, stomach upsets, nausea and muscle cramps. High levels of acute exposure may also cause brain and kidney damage. Chronic exposure can lead to effects on the blood, kidneys, central nervous system and vitamin D metabolism.

Table 6.17 and Figure 6.14 summarise the UK emissions of lead. Emissions have declined by 97% since 1970. The largest source is lead from anti-knock lead additives in petrol. The lead content of leaded petrol was reduced from around 0.34 g/l to 0.143 g/l in 1986 and since 1987 sales of unleaded petrol have increased particularly as a result of the increased use of cars fitted with catalytic converters. Leaded petrol was then phased out from general sale at the end of 1999. Consequently a decline in emissions from the road transport sector is seen.

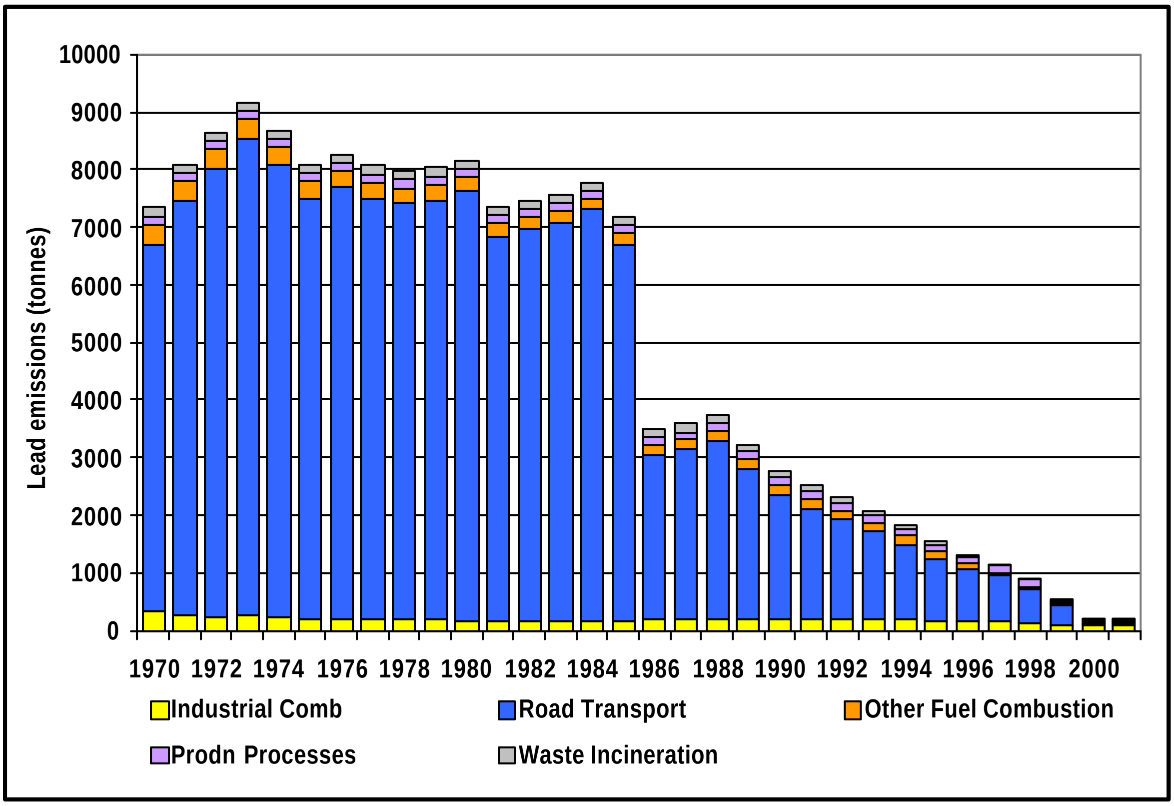
Other major sources are industrial processes and iron and steel combustion. There has been some reduction in emissions from iron and steel production processes due to improved abatement measures. Emissions have also declined as a result of the decreasing use of coal. The large reduction in waste emissions is due to improved controls on MSW incinerators from 1997 onwards and their conversion to power generating plant.

Table 6.17 UK Emissions of Lead by UN/ECE Category and Fuel (tonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001 %
BY UN/ECE CATEGORY[1]											
Combustion in Energy Prod											
Public Power	81.4	88.5	103.8	88.7	64.4	25.7	26.5	17.1	18.4	15.4	8%
Petroleum Refining Plants	0.9	0.9	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.5	0%
Other Combustion & Trans.	12.7	4.4	0.8	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0%
Combustion in Comm/Res											
Residential Plant	100.5	49.3	26.6	19.2	19.7	16.9	15.6	15.5	13.6	15.3	8%
Comm/Agricul Combustion	49.4	18.0	19.8	10.5	7.6	4.4	3.0	2.6	2.0	2.0	1%
Combustion in Industry											
Iron & Steel Combustion	72.8	27.1	48.4	46.0	47.5	47.7	46.5	44.4	39.9	36.2	19%
Non-Ferrous Metals	61.9	44.5	45.0	40.8	35.2	34.5	24.0	22.1	27.1	30.2	16%
Other Ind. Combustion	183.9	101.2	95.2	87.2	74.5	62.5	51.0	42.2	25.5	32.6	17%
Production Processes											
Iron & Steel	34.8	28.0	30.4	29.6	28.0	29.7	25.8	22.5	24.0	20.1	10%
Non-Ferrous Metals	1.6	1.1	1.3	1.2	1.2	1.2	1.2	0.8	0.7	0.5	0%
Processes in Industry	107.0	101.2	99.0	85.5	75.0	114.0	91.9	30.6	15.1	16.1	8%
Road Transport	6363	7445	2173	1065	909	799	590	320	21	21	11%
Other Trans/Machinery	119.0	91.8	18.6	10.1	8.6	7.6	5.9	3.5	0.8	0.8	0%
Waste	149.3	149.4	117.7	50.2	26.1	3.8	4.0	4.1	4.1	3.4	2%
By FUEL TYPE											
Solid	352	193	151	96	91	74	70	59	49	56	29%
Petroleum	6512	7553	2201	1081	923	810	600	326	24	24	12%
Gas	0	0	0	0	0	0	0	0	0	0	0%
Non-Fuel	475	404	428	358	284	264	217	141	120	114	59%
TOTAL	**7339**	**8151**	**2780**	**1535**	**1297**	**1147**	**886**	**526**	**193**	**194**	**100%**

[1] See Annex 1 for definition of UN/ECE Categories

Figure 6.14 Time Series of Lead Emissions (tonnes)



6.4.7 Emissions of Mercury

Acute exposure to high levels of elemental mercury vapour can lead to irritation of the lungs as well as causing coughing, chest pain and shortness of breath. High levels can also result in central nervous system (CNS) effects such as tremors and mood changes. Chronic exposure also leads to CNS disorders, with effects such as increased excitability, excessive shyness and irritability.

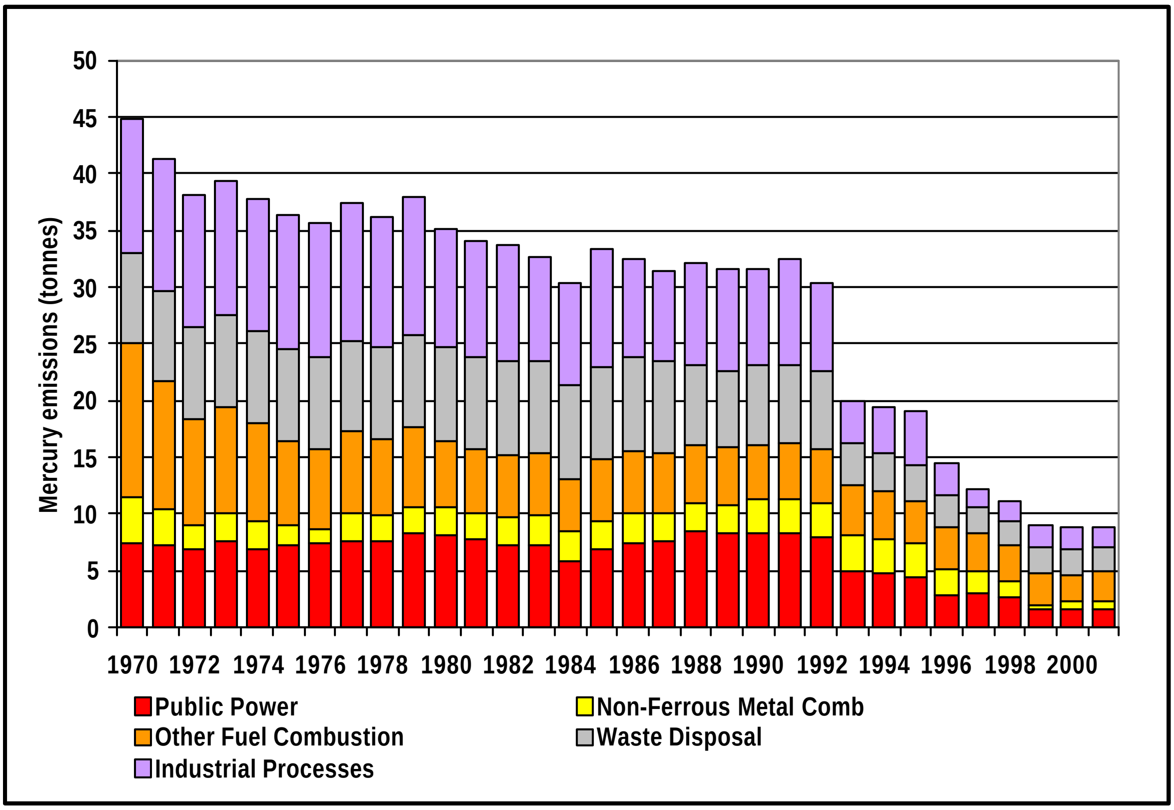
Table 6.18a and Figure 6.15 summarise the UK emissions of mercury. Emissions have declined by 80% since 1970. The main sources are waste incineration, the manufacture of chlorine in mercury cells, coal and other forms of industrial combustion. Emissions have declined as a result of improved controls on mercury cells and their replacement by diaphragm or membrane cells and the decline of coal use. The large reduction in waste emissions is due to improved controls on MSW incinerators from 1997 onwards and their conversion to power generating plant. There are only relatively minor changes since the last inventory.

Table 6.18a UK Emissions of Mercury by UN/ECE Category and Fuel (tonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[1]											
Combustion in Energy Prod											
Public Power	7.5	8.1	8.4	4.5	2.9	3.0	2.7	1.7	1.6	1.6	19%
Petroleum Refining Plants	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	1%
Other Combustion & Trans.	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Combustion in Comm/Res											
Residential Plant	3.9	1.9	1.0	0.8	0.8	0.7	0.6	0.6	0.5	0.6	7%
Comm/Agricul Combustion	2.3	0.9	1.0	0.3	0.3	0.3	0.2	0.2	0.1	0.1	2%
Combustion in Industry											
Iron & Steel Combustion	1.1	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5	6%
Non-Ferrous Metals	4.0	2.5	2.9	2.9	2.3	2.0	1.4	0.3	0.8	0.7	8%
Other Ind. Combustion	5.6	2.3	2.2	2.1	1.9	1.8	1.7	1.4	1.0	1.3	15%
Production Processes											
Iron & Steel	0.6	0.3	0.4	0.4	0.4	0.5	0.4	0.4	0.5	0.3	3%
Non-Ferrous Metals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Processes in Industry	11.3	10.2	8.1	4.2	2.4	1.1	1.3	1.5	1.4	1.5	17%
Road Transport	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Other Trans/Machinery	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Waste											
Landfill	0.6	0.6	0.6	0.4	0.4	0.4	0.4	0.4	0.4	0.4	4%
Waste Incineration	7.4	7.6	6.4	2.8	2.4	1.8	1.8	1.8	1.8	1.7	19%
By FUEL TYPE											
Solid	18.1	12.2	10.3	6.5	4.8	3.8	4.3	3.4	2.9	3.2	36%
Petroleum	1.2	0.7	0.6	0.3	0.3	0.1	0.1	0.1	0.1	0.1	1%
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Non-Fuel	25.5	22.2	20.8	12.3	9.4	8.2	6.8	5.4	5.8	5.5	63%
TOTAL	**44.9**	**35.2**	**31.6**	**19.0**	**14.5**	**12.2**	**11.2**	**9.0**	**8.8**	**8.8**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

Figure 6.15 Time Series of Mercury Emissions (tonnes)



6.4.7.1 Speciation of Mercury Emissions

When mercury is emitted to air it occurs in one of several different forms, and the emissions of each of these forms has been estimated individually- the emissions have been “speciated”.

Three species of mercury have been considered

- **Hg^0** unreactive gaseous elemental Hg
- **Hg-p** mercury attached to particulate material
- **RGM** reactive gaseous mercury (includes both inorganic and organic forms normally in the Hg^{2+} oxidised form)

The methodology for estimating the emissions of each of these three species is similar to that used for speciating the NMVOC emissions. Each source of mercury emission is considered individually. A speciation profile identifying the fractional contribution from each species to the mercury emission from that source is then applied. Summing across the individual sources then allows a total for each of the three species to be evaluated.

Table 6.18b Speciated Emissions of Mercury (tonnes)

	Hg(0)	Hg-p	RGM	Total (2001)
BY UN/ECE CATEGORY[1]				
Combustion in Energy Prod	0.75	0.15	0.80	**1.70**
Combustion in Comm/Res	0.30	0.13	0.31	**0.74**
Combustion in Industry	1.70	0.18	0.65	**2.54**
Production Processes	1.27	0.02	0.48	**1.76**
Road Transport	0.00	0.00	0.00	**0.00**
Other Trans/Machinery	0.00	0.00	0.00	**0.00**
Waste	0.46	0.02	1.60	**2.07**
TOTAL	**4.48**	**0.50**	**3.84**	**8.82**

The profiles used for the speciation are based on the recommendations given in Passant *et al* (2002). In general, these profiles are subject to great uncertainty and further measurement data are required, particularly for major sources such as coal combustion, crematoria, clinical waste incinerators, sinter plant, chloralkali processes, and primary lead/zinc production.

6.4.8 Emissions of Nickel

Inhalation of nickel can cause irritation to the nose and sinuses and can also lead to the loss of the sense of smell. Long term exposure may lead to asthma or other respiratory diseases. Cancer of the lungs, nose and sinuses as well as the larynx and stomach has been attributed to exposure to nickel.

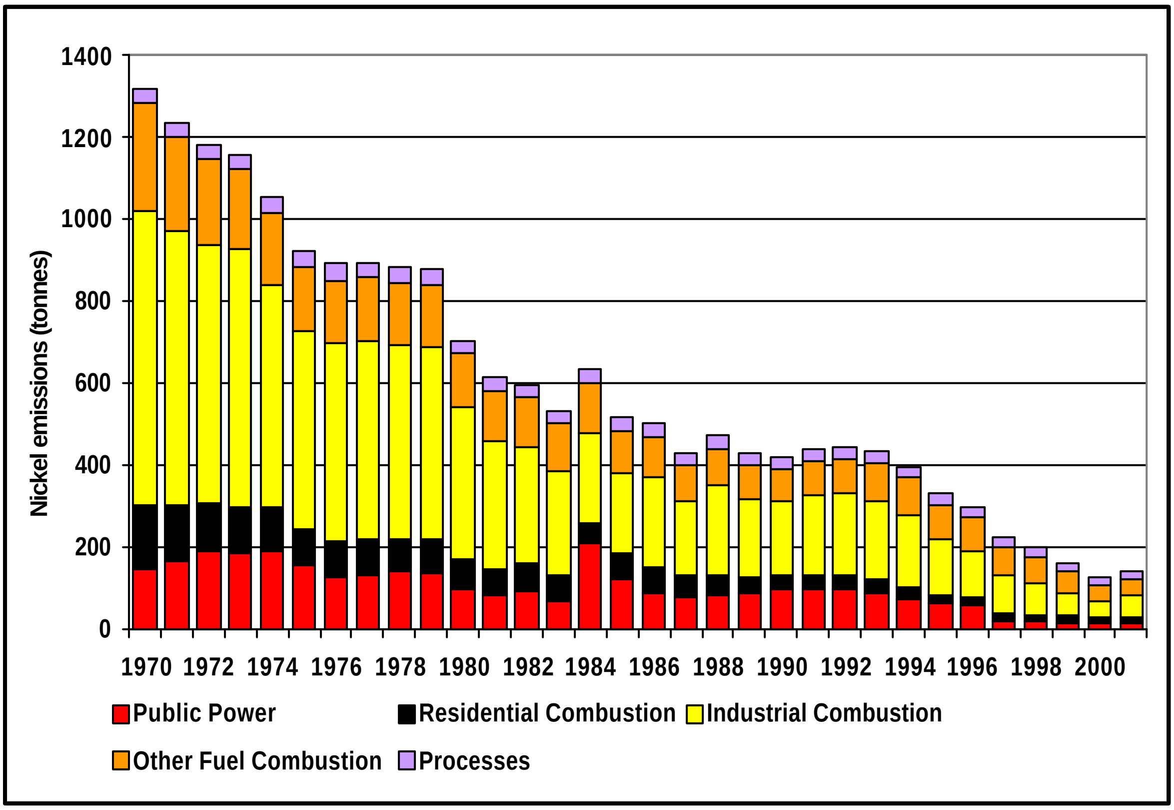
Table 6.19a and Figure 6.16 summarise the UK emissions of nickel. Emissions have declined by 90% since 1970. The main sources of nickel emissions are the combustion of coal and heavy fuel oil. These have declined in use since 1970 in favour of natural gas and are largely responsible for the reduction in total emissions. Between 1989 and 1997, heavy fuel oil was replaced by Orimulsion (an emulsion of bitumen in water) in some power stations. The nickel content of Orimulsion was higher than that of heavy fuel oil and resulted in higher emissions in spite of the flue gas cleaning equipment required on these power stations. Emissions from refineries are important because of the large amount of refinery fuel oil and residues burnt.

Table 6.19a UK Emissions of Nickel by UN/ECE Category and Fuel (tonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001 %
BY UN/ECE CATEGORY[1]											
Combustion in Energy Prod											
Public Power	143.5	95.5	97.0	61.1	54.3	17.3	15.9	11.5	12.4	10.7	8%
Petroleum Refining Plants	47.5	45.8	33.4	38.5	38.6	37.5	38.6	34.1	26.5	28.8	21%
Other Combustion & Trans.	12.1	4.2	0.7	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0%
Comb in Comm/Res											
Residential Plant	159.0	71.4	34.9	21.9	22.2	19.5	18.5	19.2	15.3	18.4	13%
Comm/Agricul Combustion	190.0	78.9	40.3	36.0	33.2	24.3	19.0	19.8	9.1	10.8	8%
Combustion in Industry											
Iron & Steel Combustion	0.8	0.4	0.4	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0%
Non-Ferrous Metals	0.3	0.2	0.2	0.3	0.3	0.4	0.4	0.8	0.5	0.5	0%
Other Ind. Combustion	713.4	372.0	177.8	134.5	113.5	94.6	76.8	52.0	38.3	50.3	37%
Production Processes											
Iron & Steel Combustion	17.6	13.2	14.8	14.4	13.8	14.6	12.8	6.5	8.9	5.0	4%
Non-Ferrous Metals	0.6	3.9	3.1	2.5	2.5	2.6	2.7	2.9	3.2	3.6	3%
Processes in Industry	10.1	6.1	7.6	9.0	8.8	7.0	7.6	7.5	7.7	6.3	5%
Road Transport	0.7	0.9	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1%
Other Trans/Machinery	13.2	2.9	2.9	7.5	6.0	4.6	3.8	2.7	1.6	1.2	1%
Waste	8.1	8.1	6.2	2.2	1.2	0.2	0.2	0.2	0.2	0.2	0%
By FUEL TYPE											
Solid	338.3	154.3	108.4	74.3	68.9	58.8	58.2	52.4	40.9	48.8	35%
Petroleum	930.6	507.7	269.2	214.4	190.3	132.5	108.6	82.8	58.8	68.2	50%
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Non-Fuel	47.9	41.4	42.9	40.7	36.8	32.8	31.0	23.7	25.6	20.5	15%
TOTAL	**1316.8**	**703.4**	**420.5**	**329.3**	**296.0**	**224.0**	**197.8**	**158.8**	**125.3**	**137.5**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

Figure 6.16 Time Series of Nickel Emissions (tonnes)



6.4.8.1 Speciation of Nickel Emissions

Nickel is emitted to air in a many different forms, which have been grouped into five 'species' for the NAEI:

- **MN** metallic nickel
- **ON** oxidic nickel compounds such as NiO and Ni_2O_3
- **SolN** soluble nickel salts such as nickel sulphates and nickel chlorides
- **NC** nickel carbonyl, $Ni(CO)_4$
- **SU** sulphidic nickel compounds such as nickel sulphide (NiS) and nickel subsulphide (Ni_3S_2)

The proportion of each form emitted by each source has been estimated and the overall split between the two forms is shown in Table 6.19b

Table 6.19b Speciated Emissions of Nickel (tonnes)

	MN	ON	SolN	NC	SU	Total (2001)
BY UN/ECE CATEGORY[1]						
Combustion in Energy Prod	0.0	15.4	22.8	0.2	1.2	**39.6**
Combustion in Comm/Res	0.0	11.4	16.8	0.1	0.9	**29.3**
Combustion in Industry	0.3	20.1	28.9	0.2	1.5	**51.0**
Production Processes	4.1	10.4	0.3	0.1	0.0	**14.9**
Road Transport	0.0	0.5	0.8	0.0	0.0	**1.3**
Other Trans/Machinery	0.0	0.5	0.7	0.0	0.0	**1.2**
Waste	0.0	0.1	0.1	0.0	0.0	**0.2**
TOTAL	**4.4**	**58.5**	**70.4**	**0.7**	**3.6**	**137.5**

The profiles used for the speciation are based on the recommendations given in Passant *et* al, 2002. In general, these profiles are subject to great uncertainty and better data are desirable, particularly for major sources such as combustion of coal, fuel oil, anthracite, and petroleum coke, and electric arc furnaces. However current measurement techniques are not able to provide much useful data and so significant improvements are not likely in the short term.

6.4.9 Emissions of Selenium

Acute exposure to selenium by inhalation results in respiratory effects such as irritation to the mucous membranes, severe bronchitis and bronchial pneumonia.

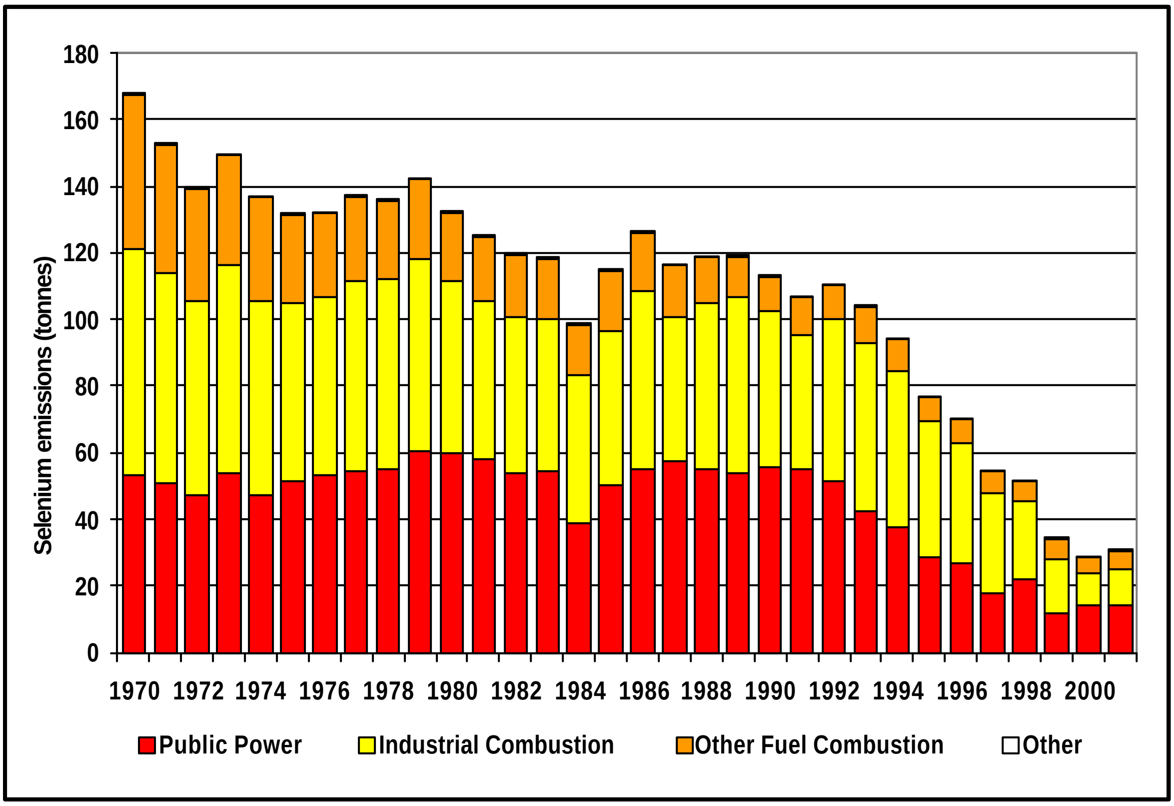
Table 6.20 and Figure 6.17 summarise the UK emissions of selenium. Emissions have declined by 82% since 1970. The main source of selenium emissions is coal combustion in early years. Only trace amounts are emitted by the combustion of petroleum based fuels. Glass production has previously been considered the dominant source. The estimates for the manufacture of the various types of glass products (flat glass, container glass etc.) are uncertain and are in the process of revision. Revised estimates have been made for flat glass and this has significantly reduced the national estimate of selenium emissions. Revised estimates for container glass will be introduced in the next version of the NAEI and will probably lead to an increased estimate of national emissions of selenium. The current estimate is therefore likely to be a considerable underestimate.

Table 6.20 UK Emissions of Selenium by UN/ECE Category and Fuel (tonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001 %
BY UN/ECE CATEGORY											
Combustion in Energy Prod											
Public Power	53.4	59.9	55.4	28.7	26.5	17.6	22.0	11.5	14.2	14.0	45%
Petroleum Refining Plants	2.0	1.9	1.1	1.2	1.2	1.2	1.2	1.0	0.7	1.0	3%
Other Combustion & Trans.	2.5	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Combustion in Comm/Res											
Residential Plant	32.7	14.8	7.3	4.5	4.7	4.1	3.9	4.0	3.2	3.9	12%
Comm/Agricul Combustion	8.7	2.9	1.8	0.9	0.9	0.8	0.5	0.5	0.3	0.3	1%
Combustion in Industry											
Iron & Steel Combustion	3.4	1.2	2.3	2.3	2.4	2.4	2.4	2.3	2.0	1.8	6%
Non-Ferrous Metals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Other Ind. Combustion	64.3	50.1	44.5	38.6	33.9	27.8	20.7	14.4	7.6	9.2	30%
Production Processes											
Iron & Steel Combustion	0.3	0.1	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.3	1%
Non-Ferrous Metals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Processes in Industry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0%
Road Transport	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	1%
Other Trans/Machinery	0.2	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0%
Waste	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
By FUEL TYPE											
Solid	116.6	84.1	70.3	40.5	37.3	27.9	31.5	20.7	20.8	22.7	73%
Petroleum	15.7	9.2	5.2	3.8	3.6	2.9	2.6	2.3	1.8	2.2	7%
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Non-Fuel	35.5	39.0	37.9	32.7	29.4	23.9	17.4	11.5	6.3	6.1	20%
TOTAL	**167.8**	**132.3**	**113.4**	**77.0**	**70.3**	**54.7**	**51.5**	**34.5**	**28.8**	**31.0**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

Figure 6.17 Time Series of Selenium Emissions (tonnes)



6.4.10 Emissions of Vanadium

Acute exposure to vanadium by inhalation can cause irritation to the respiratory tract. Chronic exposure may lead to pneumonia.

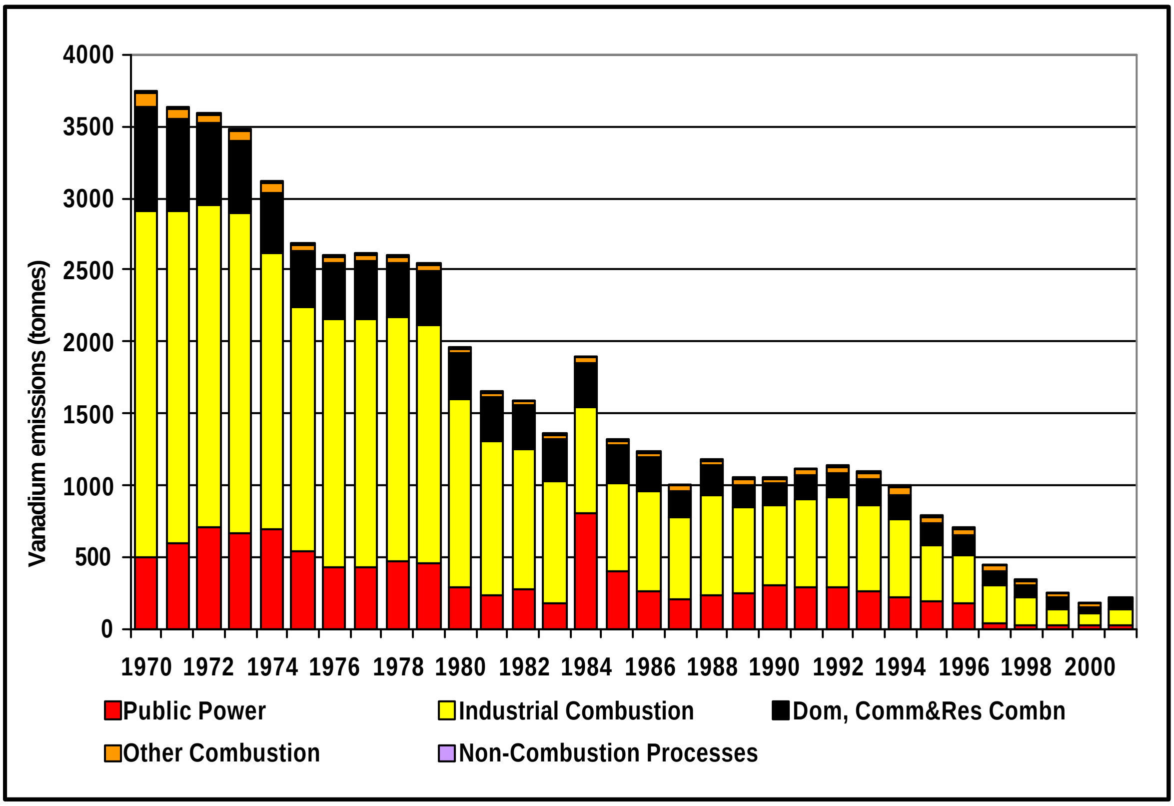
Table 6.21 and Figure 6.18 summarise the UK emissions of vanadium. Emission data are rather scarce so the estimates are very uncertain. Estimates of emissions have declined by 94% since 1970. The major source of emissions is the combustion of fuel oils with liquid fuels accounting for some 76% of the estimated emission in 2001. The reduction in emissions reflects the decline in the use of fuel oils by the electricity supply industry, industry in general and the domestic sector. Between 1989 and 1997, heavy fuel oil was partly replaced by Orimulsion (an emulsion of bitumen in water) in some power stations. Emissions from refineries are very important because of the high consumption of refinery fuel oil and residues. The vanadium content of Orimulsion was higher than that of heavy fuel oil and resulted in higher emissions in spite of the flue gas cleaning equipment required on these power stations. Of the other sources, estimates for the iron and steel industry are very uncertain since emissions will depend on the type of steel or alloy produced and its vanadium content. The available emissions data apply only to a generalised steel production process.

Table 6.21 UK Emissions of Vanadium by UN/ECE Category and Fuel (tonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[1]											
Combustion in Energy Prod											
Public Power	498	285	295	186	177	39	19	15	20	23	11%
Petroleum Refining Plants	25	18	16	20	24	14	15	13	13	16	8%
Other Combustion & Trans.	12	4	1	0	0	0	0	0	0	0	0%
Combustion in Comm/Res											
Residential Plant	68	34	18	16	14	12	10	10	9	10	5%
Comm/Agricul Combustion	663	287	140	135	124	89	71	75	34	41	19%
Combustion in Industry											
Iron & Steel Combustion	0	0	0	0	0	0	0	0	0	0	0%
Other Ind. Combustion	2412	1309	560	394	329	264	204	115	87	113	53%
Production Processes											
Iron & Steel Combustion	12	7	9	9	9	10	9	6	5	5	2%
Non-Ferrous Metals	0	0	0	0	0	0	0	0	0	0	0%
Road Transport	0	0	1	1	1	1	1	1	1	1	0%
Other Trans/Machinery	51	11	11	29	23	17	14	10	6	4	2%
Waste	3	3	2	1	0	0	0	0	0	0	0%
By FUEL TYPE											
Solid	224	110	90	66	60	50	47	42	37	43	20%
Petroleum	3502	1835	948	711	628	383	284	196	132	163	76%
Gas	0	0	0	0	0	0	0	0	0	0	0%
Non-Fuel	18	12	15	13	13	12	12	7	7	8	4%
TOTAL	**3744**	**1957**	**1053**	**790**	**701**	**446**	**343**	**245**	**175**	**214**	**100%**

[1] See Annex 1 for definition of UN/ECE Categories

Figure 6.18 Time series of Vanadium Emissions (tonnes)



6.4.11 Emissions of Zinc

Although zinc metal poses no documented health risks, if its physical state is altered during use then health risks can be created. Inhalation of metallic oxide fumes can lead to metal fume fever.

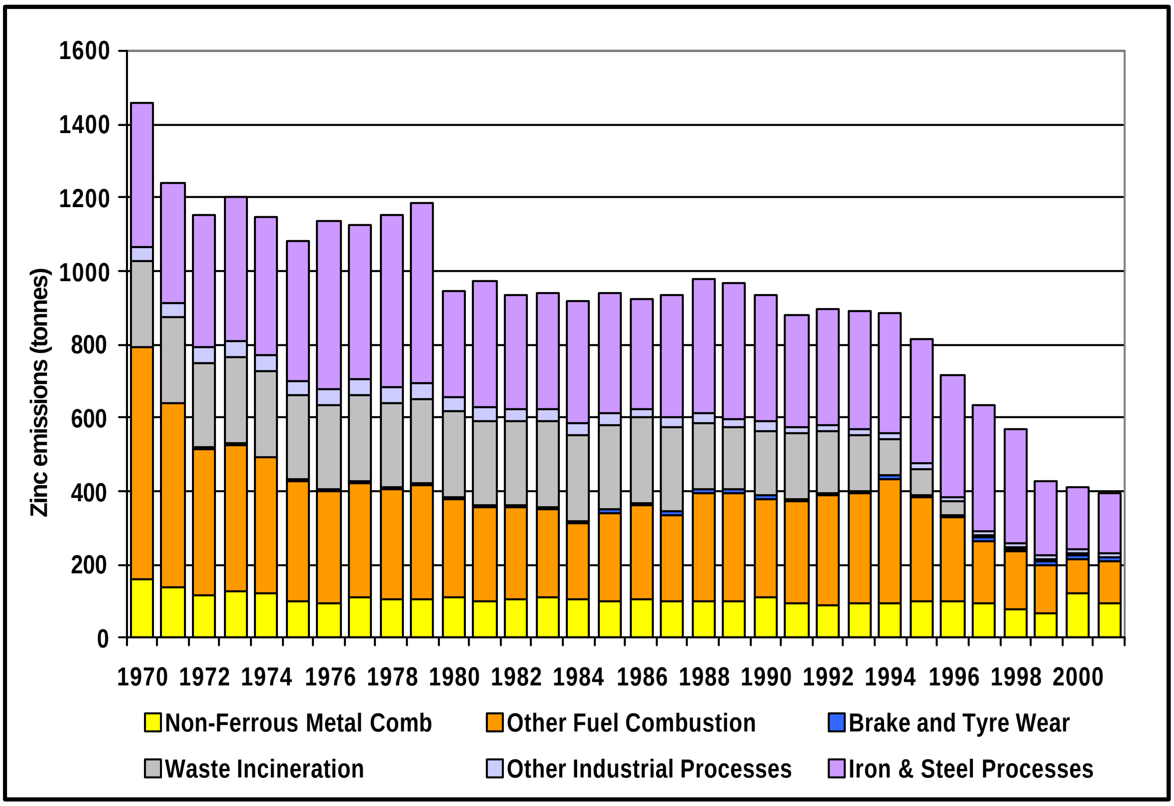
Table 6.22 and Figure 6.19 summarise the UK emissions of zinc. Emissions of zinc have declined by 73% since 1970. The main sources are iron and steel production and combustion in industry. The road transport emission is almost entirely due to tyre wear. This arises from the zinc content of the tyre rubber - around 2% ZnO by weight. The reduction in emissions over the period considered is largely due to the decline in coal combustion and improvements in abatement measures in the iron and steel industry. The large reduction in waste emissions is due to improved controls on MSW incinerators from 1997 onwards and their conversion to power generating plant.

Table 6.22 UK Emissions of Zinc by UN/ECE Category and Fuel (tonnes)

	1970	1980	1990	1995	1996	1997	1998	1999	2000	2001	2001%
BY UN/ECE CATEGORY[1]											
Combustion in Energy Prod											
Public Power	31	32	66	110	77	33	34	21	11	10	3%
Petroleum Refining Plants	16	16	11	13	13	13	13	12	9	10	2%
Other Combustion & Trans.	36	13	2	0	0	0	0	0	0	0	0%
Combustion in Comm/Res											
Residential Plant	56	25	12	7	7	7	7	7	6	7	2%
Comm/Agricul Combustion	91	27	35	17	12	7	5	3	2	2	1%
Combustion in Industry											
Iron & Steel Combustion	12	5	6	5	5	4	4	4	4	3	1%
Non-Ferrous Metals	161	114	109	99	99	97	79	67	123	93	24%
Other Ind. Combustion	386	150	137	131	114	103	92	85	59	82	21%
Production Processes											
Iron & Steel	396	290	347	339	328	345	308	201	170	162	41%
Non-Ferrous Metals	1	4	3	3	3	3	3	3	3	4	1%
Processes in Industry	39	37	19	12	11	10	10	9	11	7	2%
Road Transport											
Combustion	0	1	1	1	1	1	1	1	1	1	0%
Brake & Tyre Wear	4	6	8	9	9	9	9	9	9	9	2%
Other Trans/Machinery	0	0	0	0	0	0	0	0	0	0	0%
Waste	230	231	178	68	36	3	4	5	5	3	1%
By FUEL TYPE											
Solid	555	207	168	134	119	108	101	94	69	90	23%
Petroleum	39	28	19	17	17	16	16	14	11	12	3%
Gas	0	0	0	0	0	0	0	0	0	0	0%
Non-Fuel	866	712	749	662	579	513	452	321	333	291	74%
TOTAL	**1460**	**947**	**936**	**813**	**714**	**636**	**569**	**428**	**413**	**393**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

Figure 6.19 Times Series of Zinc Emissions (tonnes)



6.4.12 Emissions of Beryllium

Acute inhalation exposure to high levels of beryllium can lead to inflammation of the lungs. Long term exposure can cause chronic beryllium disease where non-cancerous lesions form in the lungs. Studies also suggest that inhalation can lead to an increased risk of lung cancer.

Table 6.23 summarises the UK emissions of beryllium. Estimates have only been included since the 2000 NAEI report, therefore the figures are very uncertain. Emission factors have been calculated for the combustion of coal and heavy liquid fuels, but emission factors are not available for industrial processes, with the exception of iron & steel manufacture and a few other processes, where emission estimates have been based on data given in the Pollution Inventory. Further development of the beryllium inventory will occur in future versions of the NAEI.

Table 6.23 UK Emissions of Beryllium by UN/ECE Category and Fuel (ktonnes)

	2000	2001	2000%
BY UN/ECE CATEGORY[1]			
Combustion in Energy Prod			
Public Power	0.4	0.4	2%
Petroleum Refining Plants	0.7	1.0	6%
Other Combustion & Trans.	2.5	2.2	14%
Combustion in Comm/Res			
Residential Plant	3.6	4.8	29%
Comm/Agricul Combustion	1.1	1.1	6%
Combustion in Industry	1.4	1.7	10%
Production Processes	0.2	0.2	1%
Road Transport	4.6	4.7	29%
Other Trans/Machinery	0.4	0.4	2%
Waste	0.0	0.0	0%

By FUEL TYPE			
Solid	7.3	8.4	51%
Petroleum	7.4	7.9	48%
Gas	0	0	0%
Non-Fuel	0.1	0.1	1%
TOTAL	**14.8**	**16.5**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

6.4.13 Emissions of Manganese

Long term exposure to high levels of manganese can result in effects on the central nervous system such as visual reaction time, hand-eye coordination and hand steadiness. Exposure to higher levels over a long period of time can result in a syndrome known as manganism. This leads to feelings of weakness and lethargy, tremors and psychological disturbances.

Table 6.24 summarises the UK emissions of manganese. As estimates have only been included since the 2000 NAEI report the figures remain very uncertain. Emission factors have been calculated for the combustion of coal and heavy liquid fuels, but emission factors are not available for many industrial processes, with the exception of iron & steel manufacture and a few other processes, where emission estimates have been based on data given in the Pollution Inventory. Further development of the manganese inventory will occur in future versions of the NAEI.

Table 6.24 UK Emissions of Manganese by UN/ECE Category and Fuel (ktonnes)

	2000	2001	2000%
BY UN/ECE CATEGORY[1]			
Combustion in Energy Prod			
Public Power	21	20	6%
Other Combustion & Trans.	86	78	23%
Combustion in Comm/Res			
Residential Plant	125	166	48%
Comm/Agricul Combustion	20	19	6%
Combustion in Industry	23	27	8%
Production Processes	43	33	10%
Waste	0	0	0%
By FUEL TYPE			
Solid	274	308	90%
Petroleum	0	0	0%
Gas	0	0	0%
Non-Fuel	45	35	10%
TOTAL	**319**	**343**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

6.4.14 Emissions of Tin

Inhalation of dust and fumes may cause a disease of the lungs called stannosis.

Table 6.25 summarises the UK emissions of tin. As estimates have only been included since the 2000 NAEI report the figures remain very uncertain. Emission factors have been calculated for the combustion of coal and heavy liquid fuels, but no data are available for other potential sources such as industrial processes. Further development of the tin inventory will occur in future versions of the NAEI.

Table 6.25 UK Emissions of Tin by UN/ECE Category and Fuel (ktonnes)

	2000	2001	2000%
BY UN/ECE CATEGORY[1]			
Combustion in Energy Prod			
Public Power	0.1	0.1	0%
Petroleum Refining Plants	0.2	0.3	0%
Other Combustion & Trans.	24.4	22.2	26%
Combustion in Comm/Res			
Residential Plant	35.4	47.1	56%
Comm/Agricul Combustion	5.6	5.5	6%
Combustion in Industry	6.2	7.3	9%
Production Processes	1.5	1.4	2%
Road Transport	0.5	0.6	1%
Other Trans/Machinery	0.1	0.0	0%
Waste	1.7	0.2	0%
By FUEL TYPE			
Solid	71.6	82.0	97%
Petroleum	1.1	1.3	1%
Gas	0	0	0%
Non-Fuel	3.0	1.3	2%
TOTAL	**75.7**	**84.6**	**100%**

1 See Annex 1 for definition of UN/ECE Categories

6.4.15 Spatial Disaggregation of Heavy Metals

All of the heavy metal emission estimates presented here have been spatially disaggregated with the exception of beryllium, manganese and tin, and UK maps are presented in Figures 6.20 to 6.31. The key features that are evident from the maps are briefly considered here:

Arsenic

Significant emissions arise from coal combustion, and consequently emissions in Northern Ireland are noted to be relatively high. Individual points sources are also evident.

Cadmium

The major source for 2001 arises from activities associated with non-ferrous metals, but the emissions from this source are not readily visible from the UK map.

Chromium and Copper

The dominant sources of Chromium are coal combustion, iron and steel production processes, and chromium-based chemicals manufacture. In the case of copper, the main sources are coal combustion, iron and steel manufacture and non-ferrous metals production. From the UK emission maps it can be seen that there are a number of point sources, and elevated emissions in Northern Ireland for both of these pollutants.

Lead

A significant contribution of the lead emissions comes from the non-ferrous metal industry but these point sources are not readily visible on the UK emissions map. Selected motorways are clearly visible from the UK emission map. However, there has been a substantial decrease in the emissions from road transport. The maps below compare the 1999 and 2001 Lead emissions maps.

Figure 6.20UK Emissions Map of Lead 1999

Figure 6.21 UK Emissions Map of Lead 2001

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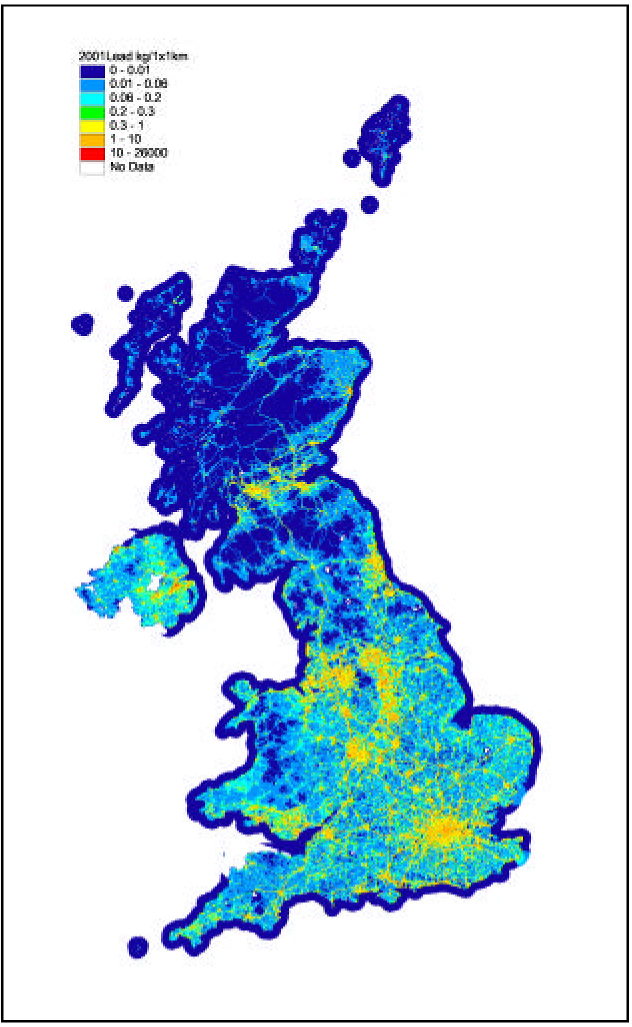


Mercury

The major sources of mercury in 2001 were waste incineration, coal combustion and specific industrial activities. As a result the UK emission map highlights a number of point sources with a more coverage.

Nickel

Emissions of Nickel are dominated by the combustion of coal and heavy fuel oil. Consequently areas of the country with refinery activities are highlighted. It is also interesting to note that urban areas are not elevated, with high population density areas often resulting in lower emissions per 1x1 km grid cell. This is due to the higher use of gas in the domestic sector in areas of higher population density.

Selenium

Emissions of selenium are dominated by the glass industry and coal combustion. Consequently the UK emissions map displays some major point sources, while other areas have very low emissions.

Vanadium

Vanadium emissions primarily arise from the combustion of heavy fuel oils- in the refinery and industrial sectors. As a result a large number of point sources may be identified from the emissions map, and large conurbations/areas of high population density show low emissions.

Zinc

Zinc emissions primarily arise from combustion in the non-ferrous metals sector, iron and steel production processes and road transport (brake and tyre wear). As a result the UK emissions map highlights the road network and a number of point sources. However, the point sources are difficult to see due to the large number of grid cells where emissions are governed by the road transport sector.

Figure 6.22 UK Emissions Map of Arsenic

Figure 6.23 UK Emissions Map of Cadmium

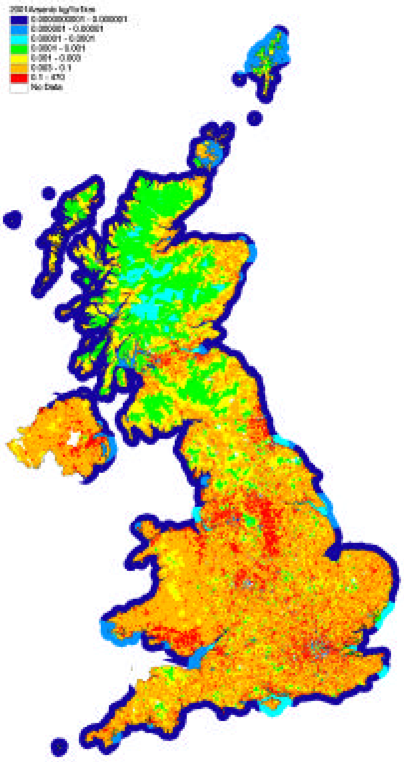


Figure 6.24 UK Emissions Map of Chromium

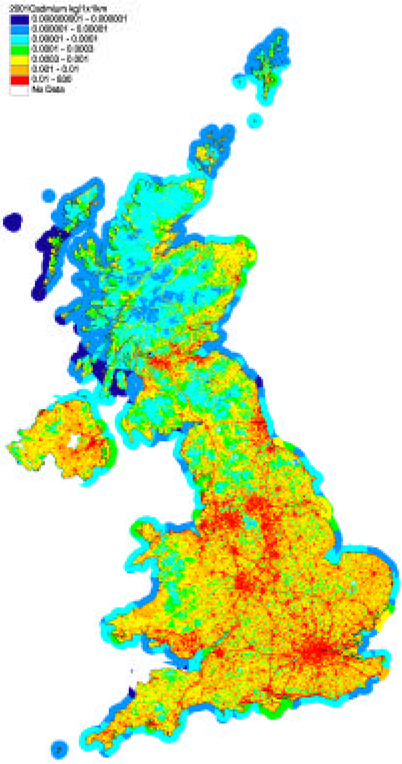


Figure 6.25 UK Emissions Map of Copper

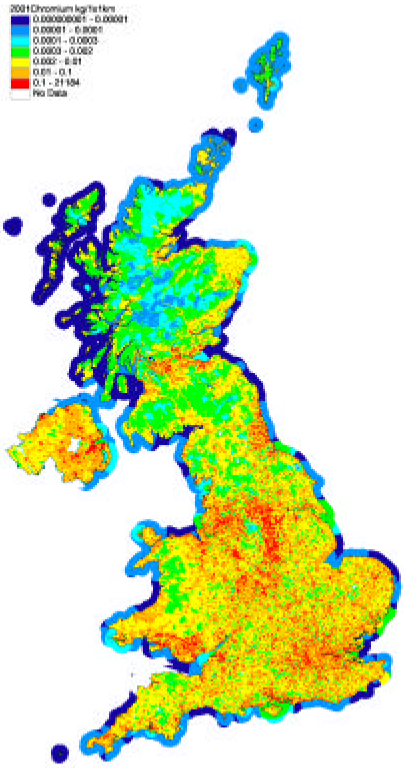


Figure 6.26 UK Emissions Map of Lead

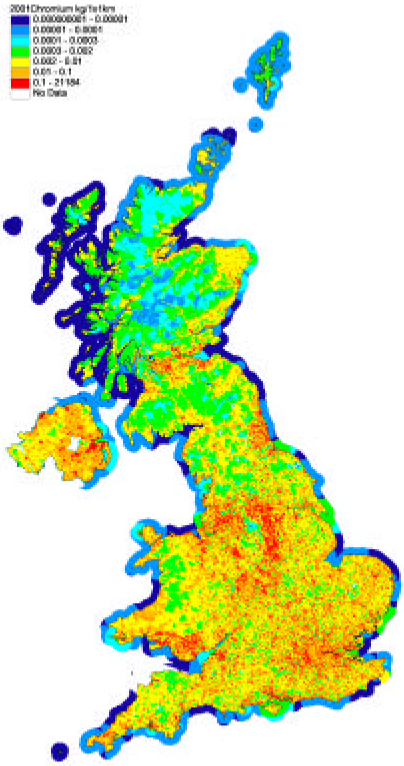


Figure 6.27 UK Emissions Map of Mercury

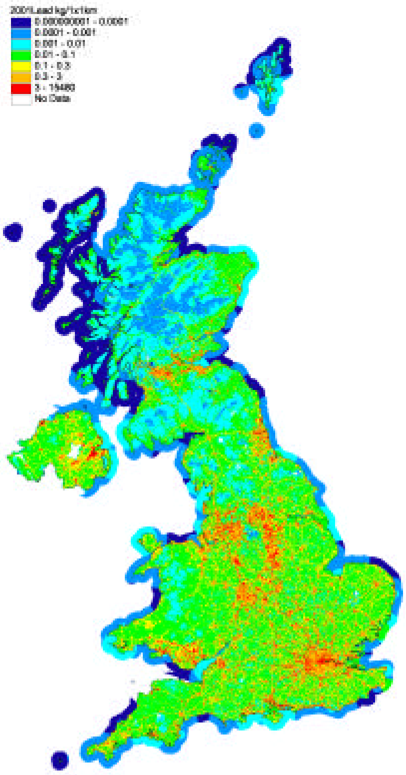


Figure 6.28 UK Emissions Map of Nickel

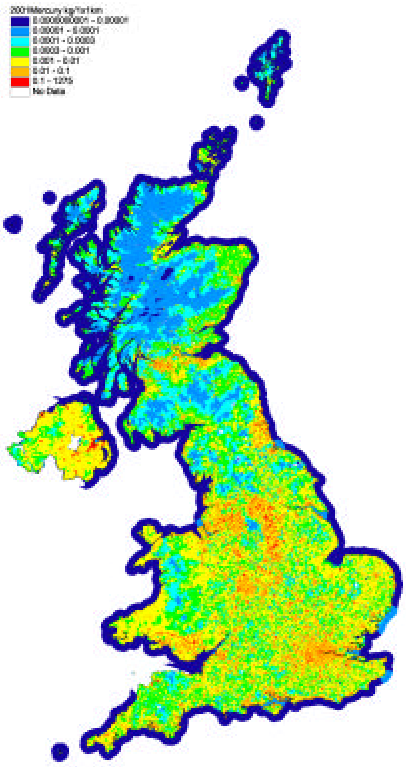


Figure 6.29 UK Emissions Map of Selenium

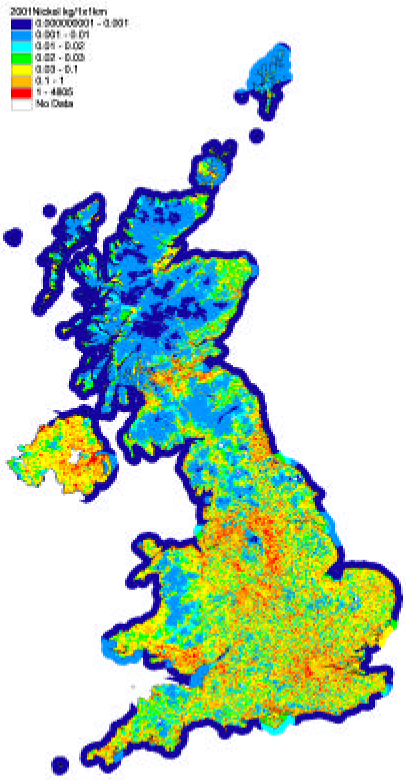


Figure 6.30 UK Emissions Map of Vanadium

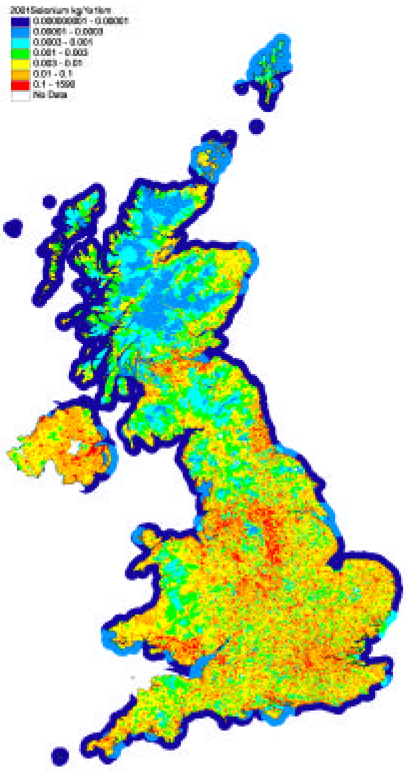
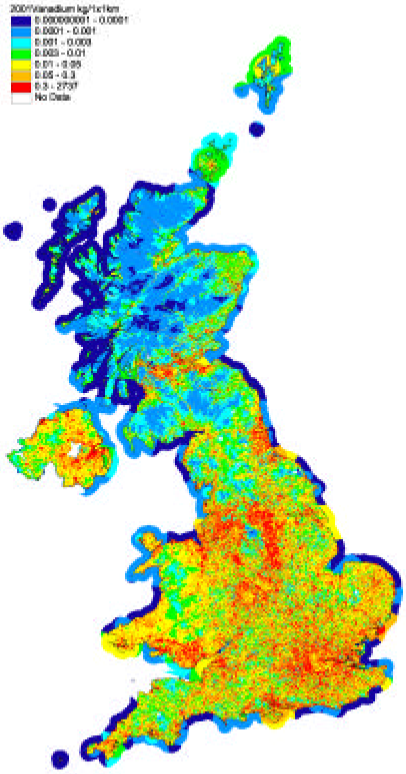
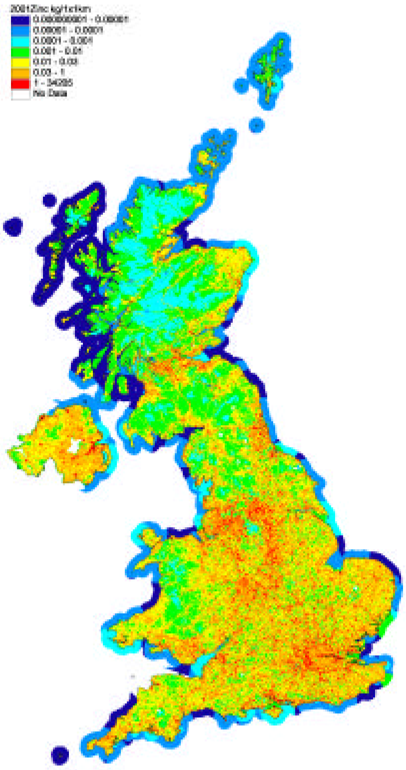


Figure 6.31 UK Emissions Map of Zinc





6.5 ACCURACY OF EMISSION ESTIMATES OF HEAVY METALS

Quantitative estimates of the uncertainties in emission inventories have been based on calculations made using a direct simulation technique, which corresponds to the IPCC Tier 2 approach recommended for greenhouse gases and also the methodology proposed in draft guidance produced by the UN/ECE Taskforce on Emission Inventories and Projections. This work is described in detail by Passant (2002b). The uncertainty estimates are shown below in Table 6.26.

Table 6.26 Uncertainty of the Emission Inventories for metals

Pollutant	**Estimated Uncertainty %**
Arsenic	-40 to +60
Cadmium	-20 to +30
Chromium	-20 to +40
Copper	-20 to +40
Mercury	±30
Nickel	-40 to +60
Lead	-20 to +30
Selenium	-30 to +70
Vanadium	-50 to +90
Zinc	-30 to +50
Beryllium	-70 to +200
Manganese	-80 to +300
Tin	-90 to +300

The inventories for beryllium, manganese and tin are still being developed and are currently much more uncertain than those for other metals.

Among the remaining metal inventories, those for lead and chromium are least uncertain, while those for arsenic, selenium, and vanadium are most uncertain. In the case of lead and chromium, these inventories are less uncertain because of the reliability of estimates for major sources such as road transport in the case of lead, and chromium chemicals in the case of chromium. The inventories for arsenic, selenium and vanadium seem to be most uncertain because of the high uncertainty in estimates of emissions for major sources including burning of impregnated wood (arsenic), flat glass production (selenium), and combustion of fuel oil (vanadium).

7 Base Cations

7.1 INTRODUCTION

Base cation emission estimates for the UK are presented in this chapter. The emission estimates cover the period 1990-2001 for Calcium (Ca), Magnesium (Mg), Sodium (Na) and Potassium (K). These estimates are highly uncertain.

A base cation is essentially a positively charged ion from group 1 or 2 of the periodic table (the alkali metals or alkaline earth metals). The most environmentally abundant of these are Na, K, Ca and Mg. Base cations are important in the environment because their deposition has an impact on the surface pH. The deposition of base cations increases the alkalinity of the surface; the effect in the environment is to buffer or neutralise the effects of the acidity generated by S and N deposition (which in their mobile anionic form, SO_4^{2-} and NO_3^-, leach Ca and Mg from the soil). Therefore the primary purpose of these emission estimates is to use them to generate spatially resolved emission maps, which enable deposition maps to be calculated.

7.2 BACKGROUND

A "critical load" approach is often taken to predict the maximum levels of acidity or alkalinity that an ecosystem can tolerate. The base cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) are known to be present in ambient air and in precipitation. The deposition of these base cations to ecosystems will offset to some extent the acidification resulting from the deposition of SO_X, NO_Y and NH_Y.

The Review Group on Acid Rain (1997) reported on the decline in base cation deposition that has been observed in Europe and N America since the early 1970's and how such a decline may offset some of the benefits of reductions in SO_2 emissions. Interest in the deposition and acid neutralising effects of base cations is mainly confined to Ca, K and Mg. It has long been assumed that the major source of these base cations in air is dust from soil erosion, but patterns of concentrations in air and precipitation also suggest significant emissions from urban and industrial sources. The concentrations of Ca, K and Mg in air and in precipitation measured at three rural sites in the UK declined dramatically between 1970 and 1991 (Lee and Pacyna, 1999). It has been suggested that the decrease in base cation deposition which has been observed is due to the reduction in emissions from urban and industrial sources. Concentrations of Na in air and rain have shown much smaller decreases over this period, consistent with its mainly marine origin as sea-salt.

The NAEI has attempted to estimate emissions from the following sources:

- **Stationary combustion of fossil fuels**: mainly in the fly ash from solid fuel combustion
- **Mineral extraction processes**: e.g. limestone quarrying
- **Processes in the mineral products industry**: e.g. cement manufacture and concrete batching
- **Industrial processes using limestone, dolomite and soda lime**:
    - iron and steel manufacture
    - glass manufacture
- **Agricultural use**: e.g. liming of soils and dust due to cultivation.

- **Construction and demolition activities**
- **Mobile sources**: mostly in the form of dust resuspension by traffic and exhaust emissions of potassium from lead replacement petrol (LRP).

There are likely to be base cation emissions from other sources, for example incineration. Currently, these are not included in the estimates as such sources are likely to be much smaller than the sources listed above.

7.3 STATIONARY COMBUSTION OF FOSSIL FUELS

The base cations emitted from stationary combustion arise from the trace concentrations of the cations found in the fuels. The base cations will enter the atmosphere contained in the primary particulate matter (PM) which is emitted from the combustion source. Calcium has been found in large amounts in the fine particle size fraction collected from combustion sources.

The NAEI currently estimates PM_{10} emissions from large combustion plant for power generation using total PM emissions data submitted by the operators to the Environment Agency and the Scottish Environmental Protection Agency. Where reported data are incomplete, PM emission factors for the appropriate fuel are derived and combined with the amount of fuel used by the combustion plant to estimate the total mass of PM emitted.

The mass content of cations in coal has been estimated from the Turner-Fairbank Highway Research Centre (US Transport Department) figures for fly ash from bituminous coal. Data regarding the composition of fuel oil is given in the Marine Exhaust Research Programme.

7.4 MINERAL EXTRACTION PROCESSES

Limestone quarrying is a major source of atmospheric emissions of base cations, principally calcium. Quarrying of dolomite ($CaCO_3$ $MgCO_3$), rock salt (NaCl) and potash (KCl) are the principle sources of magnesium, sodium and potassium respectively.

The NAEI currently estimates PM_{10} emissions from quarrying using USEPA emission factors combined with UK mineral statistics on the production of each type of aggregate. The dust emitted from limestone quarrying will be mainly particles of limestone ($CaCO_3$) itself. These particulates will be mainly in the coarse particle size range (>2.5 μm) and will be deposited close to their source. The quantities of these minerals extracted in the UK are given in the Minerals Yearbook (1990 – 2001).

7.5 PROCESSES IN THE MINERAL PRODUCTS INDUSTRY

Emissions of calcium from the mineral products industry are estimated from total PM_{10} emissions using emission factors from Lee and Pacyna (1999) or AEAT estimates of PM_{10} composition.

7.6 INDUSTRIAL PROCESSES USING LIMESTONE, DOLOMITE AND SODA ASH

Processes involving limestone, dolomite and soda ash include iron and steel production and glass manufacturing. Emissions of base cations from the iron and steel industry and the glass industry are based on the PM_{10} inventory combined with emission factors for cations taken from Lee and Pacyna (1999) or based on AEAT estimates of PM_{10} composition.

7.7 SOIL LIMING AND CULTIVATION IN AGRICULTURE

The practice of soil liming in agriculture will lead to the emission of Ca when the lime is applied to the ground. Statistics are available on the quantity of limestone used each year for liming (UK Minerals Yearbook 1990-2001) and an emission is estimated using an emission factor for non-metallic particles given by the USEPA.

The average quantities of re-suspended dust, as a result of land cultivation, may be estimated from data reported in the MAFF Report CSG 15 (2000). Emissions are estimated from the average chemical abundance of each cation in UK soil (Lindsay, 1979).

7.8 CONSTRUCTION ACTIVITIES

The NAEI currently uses a USEPA emission factor combined with UK construction activity statistics to estimate fugitive emissions of PM_{10} from these processes. A modified PM_{10} emission factor based on the fraction of total aggregate used in construction (UK Minerals Yearbook 1990-2001) that is limestone, dolomite or chalk, is used to estimate the base cation emissions.

7.9 MOBILE SOURCES

Emissions of base cations from mobile sources will mainly arise from the resuspension of road dust by traffic. Recently, Nicholson (2000) has made an estimate of the total PM_{10} emission from UK roads. Using this information with data on the average chemical composition of road dust (Sloss and Smith, 2000) Na, K and Ca emissions have been estimated. There are insignificant quantities of Mg in road dust.

Potassium compounds are the primary additives in Lead Replacement Petrol (LRP). LRP has been available since Autumn 1999 and is the main source of potassium emissions from vehicle exhausts. Emissions have been estimated from UK LRP sales in 1999 (calculated as a fraction of leaded petrol sales) to 2001 given by the Digest of United Kingdom Energy Statistics (DUKES).

Table 7.1 UK Emissions of Calcium by UN/ECE Source Category (ktonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
Combustion in Energy Prod													
Public Power	3.2	3.2	3.0	2.5	2.2	1.7	1.5	1.0	1.1	0.8	0.9	0.7	9%
Petroleum Refining Plants	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Other Combustion & Trans.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Combustion in Comm./Inst/ Res													
Residential Plant	1.7	1.8	1.6	1.6	1.3	0.8	0.9	0.9	0.9	0.9	0.6	0.9	11%
Comm., Public & Agri.	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0%
Combustion in Industry	3.1	2.8	2.7	2.7	2.8	2.5	2.6	2.6	2.8	2.7	2.3	2.1	27%
Production Processes	4.9	4.6	4.3	4.4	4.8	4.5	4.2	4.3	4.3	4.1	4.0	4.0	51%
Shipping	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Waste Treatment & Disp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Non livestock agriculture	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.0	0.0	0.0	0.0	1%
Total	**13.3**	**12.6**	**11.8**	**11.4**	**11.2**	**9.7**	**9.5**	**9.1**	**9.1**	**8.7**	**7.9**	**7.8**	**100%**

Figure 7.1 Time Series of Calcium Emissions (tonnes)

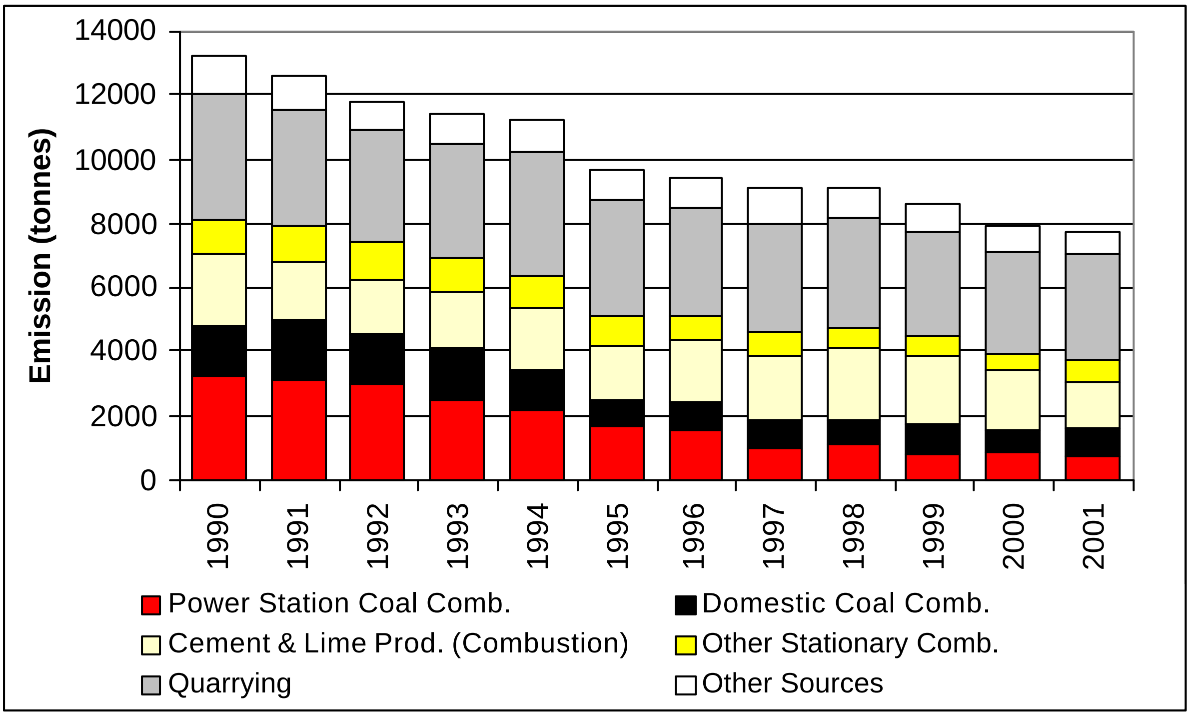


Table 7.2 UK Emissions of Magnesium by UN/ECE Source Category (ktonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
Combustion in Energy Prod													
Public Power	1.0	1.0	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	22%
Other Combustion & Trans.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Combustion in Comm./Inst/ Res													0%
Residential Plant	0.5	0.6	0.5	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.3	27%
Comm., Public & Agri.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1%
Combustion in Industry	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2	22%
Production Processes	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3	28%
Waste Treatment & Disp.	0	0	0	0	0	0	0	0	0	0	0	0	0%
Non livestock agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Total	**2.6**	**2.6**	**2.5**	**2.3**	**2.0**	**1.6**	**1.5**	**1.3**	**1.2**	**1.1**	**1.0**	**1.1**	

Figure 7.2 Time Series of Magnesium Emissions (tonnes)

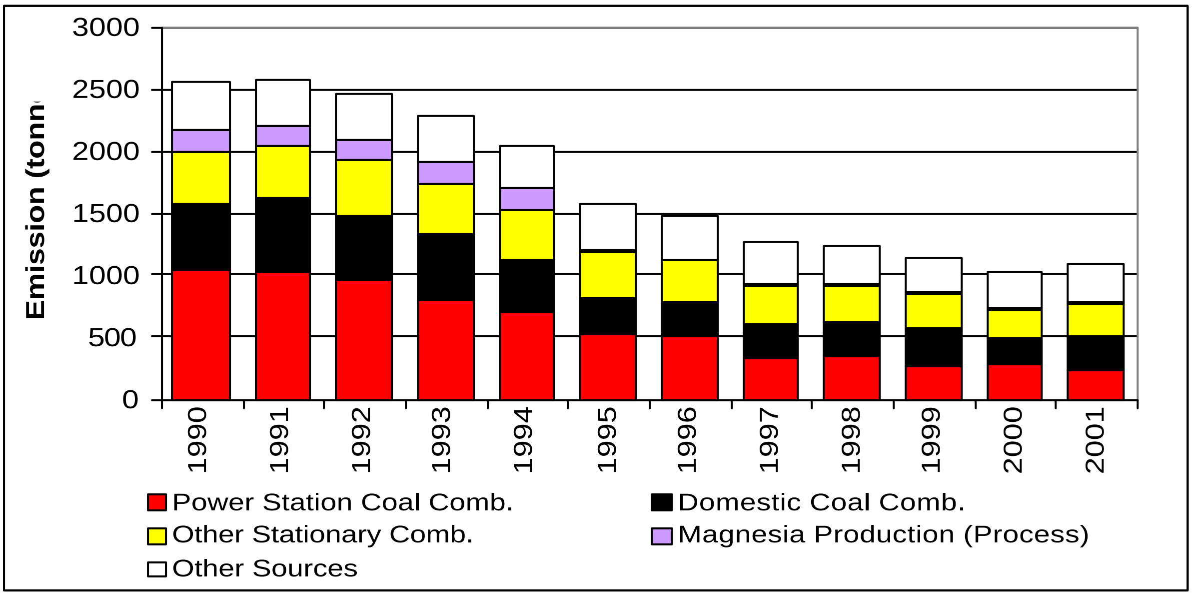


Table 7.3 UK Emissions of Sodium by UN/ECE Source Category (ktonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
Combustion in Energy Prod													
Public Power	1.0	1.0	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	20%
Petroleum Refining Plants	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Other Combustion & Trans.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Combustion in Comm./Inst/ Res													
Residential Plant	0.5	0.6	0.5	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.3	25%
Comm., Public & Agri.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1%
Combustion in Industry	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.4	0.5	39%
Production Processes	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.2	14%
Other Transp & Machinery.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Non livestock agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Waste Treatment & Disp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Total	**2.5**	**2.5**	**2.4**	**2.2**	**2.0**	**1.7**	**1.6**	**1.4**	**1.3**	**1.3**	**1.1**	**1.2**	

Figure 7.3 Time Series of Sodium Emissions (tonnes)

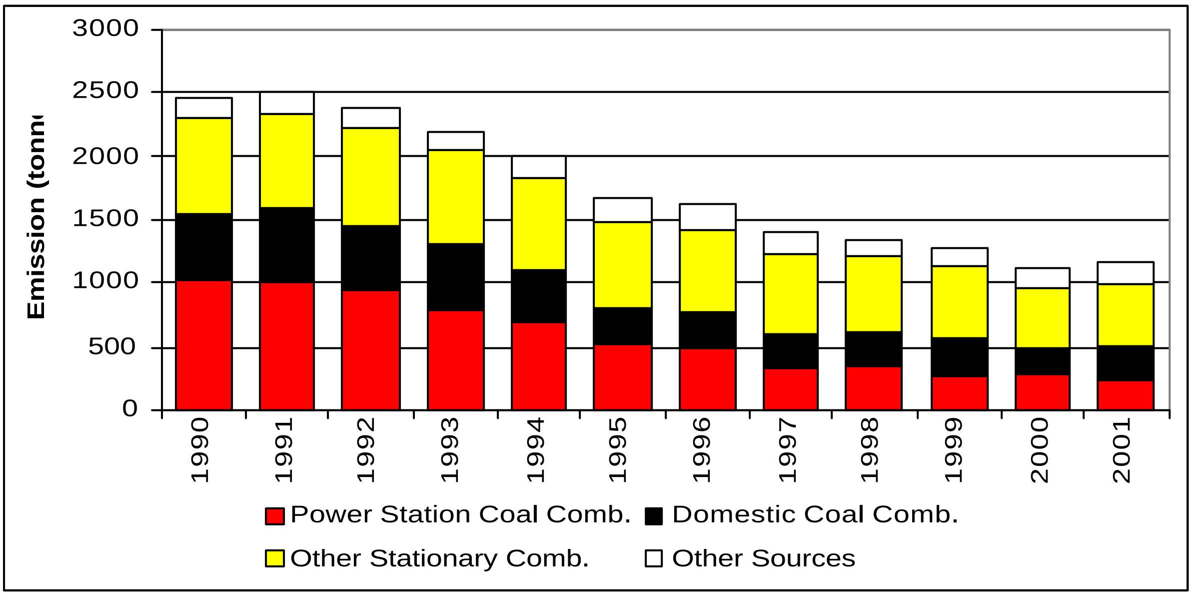
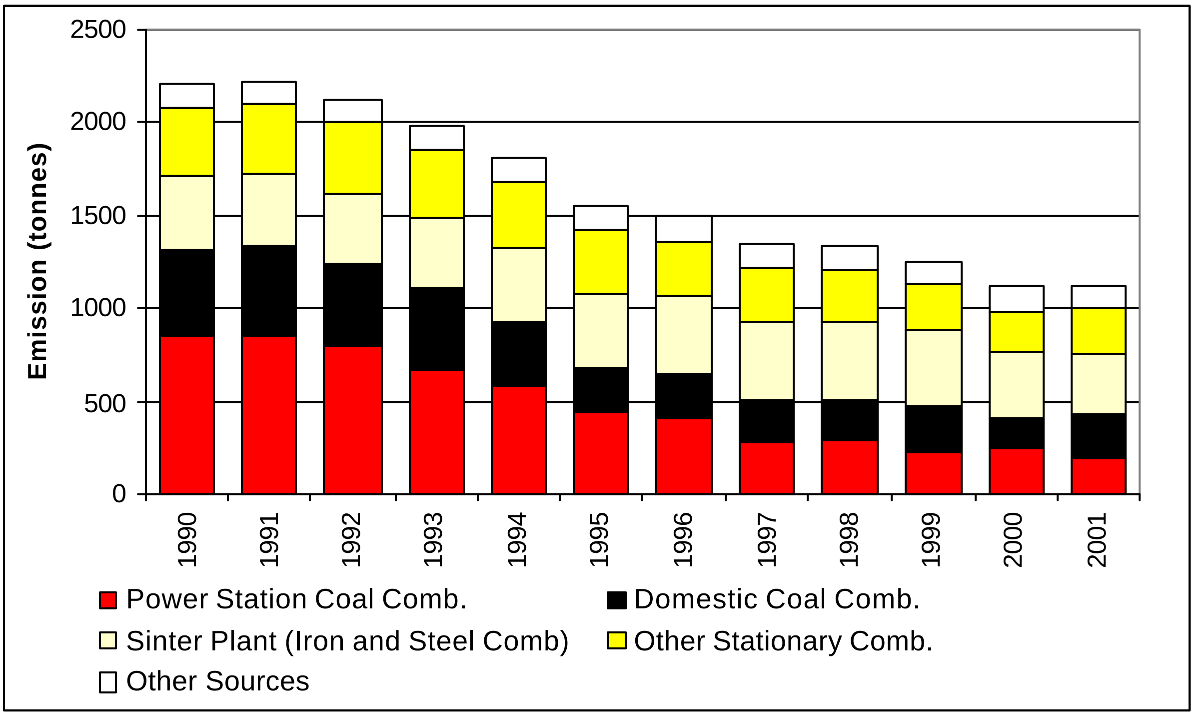


Table 7.4 UK Emissions of Potassium by UN/ECE Source Category (ktonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001%
Combustion in Energy Prod													
Public Power	0.9	0.8	0.8	0.7	0.6	0.4	0.4	0.3	0.3	0.2	0.2	0.2	18%
Other Combustion & Trans.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Combustion in Comm./Inst/ Res													
Residential Plant	0.5	0.5	0.5	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.3	25%
Comm., Public & Agri.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2%
Combustion in Industry	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	46%
Production Processes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	10%
Non livestock agriculture	0	0	0	0	0	0	0	0	0	0	0	0	0%
Waste Treatment & Disp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Total	**2.2**	**2.2**	**2.1**	**2.0**	**1.8**	**1.5**	**1.5**	**1.3**	**1.3**	**1.2**	**1.1**	**1.1**	

Figure 7.4 Time Series of Potassium Emissions (tonnes)



7.10 SPATIAL DISAGGREGATION OF BASE CATION EMISSION ESTIMATES

Emission maps for the base cations have been generated on a 1km x 1km grid by extending the methodology applied to other pollutants. The maps are presented in the following figures.

Figure 7.5 Spatially Disaggregated UK Emissions of Ca

Figure 7.6 Spatially Disaggregated UK Emissions of Mg

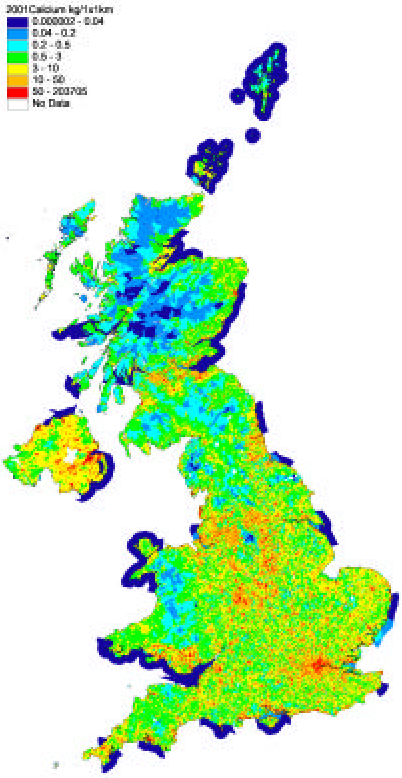


Figure 7.7 Spatially Disaggregated UK Emissions of Na

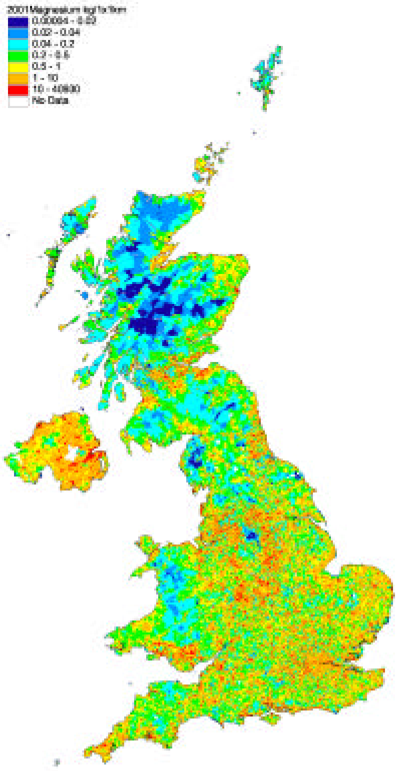
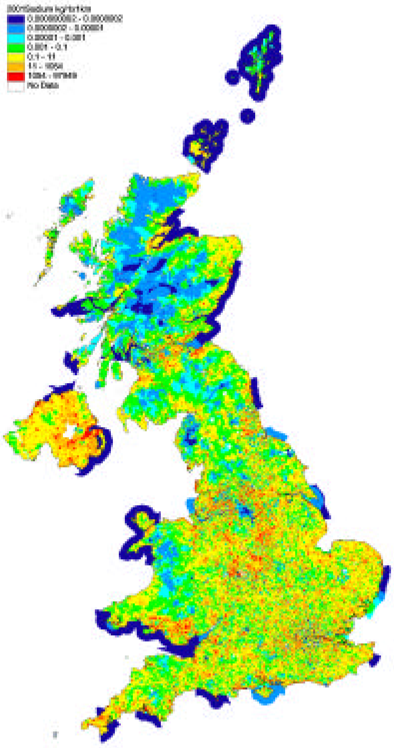
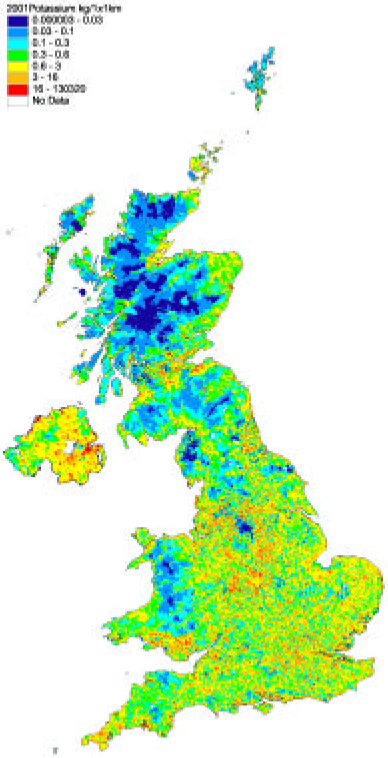


Figure 7.8 Spatially Disaggregated UK Emissions of K





7.11 ACCURACY OF EMISSION ESTIMATES OF BASE CATIONS

Quantitative estimates of the uncertainties in emission inventories have been based on calculations made using a direct simulation technique, which corresponds to the IPCC Tier 2 approach recommended for greenhouse gases and also the methodology proposed in draft guidance produced by the UN/ECE Taskforce on Emission Inventories and Projections. This work is described in detail by Passant (2002b). The estimates are shown in Table 7.5.

Table 7.5 Uncertainty of the Emission Inventories for Base Cations

Pollutant	**Estimated Uncertainty %**
Calcium	-50% to +100%
Magnesium	-40% to +80%
Potassium	-60% to +200%
Sodium	-40% to +100%

Inventories for base cations have been significantly revised since the previous version of the NAEI, but many of the emission estimates are still subject to significant uncertainty. This is because they are based on emission estimates for PM_{10} (which are themselves highly uncertain), coupled with estimates of the chemical composition of the PM_{10} which add further uncertainty.

8 Regional Emission Estimates

8.1 INTRODUCTION

Extensive work has been conducted to generate reliable emission totals for the Country Regions of the United Kingdom (England, Scotland, Wales and Northern Ireland). This has been carried out to aid policy development and monitoring at the regional level. This work has drawn on the UK emission maps presented throughout this report (which give emission on a 1 km x 1 km grid basis). In the following sections, data is given as a total emissions, and as emissions per capita to allow a simple inspection of the similarities and differences of the emissions profiles in each of the Regions. Population data has been taken from the most recently available statistics published by the ONS.

In calculating the emissions by Region, a number of approximations must be made, giving rise to potentially significant uncertainties in the resulting emissions totals. For example emissions from the road transport sector are less certain in areas dominated by minor roads (typically less traffic count data is available for these road types). Pollutants which are dominated by emissions from point sources are expected to be more accurate than those dominated by area sources as the mapping of the point sources is considered to be more reliable.

The number of significant figures to which the data is presented in the following tables should not be taken as an indication of the associated uncertainty levels.

8.1.1 Unallocated Emissions and Inclusion of Sources

There are a number of sources where it is either not sensible or not possible to allocate the emissions to a particular region. For example, a number of the UK off-shore emissions cannot readily be assigned to a particular Region. For this reason an “Unallocated” sector is also used. These data cannot sensibly be expressed on a per capita basis, and are therefore not plotted here.

Also, the UK maps presented in this report include several sources which are not reported to international organisations as part of the official UK submissions (for example some emissions arising from marine and aircraft activities). Hence, summation across the UK maps would give emissions which are fractionally higher than the totals presented in earlier Chapters of this report. Similarly, the sum of the emissions from "unallocated" and the country regions presented here will in most cases be slightly larger than the emissions reported in the earlier Chapters of this report. In most cases the difference is trivial when placed in context by the associated uncertainties.

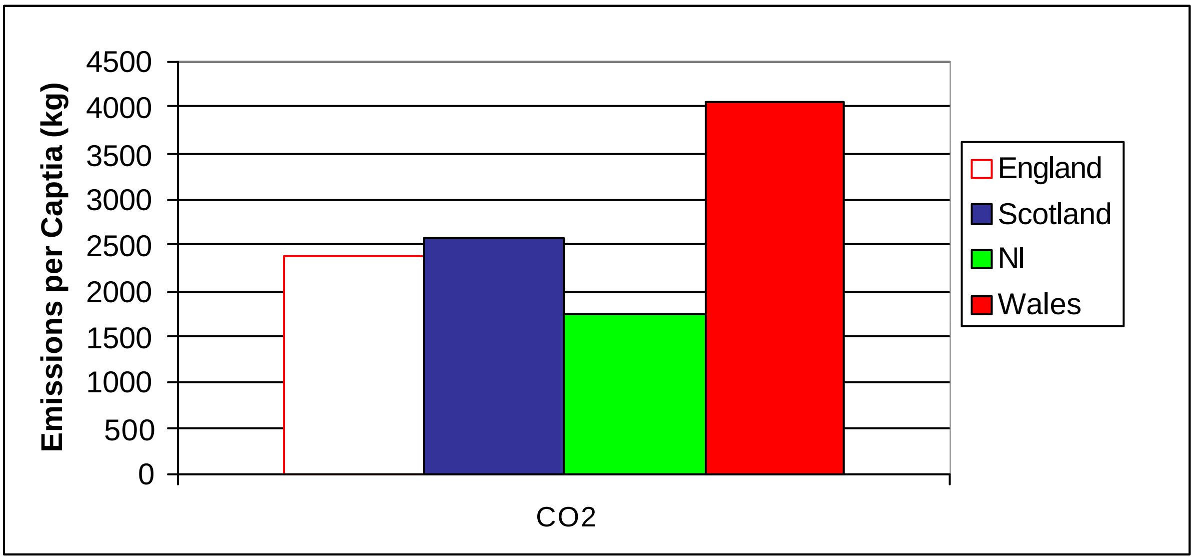
8.2 REGIONAL CO_2 EMISSIONS

The primary sources of CO_2 in the UK are stationary combustion sources and road transport. In Wales, the iron and steel industry combines with a relatively large electricity generating sector (and other industrial activities) to give substantially higher emissions per capita than England or Scotland. Northern Ireland has less of an industrial base, and therefore has a lower CO_2 emission per capita than the other countries.

Table 8.1 Emissions of CO_2 (as Carbon) by Region

	Unallocated	England	Scotland	Northern Ireland	Wales
Emissions (Mtonnes carbon)	9	116	13	3	12
Emissions/Capita (kg/cap)		2,400	2,600	1,800	4,000

Figure 8.1 Regional Emissions of CO_2 (as Carbon) per Capita



8.3 REGIONAL EMISSIONS OF AQS POLLUTANTS

Although PAHs have been added to the AQS, the emissions of B[a]P are used as an indicator. Therefore B[a]P is presented here separately as a POP, as well as PAH emissions in Section 8.5.

The emissions of CO are dominated by road transport in all of the regions except for Wales. This is because there are a relatively high number of large point sources located in Wales associated with industrial activities (as mentioned in Section 8.2). The impact on the emission per capita for the Regions is large.

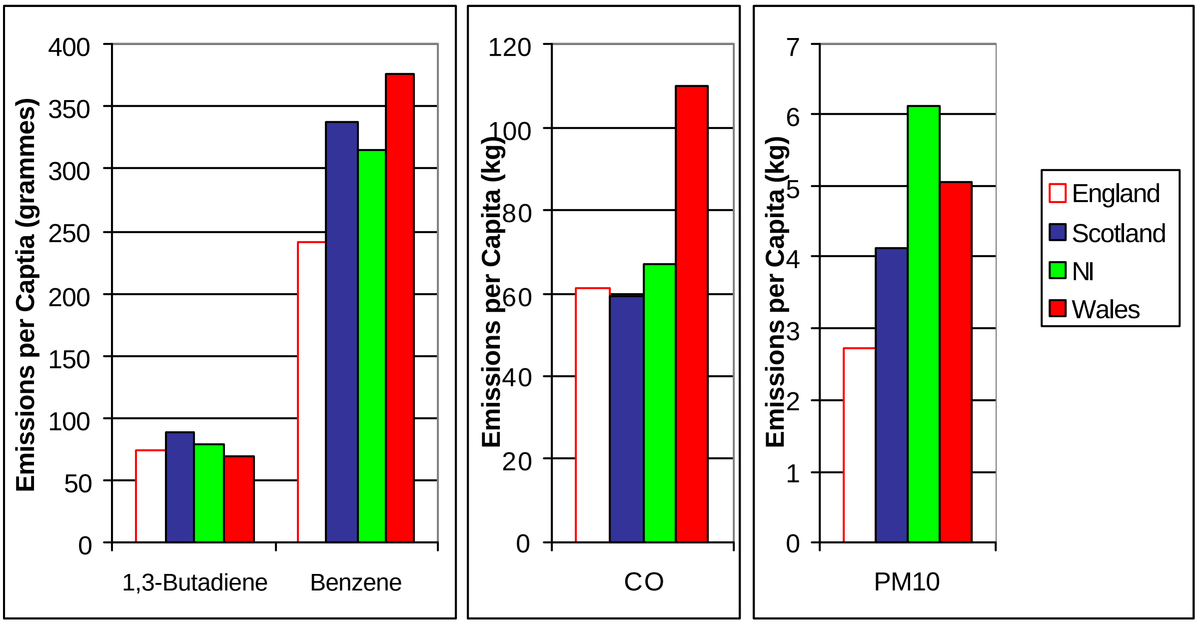
PM_{10} emissions per capita in Northern Ireland are elevated due to the relatively higher use of solid fuel in domestic heating.

Road transport accounts for some 85-90% of the total 1,3-butadiene emission for all of the regions except Scotland (where the contribution is only 70%). This is because there are a number of significant 1,3-butadiene point sources in Scotland associated with the petroleum industry (see also NMVOC emissions in Section 8.4). However, the emissions per capita are broadly similar. This is also the case for benzene. Other AQS pollutants are presented in later sections.

Table 8.2 Emissions of AQS Pollutants by Region

	Unallocated	England	Scotland	Northern Ireland	Wales
1,3-Butadiene					
Emissions (tonnes)	67	3,672	445	134	204
Emissions/Capita (g/cap)		75	88	80	70
Benzene					
Emissions (tonnes)	930	11,787	1,714	531	1,095
Emissions/Capita (g/cap)		241	339	315	377
Carbon Monoxide					
Emissions (ktonnes)	49	2,992	299	113	318
Emissions/Capita (kg/cap)		61	59	67	110
PM_{10}					
Emissions (ktonnes)	5	134	21	10	15
Emissions/Capita (kg/cap)		3	4	6	5

Figure 8.2 Regional Emissions of AQS Pollutants per Capita



8.4 REGIONAL EMISSIONS OF ACIDIFYING POLLUTANTS AND OZONE PRECURSORS

For NO_x, the relative contribution from source sectors to the regional total is generally comparable with the exception of industrial point sources. This gives rise to higher emissions per capita for Wales, and lower emissions per capita for Northern Ireland. NO_x emissions from road transport account for just under half of the total NO_x emissions for all Regions.

SO_2 emissions in the UK are generally dominated by point source emissions. There are relatively few significant point sources in Northern Ireland, but a substantial amount of solid fuel is used for domestic heating in Northern Ireland. The net effect is to give an emission per capita that is lower than the other Regions. Emissions per capita in Wales are elevated due to production process point sources.

There is a striking difference between the Regions in NMVOC emissions as a result of the distribution of point sources. The extensive emissions from the petroleum industry in Scotland give rise to a large contribution from point sources, and a considerably larger emission per capita. The emission per capita for Wales is also larger than that for England or Northern Ireland for the same reason.

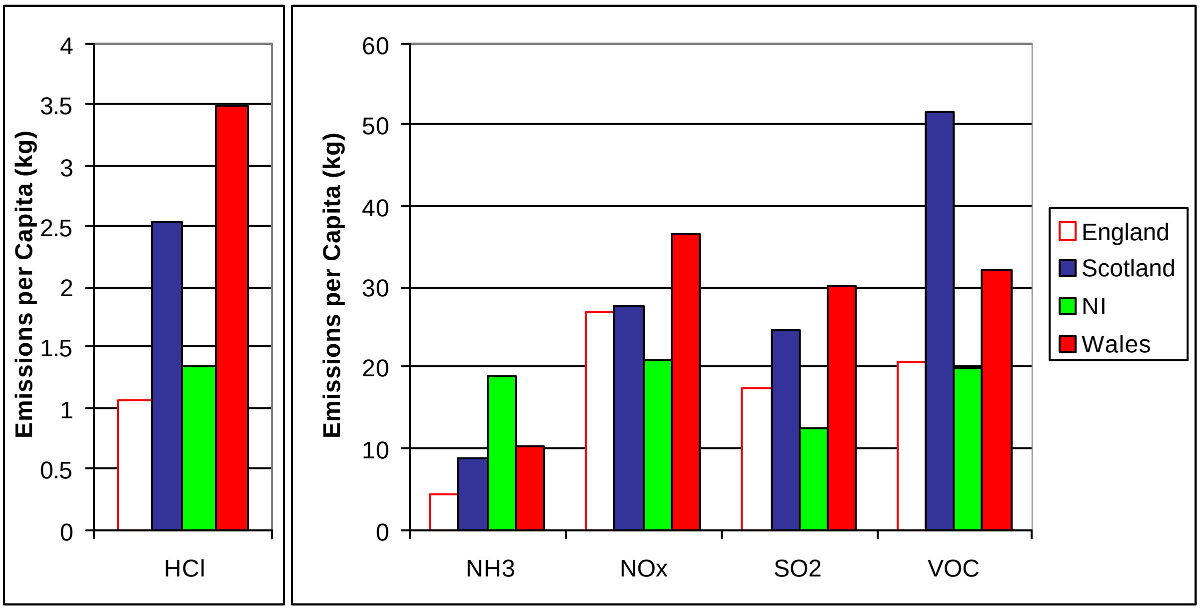
NH_3 emissions are dominated by the agricultural sector, and the distributions of livestock and population gives higher emissions per capita in Northern Ireland and lower emissions per capita in England.

As HCl emissions arise almost exclusively from coal combustion, the majority of emissions arise from point sources (electricity generation in particular). However in Northern Ireland, as previously highlighted, there are relatively few point sources, and consequently the emissions per capita are smaller than the other Regions. The emissions from England, Scotland and Wales are dominated by electricity generation, and the lower populations in Scotland and Wales gives rise to high emission per capita.

Table 8.3 Emissions of Acidifying Pollutants and O_3 Precursors by Region

	Unallocated	England	Scotland	Northern Ireland	Wales
HCl					
Emissions (ktonnes)	2	53	13	2	10
Emissions/Capita (kg/cap)		1	3	1	3
NH_3					
Emissions (ktonnes)	0	206	44	32	30
Emissions/Capita (kg/cap)		4	9	19	10
NO_x					
Emissions (ktonnes)	128	1,316	139	35	106
Emissions/Capita (kg/cap)		27	28	21	36
SO_2					
Emissions (ktonnes)	54	856	125	21	87
Emissions/Capita (kg/cap)		17	25	13	30
VOC					
Emissions (ktonnes)	118	1,014	261	33	93
Emissions/Capita (kg/cap)		21	51	20	32

Figure 8.3 Regional Emissions per Capita of Acidifying Pollutants and Ozone Precursors



8.5 REGIONAL EMISSIONS OF PERSISTENT ORGANIC POLLUTANTS

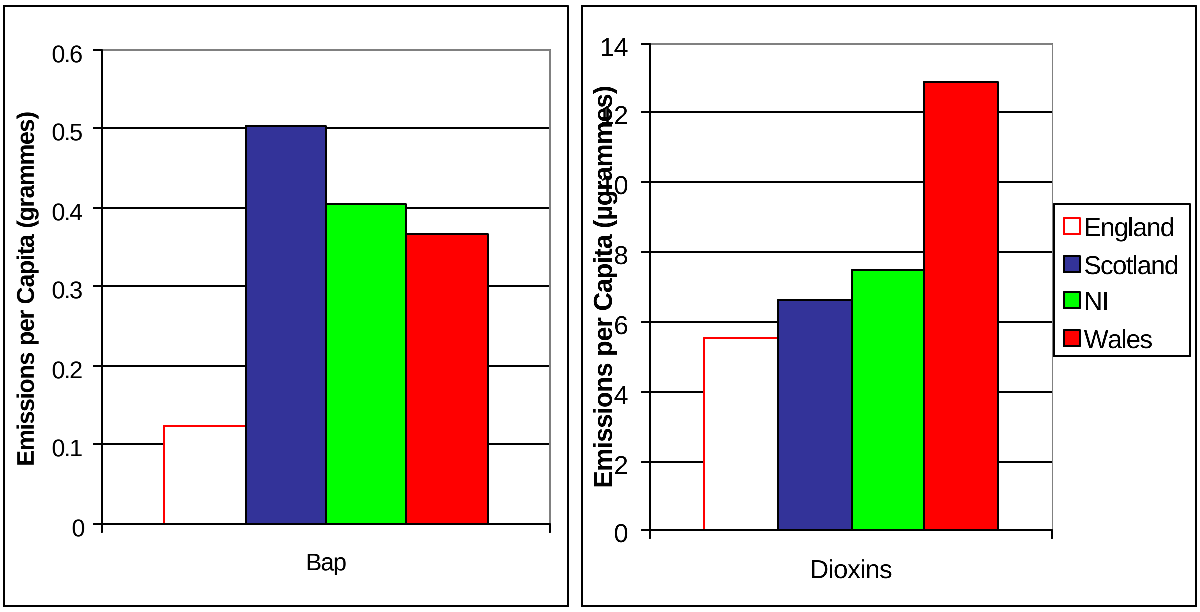
Emissions of BaP arise from a variety of sources, but primarily road transport, domestic combustion of solid fuels and various point sources. The high population in England gives rise to lower emissions per capita. In Wales the emissions are dominated by industrial point sources, and in Scotland the lower population density gives rise to a higher contribution from road transport and a higher use of solid fuel in the domestic sector- both of which enhance the BaP emissions per capita.

For dioxins and furans, emissions from point sources and the domestic sector dominate. This gives rise to elevated emissions per capita from Wales, and broadly similar emissions from the other Regions.

Table 8.4 Emissions of POPs by Region

	Unallocated	England	Scotland	Northern Ireland	Wales
BaP					
Emissions (tonnes)	0	6	3	1	1
Emissions/Capita (g/cap)		0.1	0.5	0.4	0.4
Dioxins and Furans					
Emissions (grammes)	1	272	34	13	37
Emissions/Capita (µg/cap)		6	7	7	13

Figure 8.4 Regional Emissions per Capita of Persistent Organic Pollutants



8.6 REGIONAL EMISSIONS OF HEAVY METALS

For heavy metals, the largest sectoral contribution to the total is dependent on the metal. For some, solid fuel combustion in power generation, industry and the domestic sector are important and features similar to pollutants discussed in earlier sections may be observed. For others, the consumption of liquid fuels gives rise to the most significant sources.

Emissions per capita of Arsenic are high in Northern Ireland due to the increased use of solid fuel in the domestic sector. Emissions per capita of cadmium, chromium and copper are noted to be particularly high in Wales. This is due to the relatively large amount of coal consumed for electricity generation, emissions from the iron and steel industry (both coal consumption and industrial processes), and other industrial activities located in the Region.

Emissions of lead from road transport are now much reduced, and consequently heavy industry is now a major contributor to the emissions total (through fuel combustion and production processes). On an emissions per capita basis, this gives rise to the highest levels in Wales. A similar explanation can be given for zinc emissions, which are associated with the iron and steel industry and other processes.

Vanadium emissions primarily arise from the combustion of petroleum fuels, and the relatively high use of liquid fuels in Northern Ireland give rise to higher emissions per capita.

Table 8.5 Emissions of Heavy Metals by Region

	Unallocated	England	Scotland	Northern Ireland	Wales
As					
Emissions (tonnes)	0	32	4	2	3
Emissions/Capita (g/cap)		0.6	0.7	1.3	1.1
Cd					
Emissions (tonnes)	0	4	0	0	1
Emissions/Capita (g/cap)		0.1	0.0	0.1	0.2
Cr					
Emissions (tonnes)	0	65	4	1	7
Emissions/Capita (g/cap)		1.3	0.7	0.7	2.6
Cu					
Emissions (tonnes)	0	34	4	1	5
Emissions/Capita (g/cap)		0.7	0.7	0.7	1.6
Hg					
Emissions (tonnes)	0	7	0	0	1
Emissions/Capita (g/cap)		0.1	0.1	0.1	0.2
Ni					
Emissions (tonnes)	2	94	18	8	19
Emissions/Capita (g/cap)		1.9	3.6	4.6	6.4
Pb					
Emissions (tonnes)	1	170	10	5	24
Emissions/Capita (g/cap)		3.5	2.0	2.8	8.1
Se					
Emissions (tonnes)	0	22	4	1	3
Emissions/Capita (g/cap)		0.5	0.7	0.7	1.2
V					
Emissions (tonnes)	5	139	38	15	17
Emissions/Capita (g/cap)		2.8	7.6	9.1	5.8
Zn					
Emissions (tonnes)	5	308	14	4	76
Emissions/Capita (g/cap)		6.3	2.8	2.4	26.3
Be					
Emissions (tonnes)	0	11	2	1	3
Emissions/Capita (g/cap)		0.2	0.3	0.8	0.9
Mn					
Emissions (tonnes)	1	189	30	37	87
Emissions/Capita (g/cap)		3.8	5.9	21.8	30.1
Sn					
Emissions (tonnes)	0	45	8	10	22
Emissions/Capita (g/cap)		0.9	1.5	6.2	7.4

Figure 8.5a Regional Emissions per Capita of Heavy Metals

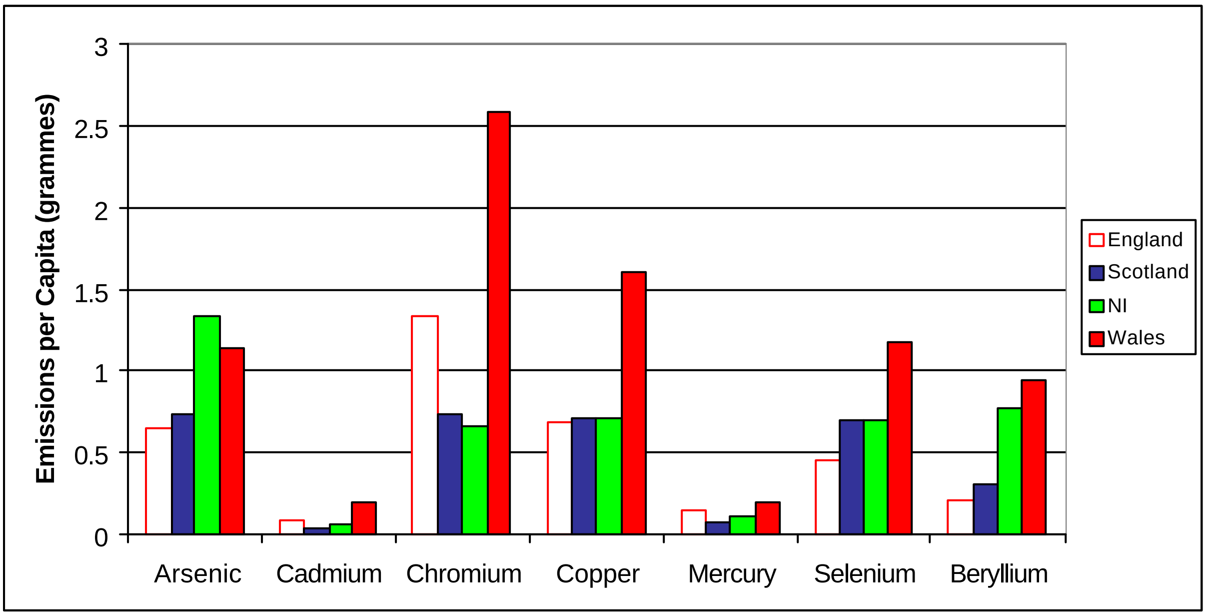
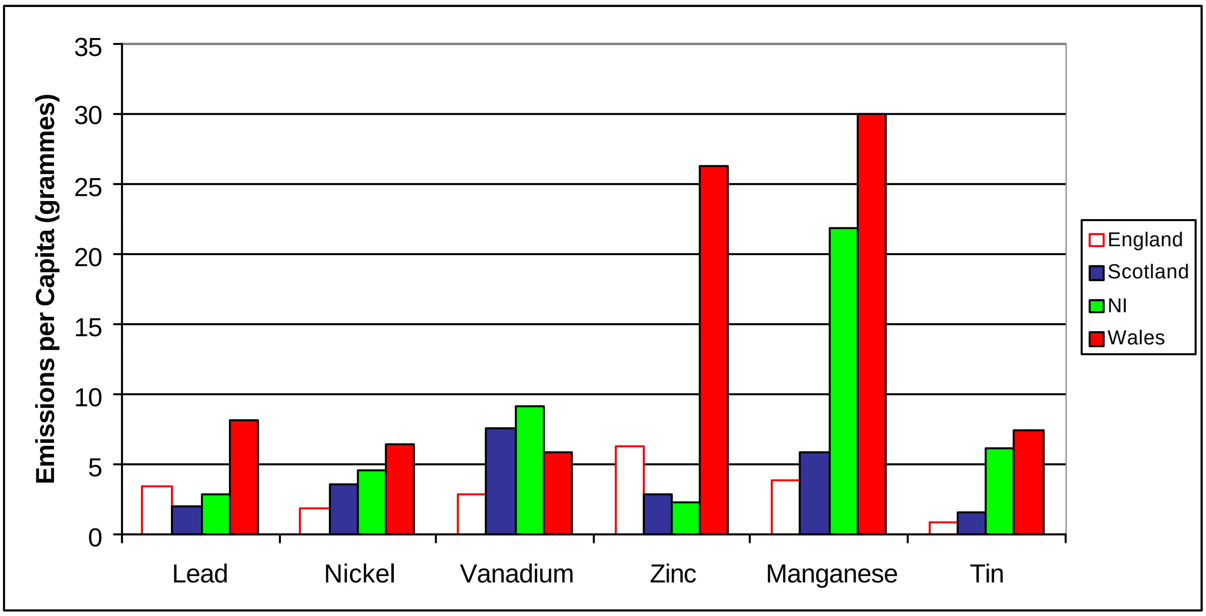


Figure 8.5b Regional Emissions per Capita of Heavy Metals



8.7 UK TERRITORIES AND DEPENDENCIES

8.7.1 Introduction

There is on-going work to compile and improve the emissions inventories for UK territories and dependencies across the last several years. This has been driven by the need to specify emissions from these areas for international reporting requirements, and to allow demonstration of compliance with emission reduction protocols. It has also allowed the generation of emission inventories which will aid local policy development.

Whilst improvements have been made across the last year, the most recent data are considered to be preliminary, and therefore not included here. The data presented here are therefore the same as those presented in the previous NAEI annual report (Goodwin *et al* 2002).

On an absolute basis, the emissions from the territories and dependencies are very small when compared with the UK (for example the population of Guernsey is some 0.1% of the UK total). However, these territories and dependencies can elect to subscribe to international protocols in their own right. They will therefore have to demonstrate similar percentage emission reductions as the UK and other subscribing countries. For some protocols, the emissions are to be included under the UK total, and in others they are to be specified as a separate footnote.

When compiling emissions estimates for these smaller communities, it is often more difficult to obtain the required data. As a result some of the data presented below is in an aggregated format, although the UN/ECE classification is used as far as possible.

When compiling or generating emission estimates for the locations in the following sections, the data has been very varied. In some cases emission estimates have already been made, and these have been used to allow consistency with existing official UK datasets. In other cases suitable data is sparse, and the methods have to be simple. It is appreciated that this gives rise to high uncertainties associated with the estimates.

8.7.2 Inclusion/Exclusion in Protocols

When agreeing to be a signatory to the various international agreements on air emissions, the precise definition of the individual elements of the UK to be included were also specified. For example, under the 1979 Geneva Convention on Long-range Transboundary Air Pollution and the 1988 Sofia Protocol (concerning Nitrogen Oxides), the "UK" is specified as including the Bailiwicks of Jersey and Guernsey, the Isle of Man, Gibraltar, and the United Kingdom Sovereign Base Areas of Akrotiri and Dhekhelia on the Island of Cyprus. As a result NO_x and NMVOC emission estimates have been (or are being) generated for these locations. In addition, for other protocols, several locations are excluded as the "UK" is defined as including the Bailiwicks of Jersey and Guernsey and the Isle of Man only.

8.7.3 The Bailiwick of Guernsey

Population: 58,681 (1996), approx. 0.1% of UK
Area : 78 km^2, approx. 0.03% of UK

The Bailiwick of Guernsey consists of Guernsey and a number of other smaller islands (which are not significant with respect to air emissions). Although an extensive amount of farming is still present in Guernsey, this has declined over recent years along with fishing. Tourism has also declined, leaving financial activities as the dominant sector of the economy.

Compared with the UK mainland, there is very little industry in Guernsey. Ownership and use of private cars is relatively high, and being an island community there are relatively high marine and aircraft activities (on a per capita basis). Electricity has been provided by an oil fired power station, but the recent completion of an undersea electricity cable link from France (via Jersey) is expected to have a significant impact on the use of the power station. A waste to energy power station is planned to alleviate the pressure on the limited landfill space, which has been used as the main disposal route. There is no mains gas, and therefore the domestic sector uses coal, oil and bottled gas for heating.

Table 8.7a. NO_x and NMVOC Emission Estimates for Guernsey[1]

	NO_x	NMVOC

		tonnes	tonnes
1	**Public Power Generation**	608	1
2a	**Residential Combustion**	49	108
2b	**Combustion in Agriculture**	100	3
3	**Industrial Combustion**	included in Category 2	
4	**Production Processes**	0	84
5	**Extrac/Distrib. Fossil Fuel**	0	179
6	**Solvent Use**	0	12
7	**Road Transport**	396	609
8	**Other Mobile Sources**		
	Shipping	128	14
	Aircraft	539	246
	Other Off-Road	449	55
9	**Waste Treatment and Disposal**	1	0
10	**Agriculture**	0	0
11	**Nature**	0	0
	TOTAL	**2270**	**1312**

[1] Based on work by Cook (2000).

Whilst the above emission estimates represent the general profile in Guernsey, it is thought probable that the emissions given for road transport are an underestimate. In addition, it is not possible to resolve industrial emissions with the current data. More work will be conducted on this in the near future.

8.7.4 The Bailiwick of Jersey

Population: 87,186 (2001), approx. 0.15% of UK
Area : 116 km^2, approx. 0.05% of UK

Jersey is similar in profile to Guernsey, although with a higher population, but lower population density. There have been declines in agriculture, fishing and tourism, and the finance sector has become increasingly important.

The undersea electricity cable link from France is having a significant impact on the electricity generating profile on the island. The States of Jersey are currently compiling an air quality management strategy. The primary exposure to air pollutants is associated with road vehicle emissions.

Table 8.7b. NO_x and NMVOC Emission Estimates for Jersey

		NO_x tonnes	NMVOC tonnes
1	**Public Power Generation**	849	13
2	**Residential Combustion**	176	61
3	**Industrial Combustion**		
4	**Production Processes**	0	19
5	**Extrac/Distrib. Fossil Fuel**	0	130
6	**Solvent Use**	0	485
7	**Road Transport**	1777	2022
8	**Other Mobile Sources**		
	Shipping	190	21
	Aircraft	148	32
	Other Off-Road	1112	136
9	**Waste Treatment and Disposal**	1	1
10	**Agriculture**	0	0
11	**Nature**	0	0
	TOTAL	**4252**	**2920**

The methodology employed for estimating emissions from road transport (and Other Off-Road mobile sources) may give rise to overestimates. This is because the useage data applied to goods vehicles is thought to be too high. For Other Off-Road mobile sources a similar argument may be used (primarily regarding the use of tractors).

8.7.5 The Isle Of Man

Population: 72,017 (1994), approx. 0.12% of UK
Area : 572 km^2, approx. 0.23% of UK

As with the Channel Islands, in the Isle of Man, offshore banking dominates over tourism and agriculture. The population density is relatively lower than the Channel Islands, and there is considerably more agricultural land.

Table 8.7c. NO_x and NMVOC Emission Estimates for The Isle of Man[1]

	NO_x tonnes	NMVOC tonnes
Point Sources	3715	1
Residential Combustion	65	308
Road Transport	688	1723
Other Mobile Sources	223	34
Agriculture	0	0
Nature	0	0
TOTAL	**4691**	**2066**

[1] Based on Wilkinson *pers. comm.*

Compared with the Channel Islands, data is currently available to a lower level of sectoral disaggregation. However, the apportionment of the emissions across the sectors is generally consistent with the Channel Islands.

8.7.6 Gibraltar

Population: 27,192 (1997), approx. 0.05% of UK
Area : 6.5 km^2, <0.01% of UK

Although Gibraltar has a land border with Spain, many of the imports/exports arrive and leave by sea. Much of the land in Gibraltar is not available for building on, being dominated by the famous rock at its centre. As a result the population density is high in areas of housing, although virtually no fuel is used for domestic heating due to the warm weather. As with the islands above, there is a relatively high marine and aircraft activity, and virtually no industrial emissions present in Gibraltar. However, Gibraltar differs in that there is a large military base located at the Southern end of the peninsula. Although the size of the base has significantly reduced over recent years, the activities are a significant fraction of the emissions to air from Gibraltar, and have been incorporated in the emission estimates presented below.

		NO_x tonnes	**NMVOC tonnes**
1	**Public Power Generation**	472	5
2	**Inst, Comm.&Res. Combustion**	0	0
3	**Industrial Combustion**	93	1
4	**Production Processes**	0	0
5	**Extrac/Distrib. Fossil Fuel**	0	143
6	**Solvent Use**	0	372
7	**Road Transport**	208	415
8	**Other Mobile Sources**		
	Shipping	55	6
	Aircraft	37	20
	Other Off-Road	69	9
9	**Waste Treatment and Disposal**	53	16
10	**Agriculture**	0	0
11	**Nature**	0	0
	TOTAL	**986**	**987**

These emissions were calculated in some detail and are considered to be fairly robust.

8.7.7 Sovereign Bases in Cyprus (Akrotiri and Dhekhelia)

The compilation of emissions estimates from military activities in the two Cyprus sovereign bases are not yet complete. Provisional NO_x and NMVOC estimates have been made, but these are not yet sufficiently complete for publication.

9 Foot & Mouth Animal Pyres

9.1 INTRODUCTION

During 2001 the UK suffered from an outbreak of foot and mouth disease, a highly infectious viral disease that affects sheep, cattle, pigs and other ruminants. The outbreak was confirmed on 20 February 2001 and the final case was confirmed on 30 September 2001. Due to the highly infectious and debilitating nature of the disease, action taken to contain the outbreak included the slaughter of over six million farm animals and the subsequent disposal of carcasses. The slaughter included 4.2 million animals for disease-control purposes, and 2.3 million animals for welfare reasons.

Approximately one third of carcasses were disposed of by burning (including in-situ burning, mass pyres and incineration). The burning of carcasses on mass pyres occurred between March and May 2001 and involved the burning of animals together with specified quantities of fuels. The fuels included wooden railway sleepers, kindling wood, straw, coal and diesel oil. Emissions of air pollutants occurred both due to the combustion of these fuels and the burning of the carcasses. Emissions of CO, NO_x, SO_2, HCl, PM_{10}, PAH, and PCDD/F were considered to be most significant from pyres and have been estimated for inclusion in the inventory.

9.2 ESTIMATION OF NUMBERS OF CARCASSES BURNT

Estimates of numbers of carcasses burnt are based on data given in the National Audit Office's report on handling of the foot and mouth outbreak (National Audit Office, 2002). This report gives data on numbers of animals slaughtered and the proportion of carcasses disposed of by burning **where slaughter was for disease control purposes only**. These data are shown in Table 9.1 together with our estimates of the number of carcasses burnt.

Table 9.1 Estimates of numbers of animals slaughtered

Animal type	**Numbers slaughtered for reasons of:**		**Proportion burnt[1]**	**Estimated carcasses burnt**
	Disease-control	**Welfare**		
Sheep	3,428,000	1,821,000	27	925,560
Cattle	592,000	166,000	41	242,720
Pigs	143,000	306,000	39	55,770
Goats / Deer	4,000	3,000	-[2]	1,160
TOTAL	**4,167,000**	**2,296,000**	**29**	**1,225,210**

1 Refers to proportion of carcasses from animals slaughtered for reasons of disease control only

2 No figure available

Estimates of the total numbers of carcasses disposed of by burning were calculated assuming that animals slaughtered for welfare reasons were not burned. This assumption was made because no data on the proportion burnt are available and the use of pyres stopped after 7 May 2001 (welfare slaughters started on 30 March 2001 with many occurring later in the outbreak).

9.3 ESTIMATION OF QUANTITIES OF FUELS CONSUMED

Estimates of quantities of fuels burnt on pyres were based on the following Government recommendations for fuel use for animal pyres:

1 railway sleeper (2.8 x 0.3 x 0.2 metres) per cow;
25 kg wood kindling per cow;
1 bale of straw per cow;
203 kg coal per cow;
1 gallon (or 3.21 kg) of diesel oil per metre length of pyre;
24.6 kg of Feedol 17 (an inorganic chemical accelerant) per tonne of coal

Some additional assumptions were required. The a density of a wooden railway sleeper was estimated to be 500 kg/m^3, and the mass of a bale of straw was estimated to be 20 kg. Typical animal masses were taken from official UK agricultural statistics, and were 335 kg, 80 kg and 18.2 kg for a cow, pig and sheep respectively. A 150 m pyre was assumed to contain 250 cattle or 800 pigs or 4600 sheep.

Based on these data and assumptions, the estimates of fuel consumption shown in Table 9.2 were derived.

Table 9.2 Estimates of quantities of fuels consumed

Fuel	Fuel / kg of carcass	Fuel / m of pyre	Fuel burnt / tonnes
Coal	0.61 kg		62,200
Wood (sleepers)	0.25 kg		25,700
Wood (kindling)	0.075 kg		7,660
Straw	0.060 kg		6,130
Diesel oil		3.21 kg	600
Feedol 17	0.015 kg		1,530

9.4 EMISSION FACTORS FOR ANIMAL PYRES

Emission factors for animal pyres do not exist in the literature, so emission factors for domestic combustion sources, straw burning or crematoria were used to compile the inventory. Towards the end of the outbreak, emission factors were calibrated (by using measurements made at actual pyres, and dispersion modelling). Modelling studies conducted by the Environment Agency (EA) suggested good agreement for most pollutants including NO_X, CO, SO_2, HCl, and PM_{10}. For PCDD/Fs and PAHs studies at different pyre sites indicated an overestimation of emissions by varying degrees.

Table 9.3 shows the factors used and gives details of the rationale for their selection.

Table 9.3 Emission Factors for foot and mouth pyres

	NO_X	CO	SO_2	HCl	PM_{10}	Dioxins	B[a]P
	kt/Mt	kt/Mt	kt/Mt	kt/Mt	kt/Mt	g/Mt	kg/Mt
Coal	1.42[a]	45[a]	20[b]	2.35[a]	40.57	-	1500[a,l]
Wood (sleepers)	0.722[c]	99.3[c]	0.037[c]	1.175[d]	7.9[c]	-	1300[c,l]
Wood (kindling)	0.722[c]	99.3[c]	0.037[c]	1.175[d]	7.9[c]	-	1300[c,l]
Straw	2.32[e]	71.3[f]	0.037[c]	-	5	-	7200[e,l]
Diesel oil	2.16[g]	0.24[g]	2.8[g]	0.01[h]	0.25[g]	-	-
Carcasses	4.63[i]	142.6[i]	1.4[j]	0.7[j]	10[i]	-	7200[e,l]
Combined material	-	-	-	-	-	1000[k,l]	-

[a] as for domestic coal combustion
[b] based on assumed sulphur content of 1%
[c] as for domestic wood combustion
[d] assumed to be 50% that of coal
[e] as for open burning of straw
[f] as for agricultural use of straw as a fuel (not open burning)
[g] as for domestic combustion of gas oil
[h] as for domestic fuel oil combustion
[i] assumed double that of straw
[j] assumed as for crematoria on mass basis
[k] Initial estimate from expert judgement- NAEI & EA (Coleman & Foan *pers. comm.* 2001)
[l] Correction factors derived from a comparison of modelled and measured deposition during animal pyres. Correction factors are 0.259 for B[a]P and 0.00334 for dioxins.

The emission factors shown in Table 9.3 were used to calculate emissions and, using these emission estimates, it is possible to calculate emission factors expressed in terms of emissions per animal carcass burned, as shown in Table 9.4.

Table 9.4 Emission Factors for foot and mouth pyres per animal carcass

	NO_X	CO	SO_2	HCl	PM_{10}	Dioxins	B[a]P
	kg	kg	kg	kg	kg	μg	g
Cattle	1.970	69.2	4.54	0.840	12.5	2.25	1.250
Sheep	0.107	3.76	0.247	0.046	0.682	0.122	0.0677
Pigs	0.473	16.6	1.09	0.202	3.01	0.541	0.299
Goats	-	-	-	-	-	0.122	0.0677
Deer	-	-	-	-	-	2.25	1.250

9.5 EMISSION ESTIMATES

Table 9.5 shows emission estimates for foot and mouth pyres. Emissions are not particularly significant compared with national totals except in the case of PM_{10}, B[a]P and CO. In the first two cases, the pyres contributed a few percent to national totals whereas the figure for CO was about half a percent. Since animal pyres were used as a disposal method only in the period March - May 2001 and most occurred in a relatively small part of the UK (e.g. North & West Cumbria, North Devon), the contribution to local air emissions in these areas, especially in the case of PM_{10}, B[a]P and CO would have been much greater.

Table 9.5 Emissions from foot and mouth pyres

	NO_X	CO	SO_2	HCl	PM_{10}	Dioxins	B[a]P
	kt	kt	kt	kt	kt	g	kg
Cattle	0.48	16.78	1.10	0.20	3.05	0.547	302
Sheep	0.10	3.48	0.23	0.04	0.63	0.113	63
Pigs	0.03	0.93	0.06	0.01	0.17	0.030	17
Goats	-	-	-	-	-	0.000	0
Deer	-	-	-	-	-	0.001	1
TOTAL	**0.60**	**21.19**	**1.39**	**0.26**	**3.84**	**0.691**	**383**
Other UK sources	1680	3737	1125	79.7	178.5	357	10090
percentage contribution from pyres to UK total	**0.04%**	**0.57%**	**0.12%**	**0.33%**	**2.15%**	**0.19%**	**3.80%**

9.6 UNCERTAINTIES

The emission estimates for animal pyres presented above are very uncertain. The uncertainties derive mainly from the lack of fully appropriate and robust emission factors for the pyres. The emission factors used for estimating emissions have been derived for significantly different types of combustion process such as domestic fires, small industrial-scale combustion plant, crematoria, and open burning of straw. None of these types of combustion processes are as large as the animal pyres used for carcass disposal, none will have the same mixture of fuels as the pyres and none will also involve open burning of animal matter. Combustion in the pyres would not be expected to be as efficient as obtained in industrial combustion plant or crematoria and it is likely that the actual efficiency achieved could vary significantly with local factors such as construction of the pyres and weather conditions. Emission factors for pyres are therefore subject to considerable uncertainty.

Estimates of carcass numbers are also uncertain although not to the same extent as for emission factors. Perhaps the most significant source of uncertainty relates to the fate of carcasses from animals slaughtered for reasons of welfare. We have assumed that these carcasses were not burnt on the basis that these animals were mainly slaughtered later in the foot and mouth outbreak, after 7 May 2001 the date when animal pyres were no longer used.

Overall, we estimate that emission factors for toxic organic pollutants used in the emission calculations may be accurate to within a factor of five (i.e. the 'true' emission factor would be between 20% and 500% of the values used in the calculations). For other pollutants, the accuracy is expected to be better, perhaps within a factor of two.

There are a number of potential air pollution issues which are not addressed by the emission estimates presented above. This is either because they have been assumed to be trivial or because no evidence exists to suggest that they occurred. These issues include:

- Emissions of other air pollutants from the combustion of fuels and animal carcasses including methane, volatile organic compounds (including benzene and 1,3-butadiene), nitrous oxide, ammonia, and metals. Emissions of these pollutants have been considered to be trivial compared with other UK sources and not estimated (however see the following point regarding metals);

- Emissions of arsenic, copper and chromium due to the presence of CCA (copper-chrome-arsenic) wood preservatives in treated wood or emissions of toxic organic pollutants due to the presence of lindane or PCP in treated wood used in the pyres. It has been confirmed that UK-sourced railway sleepers would have been untreated or treated with creosote only, although any overseas-sourced railway sleepers might have been treated using other preservatives including CCA, lindane or PCP formulations. No data are available on the use of overseas-sourced wood but it has been assumed that none was used. The presence of creosote in wood is perhaps of concern because, since creosote contains polycyclic aromatic hydrocarbons, it has the potential to cause emissions of PAHs and dioxins to air. However, current information suggests that the presence of creosote in wood does not lead to increased emissions of PAHs and dioxins compared with untreated wood. Therefore, we have not attempted to estimate whether any creosote was present in wood used in pyres.
- Emissions of toxic organic pollutants due to the presence of plastics in the pyres. Plastic bags were used to cover the heads and feet of animals which had lesions, however guidance was issued that no PVC should be used. PVC bags would have provided a source of chlorine and might have increased the potential for dioxins to be formed. We have assumed that no PVC was present in the pyres.

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Annex 1

Definitions of UN/ECE Source Sectors

CONTENTS

1. UN/ECE Classification of Emission Sources

The NAEI reports emissions from the combustion of fuels and non-combustion emissions from a range of sectors. The fuels data are taken from the Digest of UK Energy Statistics (DUKES), (DTI, 1999). Hence the fuel definitions and the choice of base sector categories used in the NAEI often reflect those in the DUKES publications. The choice of non-combustion sources generally reflects the availability of data on the emissions from specific activities.

The 1998 NAEI emission estimates are reported according to the UNECE/CORINAIR SNAP 94 Version 1.0 eleven sector classification which is less detailed than the NAEI base categories. A listing of the NAEI base categories and their mapping onto the UNECE/CORINAIR SNAP 94 categories is shown in Table A1 below. In some cases the NAEI categories shown here are aggregates of more detailed emission sectors. The sectors are presented in this way in Table A1to allow an in depth understanding of the source sector content without presenting an excessive amount of information. In addition, the names of several NAEI categories have been changed to enable a fuller understanding by those not familiar with some of the nomenclature.

At the least detail level, there are 11 categories for the UN/ECE emission inventory format. These are as follow:-
01 Combustion in Energy Production & Transformation
02 Combustion in Commercial, Institutional & Residential & Agriculture
03 Combustion in Industry
04 Production Processes
05 Extraction & Distribution of Fossil Fuels
06 Solvent Use
07 Road Transport
08 Other Transport & Mobile Machinery
09 Waste Treatment & Disposal
10 Agriculture Forestry & Land Use Change
11 Nature

The allocation of a particular source to one of these sectors is well defined and given in more detail in Table A1. The majority of allocations are easy to understand. For example, emissions arising from fuel combustion in the manufacture of glass will come under “03 Combustion in Industry”. Emission arising from the manufacture/handling of the glass material itself and the raw materials will come under “04 Production Processes”.

Table A1 Mapping of NAEI Base Categories to CORINAIR SNAP 94

CORINAIR SNAP 94 Source Category	NAEI Class
01 Combustion in Energy Production & Transformation	Coke Production
	Collieries
	Gas Production
	Nuclear Fuel Production
	Offshore- own gas use
	Power Stations
	Refineries- Combustion activities only
	Solid Smokeless Fuel Production
	Town Gas Production
02 Combustion in Commercial, Institutional & Residential & Agriculture	Accidental Fires
	Agricultural Combustion
	Domestic Combustion
	Miscellaneous
	Other Non-Industrial Combustion
	Public Services (Public buildings etc.)
	Railways (Stationary sources only)
03 Combustion in Industry	Ammonia Combustion
	Power Station supplying to industrial activities only
	Cement & Lime Production- Combustion activities
	Cement (combustion for non-decarbonising activities)
	Ceramic manufacture
	Glass Production
	Iron and Steel (Blast Furnaces)
	Iron and Steel (Combustion)
	Iron and Steel (Grey Iron Foundry)
	Iron and Steel (Sinter Plant)
	Lead Crystal Glass Production
	Lime Production (Combustion)
	Nickel Production
	Primary Copper Production
	Primary Lead Production
	Primary Lead-Zinc Production
	Secondary Aluminium Smelting
	Secondary Copper
	Secondary Lead
	Other industry- Combustion activities

Table A1 Continued..

CORINAIR SNAP 94 Source Category	NAEI Class
04 Production Processes	Adipic Acid Production
	Ammonia Production and use of feedstocks
	Bread Baking
	Brewing
	Cement and Concrete Batching
	Cement (decarbonising activities)
	Chemical industry (Organic Chemicals)
	Chloroalkali Industry
	Cider Manufacture
	Coke Production (Door Leakage)
	Building/Construction and Road Construction
	Glass Production (non fuel combustion emissions)
	Iron and Steel (Ni-Cr Use, Steel Pickling, Furnaces, Flaring)
	Lead Mining (Dewatering)
	Lime Production (Decarbonising)
	Magnesium alloying
	Nitric Acid Production
	Non-Ferrous Metals (Other non-ferrous metals)
	Aluminium Production (General)
	Primary Zinc Production
	Tin Production
	Other Food (animal feed;cakes, biscuits, cereals; coffee, margerine and other solid fats; meat ,fish and poultry; sugar)
	Asphalt Manufacture
	Other Industrial Processes
	Phosphate Fertiliser Production
	Pigments & Stabilisers
	Quarrying
	Refineries (drainage, process & tankage)
	Rolling Mills (Hot & Cold Rolling)
	Solid Smokeless Fuel Production
	Spirit Manufacture
	Sugar Beet processing
	Sulphuric Acid Production
	Textile Coating
	Wine Manufacture
	Wood Impregnation

Table A1 Continued….

CORINAIR SNAP 94 Source Category	NAEI Class
05 Extraction & Distribution of Fossil Fuels	Coal Storage & Transport
	Deep-Mined Coal
	Gas Leakage from Pipes etc.
	Gasification Processes
	Offshore Loading of fuel
	Offshore Oil & Gas
	Oil Terminal Storage
	Onshore loading of fuel
	Open-Cast Coal
	Petrol distribution (storage, dispatch, petrol stations, delivery tankers)
	Petroleum Processes
06 Solvent Use	Aerosols (Car care, Cosmetics & toiletries, household products)
	Agrochemicals use
	Coating manufacture (glue, ink, paint)
	Creosote use
	Decorative paint
	Dry cleaning
	Film coating
	Industrial adhesives
	Industrial coatings (automotive, coil coating, commercial vehicles, heavy duty, marine, metal and plastic, metal packaging, vehicle refinishing, wood)
	Leather degreasing
	Leather coating
	non aerosol products (household, automotive, cosmetics & toiletries, adhesives and sealants, paint thinner or remover)
	Other rubber products
	Other solvent use
	Paper Coating
	Printing
	Seed Oil Extraction
	Surface cleaning
	Textile coating
	Tyre Manufacture
	Wood impregnation

Table A1 Continued….

CORINAIR SNAP 94 Source Category	NAEI Class
07 Road Transport	Road transport (buses)
	Road transport (cars)
	Road transport (cars CAT)
	Road transport (cars non CAT)
	Road transport (HGV Articulated)
	Road transport (HGV rigid)
	Road transport (LGVs)
	Road transport (LGVs CAT)
	Road transport (LGVs non CAT)
	Road transport (motorcycles)
08 Other Transport & Mobile Machinery	Agricultural Power Units
	Aircraft (Military)
	Aircraft Support vehicles etc.
	Aircraft Take-Off and Landing (domestic)
	Aircraft Take-Off and Landing (international)
	Shipping (UK shipping up to 12 km of coastline)
	Domestic House and Garden machinery
	Fishing
	Other Industry Off-Road (e.g. forklifts etc.)
	Railways (Freight)
	Railways (Intercity)
	Railways (Regional)
	Shipping Naval
09 Waste Treatment & Disposal	Batteries
	Electrical Equipment
	Incineration
	Landfill
	Lighting
	Measurement and Control Equipment
	Offshore Flaring
	Refineries (flaring)
	Regeneration of Activated Carbon
	Sewage Sludge Disposal
10 Agriculture Forestry & Land Use Change	Agricultural Soils
	Agricultural Pesticides
	Agricultural Livestock
	Field Burning
11 Nature	Forests Natural Fires