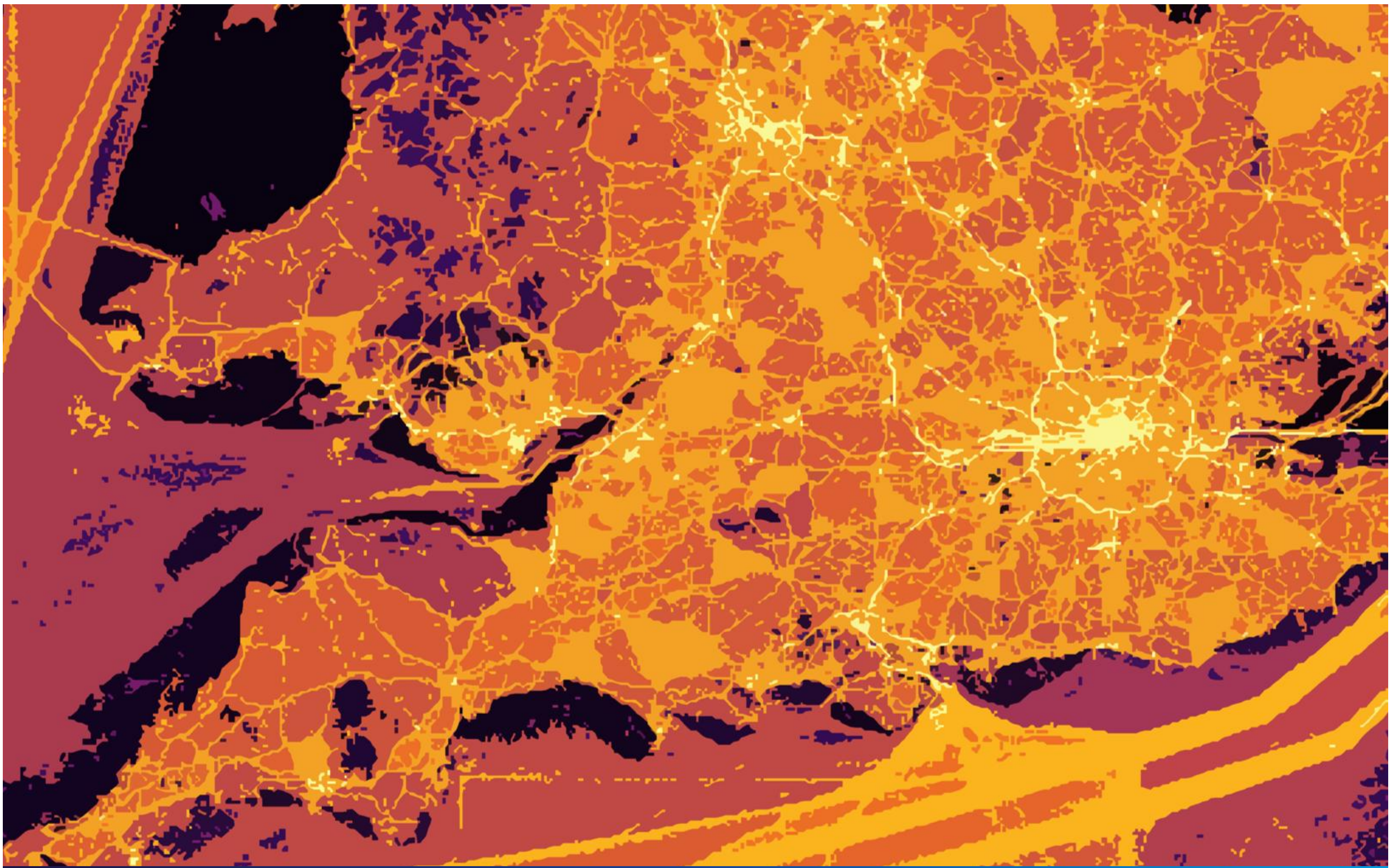
National Atmospheric Emissions Inventory



UK SPATIAL EMISSIONS METHODOLOGY

National Atmospheric Emissions Inventory 2023

Report for: Department for Energy Security and Net Zero; Department for Environment, Food and Rural Affairs

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LIST OF ABBREVIATIONS

AADF	Annual Average Daily Flow
ANPR	Automatic Number Plate Recognition
AQPI	Air Quality Pollutant Inventory
BEIS	Department for Business, Energy and Industrial Strategy
BRES	Business Register and Employment Survey
BRT	Below the Reporting Threshold
BSOG	Bus Service Operators Grant system
CEH	Centre for Ecology & Hydrology (now called UK CEH)
CLRTAP	Convention on Long-range Transboundary Air Pollution
DG	Devolved Government
DAERA	Department of Agriculture, Environment and Rural Affairs
Defra	Department for Environment, Food and Rural Affairs
DESNZ	Department for Energy Security and Net Zero
DfI	Department for Infrastructure
DfT	Department for Transport
DUKES	Digest of UK Energy Statistics
DVLA	Driver and Vehicle Licensing Agency
PRTR	Pollutant Release and Transfer Register
EA	Environment Agency
ECUK	Energy consumption in the UK
EEMS	Environmental and Emissions Monitoring System
EMEP	European Monitoring and Evaluation Programme
ETS	Emissions Trading Scheme[1]
GHGs	Greenhouse Gases
GIS	Geographic Information Systems
GNFR	Gridded Nomenclature for Reporting
HGVs	Heavy goods vehicles
IDBR	Inter-Departmental Business Register
IGER	Institute of Grassland and Environmental Research
IIR	Informative Inventory Report
IPC	Integrated Pollution Control
IPPC	Integrated Pollution Prevention and Control
LA	Local Authority

[1] The UK participated in the EU ETS until 31 December 2020. This was then replaced with the UK Emissions Trading Scheme From 1 January 2021.

LAPC	Local Authority Pollution Control
LAPPC	Local Air Pollution Prevention and Control
LGVs	Light goods vehicles
LPG	Liquid Petroleum Gas
LSOA	Lower Layer Super Output Area
MAAQ	Defra's Modelling of Ambient Air Quality
MCGA	Maritime and Coastguard Agency
MMR	Monitoring Mechanism Regulation
MSOA	Middle Layer Super Output Area
MSW	Municipal Solid Waste
NAEI	National Atmospheric Emissions Inventory
NECR	National Emissions Celling Regulations
NFR	Nomenclature for Reporting
NID	National Inventory Document
NIPI	Northern Ireland Pollution Inventory
NISRA	Northern Ireland Statistics and Research Agency
NMVOC	Non-Methane Volatile Organic Compounds
NRS	National Records of Scotland
NRW	Natural Resources Wales
ONS	Office for National Statistics
OPRED	Offshore Petroleum Regulator for Environment & Decommissioning
OS	Ordnance Survey
OSNI	Ordnance Survey of Northern Ireland
PCM	Pollution Climate Mapping
PM	Particulate Matter
SECA	Sulphur Emission Control Area
SEPA	Scottish Environment Protection Agency
SIC	Standard Industrial Classification
SMMT	Society of Motor Manufacturers & Traders
SNAP	Selected Nomenclature for reporting of Air Pollutants
SPRI	Scottish Pollutant Release Inventory
TfL	Transport for London
TRL	Transport Research Laboratory
UK CEH	UK Centre for Ecology & Hydrology (previously CEH)
UKPIA	UK Petroleum Industries Association
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VKM	Vehicle kilometres
WEI	Welsh Emission Inventory

EXECUTIVE SUMMARY

This report describes the methods used to map emissions in the National Atmospheric Emissions Inventory (NAEI). The maps provide spatially resolved modelled estimates of emissions, compiled at 1x1 km resolution for each Selected Nomenclature for reporting of Air Pollutants (SNAP) sector. As of the current reporting year, NAEI 2023, time-series of spatial emissions data for air quality pollutants and greenhouse gases are produced. The new data includes yearly outputs for all the years back to 2005 and starting the most recent inventory year, 2023, as the inventory is reported two years in arrears. The spatial emissions data for the years 2005 - 2023 are made freely available on the NAEI website at:

https://naei.energysecurity.gov.uk/data/maps.

The geographical distribution of emissions across the UK is built up from several data sources and methods that are individually tailored to each sector. For large industrial and commercial sources, emissions are compiled based on data from a variety of official UK regulatory sources. For diffuse emission sources, distribution maps are generated using appropriate surrogate statistics that indirectly indicate the spatial distribution of emissions for each sector. The method used for each source sector varies according to the data available.

Spatial emissions data are a crucial evidence base, supporting a variety of government policy work at the national level. In particular, the maps are used as input into a programme of air pollution modelling studies. They also provide a spatial overview of emissions and are used to compile and report gridded emissions to the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP). Local area statistics are compiled from the maps and related data as well. For example, carbon dioxide (CO_2) emissions from fuel use at the local authority area level have been produced for the Department for Energy Security and Net Zero (DESNZ) since 2005 using data from the NAEI's spatial emissions work. As of March 2008, these datasets were designated as Accredited Official Statistics[2]. In addition, the emission maps provide an illustrative and intuitive way for engaging with non-technical audiences who may wish to find out about emissions in their area.

Uncertainty analyses have been undertaken to consider the accuracy of the emission maps for some of the major air quality pollutants and greenhouse gases. Quality ratings have been used for this purpose. The pollutants with the highest quality ratings have a large proportion of their emissions from point sources, whereas pollutants with a greater proportion of their emissions from area sources have lower quality ratings.

The distribution of emissions presented in the NAEI maps has been verified for key pollutants used in UK-scale air quality modelling through an independent methodology which uses monitoring stations and remotely sensed data. This is described in sections 5.2 and 5.3, respectively.

[2] Accredited official statistics – Office for Statistics Regulation

CONTENTS

1. INTRODUCTION

The UK National Atmospheric Emission Inventory (NAEI), Greenhouse Gas Inventory (GHGI) and Air Quality Pollutant Inventory (AQPI) are compiled by Ricardo on behalf of the DESNZ, the Department for Environment Food and Rural Affairs (Defra), the Scottish Government, the Welsh Government, and the Department of Agriculture, Environment and Rural Affairs (DAERA) for Northern Ireland. This report describes the methodology used to compile spatially disaggregated emissions maps at a 1x1 km grid resolution under the NAEI system.

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

A series of reports describing the methods used for calculating national total emission estimates under the NAEI and other outputs of the inventory system are published annually on the NAEI website at https://naei.energysecurity.gov.uk/reports/. These includes the Informative Inventory Report (IIR) and Greenhouse Gas National Inventory Document (NID), which present detailed information on the methodologies, emission estimates and trends for air quality pollutants and greenhouse gas emissions, respectively.

1.1 EMISSION MAPPING SCOPE AND PURPOSE

Emission maps which provide modelled estimates of the distribution of emission at a 1x1 km resolution are routinely produced within the NAEI for the 33 pollutants[3], listed below in Table 1-1.

Table 1-1 Pollutants mapped in the NAEI

No.	Pollutant name	No.	Pollutant name
1	1,3-butadiene	16	Hydrogen chloride
2	Ammonia	17	Indeno[123-cd]pyrene
3	Arsenic	18	Lead
4	Benzene	19	Mercury
5	Benzo[a]pyrene	20	Methane
6	Benzo[b]fluoranthene	21	Nickel
7	Benzo[k]fluoranthene	22	Nitrogen Oxides (NO_x)
8	Black Carbon	23	Nitrous oxide
9	Cadmium	24	Non-Methane Volatile Organic Compounds
10	Carbon dioxide (CO_2)	25-28	Particulate Matter (PM_{10} $PM_{2.5}$ PM_1 & $PM_{0.1}$)
11	Carbon monoxide	29	Polychlorinated biphenyls
12	Chromium	30	Selenium
13	Copper	31	Sulphur dioxide (SO_2)
14	Dioxins	32	Vanadium
15	Hexachlorobenzene	33	Zinc

The emission maps are aggregated to UNECE sectors using the SNAP. There are 11 SNAP reporting sectors and are shown in Table 1-2 . Data for large point sources are reported separately.

[3] 29 pollutants plus 4 particulate matter size fractions.

Table 1-2 UNECE emissions sectors classification

UNECE Sector Code	Description
1	Combustion in energy production and transfer
2	Non-industrial combustion plants
3	Combustion in manufacturing industry
4	Production process
5	Extraction and distribution of fossil fuels and geothermal energy
6	Solvent and other product use
7	Road transport
8	Other mobile sources and machinery
9	Waste treatment and disposal
10	Agriculture and farming
11	Other sources

Mapped emissions data are made freely available in ASCII Grid format and GeoTIFF files for area sources on the NAEI website at https://naei.energysecurity.gov.uk/data/maps. The maps are also available through an online interactive GIS tool at https://naei.energysecurity.gov.uk/emissionsapp.

Both formats provide a valuable resource for user groups interested in local air quality and greenhouse gas emissions:

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

The emission maps provide an important evidence base which is used to support a variety of policies at the UK and Devolved Government (DG) scales. In particular, spatially disaggregated emission estimates (1x1 km) and road link-specific emissions information from the NAEI are used annually to underpin Defra's modelled air quality data[4]. These models are incorporated into the UK national air quality compliance assessments that are published by Defra.

They are also used to compile and report on emissions as part of the UK commitment to the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) and National Emissions Ceiling Regulations (NECR). Under these reporting conventions, UK emissions are aggregated to the prescribed nomenclature for reporting sectors (NFR and GNFR sectors) and mapped at the European Monitoring and Evaluation Programme (EMEP) Grid, with a resolution of 0.1º x 0.1º Longitude/Latitude in the WGS84 coordinate reference system. These are reported every 4 years, with the last submission being in May 2025. These datasets are available through the WebDab emission database[5].

Local area statistics are also compiled from the maps and related data e.g., the local authority area data on greenhouse gas emissions[6] and fuel use[7 & 8] which have been produced for Defra, DESNZ and DGs since the 2005 release. These datasets were classified as Accredited Official Statistics subject to implementing a small number of requirements across the range of DESNZ statistics.

[4] Modelled air quality data - DEFRA UK Air - GOV.UK
[5] Emissions Database | European Monitoring and Evaluation Programme
[6] UK local authority and regional greenhouse gas emissions statistics - GOV.UK
[7] Sub-national road transport consumption data - GOV.UK
[8] Sub-national residual fuel consumption data - GOV.UK

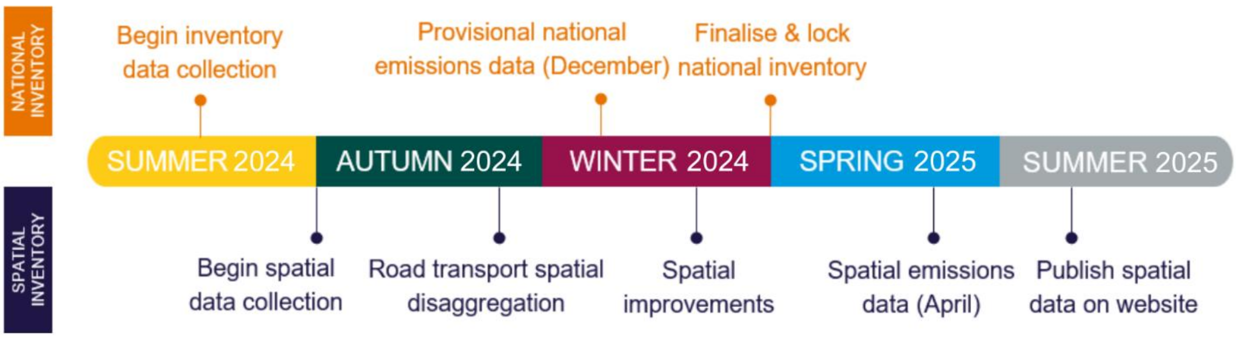
1.2 ANNUAL CYCLE OF MAP COMPILATION

The NAEI is compiled on an annual basis, with the inventory year being two years in arrears from the current year. Each year, the full inventory time series (1990 – latest inventory year) is recalculated to take account of updated or improved data inputs and any advances in compilation methods. Updating the full time series is an important process as it ensures that the entire dataset is calculated using the latest methodology. National totals and temporal trends are reported under the UK National Emissions Ceiling Regulations 2018 (NECR)[9], UNECE, UNFCCC and other international commitments.

Emissions maps are compiled from 2005 to 2023, the latest year in the NAEI cycle. These maps and datasets are developed to support national policy on air quality emissions on behalf of Defra, and on energy consumption and greenhouse gas emissions on behalf of DESNZ. There is a commitment in future years to back-calculate the spatial emissions data for end-user GHGs and fuel use to take into account improvements in mapping methodology and ensure that a comparable time-series starting in 2005 is always maintained.

The maps are compiled after the inventory is finalised in March each year. This annual timeline of activity is represented schematically in Figure 1-1.

Figure 1-1 The NAEI Inventory and Spatial Inventory development timeline



[9] The NECD was transposed into UK law via the 232/2018 -European Union (National Emission Ceilings) Regulations 2018, see The National Emission Ceilings Regulations 2018

2. NATIONAL INVENTORY COMPILATION

The NAEI compiles emissions for several individual sectors, producing detailed and accurate estimates of emissions across the UK. For each sector, a national total estimate is produced from a combination of emissions defined by reported activity data and emission estimates based on modelling. For example, minor road traffic emissions are modelled from regional flow and fleet mix data, while emissions from commercial & public sectors are described by an employment-based energy consumption model, adjusted by recorded levels of gas consumption.

The NAEI obtains most of its data on fuel consumption from the Digest of UK Energy Statistics (DUKES)[10]. National totals based on these data are further refined for the industrial and energy generation sectors taking into account other more detailed data from the regulators of industrial processes: the Environment Agency (EA), the Scottish Environment Protection Agency (SEPA), Natural Resources Wales (NRW) and the Department of Agriculture, Environment and Rural Affairs Northern Ireland (DAERA). Data from the returns under the Emissions Trading Schemes (ETS) are also used.

Emission estimates are calculated by applying an emission factor to an appropriate activity statistic:

$$\textit{Emission} = \textit{Emission Factor} \times \textit{Activity Data}$$

An emission factor is defined as the average emission rate of a given pollutant for a given source, relative to units of activity. These are generally derived from (1) measurements made on various sources representative of an emission sector, (2) the concentrations of elements in fuels burnt – represented in an emission factor; or, (3) stoichiometric[11] or empirical relationships between emissions and specific activities. Examples of emission factors include the amount of NO_x emitted from a car per kilometre it travels and the amount of SO_2 emitted from a power station per tonne of coal burned.

Activity statistics are obtained from Government statistical sources, such as DUKES and Transport Statistics Great Britain[12] alongside those from organisations such as trade associations and research institutes. For example, the UK Petroleum Industries Association (UKPIA)[13] provided data on the sulphur content of fuels, and the Institute of Grassland and Environmental Research (IGER) provides data on livestock numbers and fertiliser usage.

Emissions of NO_x, PM_{10} and CO_2 for the NAEI source sectors in the year 2023 are presented in Figure 2-1, Figure 2-2 and Figure 2-3 respectively, whose comparison illustrates how the relative contribution of emissions from different sectors varies by pollutant. The UK Informative Inventory Report (Elliott, et al., 2025)[14] and Greenhouse Gas Inventory Report (Brown, et al., 2025)[15], provide details of emissions by sector at a national level.

Figure 2-4 shows a map of the spatial distribution of UK total NO_X emissions in 2023, with emissions from sources on mainland UK and from shipping routes.

The emission estimates for NO_X and other pollutants are compiled with a significantly greater level of detail than what is presented in these figures. Throughout this report, the NO_X inventory will be utilized as a tool to showcase the mapping methods that have been employed.

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[10] Digest of UK Energy Statistics (DUKES)

[11] refers to the exact proportions of elements or compounds involved in a chemical reaction, based on the balanced chemical equation

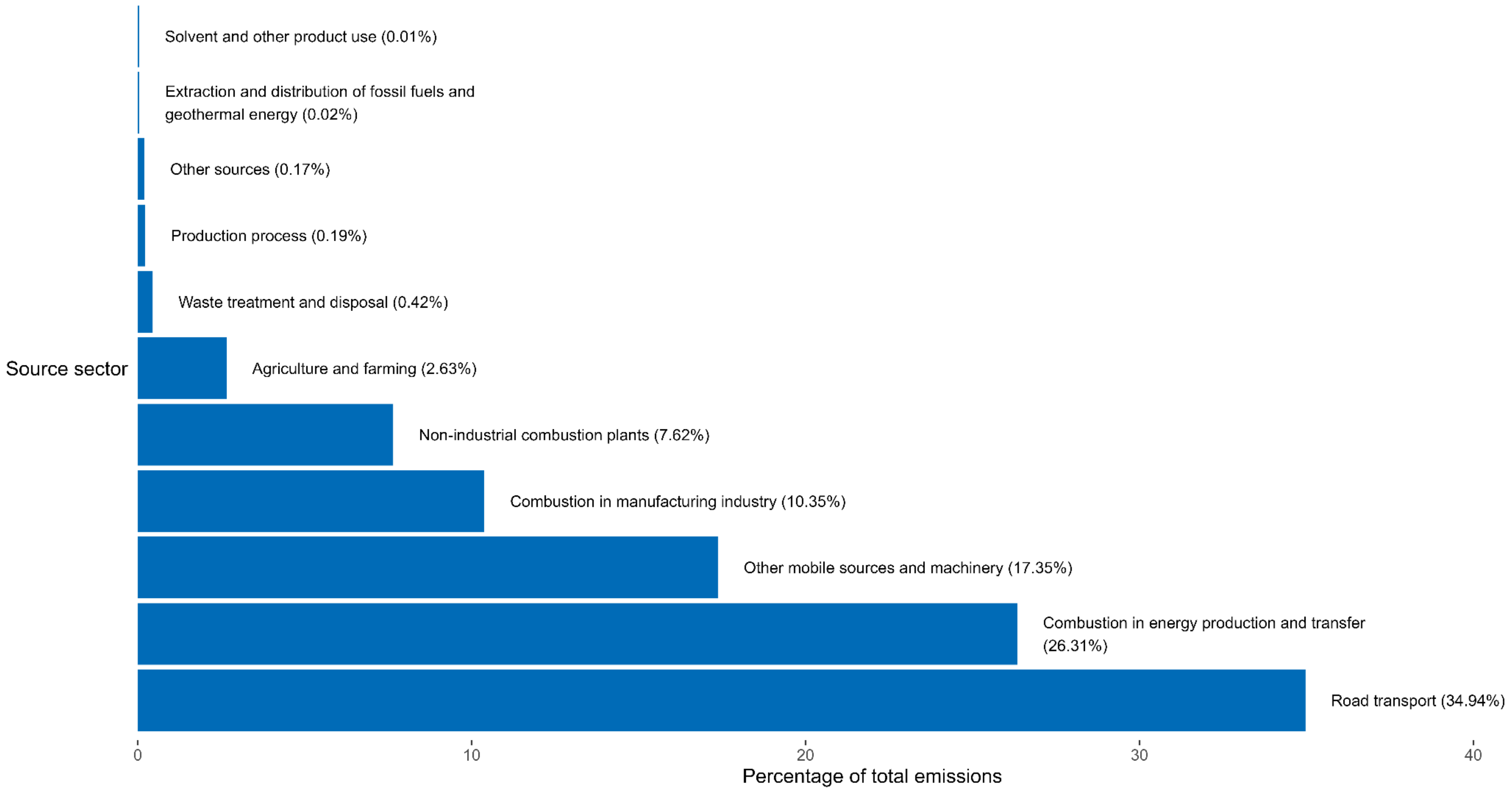
[12] Transport Statistics Great Britain

[13] Now restructured as Fuels Industry UK - https://www.fuelsindustryuk.org/

[14] UK Informative Inventory Report (1990 to 2023) | National Atmospheric Emissions Inventory

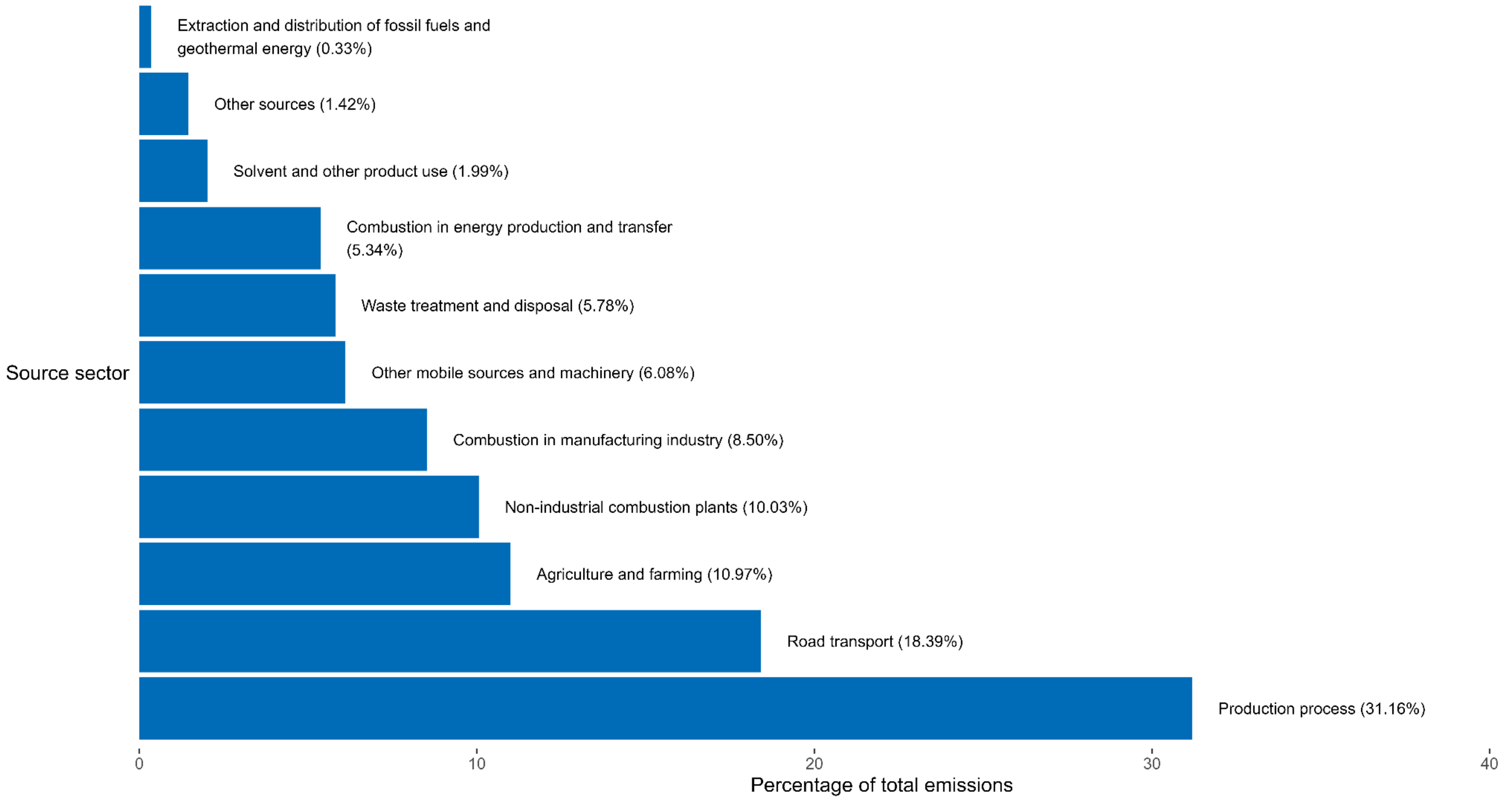
[15] UK Greenhouse Gas Inventory, 1990 to 2023: Annual Report for submission under the Framework Convention on Climate Change | National Atmospheric Emissions Inventory

Figure 2-1 UNECE Source Sector contribution to the total NO_x emissions in 2023 as shown on the NAEI 1x1 km data[16]



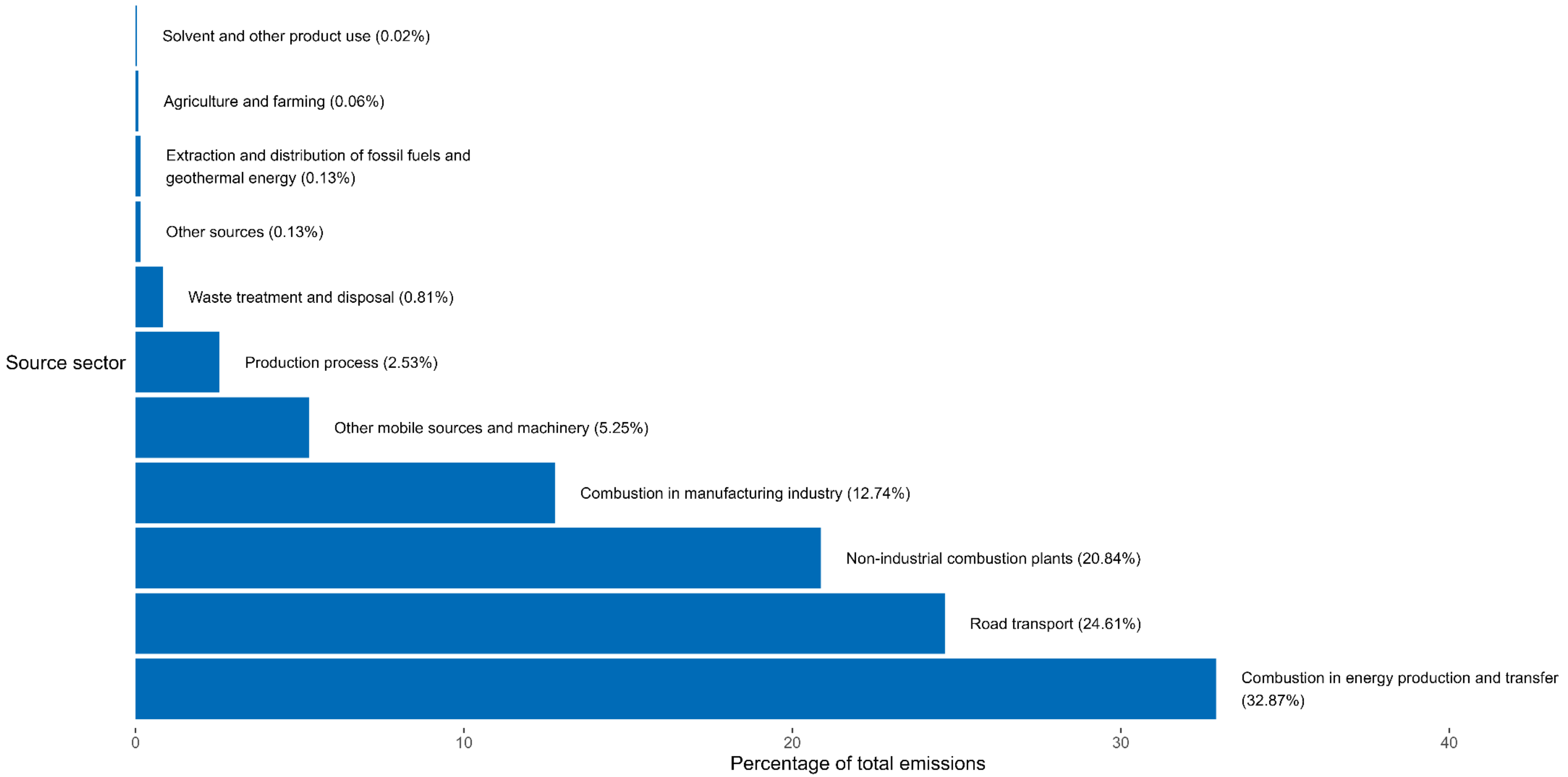
[16] Includes emissions from shipping activity outside the UK territory, but within the extent of the emission maps as published. These emissions are not included in the national totals.

Figure 2-2 UNECE Source Sector contribution to the total PM_{10} emissions in 2023 as shown on the NAEI 1x1 km data [17]



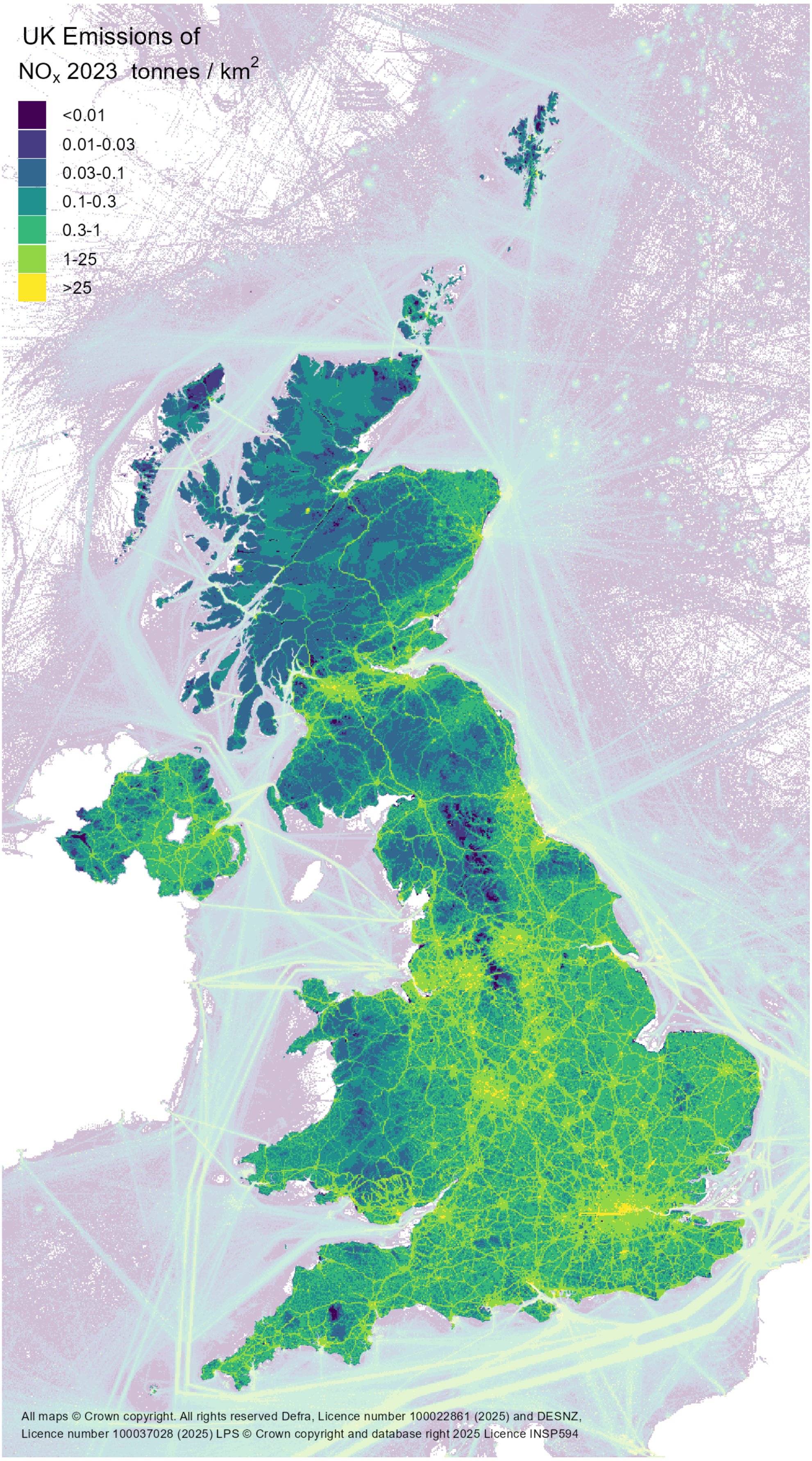
[17] Includes emissions from shipping activity outside the UK territory, but within the extent of the emission maps as published. These emissions are not included in the national totals.

Figure 2-3 UNECE Source Sector contribution to the total CO_2 emissions in 2023 as shown on the NAEI 1x1 km data [18]



[18] Includes emissions from shipping activity outside the UK territory, but within the extent of the emission maps as published. These emissions are not included in the national totals.

Figure 2-4 UK total NO_x emissions in 2023 at 1x1 km resolution



3. METHODS FOR CALCULATING EMISSION DISTRIBUTIONS

Spatial characterisation of emission distributions across the UK is built up from several distribution components for each NAEI emission sector. These individual sectoral distribution components are developed using statistics appropriate to each sector.

For large industrial localised ('point' sources) emissions are compiled from detailed official sources prepared by the EA, SEPA, NRW, DAERA, DESNZ Offshore Petroleum Regulator for Environment & Decommissioning (OPRED) and local authorities. These provide both the geographical location and the magnitude of the emissions to be characterised. For other smaller and more widely distributed sources, known as 'area' sources, less detailed information on the location and magnitude of emissions is available. For these sources, a map of the distribution of emissions is generated using appropriate surrogate statistics at a sector level. The method used for each source sector varies according to the data available. Table 3-1 presents the types of mapping distributions used for each of the UNECE sectors (described in Table 1-2) within the NAEI. The mapping methods used to develop these distributions are explained in the following sections.

Table 3-1 Methods used to map emissions in each of the 11 UNECE emission sectors.

Source sector and method	Report Section	UNECE Emission Sectors[19]										
		1	2	3	4	5	6	7	8	9	10	11
Accidental fires	Section 3.11 (p.41)									✓		✓
Agriculture	Section 3.5 (p.30)								✓		✓	
Airports	Section 3.9 (p.36)								✓			
Domestic	Section 3.4 (p.26)		✓			✓						
IDBR[20] agriculture	Section 3.2 (p.15)		✓									
IDBR commercial & public	Section 3.2 (p.15)		✓									
IDBR employment	Section 3.2 (p.15)	✓	✓	✓	✓		✓		✓	✓		
IDBR industry	Section 3.2 (p.15)			✓								
Landfill	Section 3.12 (p.41)									✓		
Offshore	Section 3.13 (p.42)	✓				✓				✓		
Other	Section 3.14 (p.43)				✓	✓			✓			✓
Point Sources	Section 3.1 (p.10)	✓	✓	✓	✓	✓	✓			✓		
Population	Multiple Sections				✓	✓	✓		✓			✓
Rail	Section 3.6 (p.30)								✓			
Road transport	Section 3.3 (p.18)				✓			✓				
Shipping	Section 3.7 (p.31)				✓				✓			

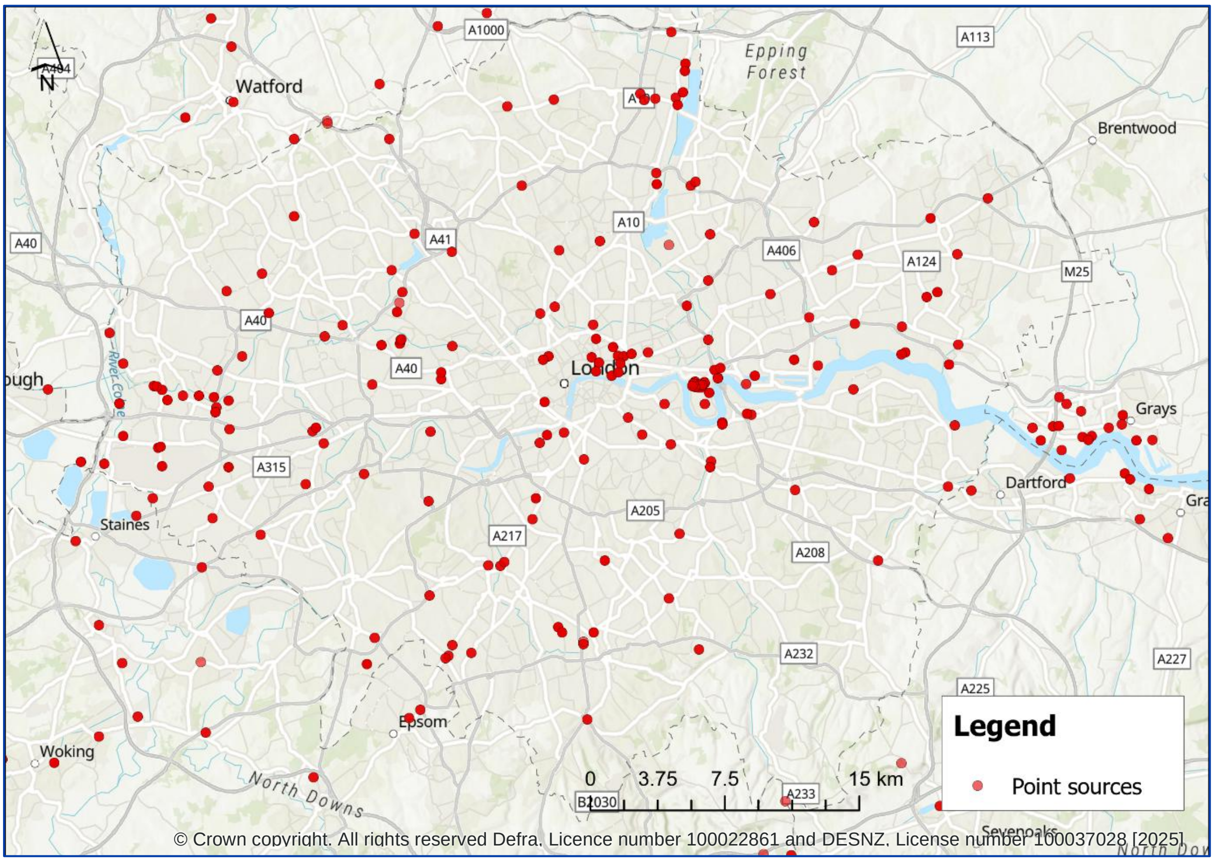
[19] SNAP nfr09_to_snap.xls

[20] Inter-Departmental Business Register (IDBR) - Office for National Statistics

3.1 INDUSTRIAL AND COMMERCIAL SOURCES

The NAEI receives detailed data on individual point sources in the industrial and commercial sectors. A point source is an emission source at a known location and can be mapped directly; see an illustrative example for the London area in Figure 3-1. Point sources across the UK may be either collectively responsible for the total emission for that sector, such as coal-fired power stations, where the sector is made up solely of large operational facilities, for which emission reporting is mandatory; or in part such as combustion in industry, for which only the larger combustion plants within the sector are required to report emissions. In the latter case, the residual emission, i.e. the portion of the national total emission not released by installations represented by point sources, is mapped as an area source.

Figure 3-1 Illustration of industrial and commercial NAEI point sources within the Greater London area



Point source emissions are compiled using a variety of different data sources and techniques, which can be broken down into the following data streams:

1) Emissions Trading Schemes
2) Regulator Inventories
3) Operator Reported Data
4) Historic survey of industrial activities
5) Modelled Points Data

3.1.1 Emissions Trading Schemes

The ETS, are schemes where point source operators report annually data regarding their fuel use, fuel quality (calorific values) and the CO_2 emissions that arise from each fuel stream. Reported emissions data is third-party verified and hence is regarded as the most reliable data set.

Since the inception of the EU Emissions Trading System in 2005, its scope has expanded multiple times during the different phases, and in 2021, the UK ETS was introduced following the UK's departure from the EU. These changes are summarised in Table 3-2.

Table 3-2 Phases and scope changes of the ETS over the years

Years	Phase	General scope
2005-2006 (EU ETS)	I	'Medium' definition of combustion. Many sites involved in UK trading systems and Climate Change Agreements have opt-outs and not included in the dataset.
2007 (EU ETS)	I	'Medium' definition of combustion. Most sites previously in UK trading systems now reporting in the dataset.
2008-2012 (EU ETS)	II	'Medium' definition of combustion. Increased scope of reporting for some industrial sites – for example, now including rolling mill furnaces at steelworks, and flaring at oil and gas facilities and at petrochemical works. Remaining sites previously in UK trading systems now reporting in the dataset. Opt-out for various hospitals and other sites with relatively small emissions, so many installations in Phase I no longer appear in the dataset.
2013-2020 (EU ETS)	III	'Broad' definition of combustion, so significant increase in coverage for sectors such as food & drink, chemicals, minerals (e.g. roadstone coating), metals. Addition of certain process sources of CO_2 including titanium dioxide production, soda ash production.
2021-Present (UK/EU ETS)	III	The vast majority of installations now report to the UK under the UK ETS, however a small number of sites in Northern Ireland (public electricity generators) are in the EU ETS.

3.1.2 Regulator Inventories

The regulator inventories cover processes regulated under the Environment Protection Regulations (EPR), and formerly the Industrial Emissions Directive (IED). These are produced annually by the EA, SEPA, NRW and the Northern Ireland Environment Agency (NIEA) on behalf of England and the respective devolved governments.

The regulators provide the datasets as follows:

- EA provide the Pollution Inventory (PI) annually from 1991 onwards;
- SEPA provide the Scottish Pollutant Release Inventory (SPRI) for 2002 and annually from 2004;
- NRW provide the Welsh Emissions Inventory (WEI) annually from 1991 onwards;
- NIEA provide the Northern Ireland Pollution Inventory (NIPI) annually from 1999 onwards.

In each of the regulator inventories, operators are only required to report emissions for a pollutant if they exceed a specified 'Reporting Threshold', for example, as of 2012, the Reporting Threshold for NO_X emissions is 100 tonnes[21].

The regulators' inventories provide much of the point source data used in the NAEI maps for NO_X, SO_2, CO, HCl, benzene, 1,3-butadiene, NMVOC, PM_{10}, heavy metals, and persistent organic pollutants. Sectors covered include power stations, refineries, chemicals manufacture, cement kilns, lime kilns, non-ferrous metals production, and large industrial combustion plants.

The Pollutant Release and Transfer Register (PRTR) is compiled from the regulator inventories, and as such, much of the data captured through this reporting mechanism is also captured via the regulator inventories such as the PI. This includes some activities which are regulated by local authorities (including large solvent-using activities).

3.1.3 Operator Reported Data

In a few cases, operators and trade associations provide data to the NAEI in a more disaggregated form than is available in the relevant regulator inventory; these are:

- Tata Steel Ltd & British Steel Ltd - provide emissions data for integrated steelworks broken down into emissions from coke ovens, sinter plant, blast furnaces, basic oxygen furnaces, electric arc furnaces, flaring/losses, stockpiles and combustion plant. PI & WEI emissions data for the steelworks do not give this breakdown. Tata Steel has also previously supplied data for their electric arc steelmaking facility, however, this is now operated by Liberty and so data have not been collected after 2016. The Tata Steel / British Steel data cover most of the pollutants mapped in the NAEI for steelworks;
- Fuels Industry United Kingdom supplies NO_X, SO_2, CO, PM_{10} & NMVOC emissions data for fuel combustion and non-combustion processes at crude oil refineries;
- Offshore Energies UK (OEUK) provides emissions data for offshore oil and gas exploration and production installations, as well as various onshore installations linked to oil and gas production. These data are taken from the Environmental Emissions Monitoring System (EEMS) database, which is compiled for OEUK and DESNZ OPRED. The data cover NO_X, SO_2, CO & NMVOCs.

3.1.4 Historic survey of industrial activities

There are additional sites which are regulated under the Local Authority Pollution Control (LAPC) / Local Air Pollution Control (LAPPC).

This was an important information stream for processes using solvents during the late 1990s and early 2000s. However, this type of information has not been collected since, due to the resource-intensive nature of the data collection, both for the inventory agency and, potentially, for the regulators asked to provide such information. Most of these points data are based on historic reported data and therefore subject to considerable uncertainty.

3.1.5 Modelled Points Data

Even given the comprehensive information compiled in the previously mentioned registers and datasets, point source data are not available for all installations. For most pollutants, the available data are likely to cover those sites and sectors that emit significant quantities (that is why the sites are regulated and emissions reported in the various data sets), but for those sites with emissions below the reporting thresholds, or for most sites regulated by local authorities, the NAEI will not be able to collect any emissions data from the regulator. This also applies to some industrial emission sources that are

[21] Form PI-3(UK-PRTR): Pollution Inventory reporting – UK-PRTR

not regulated. In the case of NMVOCs and, to a lesser extent, particulate matter, there are likely to be emissions from the sites regulated by local authorities where emissions data are not generally available.

As an example, for NMVOCs, there are notable emissions from industrial processes which are not regulated under air pollution legislation (for example, emissions of ethanol and other NMVOCs from bakeries, breweries and the manufacture of malt whisky and other spirits). In these cases, 'modelled' point source data are generated using national emission factors and a 'surrogate' activity statistic. Examples of this approach are given below:

- Estimates of plant capacity, including estimates made by Ricardo, can be used to allocate the national emission estimate. This approach is, for example, used for bread bakeries where the capacities of approximately 70 large mechanised bakeries are estimated;
- Emission estimates for one pollutant can be used to disaggregate the national emission estimate of another pollutant. For example, emissions of PM_{10} from certain coating processes have been estimated by allocating the national total to sites based on their share of the national NMVOC emission;
- Assuming that plants which do not report emissions have similar rates of emission as plants within the same sector which do report emissions. In these cases, emissions are calculated using the same emission factor as other sites where data exists, which are comparable in size and with similar abatement measures in place, where recorded;
- Emissions can be distributed using surrogate data other than capacity. For example, in the case of malt whisky distilleries, emissions of NMVOCs from distillation are distributed using capacity, except in cases where this is not known, where the number of stills is used as a measure of the scale of operations and therefore emissions;
- Assuming that all plants in a given sector have equal emissions. In a few cases where there are relatively low emissions per plant in a sector, and no activity data can be derived at the site level, emissions are assumed to be equal across all of the sites. This approach is used for only a small number of sources, for example, animal rendering plants and animal feed manufacturers.

With the possible exception of using plant capacity as a surrogate, many of the approaches listed above will yield emission estimates which are subject to much higher uncertainties than the emissions reported by site operators in the PI/SPRI/NIPI or ETS. However, most of the emission estimates generated using these methods are, individually, relatively small, and the generation of point source data by these means is judged better than mapping the emissions as area sources. This would mean mapping emissions across the whole of the UK using much less targeted surrogate data, such as employment data or population, which are likely to be poorly correlated with emissions.

3.1.6 Limitations of data

The data reported under the various mechanisms do have limitations, the main one being limited data capture through the regulator inventories. As discussed in 3.1.2, each of the regulator inventories has reporting thresholds which vary by pollutant, where if a site emits below a certain amount, they are not required to report emissions for an individual pollutant. Some sites do still report emissions if the release is Below the Reporting Threshold (BRT). There are also instances where operators provide no information at all on pollutants that might be expected to be emitted i.e. they neither report an emission nor do they report that releases are below the threshold.

The Inventory Agency therefore reviews the available data and identifies potential gaps, before generating emission estimates to fill these gaps; gaps are often filled through extrapolation/interpolation from emissions data for other years and/or other processes.

This gap-filling is carried out for the UK inventory, and the gap-filled point source data are then also used in the UK maps. These gap-filled point source data are likely to be considerably more uncertain than point source data based on emissions data in the regulators' inventories, but they also tend to make only a relatively small contribution to total UK emissions of each pollutant.

3.1.7 Integration of data across different data streams

It is possible, and is often the case, that one site will report emissions under more than one obligation, the most common of these is where sites report data to both ETS and the regulator inventories. When this is the case, it is necessary to:

i) Cross-check the reported data to ensure that there is no duplicating of data

CO_2 data needs to be compared between the ETS, regulator inventories, and operator data to ensure there is no duplication of data. This requires a thorough understanding of how the various processes permitted under EPR and reported in the regulator inventories relate to processes that are permitted under ETS. Identifying the same installation in each of the data sets is not always straightforward since operator names, site names and even site addresses and postcodes can differ for the same site in both sets of data.

ii) Ensure that the most appropriate data set is used

Where a given installation is present in both the ETS and other data sets, the exact scope of the emissions data may not be the same. For example, emissions data in the PI and other regulators' inventories will include CO_2 from biofuels, whereas the ETS data will not.

The PI will also include emissions from driers, furnaces and other plants where fuels are burnt to provide heat which is used within the combustion device. In many cases, the ETS data set will exclude the emissions from these types of plant prior to 2012 (ETS phase III). As a result, there is a need to understand how the scope of each EPR permit compares with the scope of each ETS permits. This is a major task which would require significant resources to do fully. As a proportionate interim measure, resources have been focussed on understanding the relative scope of permits for those installations which report very different carbon emissions in different data sets. Good progress has been made in understanding key differences; even so, fully understanding these is a work in progress.

iii) Augmenting regulator inventory data with ETS

Whilst the regulator inventories provide the site emissions for the majority of pollutants (excluding CO_2), it only provides a site total and does not break emissions down by fuel type. The ETS data gives detailed information on the types of fuels burnt at each site. This is used to split emissions data for pollutants other than CO_2 that are available from the PI, SPRI, WEI and NIPI. The procedure involves generating a fuel consumption profile for each facility and year. Subsequently, a series of default emission factors, taken from the NAEI, is used to calculate a theoretical emission of each pollutant and fuel type. These theoretical emissions are then used to calculate an emissions profile for each facility, indicating the likely distribution of emissions between the different fuels burnt at that site. Finally, the emissions profile is combined with the emission data reported in the PI/SPRI/WEI/NIPI to give fuel-specific emission estimates.

One particularly complex sector is that of the terminals receiving crude oil and gas from the North Sea production installations. For these facilities, we have emissions data from the ETS, the PI & SPRI, and also from the EEMS database, compiled for OEUK and OPRED. These datasets often contain very different emissions data for the same installation, and it is not always possible to identify a clear reason for this. CO_2 point source emissions data for complex sources such as these are, therefore, subject to a high degree of uncertainty and are liable to be revised if new information becomes available. To address these complex issues, the NAEI has produced a model to calculate the best estimate for emissions of each relevant pollutant at all upstream oil and gas sites. Further details can be found in the Upstream Oil and Gas improvement report (Thistlethwaite, Richmond, & Hoskin, 2022)[22].

3.2 OTHER INDUSTRIAL, COMMERCIAL AND PUBLIC SECTOR CONSUMERS

As indicated above, the emissions at large point sources represent a substantial proportion of the total industrial and commercial fuel consumption. Subtracting these site-specific emissions from each NAEI sector total calculates a residual emission[23], which is mapped as an 'area source'. This residual emission is allocated to the UK grid using distribution maps for each sector derived from employment statistics. Each distribution map provides the percentage of the UK residual sector fuel consumption estimate for each 1x1 km.

The method used is described in a separate document - Employment based energy consumption mapping in the UK[24]. The following data sets were used:

- Office of National Statistics Inter-Departmental Business Register (IDBR), which provides data on employment at business unit level by Standard Industrial Classification (SIC) code[25];
- Energy Consumption in the UK (ECUK) data on industrial and service sector fuel usage[26];
  - Site-specific fuel consumption as described in Section 3.1. These are compiled from data for regulated processes reported in the EA Pollution Inventory, Scottish SPRI, DoE NI Inventory of Statutory Releases, by the ETS and from other data obtained by the inventory;
  - Postcode level gas consumption data provided by DESNZ;
- Business Register and Employment Survey (BRES) annual employment estimates for the UK split by Region and Broad Industry Group (SIC2007)[27];
  - Energy performance certificates (EPC) to identify buildings that use other fuels for heating.

The first step was to allocate NAEI point sources to SIC codes and to identify the relevant individual businesses at these locations in the IDBR employment database. This was to calculate the energy use for each sector which is already accounted for by point sources and therefore allows the subsequent estimation of the residual energy that needs to be distributed using the employment data.

Based on address matching, the EPC data were then joined with the IDBR data. The EPC data contains information on fuel use on non-domestic premises, which allowed each IDBR record to be tagged with the fuel used.

The employment data by SIC codes in the IDBR database were matched with the DESNZ energy consumption datasets to calculate total employment for each sector for which energy consumption data were available. Fuel intensity per employee was calculated for each sector. For commercial and public service sectors, the employment data needed to be aggregated to match the level of aggregation of the energy data. In the case of industrial sectors, a comparable approach was used, and the energy intensity calculation was done at the level of 2-digit SIC codes. Energy consumption data were available for coal, gas oil, fuel oil and natural gas. These were combined to calculate industry-specific fuel intensities for coal, oil and gas.

The IDBR employment data at a local unit level were aggregated to 2-digit SIC codes at local authority area resolution using postcodes and grid references provided as part of the database. The employment totals for each sector were then multiplied by the appropriate fuel intensity per employee values to make fuel use distributions across the UK. It has been assumed that fuel intensity for each sector is even

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[22] UK GHG Inventory Improvement: Upstream Oil and Gas | National Atmospheric Emissions Inventory
[23] Residual emission = national total – point source emission total
[24] Employment Based Energy Consumption Mapping in the UK
[25] Inter-Departmental Business Register (IDBR) - Office for National Statistics
[26] Energy consumption in the UK 2024 - GOV.UK (Industrial and Services tables)
[27] Previous releases for Employees in Great Britain - Office for National Statistics

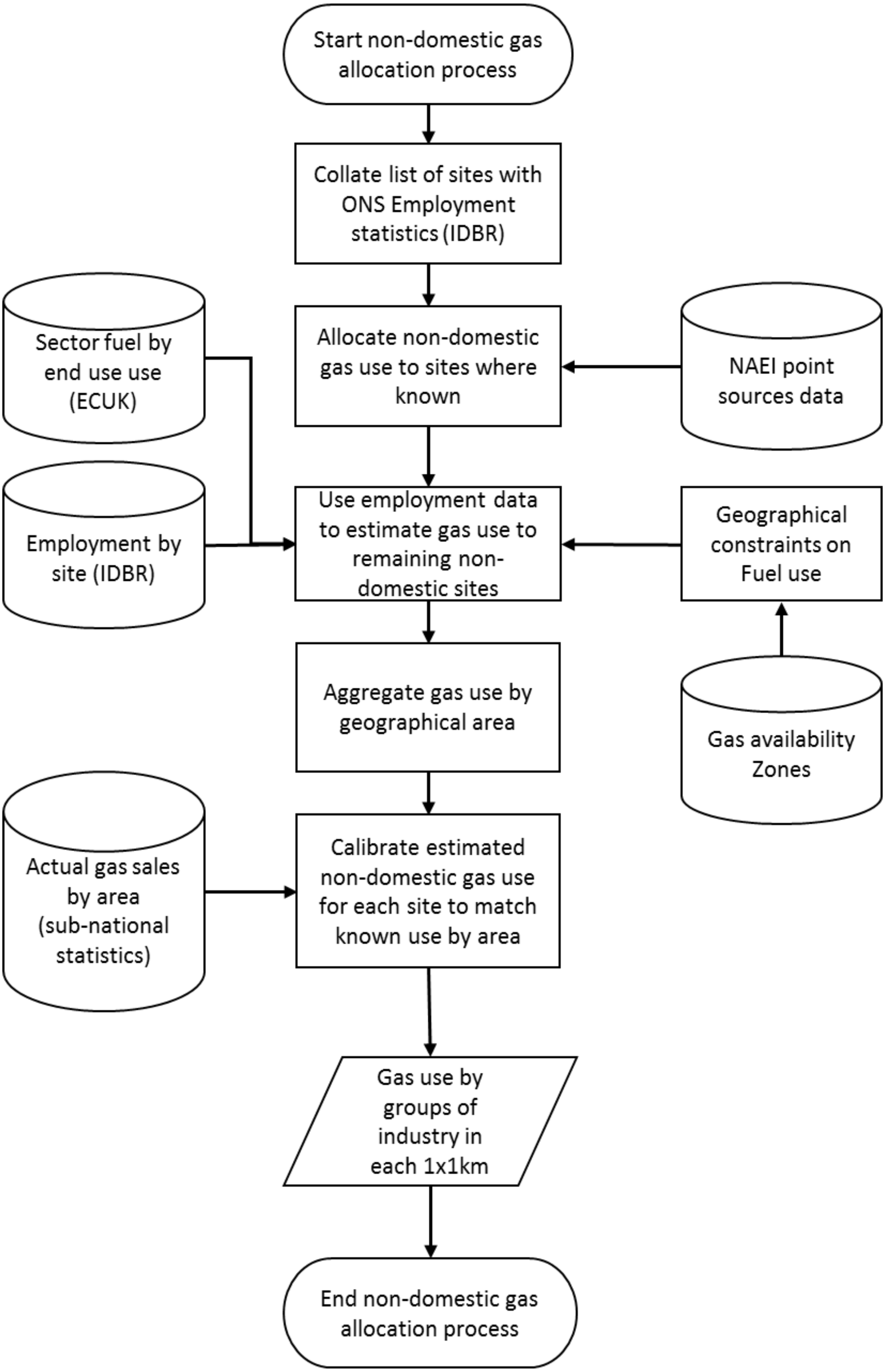
across the sector. This is a simplification of reality, but it is necessary because of a lack of more detailed estimates of fuel use.

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

- Sites of employment corresponding to the locations of the highest emissions (as defined by the NAEI point source database) have been removed from the distributions. This is to prevent double-counting of emissions at these locations (emissions are mapped as point sources);
- High-resolution gas consumption data at the individual postcode level has been used to adjust the distribution of gas predicted by the employment and energy intensity data. An adjustment has also been applied in Northern Ireland based on local authority level gas consumption data;
- Evidence of areas with natural gas availability, DESNZ natural gas consumption at postcode dataset has been used to identify sites that are in or out of the natural gas grid.

Figure 3-2 shows the process to convert industrial & commercial fuel usage from individual employment sites into emissions.

Figure 3-2 Non-domestic gas use allocation process.



3.3 ROAD TRANSPORT

Exhaust emissions from road vehicles and the related fuel consumption estimates are calculated within the NAEI using emission factors and activity data for each vehicle type. The emission factors are calculated based on the composition of the vehicle fleet (age profile and fuel mix), and together with fuel consumption are applied to detailed spatially resolved traffic movements. The vehicle fleet age profiles, Euro standard and fuel mix estimated within each of the DGs are derived using Regional Vehicle Licensing Statistics from the Driver & Vehicle Licensing Agency (DVLA) and the Department for Transport's (DfT) Automatic Number Plate Recognition (ANPR) database. Therefore, as the fleet mix varies by location, different emission factors are applied to different road types in the DGs.

3.3.1 Emission factors and fuel consumption factors

Fuel consumption factors and emission factors combined with traffic data for 6 major classes of vehicles are used to estimate national fuel consumption and emissions estimates from passenger cars (conventional and hybrid), light goods vehicles (LGVs), rigid and articulated heavy goods vehicles (HGVs), buses/coaches and mopeds/motorcycles. The vehicle classifications are further subdivided by fuel type (petrol or diesel) and the regulatory emission standard the vehicle or engine had to comply with when manufactured or first registered. The vehicle Euro emission standards apply to the pollutants NO_x, PM, CO and hydrocarbons, but not to CO_2 or fuel consumption. Nevertheless, the Euro standards are a convenient way to represent the stages of improvement in vehicle or engine design that have led to improvements in fuel economy and are related to the age and composition profile of the fleet. For example, the proportion of vehicles by Euro standard in the national car fleet can be associated with the age of the car fleet (year of first registration).

Fuel consumption and emission factors are expressed in grams of fuel or emissions per kilometre driven, respectively, for each detailed vehicle class. The methodology combines traffic activity data (from DfT's national traffic census) with fleet composition data and fuel consumption/emission factors. The vehicle fleet composition data are based on licensing statistics and evidence from ANPR data from DfT; these provide an indication of the vehicle mix by engine size, vehicle size, age, engine and exhaust treatment technology, Euro emission standards, and fuel type as observed on different road types. Fuel consumption factors are based on a combination of published compilations of factors derived from vehicle emission test data from European sources and factors from industry on the fuel efficiency of cars sold in the UK. In the former case, representative samples of vehicles are tested over a range of drive cycles associated with different average speeds on different road conditions. Many parameters affect the amount of fuel a vehicle uses, such as the speed, so the NAEI uses functions that relate fuel consumption to average speed.

The emission and fuel consumption factors are taken from the EMEP/EEA Emissions Inventory Guidebook 2023 (Update 2024)[28] where they are expressed as functions related to average speed and are consistent with the factors in COPERT 5.8. The COPERT 5 "*Computer Programme to Calculate Emissions from Road Transport*" is a model and database of vehicle emission factors developed on behalf of the European Environment Agency and is used widely by other European countries to calculate emissions from road transport. For fuel consumption, the approach includes a method for estimating emissions from passenger cars, which applies a year-dependent 'real-world' correction to the average type-approval CO_2 factor weighted by new car sales in the UK from 2005-2023. The new car average type-approval CO_2 factors for cars in different engine size bands were provided by the Society of Motor Manufacturers and Traders[29]. The real-world uplift uses empirically derived equations in the Guidebook that take into account the average engine capacity and vehicle mass, and it is applied to the speed-related functions given in the Guidebook. For other vehicle types, different from passenger cars, the fuel consumption-speed curves provided in the Guidebook are used without a further uplift.

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

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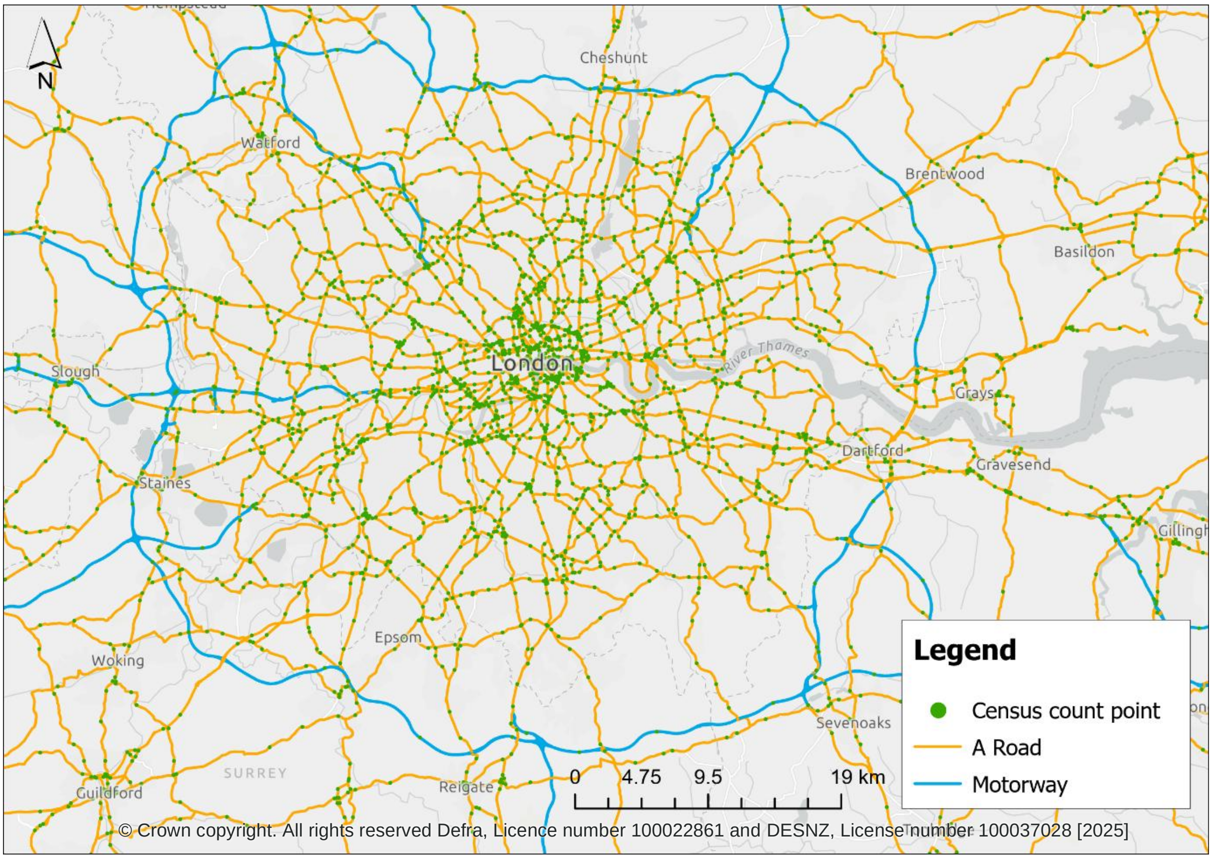
[28] EMEP/EEA air pollutant emission inventory guidebook 2023 | European Environment Agency
[29] UK Motor Trade Association | Society of Motor Manufacturers & Traders | SMMT

3.3.2 Road transport mapping methodology

The base map of the UK road network used for calculating hot exhaust road traffic emissions has been developed from a range of mapping datasets. The Ordnance Survey Open Roads (OSOR) dataset (see Figure 3-3) provides locations of all roads (motorways, A-roads, B-roads and unclassified roads) in Great Britain. For Northern Ireland a dataset of roads was obtained from Ordnance Survey of Northern Ireland, part of Land & Property Services Northern Ireland.

Figure 3-3 Illustration of the major road network and DfT count point data in the Greater London area.



Traffic flow data for major roads (A-roads and motorways) are available on a census count point basis for both Great Britain[30] and Northern Ireland[31]. The data comprise counts of each type of vehicle as an Annual Average Daily Flow (AADF), aggregated up to annual flows by multiplying by 365. These AADF statistics take account of seasonal variation using 'expansion factors' applied to single-day counts based on data from automatic counts for similar roads and vehicle types. These expansion factors are developed and applied by DfT directly to the released AADF statistics.

Differences between the Great Britain and Northen Ireland datasets should be noted. The census count point coverage of roads in Great Britain is considerably denser than that for Northen Ireland. Additionally, in Northern Ireland, some count points hold records only for the total vehicles rather than a split of different vehicle types. To get a vehicle breakdown for these count points, an average vehicle split has been applied to the records.

The Northen Ireland traffic data provided by Northern Ireland's Department for Infrastructure (DfI) from 2018 and the following reporting years has a different vehicular classification from previous years. Specifically, the LGV class was omitted and the LGV count was merged with the Car class. As a result,

30 Map Road traffic statistics - Road traffic statistics

31 Traffic and travel information (incorporating annual traffic census and variations in traffic flow) | Department for Infrastructure

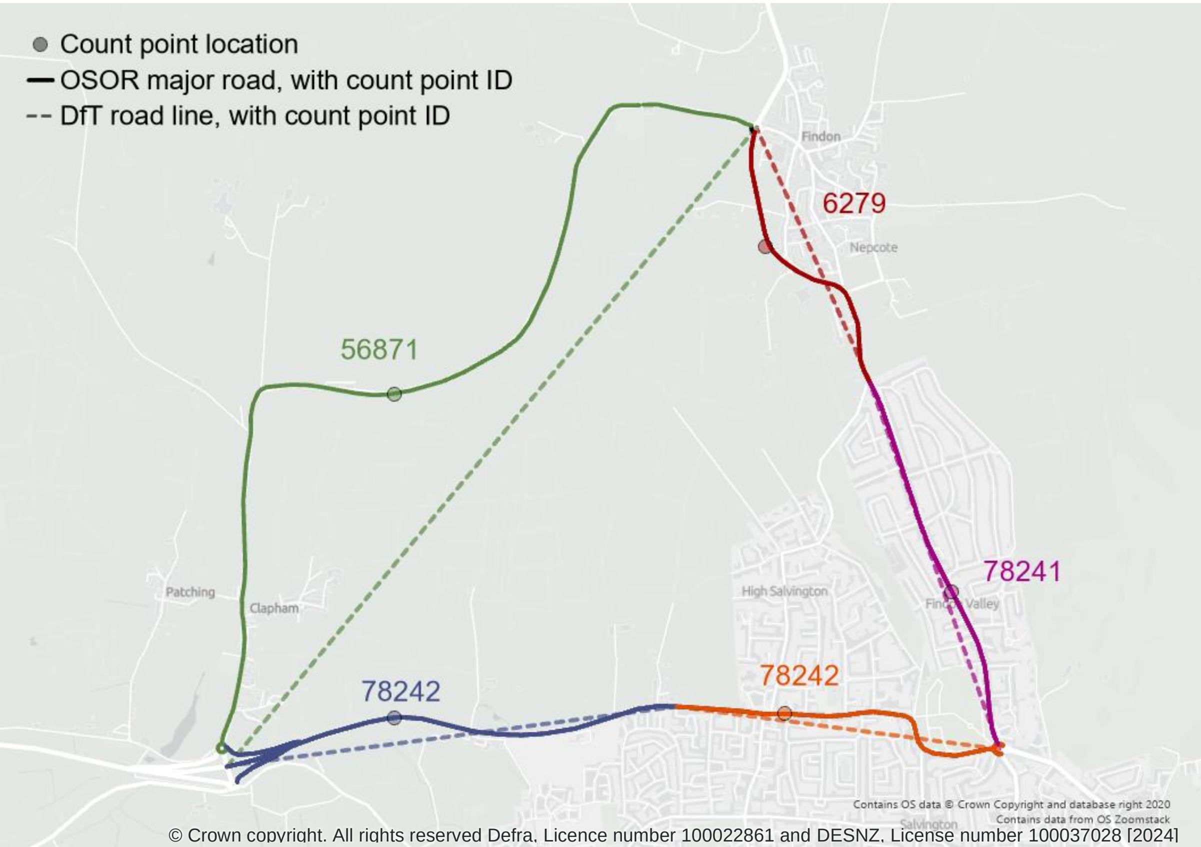
and in order to be consistent with the previous vehicular classification (as well as the data for Great Britain), historic traffic pattern data by road type and urban status was utilised to generate an LGV-to-Car ratio.

In addition, DfI in Northern Ireland has provided limited traffic count points compared to the number of major roads in Northern Ireland. To fill the gaps for the major roads without traffic, there is an additional step of scaling historic traffic counts which were previously released by the DfI.

For Northern Ireland, traffic counts were allocated according to the proximity of the point where the count was made and major roads with the same road number – i.e. each link has the nearest count point with the same road number assigned to it – using a computer script.

For Great Britain, the OSOR network is more complex than the Northern Ireland road network, and the count point allocation required a different approach. Here, count points were allocated to a section of the major road network according to shared road number and spatial proximity to the stretch of road that each count point covers (Figure 3-4). This was done by using a highly simplified straight-line representation of the start and end of each count points' coverage ('count point lines') from DfT. A series of computer-based processes were used to automatically perform this allocation. Where count point lines overlapped local authority area boundaries, OSOR roads were split at that boundary, and each split was assigned to the relevant local authority area. Automated allocation was followed up with manual checking and verification.

Figure 3-4 Traffic flows are assigned to the road network (Ordnance Survey Open Roads) by selecting OSOR sections that fall between the start and end points of traffic census count point coverage (DfT road line).



The urban or rural classification of a section of OSOR road covered by a count point (here called a 'count point road') was determined through the following logic:

1. Count point roads that have at least two-thirds of their DfT-defined length[32] as urban: classify as urban.
2. Count point roads that have at least two-thirds of their DfT-defined length[33] as rural: classify as rural.

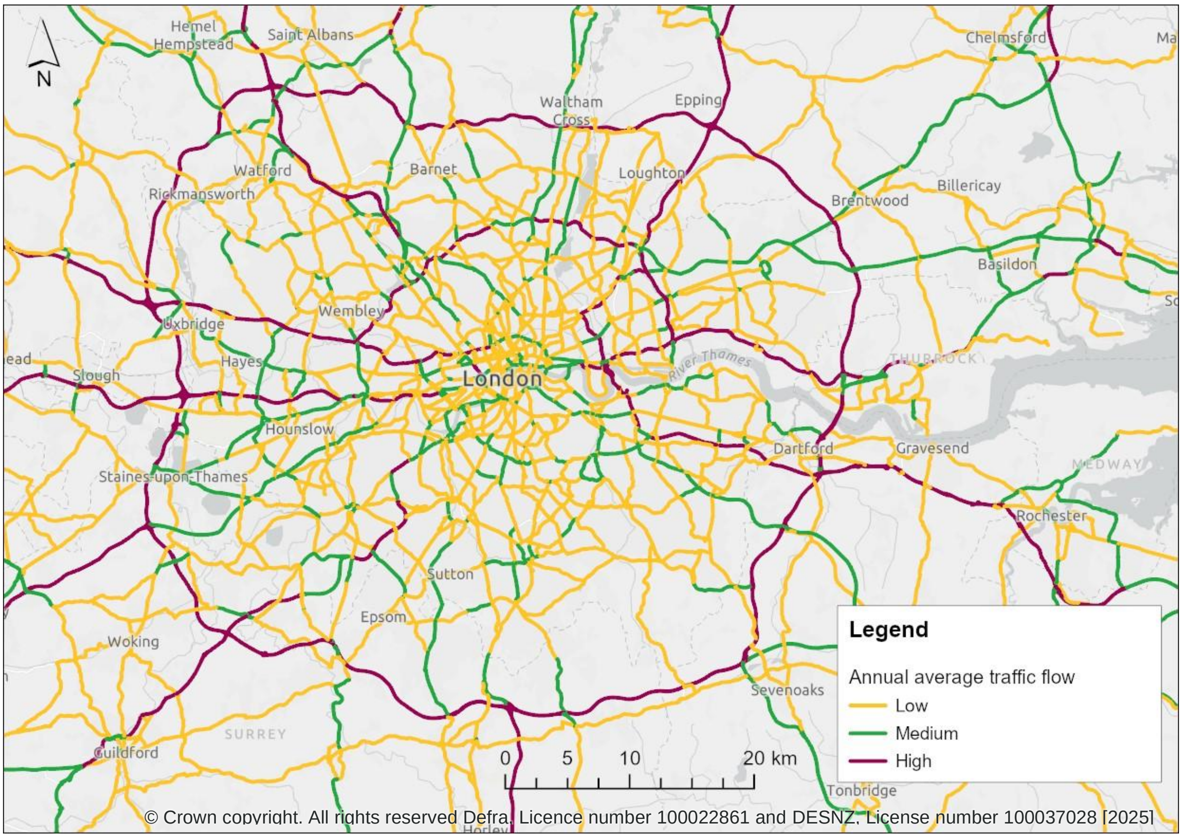
Count point roads not captured by cases 1 or 2 were split at the urban boundary, and further logic applied:

3. Count point road link intersecting the boundary once were split into two unique count points: one urban and one rural. Any new count point road of less than 100 m was given the urban or rural classification of their counterpart, and splits of less than 15% of the total count point road length were manually inspected for validity.
4. Count point roads intersecting urban areas more than twice were classed based on the majority urban or rural length of the whole road section.

Due to the variety of reasons that a road may cross a boundary twice, these were manually assessed and classified as urban or rural accordingly.

Urban areas for England and Wales are defined as built-up areas[34] with a population of at least 10,000 or for Scotland[35] a population of at least 3,000 (according to 2011 Census data). Figure 3-5 shows the traffic flows that are assigned to the road links after count point allocation.

Figure 3-5 Traffic flows are assigned to the road links after count point allocation.



Traffic flow data are not available on a link-by-link basis for the majority of minor roads, and traffic flows have been modelled based on average regional flows and fleet mix (data from DfT) in a similar way to previous years. Regional average flows by vehicle type have been applied to each type of minor road

[32] This length is provided directly by DfT and therefore further analysis is not necessary
[33] This length is provided directly by DfT and therefore further analysis is not necessary
[34] Built-up Areas (December 2011) Boundaries EW BGG (V2) | Open Geography Portal
[35] Urban Rural Classification 2016 - Urban Rural Classification - Scotland - data.gov.uk

– B and C roads or unclassified roads. DfT have carried out their routine benchmarking exercise for their estimates of road traffic on minor roads; this exercise happens approximately every 10 years and aims to reduce incremental errors. The result of this exercise was an increase in their estimates of traffic flow on minor roads for historic years. Full details of the benchmarking exercise can be found on GOV.UK[36].

For Northern Ireland, vehicle-specific minor road flows have been calculated from data in the *Annual Road Traffic Estimates: Vehicle Kilometres Travelled in Northern Ireland*[37] which provides information on vehicle kilometres (VKM) travelled for vehicle types and by road types.

County-level VKM estimates from DfT (unpublished) have been provided to ensure consistency between the NAEI and DfT modelling and have been used to correct at county level the estimates of VKM in the NAEI mapping.

The VKM travelled by electric vehicles (EVs) are calculated and removed from the vehicle count. For cars and buses, the proportion of EVs varies each year by road type and land use (urban/rural); A-roads, motorways and minor roads all have a separate EV proportion, with A-roads and minor roads further split into urban and rural. For other vehicle types, the same proportion of EVs is applied to all road types, with the fraction only changing by year. In London, all vehicle types are split out by area type[38]. The proportion of VKM travelled by EVs in 2023 is shown in Table 3-3.

Table 3-3 VKM travelled by electric vehicles on major & minor roads in 2023

Vehicle Type	eVKM on major roads	eVKM on minor roads
Buses	5.43%	3.40%
Cars	6.51%	6.58%
HGVs	0.15%	0.13%
LGVs	2.15%	2.15%
London taxis[39]	32.71%	34.28%

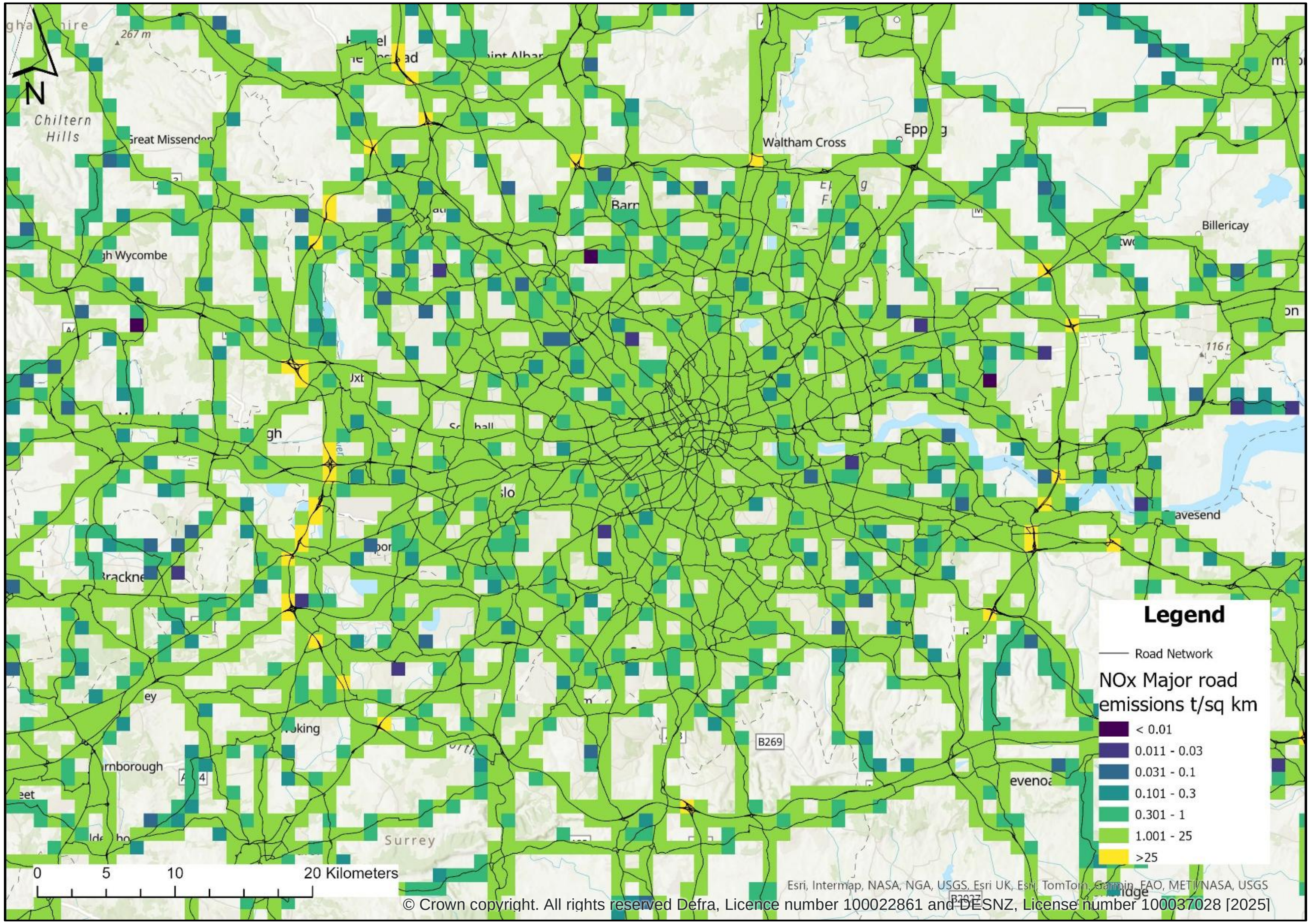
Similarly, the VKM of hybrid cars are split out from the VKM of passenger vehicle count based road type (urban, rural, motorway) and London area type. Hybrid specific fuel consumption factors are then applied separately for full hybrid and plug-in hybrid vehicles.

The next step after mapping vehicle movements was to apply the emissions and fuel consumption factors discussed earlier. VKM estimates by vehicle type for each road link were multiplied by fuel consumption or emission factors taking into account the average speed on the road of concern and the vehicle and fuel type and the national fleet composition in terms of the mix of each Euro emission standard of vehicles on the road for the inventory year. These calculations were performed for each major road link in the road network, resulting in maps of fuel use by fuel type and emissions by pollutant. Each road link was then split into sections of 1 km grid squares which enabled the mapping of emissions and energy estimates (for example for London in Figure 3-6).

A similar calculation is performed for minor roads estimates using average speeds for different types of minor roads and applying the relevant fuel consumption factor for that road type to the VKM data modelled as described above. Calculations for minor roads are undertaken at a resolution of 1x1 km across the UK.

[36] Road traffic statistics information - GOV.UK
[37] Annual road traffic estimates: vehicle kilometres travelled in Northern Ireland 2014 | Department for Infrastructure
[38] Central, Inner, Outer
[39] Black cabs only – private hire vehicles (e.g., Uber) are not counted here.

Figure 3-6 2023 NO_X road transport emissions on major roads aggregated to 1x1 km resolution.



3.3.3 Cold start, evaporated, break, tyre wear and other road transport emissions

Catalytic converters within a vehicle's engine have an optimum operating temperature and therefore, the emissions from a vehicle before the engine reaches its most efficient need to be calculated and distributed separately.

For cars and LGVs, each trip is assumed to fall into one of three categories: 'home to work', 'home to other locations' or 'work based' trips. Each of these categories has a different methodology.

The 'home to other' trips were distributed across the UK using detailed data on car and van ownership taken from the 2021 census[40]. The 'Home to work' distributions combined this car and van availability data with commuting statistics also taken from the 2021 census.

Work based cold start emissions were mapped on a distribution of all employment across the UK and were reconciled with the outputs from DfT's TEMPRO model (DfT, 2017)[41]. Predicted population movements by mode of transport in the TEMPRO model were produced through reconciling the National Trip End Model (NTEM) version 7.2 (March 2017) datasets, which contains a long-term travel response to demographic and economic trends within Wales, Scotland and the 9 regions of England.

These 3 trip types were combined using a weighting factor based on TEMPRO travel data.

For calculating the cold start distribution of buses and HGVs, the (IDBR)[42] was used. The IDBR indicates the number of employees registered at each business premises in the UK and this employment number was used as a proxy for activity.

For the cold start emissions distribution of buses, the IDBR data was limited to SIC code 49319: *Other urban, suburban or metropolitan passenger land transport (not underground, metro or similar).*

For the cold start emissions distribution of HGVs (both rigid and articulated) the IDBR data was limited to the SIC codes shown in the Table 3-4. Locations in central London[43] were excluded as these were deemed to be office locations.

Table 3-4 SIC codes used to distribute cold start emissions from HGVs

SIC Code	Description
49200	Freight rail transport
49410	Freight transport by road
50200	Sea and coastal freight water transport
50400	Inland freight water transport
51210	Freight air transport
52101	Operation of warehousing and storage facilities for water transport activities
52102	Operation of warehousing and storage facilities for air transport activities
52103	Operation of warehousing and storage facilities for land transport activities
52211	Operation of rail freight terminals
52241	Cargo handling for water transport activities

[40] Scottish data was not yet released at the time, so Scotland still uses 2011 census data
[41] Trip End Model Presentation Program (TEMPro) download - GOV.UK
[42] Inter-Departmental Business Register (IDBR) - Office for National Statistics
[43] defined by the congestion charge zone

SIC Code	Description
52242	Cargo handling for air transport activities
52243	Cargo handling for land transport activities

After reviewing satellite and street imagery, records were screened to identify and exclude businesses that had fewer than 10 or more than 1,000 employees. Upon review, locations with fewer than 10 employees had no visible evidence of HGV or warehouse operations and were often in residential areas. Similarly, locations with more than 1,000 employees were head offices, which did not include any HGV activity.

For all vehicle types, the activity was calibrated using DA level data for consistency and accuracy between the gridded, LA and DA inventories. This creates distribution grids that are year, pollutant and fuel type specific.

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

PM_{10} and $PM_{2.5}$ emissions from brake and tyre wear and road abrasion were distributed using a 1x1 km resolution map of estimated total VKM on major and minor roads.

There are three other small sources of emissions from road traffic included in the inventory - combustion of lubricants and emissions from natural gas and Liquid Petroleum Gas (LPG) vehicles. These sources were distributed using estimates of total VKM calculated from the NAEI maps of traffic flows.

3.4 DOMESTIC

3.4.1 Natural gas

Sub-national energy statistics were used to generate domestic gas use spatial distribution for England, Wales and Scotland. Gas consumption has been aggregated from the bottom-up gas meter at postcode level to 1x1 km resolution. For Northern Ireland, gas connections information for domestic properties was provided by SSE Airtricity[44] and Firmus Energy[45]. Residential use of LPG is allocated to off gas grid output areas, where census returns gas central heating.

3.4.2 Oil and solid fuels

Domestic oil and solid fuel use distributions were created by spatially resolving detailed local information on central heating and house type data from census with data from DESNZ National Household Model (NHM)[46]. This provides average household energy consumption estimates across the 13 regions of England, Wales and Scotland. The domestic oil distribution uses data from the 2011 census while the domestic solid fuel distribution has been updated this year to use the 2021 census (2022 census for Scotland). Regions within England and Wales follow the regional classification scheme, with Scottish regions aligned with the Met Office's 3-tier regional climate (Northern, Eastern and Western) classification to represent the spatial shifts in climate[47]. The census data were combined with full-address matched dwelling locations from Ordnance Survey data to give a more accurate distribution of households at 1x1 km resolution. The following data series were used in the domestic model:

1. **Ordnance Survey (OS) AddressBase products**
   a) AddressBase Plus
   The AddressBase data contains current properties using addresses sourced from local authorities, Ordnance Survey and Royal Mail for England, Wales and Scotland. The product currently contains approximately 37 million records.
   b) AddressBase Islands
   This product includes a comprehensive and authoritative address data for Northern Ireland, containing location data for just under 740,000 residential address records. Each record adheres to the OS common address standard.
2. **Census returns on dwelling type and central heating fuel types**
   a) Office for National Statistics (ONS)
   - The census provided estimates classifying all occupied households by type of central heating at the Output Area (OA) level in England and Wales on census day. A household's accommodation is classified according to the presence and type of central heating if it is present in some or all rooms (whether used or not).
   - OA information of dwelling type (allowed for a more spatially detailed analysis.
   - National Records of Scotland (NRS)[48] - cross-tabulated records
   Estimates classifying all occupied households by type of central heating by dwelling type at the Output Area (OA) level in Scotland on census day.

   b) Northern Ireland Statistics and Research Agency (NISRA) - cross-tabulated records
   Estimates classifying all occupied households by type of central heating by dwelling type at the Small Area (SA) level in Northern Ireland on census day.

- **DESNZ National Household Model[49] (NHM) regional energy consumption estimates per household by house type by fuel type**

  Regional energy consumption estimates of a detailed build form/type (subsets of census dwelling type) and in the presence of central heating were created by the then Department for Energy and

[44] Greater Belfast's Premier Gas Supplier
[45] Natural gas for home & business N.Ireland NI | firmus energy
[46] NHM is now replaced by the National Buildings Model (NBM). However, NHM was used when this dataset was last updated
[47] UK regional climates - Met Office
[48] National Records of Scotland (NRS)
[49] National Household Model - data.gov.uk

Climate Change (DECC) on 31st March 2014 from the NHM scenario "GHG_Emissions_Data_Request" version 3. Coal and oil have been calibrated to DUKES; gas and electricity have been calibrated to metered readings.

- **Defra Domestic Burning Survey**

  Defra undertook a survey of domestic solid fuel use during 2022-2023 and this provides estimate of wood and coal used at regional level as well as urban and smoke control area status. The Number of Wood Fuel users by region from the summary results[50] allowed additional assessment of the wood use mapping.

A summary of how these datasets were utilised in the process is given in Table 3-5.

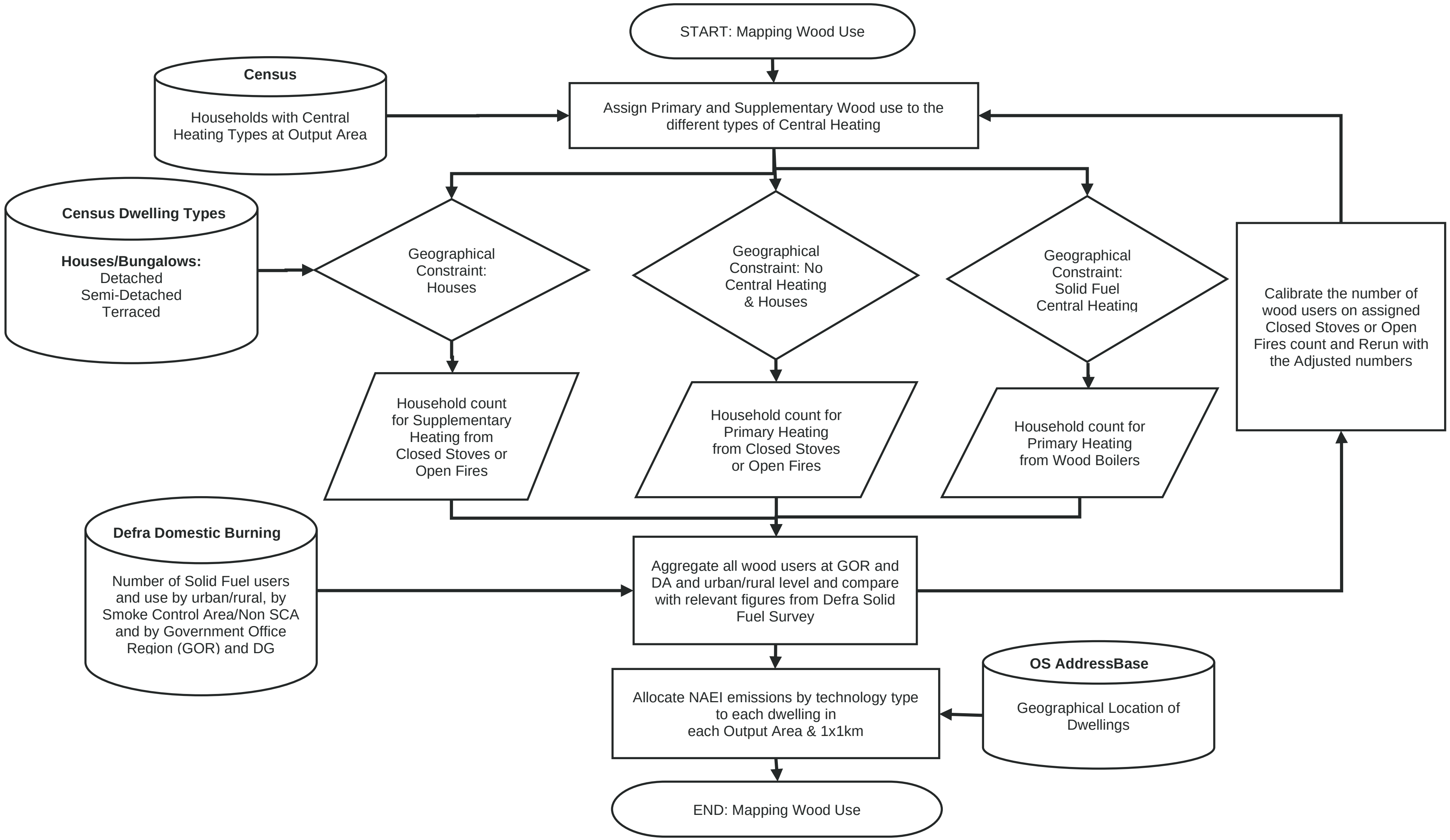
Table 3-5 Description of methods using the above data series.

Data series	Application description
1	OS AddressBase Premium geographies were used to generate a spatially resolved database of ONS/NRS/NISRA census dwelling types distributed within the Census output area boundaries by unique address level coordinates of residential structures within each of England, Wales and Scotland's Output Areas (OA). Northern Ireland has Data Zone (DZ) equivalents to Great Britain's OAs, although on average, DZs contain 200 households while OAs contain 145 households.
2	For England & Wales, ONS cross-tabulated census data provided a breakdown of dwelling type (Detached, semi-detached, terraced, flat/other) by central heating characteristics (gas, electricity, oil, solid, and multiple) at the census Lower Layer Super Output Areas (LSOA)[51]. Fuel splits for a given dwelling type were then applied to OA central heating type counts, based on geographic nesting. NRS & NISRA data across Scotland and Northern Ireland provided a complete breakdown of dwelling type by central heating characteristics at the OA & SA level, respectively. As such, no additional data processing was required.
3	NHM Regional energy statistics by dwelling type and heating type were used to generate spatial distribution databases for domestic gas, oil and solid fuel consumption across England/Wales and Scotland. Households characterised as having a central heating system operating with multiple fuel types were assumed to have an even split of the gas, electricity and solid fuel central heating returns occurring in matching house types of that OA. The NHM is a domestic energy policy and analytical tool constructed from the national housing surveys (English Housing Survey and Scottish House Condition Survey) to characterise Great Britain's housing stock. The Welsh housing stock model is derived from a reweighting of the English Housing Survey, with insufficient information available for the inclusion of Northern Ireland. Energy statistics for 'Western Scotland' were adopted by the NAEI as the most appropriate (with regard to building forms and climate) to represent the domestic energy factors within Northern Ireland.
4	Solid fuel use was assigned to solid fuel burnt in boilers and non-boiler appliances (such as open fireplaces, closed stoves). It was assumed that solid fuel activity for boilers was used in properties which, according to Census 2011, had Solid Fuel Central Heating. Solid fuel activity for non-boiler appliances was assumed to be used in houses and bungalows with No Central Heating.

[50] Quantification of the 2022-2023 Defra Domestic Burning Survey - AQ1050 (Table 1.1)
[51] Lower Layer Super Output Areas (LSOAs) - data.gov.uk

Data series	Application description
	Supplementary heating from the same technologies was considered more likely to be located in houses and bungalows only. Apartments were excluded for solid fuel use to be in line with NHM assumptions on wood use. The number of supplementary heating users for wood was calibrated at a regional level by comparing the total wood user count (as derived from all the above assumptions) against the regional count from the Defra Domestic Burning Survey. Figure 3-7 on the next page presents a summary of how wood use was mapped. Emissions were mapped from the NAEI estimates for residential boiler and non-boiler technologies.

Figure 3-7 Domestic wood use allocation process



3.5 AGRICULTURE

The distributions of PM_{10}, $PM_{2.5}$, NMVOC and NO_x emissions from agricultural sources were mapped by the UK Centre for Ecology & Hydrology (UKCEH) for the first time in 2023. These gridded estimates use the same methodology as applied to agricultural emissions of NH_3, CH_4 and N_2O, which are also submitted by UKCEH. Agricultural census/survey data for 2023 were acquired at the holding level from the four UK countries' statistical authorities, i.e. Defra (England), the Scottish Government (Scotland), the Welsh Government (Wales) and DAERA (Northern Ireland). Aggregated cattle population data were supplied to and processed by Cranfield University from cattle tracing system (CTS) data. The holding level data for the different countries were aggregated to a common set of emission source categories used by the agricultural emission inventory model to ensure compatibility between the different countries' systems and consistency.

The emission estimates are based on a model jointly developed and first implemented for the 2016 inventory by Rothamsted Research, ADAS, UKCEH and Cranfield University. The 10x10 km estimates from the agricultural emissions model have been spatially resolved to produce non-disclosive high-resolution 1x1 km emission maps. The original holding level data are used to derive non-disclosive high-resolution 1x1 km emission estimates. The area-based non-disclosive distribution methodology works by identifying and merging civil parishes which contain fewer than 5 holdings. Within these (parish) areas, emissions were then distributed to suitable land cover types (e.g. arable land, improved grass, part-improved grass, rough grazing etc.), using the UKCEH land cover data (Morton, Marston, O'Neil, & Rowland, 2024). All pollutants and GHGs were distributed using the same methodology, but accounting for the different spatial patterns of the emission sources for each compound.

Agriculture stationary combustion was also mapped using the IDBR employment data and the UK agriculture energy consumption by fuel (ECUK)[52]. The distribution of solid and liquid fuels was made based on the location of smoke control areas and the geographical distribution of gas availability. The method used is explained in summary in Section 3.2 and further detailed in the supporting document *Employment based energy consumption mapping in the UK*[53].

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

3.6 RAIL

The UK total diesel rail emissions are compiled for three journey types: freight, intercity and regional. The rail mapping methodology was updated for the 2019 emission maps and the emissions were spatially disaggregated based on the Rail Safety and Standards Board (RSSB) project that mapped 2019 emission estimates for each line in Great Britain for passenger and freight trains. The emissions along each rail link between Timing Point Locations (TIPLOCs) were assumed to be uniform along the length of the rail link, as no information on either load variation or when engines were on or off is yet available on a national basis. For years other than 2019, emissions along each line have had to be scaled appropriately, as described in the UK Informative Inventory Report (Elliott, et al., 2025), using trends from national statistics on fuel consumption by rail operators.

Rail emissions are distributed across Northern Ireland based on 2019 data from Translink on the number of services run on different routes. These data are for passenger trains only as there is no freight activity in Northern Ireland.

[52] Energy Consumption in the UK - GOV.UK
[53] Employment Based Energy Consumption Mapping in the UK

3.7 SHIPPING

Starting from NAEI 2016, the approach described in Scarbrough et al. (2017)[54] gives a high resolution and greater accuracy to emissions estimates (through improved coverage of various vessel types), as well as enabling a deeper understanding of the spatial pattern of emissions.

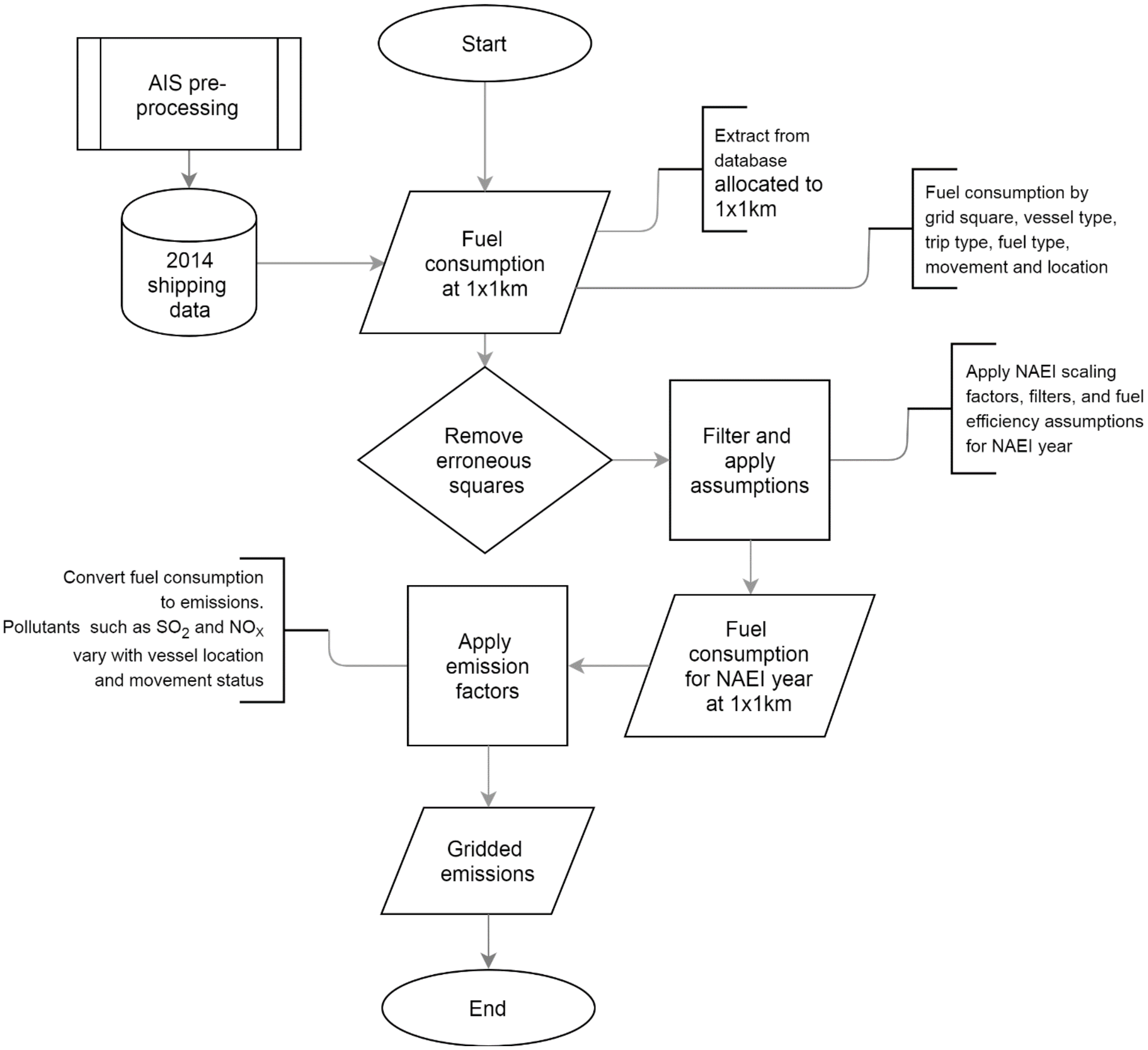
The revised method was developed using Automatic Identification System (AIS) data supplied by the Maritime and Coastguard Agency. AIS is an onboard ship system that transmits a message containing a vessel's position - and other information such as speed - every few seconds, to be received by other vessels, onshore or by satellites[55]. A complete set of one year's worth of AIS data received by terrestrial UK receivers was obtained and processed to give a dataset that records shipping activity at five-minute intervals for the whole of the year 2014. This was then used to calculate fuel consumption and emissions for each vessel for the year 2014 in conjunction with a second dataset of technical characteristics of individual vessels. The estimates for year 2014 were then forecast to the current NAEI year accounting for activity changes over time, the 2015 sulphur emission control area[56] change in sulphur content limit, fleet-wide efficiency gains and additional NO_X emission factor changes to account for fleet turnover.

A detailed discussion of the methodology used to develop a shipping emissions inventory from AIS data can be found in Scarbrough et al. (2017). The mapping process closely followed this approach and is summarised in Figure 3-8. However, differences in reporting requirements between the UK inventory and NAEI maps, and the requirements of the air quality modelling community, necessitate that the map production process diverges from National Inventory compilation in several key ways.

The process of inventory mapping seeks to spatially disaggregate NAEI inventory totals in a way that represents how those emissions are geographically distributed in the real world. AIS data are inherently spatial as they record a vessel's position, and so emissions from each ship can be easily attributed to a 1 km^2 grid using the longitude and latitude accompanying each AIS message. A small number of messages are erroneously located upon terrestrial grid squares (Scarborough et al., 2017, p. 10) or are legitimately in non-UK water bodies within the NAEI mapping area (e.g. vessel movements within major rivers in north-eastern France). These emissions should not exist within the UK shipping map and have been removed.

[54] A review of the NAEI shipping emissions methodology | National Atmospheric Emissions Inventory
[55] AIS transponders
[56] Extending the emission control area to all UK waters - GOV.UK

Figure 3-8 Shipping emissions mapping process.



Other differences between mapping and inventory production processes are listed in Table 3-6, along with the reason why the two datasets differ and a description of how this may influence interpretation. The effect of one of these differences is illustrated in Figure 3-9, which shows NO_X emissions from different trip types included in the NAEI maps. More specifically, the map on the left indicates domestic activity (including fishing vessels), whereas the map on the right shows all remaining activity, such as vessels travelling to international ports, vessels travelling from Crown Dependencies and any passing through activity (e.g. navigating through the English Channel).

Table 3-6 Differences between shipping emissions represented by NAEI gridded emissions and the NAEI National Totals.

Difference	Description		Motivation for difference	Consequence(s) of difference
	NAEI National totals	NAEI gridded emissions		
Vessels 'passing through'	Emissions from vessels passing near the UK but not calling at the UK were excluded.	Emissions from vessels passing near the UK but not calling at the UK are included.	The NAEI gridded emissions aim to provide as complete an evidence base as possible of pollution sources that affect concentrations in the UK, and is not bound by adherence to the reporting requirements of the NAEI.	Including this category of activity will lead to higher intensity of emissions in certain geographic areas and is a better representation of the total emissions burden from all shipping sources.
UK international emissions	Emissions for UK international shipping based on fuel sales records from DUKES.	Emissions for UK international shipping based on AIS data (same method as domestic and non-UK shipping).	As above.	As above. Additionally: Emissions for UK international shipping based on AIS data (fuel consumption basis) is higher than that estimated from DUKES (fuel sales basis). But these two estimates are not directly comparable as UK international shipping also uses fuel not sold in the UK.
AIS message gaps	Emissions calculated from gaps between consecutive AIS messages of >24hours were included as "domestic" for selected vessel types.	Emissions calculated from gaps between consecutive AIS messages of >24hours have been excluded	To avoid allocating a large emission estimate representing >24 hours vessel operation to a single 1km grid cell, which would misrepresent the location of emissions. There was no need to exclude this from the NAEI as that inventory is not spatially disaggregated.	Lower emissions included in the NAEI gridded emissions than in the National inventory total. However, the emissions not included in gridded data are far from the UK coastline and not expected to have a large impact on pollutant concentrations in the UK.
Geographic limits	Emissions from vessels were calculated from AIS data, which were limited by the distance from shore-based AIS receivers, without an additional imposed geographical limit.	Emissions from vessels were calculated from AIS data, which were limited by the distance from shore-based AIS receivers, and with an additional imposed geographical limit of the NAEI grid extent.	To align with the technical specification of the NAEI gridded emissions outputs.	As above.

Figure 3-9 NO_x shipping emissions by trip type for 2023.

Although differences exist between NAEI maps and the UK inventory, mapping outputs also illustrate how key features of the inventory compilation process affect the geography of emissions. One such example is the impact that emissions control areas have on the pattern of SO_2 emissions. From 2015 onwards, vessels within emission control areas are assumed to switch from fuel oil to gas oil[57]. The boundary of the Sulphur Emission Control Area (SECA) around the UK is clearly visible in maps of SO_2 from shipping emissions. Part of the SECA boundary is present off the coast of south-west Britain, and this is shown in Figure 3-10. Along the length of the SECA boundary (dotted white line), a pronounced linear drop in emissions can be seen from west to east. This reflects the model parameter of the fuel switching process, as vessels burn cleaner gas oil when within the SECA (to the east of the boundary) but burn fuel oil when outside its limits, emitting greater amounts of SO_2.

[57] The International Maritime Organisation (IMO) framework of the International Convention for the Prevention of Pollution from Ships (MARPOL) has regulated in MARPOL Annex VI to limit the sulphur content of fuels used by ships and allow the introduction of emission control areas.

Figure 3-10 SO_2 emissions from all shipping around the south-west of the British Isles. The SECA (Sulphur Emission Control Area) to the east of the dotted white line (bottom centre) can be seen as a reduction in emissions.

3.8 INLAND WATERWAYS

Emissions from inland waterways were first included nationally in the 2010 inventory. These were previously not reported in the UK inventory because there are no national fuel consumption statistics on the amount of fuel used by this sector in DUKES. However, as the inventory captures all fuel consumed across all sources in the UK, emissions from inland waterways were effectively captured; however, they were previously being misallocated to other sectors using the same types of fuels.

Emissions from the inland waterways class are now calculated according to the following categories and sub-categories:

1. Sailing Boats with auxiliary engines;
2. Motorboats / Workboats (e.g. dredgers, canal, service, tourist, river boats);
    a. recreational craft operating on inland waterways;
    b. recreational craft operating on coastal waterways;
    c. workboats;
3. Personal watercraft i.e. jet ski; and
4. Inland goods carrying vessels.

A bottom-up approach was used based on estimates of the population and usage of different types of craft and the amounts of different types of fuels consumed. Estimates of both population and usage were made for the baseline year of 2008 for each type of vessel used on canals, rivers and lakes and small commercial, service and recreational craft operating in estuaries or occasionally going to sea. For this, data were collected from stakeholders, including British Waterways (now the Canal and Rivers Trust), DfT, Environment Agency, Maritime and Coastguard Agency (MCGA), and Waterways Ireland. Various proxy statistics were used to scale activities from 2008 to other years, as described in the UK Informative Inventory Report (Elliott, et al., 2025).

Sparse data were available to estimate the distribution of emissions from this sector. As a result, total emissions from the inland waterways sector were mapped using datasets of vessel activity for a limited number of Great Britain and Northern Ireland's waterways. Lock passage information for Northern Ireland were provided by Waterways Ireland for the Shannon Erne Waterway and the five Locks on the Lower Bann Navigation as well as a geospatial dataset. Data for GB, including geospatial data, were provided by the British Waterways. Where data gaps were identified, additional activity data were taken from the 'Members' area of the Association of Inland Navigation Authorities website[58].

The activity data were used in combination with geospatial information to calculate the product of boat activity and distance. This was subsequently combined with the UK's emissions data.

3.9 AIRCRAFT

The NAEI estimates national total emissions from aircraft operating on the ground and in the air over the UK, up to an altitude of 3,000 feet (equating to the take-off and landing cycle). Emissions estimates are calculated from the number of aircraft movements by type at UK airports (data provided by the Civil Aviation Authority) and from estimates of fuel consumption for component phases of the take-off and landing cycle. Figure 3-11 shows the UK airports listed by DfT. Emissions from aircraft at cruise (above 3,000 feet altitude) are also included in the NAEI, although these emissions are not mapped.

[58] Association of Inland Navigation Authorities (AINA)

Figure 3-11 A map of UK reporting and summary airports (source DfT)[59]

59 Department for Transport table code: AVI0109 (TSGB0209)

The locations of airports and their ground-level footprints were revised and mapped with the use of satellite imagery. Take-off and landing emissions were allocated to the individual airports based on the modelled emissions at each airport using the CAA data as outlined above. In addition, at larger airports emissions from aircraft on the ground (e.g. whilst taxiing or in a holding pattern) have been separated from emissions whilst in the air (e.g. climb and approach phases below 3,000 feet) as such activities tend to be more prevalent at larger airports, where greater movement by aircraft on the ground is often required. The former was mapped evenly over the airport apron and runway, the latter over a 4 km strip adjacent to the end of the airport runways, representing emissions from aircraft at climb or descent below 3,000 feet. For smaller airports, all emissions were mapped evenly over the airport footprint. Unlike the rest of the airports, emissions from Heathrow were distributed based on the geographical aircraft activity, as this is reported by the Heathrow Airport Emission Inventory (Walker, 2018)[60].

As a result of recent updates to the UK inventory methodology, estimates of lead emissions from aviation fuel additives have increased. To better understand any local impacts from this source, improvement work was carried out to allow lead additives to Aviation Spirit (AS) to be mapped in the correct locations (as opposed to being allocated at large airports). Specifically, AS, which contains lead additives, is used in aircraft with spark-ignited internal combustion engines. These tend to be small aircraft used for private/pleasure, aero club flights, and heritage military transport aircraft. Therefore, the emissions from such smaller airfields are now included in the spatial emissions inventory. An example of these smaller runways can be seen in Figure 3-12 (Wellesbourne Mountford Airfield).

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

[60] Heathrow Airport 2016 Emission Inventory

Figure 3-12 Line feature class drawn over runways at Wellesbourne Mountford Airfield.

3.10 NON-ROAD MOBILE MACHINERY

Recent improvements to the National Atmospheric Emissions Inventory (NAEI) resulted in the expansion of Non-Road Mobile Machinery (NRMM) to ten separate categories (Elliott, et al., 2025). To align this with the spatial inventory, the NRMM distribution grids required replacing to reflect the following categories: agriculture, airports, construction, forklifts, generators, mining & quarrying, other industry, refrigerated transport, seaports and waste.

Table 3-7 summarises the methodology taken for each of the ten NRMM categories.

Table 3-7 Approaches taken to create the new NRMM distribution grids with their respective UK annual emissions (t) in the spatial inventory for 2023

NRMM Category	Method	CO_2 (t)	NOx (t)	$PM_{2.5}$ (t)
Agriculture	UKCEH land cover maps for arable and improved grassland were weighted according to the inventory NRMM model hours of use per arable/pasture hectare.	1,277,119	8,399	417
Airports	Airport ground footprints were combined with air traffic movements (freight and passenger), with emissions distributed across the airport footprint evenly.	115,526	1,140	41
Construction	CCS construction site data was weighted according to the length of the construction project.	526,248	3,850	150
Forklifts	Combined construction, mining and port distribution grids with an ‘other’ grid using NRMM model contribution proportions. The ‘other’ grid was based on logistics sites and size was used to determine NRMM activity (area for England/Wales and employment for Scotland/Norther Ireland).	101,725	2,340	38
Generators	Combined the construction and industry other distribution grids using NRMM model contribution proportions.	260,681	1,675	80
Mining and Quarrying	The BGS mine and quarry directory was combined with mineral resource and regional production data.	94,153	631	21
Other Industry	Combined the updated IDBR employment distribution grid with the road network using NRMM model machinery type contribution proportions.	92,758	1,462	88
Refrigerated Transport	HGV and LGV VKM grids combined to distribute refrigerated transport emissions across the UK.	88,110	2,446	220
Sea Ports	Port data was combined with DfT freight tonnage traffic to indicate NRMM activity.	96,650	380	16
Waste	For Great Britain, the amount of waste handled at permitted waste sites was used to determine NRMM activity. For Northern Ireland, the maximum quantity of waste to be accepted at permitted waste sites was used.	123,080	273	8

3.11 ACCIDENTAL FIRES AND SMALL-SCALE WASTE BURNING

As with last year's submission of the NAEI, the distribution of biomass fires across the UK was based on Climate TRACE's fire data. These datasets have been developed using a combination of satellite sources such as microwave radar measurements (onboard ALOS), thematic mapping data (Landsat 5), MODIS measurements and the Copernicus' Digital Elevation Models. The full documentation on the methodology can be accessed through the ClimateTRACE methodology report (Saatchi and Yang, 2022). The type of biomass used for these emissions were shrubgrass, wetlands and forest and their usage can been in detail in Table 3-8. Climate TRACE's datasets have been used to create distribution grids of biomass fires for 2015-2023. For 2005-2014 of the timeseries, the UK inventory fire emissions totals were distributed using generic Land Cover Map grids.

The non-biomass distribution of accidental fires, small scale burning and residential outdoor burning across the UK is particularly uncertain. Distribution maps were made using the Land Cover Map supplied by UKCEH[61]. The land cover type was matched to the type of accidental fire as shown in Table 3-8. Classes were added together on an equal basis to make aggregated land cover maps for each NAEI sector.

The 'Accidental fires – dwellings' and 'Accidental fires – other buildings' sectors have been mapped using the ONS population estimates[62].

Table 3-8 Land cover data used to distribute non-biomass emissions from fires.

NAEI Source sector	Land Cover classes (UK CEH)/ Types of fires (Climate TRACE)	Source
Accidental fires - forests	Forest	Climate TRACE
Accidental fires - straw	Wetlands Shrubgrass	Climate TRACE
Accidental fires - vegetation	Wetlands Shrubgrass	Climate TRACE
Accidental fires - vehicles	Suburban	UK CEH
Small scale waste burning	Suburban	UK CEH
Residential outdoor burning	Suburban	UK CEH

3.12 LANDFILL SITES

Emissions from landfill sites feature in the NAEI in two different source sectors. The first is landfill gas combustion, used for electricity generation and/or heating, which is allocated to the energy sector. These emissions are mapped as point sources. The second sector comprises emissions from the landfill sites themselves, which are allocated to the waste sector. This sector was mapped as an area source as gas release has the potential to occur across these open-surface waste sites (uniform release rates are assumed across individual sites due to limitations in the spatial information).

The information on the location and scale of landfill activity varied across the UK, and is based on 2010 datasets. Information on the geographical extent of landfill sites in England and Wales was available from the Environment Agency in GIS format. In Scotland and Northern Ireland, the geographic locations of landfill sites were available from SEPA and DAERA, but not the spatial extent. SEPA figures, however, also provided estimates of infill received by each landfill in 2008. Using this information, estimates of the Municipal Solid Waste (MSW) arisings received by each landfill site were made and used as a proxy for the emission rates for landfills in the UK. Distributions were calculated using:

[61] UKCEH Land Cover Maps | UK Centre for Ecology & Hydrology
[62] Population estimates - Office for National Statistics

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

For the methane emission maps, a set of landfill site boundaries was generated for the NAEI 2017 to allow a more accurate representation of methane emissions from current and historic sites. The information on the location and scale of landfill activity varied across the UK. Information on the geographical extent of landfill sites in England and Wales was available from the Environment Agency and Natural Resources Wales in GIS format. In Scotland and Northern Ireland, only the geographic locations of landfill sites were available from SEPA and DAERA. Approximate spatial extents for each site location were created based on a combination of aerial images, OS MasterMap and/or OpenStreetMap. For England and Wales, where all or part of a historic site had been re-opened, this part was removed where it overlapped the new site boundary data to avoid double counting. An age band was assigned to each landfill site boundary based on current or historic site details and Waste Return Notices. Each band was allocated to a proportion of the total annual emissions recorded per Devolved Administration as shown in the table below.

Table 3-9 Proportions of the 2017 landfill methane emitted from sites operated in different periods.

Site class	Waste deposited in years	Methane generated in 2017
1	1945-1979	4.5%
2	1980-1989	7.5%
3	1990-1999	19%
4	2000-2009	35%
5	2010-2017	34%

3.13 UPSTREAM OIL AND GAS

Emissions from offshore installations are provided by DESNZ OPRED, based on information supplied by the operators of those installations. These include:

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

These estimates are aggregated for the UK totals. For the UK emission maps, the reported emissions by installation were split into emissions from fixed platforms and mobile units such as diving support vessels and drill rigs. The position of wells is known, and so the location of the well that led to the discovery of each field is then used as the location of all fixed platforms associated with that field. It is unlikely that the position of these initial discovery wells will exactly coincide with the position of the platforms intended to exploit those discoveries. However, it was assumed that they would be in that vicinity, and, in the absence of better information, this is the best compromise that can currently be achieved. In some cases, this will inevitably lead to platforms being mapped some distance away from their actual position. This is more evident in large fields with multiple platforms that clearly cannot all be located in the same place. For example, the Brent & Forties fields have multiple platforms that are located some kilometres apart but are mapped at the same location. However, for the purposes of modelling long-range air pollution from these sources, this is not a significant problem. Similarly, there is no population exposure to released pollutants from these sources within their vicinity, other than workers present on the platforms themselves, as there might be for terrestrial industrial installations. Other platforms are used to exploit multiple small fields, and so are likely positioned between those fields. For the moment, though, they are mapped by allocating to a single field and therefore located using the discovery well for that field.

3.14 OTHER SECTORS

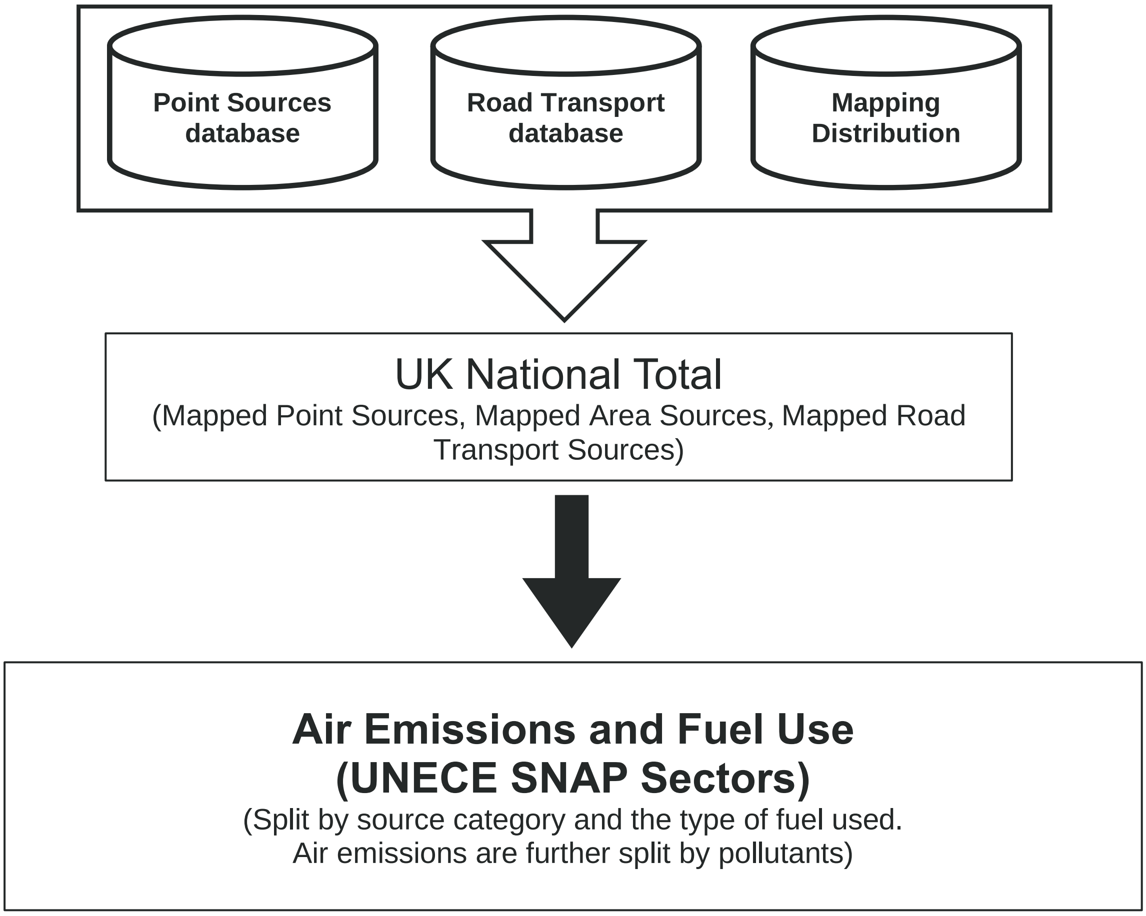
Emissions of PM_{10} from mines and quarries were distributed using historic data from the British Geological Survey on the locations of mines and quarries in the UK. This data set includes the location of the site and a brief description of products and commodities. There are no data on actual production amounts for each mine or quarry. Regional production statistics for the various commodities were therefore distributed across the sites in each region on an equal weight basis. Only open cast mining and quarrying activities are included. The production statistics were aggregated to 1x1 km grid, and PM_{10} emissions were distributed on this basis.

4. EMISSION MAPS AND DATA PRODUCTS

4.1 COMPILATION OF MAPS

The 1x1km resolution maps are compiled in a GIS environment. Maps for each sector are generated by summing the spatially distributed proportions of the NAEI national total (see Figure 4-1).

Figure 4-1 GIS based methodology



Area and road transport source emissions are aggregated for the 11 UNECE source sectors and (GNFR sectors for international reporting), and point source emissions aggregated to a 1x1km grid are added to the area source emissions to calculate a UK total emission map such as those shown in Figure 4-2, Figure 4-3, and Figure 4-4 below for PM_{10}, SO_2 and CO_2 emissions respectively.

A full set of gridded emissions data and maps is available at: https://naei.energysecurity.gov.uk/data/maps including:

- An online interactive UK Emissions Map 2023 at: https://naei.energysecurity.gov.uk/emissionsapp/
- Emissions from point sources 2005 - 2023: https://naei.energysecurity.gov.uk/data/maps/emissions-point-sources
- A set of Gridded emissions data 2005 – 2023: https://naei.energysecurity.gov.uk/data/maps/download-gridded-emissions
- Major roads emissions data: https://naei.energysecurity.gov.uk/data/maps/major-road-emissions

Figure 4-2 UK total PM10 emissions in 2023

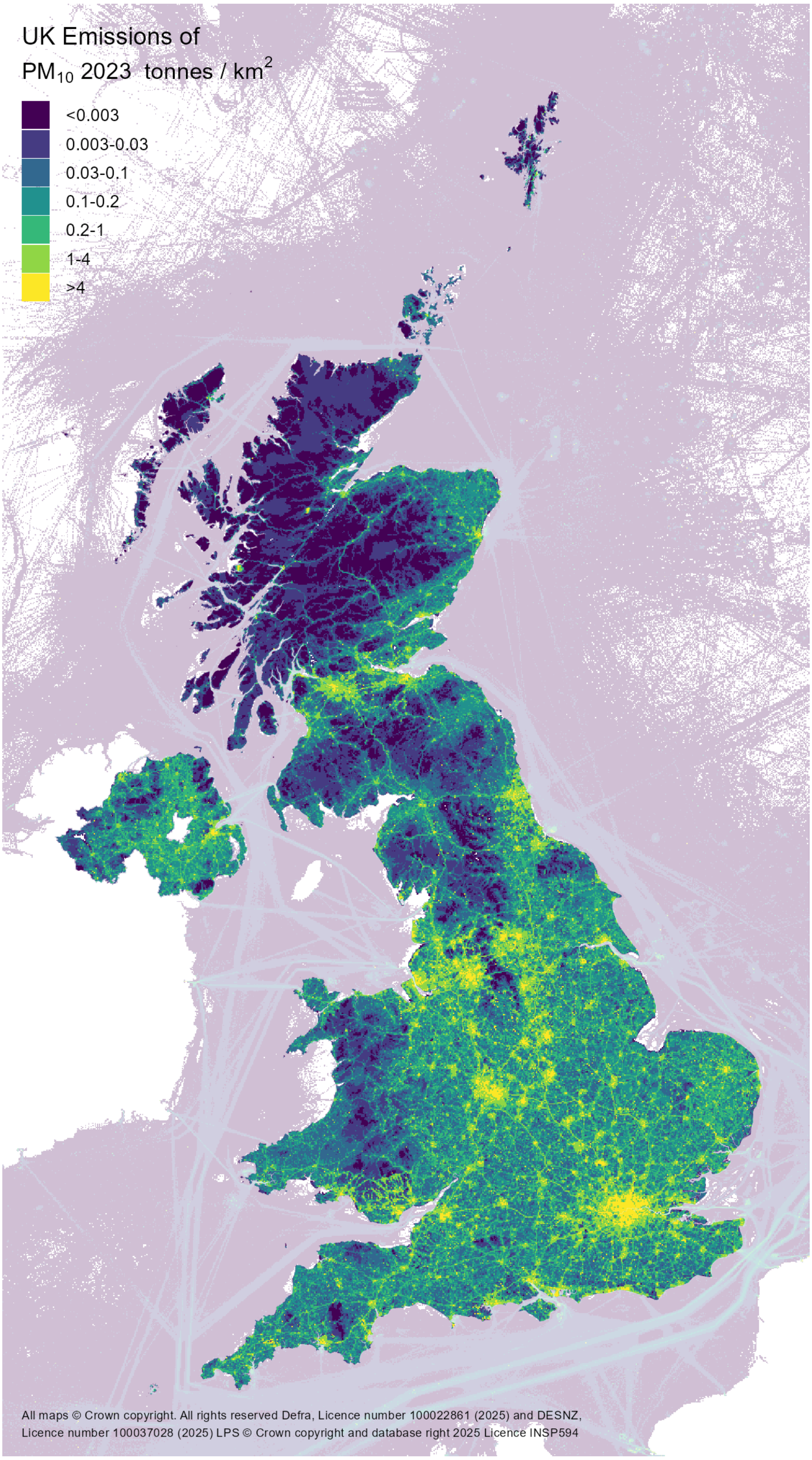
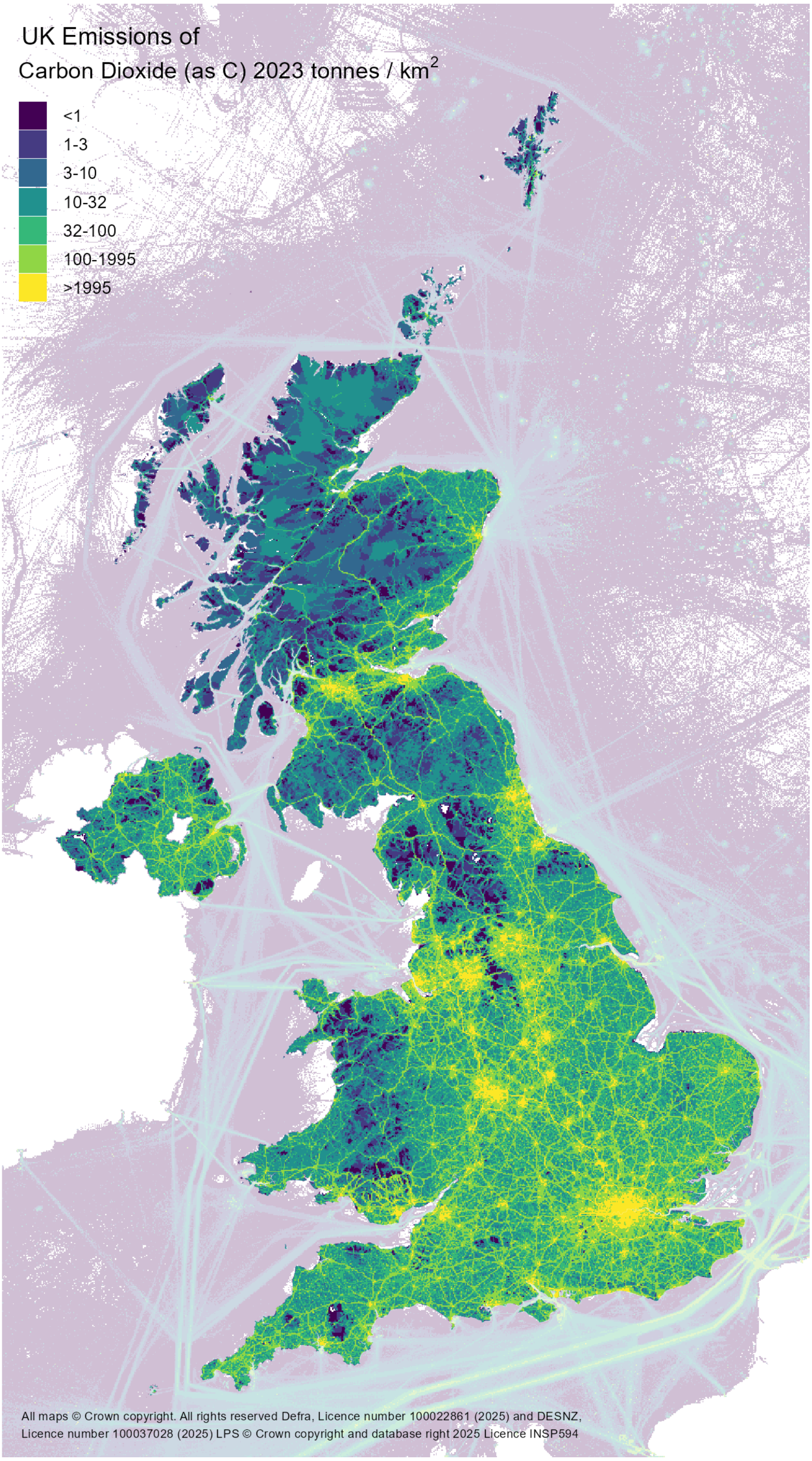


Figure 4-3 UK total SO_2 emissions in 2023

Figure 4-4 UK total CO_2 emissions in 2023 excluding emissions from Land Use Change



5. UNCERTAINTIES AND VERIFICATION

The assessment of uncertainties to spatially disaggregate the emissions is achieved via a semi-quantitative and quantitative approach outlined in the following sections. It should be noted that these assessments of uncertainty do not include an assessment of uncertainty of the emissions themselves.

The semi-quantitative approach for assessing the overall emission map quality involves comparing the proportion of emissions, by pollutant, mapped as point or area sources against the national total. Lower uncertainty is associated with emissions from point sources, as the emissions are geographically constrained to a particular location (i.e. industrial stacks). In terms of emission outputs, point sources are often directly monitored by operators and/or have a record of the materials processed on site, used to inform the mapping and therefore are inherently less uncertain.

A quantitative approach for assessing uncertainty in the pollutant maps is subsequently achieved through the application of uncertainty scores to emissions associated with different polluting activities derived from comparison of NAEI and modelled emissions. This better represents the uncertainty in the geographic distribution of emissions of area sources, with area source grids based on actual production/emission data providing a low uncertainty score. For uncertainties related to the GHG inventory please refer to Brown, et al (2025) and see Annex 2. For uncertainties related to AQPI please refer to UK Informative Inventory Report (Elliott, et al., 2025) and section 1.7.

Verification, involving the comparison of independently-derived data (i.e. ambient air quality monitoring of pollutant concentrations) and air quality model output estimates of pollutant estimates derived using mapped emissions to provide a 'reality check' on the emissions estimates is briefly outlined, and discussed in further detail by Pugsley et al. (2025)[63]. Verification is also a way of addressing uncertainty in spatial emissions by checking spatial patterns, identifying systematic errors, and could inform uncertainty ranges indirectly (e.g. difference between modelled and observed concentrations)

5.1 ESTIMATING UNCERTAINTY

Whilst there is an internationally agreed methodology on how to create spatial maps[64], there is no internationally agreed methodology on how to estimate uncertainty from such maps. Countries develop their own approaches, although many elements are likely to be common between them. Our approach, which is also used as a reference in the relevant section of the EMEP Guidebook 2023 – Spatial mapping of emissions, is discussed in this section. The aim of this uncertainty analysis is to understand areas for methodological improvements in the spatial distribution of emissions and to prioritise them accordingly.

As noted in previous sections, the mapping of emissions has been divided into point and area sources. In general, mapped point source data are expected to be more accurate than those for area sources since they are based upon reliable data produced for regulatory purposes. In contrast, area source emissions are mapped using a variety of surrogate data types of varying quality. Every attempt is made to use the highest quality area source data available (within overall budgetary constraints), and the NAEI team seeks to constantly improve the accuracy of area source mapping by using new, updated, and additional information when this will improve mapping. However, in some cases, surrogate statistics used to spatially distribute emissions from a pollutant source may not be ideally suited to this task. For example, for the road dressing emissions, due to a lack of data on the exact location where the roads have been repaved, a distribution of generic road transport traffic has been used instead. As a result, instead of allocating the emissions to the exact locations where they occurred, these emissions have been spread across the entire road network.

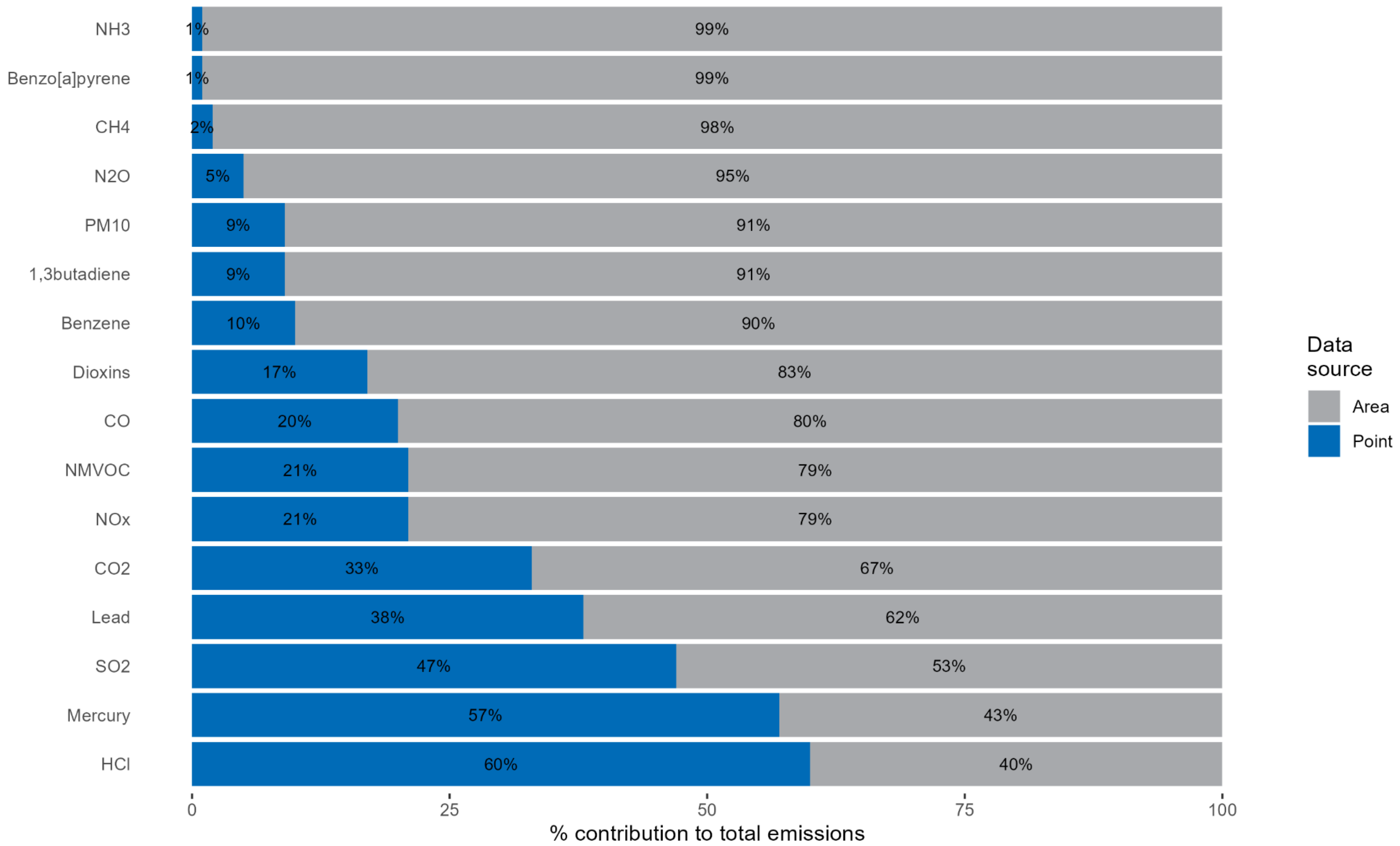
Assessing the overall quality of emission maps is an important component of mapping the NAEI, and the project has approached this in two ways. Firstly, a high-level appreciation of uncertainty can be obtained by comparing the proportion of the national total emissions that are mapped as point or area

[63] Report: Technical report on UK supplementary modelling assessment under the Air Quality Standards Regulations 2010 for 2023 - DEFRA UK Air - GOV.UK

[64] Section A.7: EMEP/EEA air pollutant emission inventory guidebook 2023 | European Environment Agency

sources. Point sources are generally recognised as superior to area sources in terms of the accuracy and precision of both emissions estimates and their location. The percentage of point and area sources that contribute to pollutant totals is shown in Figure 5-1, and suggests that maps for mercury, dioxins, HCl, SO_2 and CO_2 are likely to be of higher quality than those for NH_3, benzo[a]pyrene, CH_4, NO_X and PM_{10} for example. However, this assessment does not differentiate between point source data which are derived from good site-specific emissions data and those which are based on simple modelling, nor does it differentiate between area sources which are mapped using reliable appropriate surrogate statistics and those which use less optimal datasets.

Figure 5-1 Contribution of point sources to mapped emission totals (2023)



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

$$\mathbf{(Emission_A \times Rating_A + Emission_B \times Rating_B\ etc.) / Emission_{Total}}$$

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

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

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

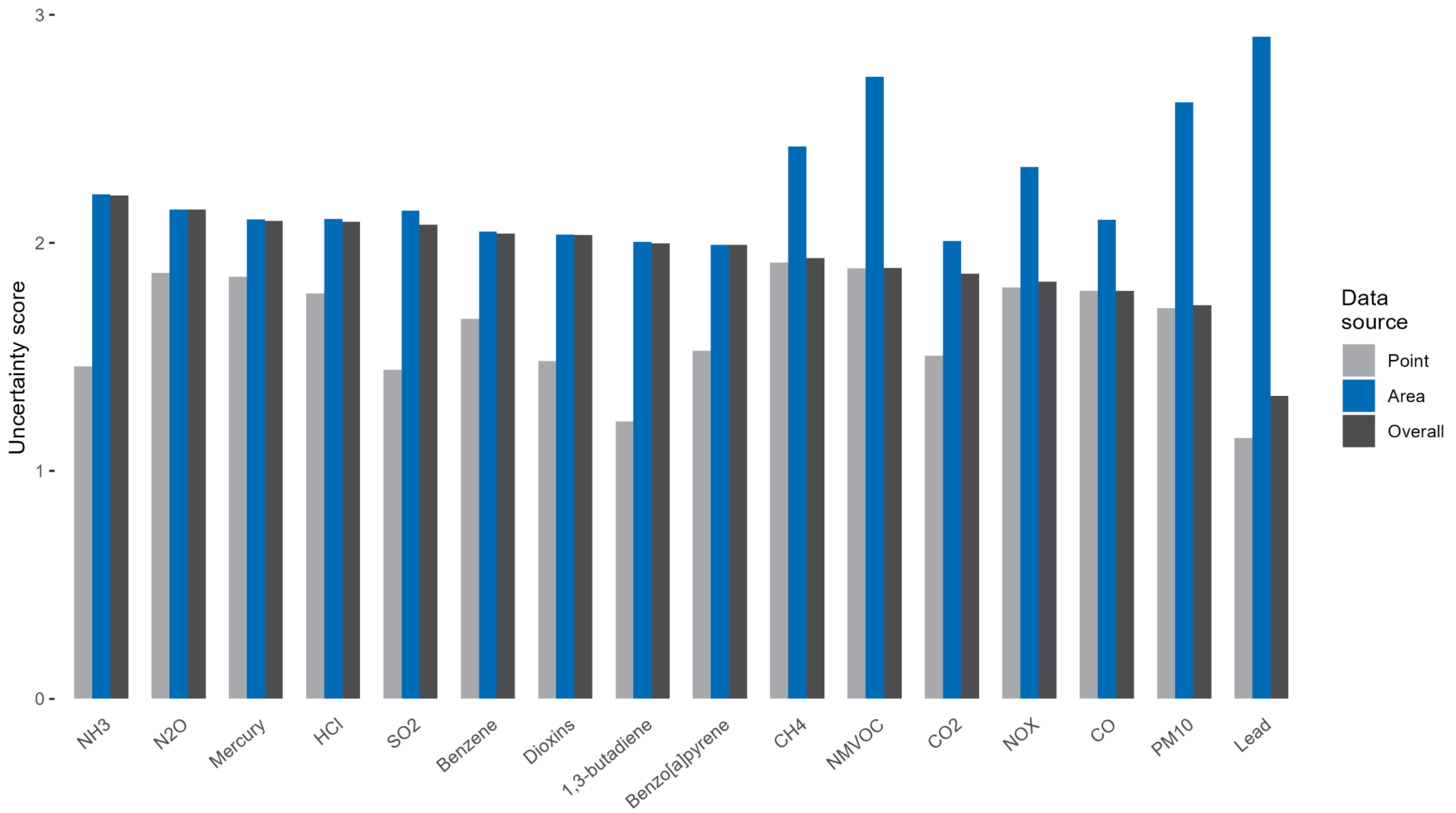
We have not assigned an uncertainty range to each scale point e.g. a score of 1 being equivalent to an uncertainty of <10%. Considerable work would be needed to quantify all the grids sufficiently accurately. In the future, we are considering quoting the uncertainty of spatially disaggregating the emissions based on information such as activity data, fuel consumption or emissions. This would accompany the information in Table 5-1 and this would provide at least an indication of the underlying uncertainty in the data used for the gridded data. Even though the current uncertainty approach does not generate a full quantitative assessment of uncertainty, the resource-efficient semi-quantitative approach still allows the prioritisation of methodological improvements of the gridded emissions.

Table 5-1 Spatial uncertainty scoring system

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

A rating is defined for each of the above parameters, and the mean is used as the overall data quality rating for the source sector. For example, a grid based on ONS population estimate data has been allocated a rating of 2 since it is based on very accurate census data which is generalised across the 1x1 km grid. The use of such a grid to map emissions from decorative paint use is considered appropriate and has been assigned a rating of 1. The area source data for decorative paints therefore has an overall quality rating of 1.5. On the other hand, while a grid based on suburban land cover is also good quality and assigned a rating of 2, its use to map emissions from small-scale waste burning (bonfires) is considered much less reliable and is given a rating of 4. Area source data for these emissions has an overall quality rating of 3. Figure 5-2 shows the resulting confidence ratings for the NAEI pollutant maps.

Figure 5-2 Confidence ratings for mapping elements of the 2023 NAEI maps



5.2 VERIFICATION

Verification can be used to help build confidence in the mapping work and to prioritise future methodological improvements. It is good practice to verify emissions maps, particularly if they are to be reliably used in dispersion models to predict potential exceedances of air quality objectives and UK limit values.

Within this context, it is helpful to draw a distinction between emission inventory verification and validation. Validation is the process of checking that emissions have been estimated using the appropriate protocols, while verification involves comparison with independently derived data such as ambient monitoring data and air quality model output concentration estimates derived using emission maps to provide a 'reality check' on the emissions estimates. Verification is also a way of addressing uncertainty in spatial emissions by checking spatial patterns, identifying systematic errors, and could inform uncertainty ranges indirectly (e.g. difference between modelled and observed concentrations).

There are no other emission maps which can verify, in other words be directly compared to, the maps which are produced from this work[65]. However, there are steps which can be taken to help verify this work.

The NAEI uses the outputs from Defra's Pollution Climate Model (PCM) maps (produced under the Modelling of Ambient Air Quality, MAAQ project) to help judge the quality of the emission maps generated in this work. Since atmospheric concentrations depend on complex processes of atmospheric chemistry and dispersion of emissions in the atmosphere there will not be a direct relationship between the atmospheric concentration and emission maps.

The model calibration indicates how well the modelled concentrations, based on the NAEI emission maps, correlate with the measured concentrations at the locations where those measurements are made. The model calibration is completed after the spatial emissions team finishes and reports the NAEI emission maps and methodology report. Therefore, the team does not have this information available when writing the report. The closest alignment of data sets is a comparison of the previous year's MAAQ with the current NAEI emission maps. The spatial emissions team routinely seeks feedback from the MAAQ project in a programme of continuous improvement so that features identified through the application of the emissions data can be challenged and methodologies reviewed.

The estimates of annual mean background concentration of air pollutants are made up of three parts:

- Contributions from relatively distant major point and area sources such as power stations, large conurbations and transboundary sources. Measurements from monitoring sites well away from local sources, for example from rural stations within the UK's Automatic Urban and Rural Network[66] (AURN), provide good indications of the spatial variation of concentrations arising from distant sources;
- Contributions from local point sources; where for example, concentrations are modelled using dispersion models parameterised using data from individual industrial sites;
- Contributions from more local diffuse sources treated as area sources with emissions from sectors such as road transport and residential combustion.

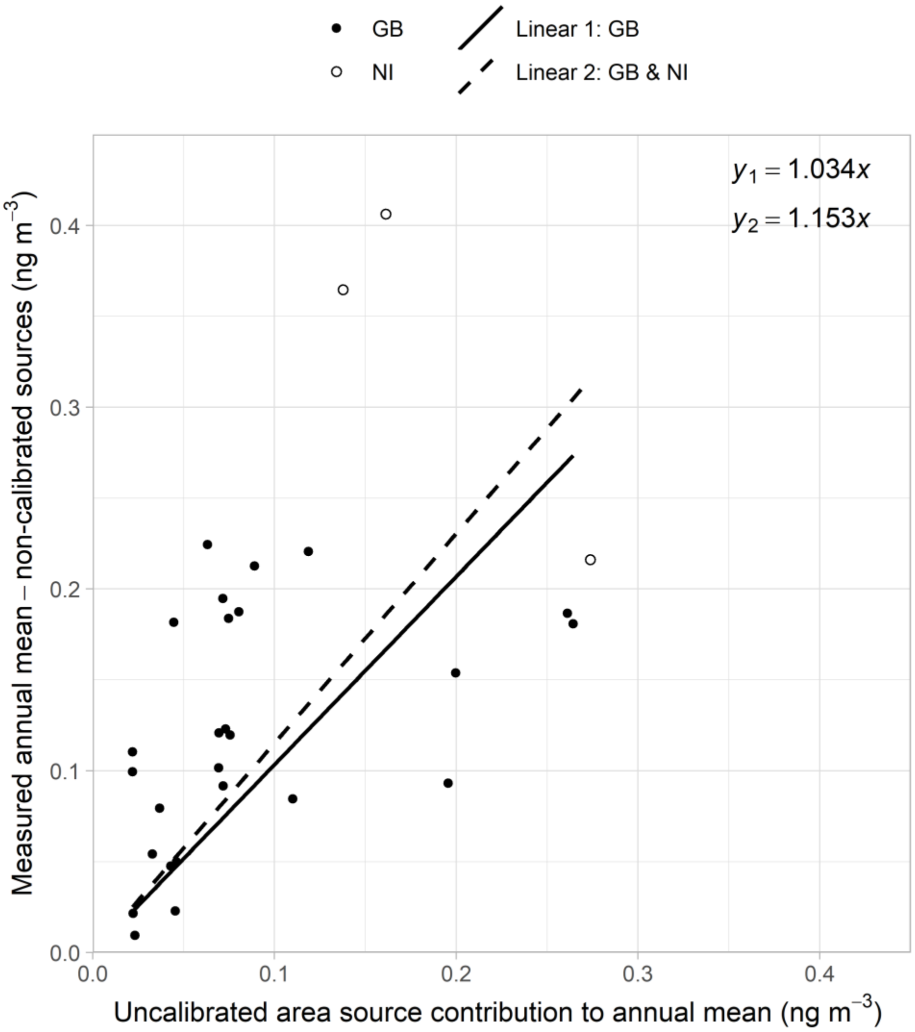
The NAEI area source maps are routinely used in air quality models to characterise the local contribution to ambient concentrations of air pollutants. National-scale air quality modelling activities use emissions from the NAEI area source maps to model ambient concentrations across the whole UK. As part of this work, a dispersion kernel modelling approach is applied to the area source emission maps within an area of 33x33 km square surrounding each receptor location, to calculate the uncalibrated contribution from area sources to the ambient concentration at a central receptor. Ambient measurements from monitoring sites are then used to calibrate this modelled area source contribution. The strength of the relationship between measured concentrations and the model results (based on the NAEI emissions) provides an indication of the quality of the emission distribution as it compares actual concentrations measured with predicted concentrations from the mapped emissions. The example shown in Figure 5-3 below, indicates scatter in the B(a)P area source calibration as modelled using NAEI 2022 emission maps. The calibration coefficient for Great Britain (1.034 for the year 2023 has improved over UK-wide calibration coefficients for previous assessments using older versions of NAEI (e.g. 6.434 for the year 2014). The improvement in the coefficients and reduced scatter in

[65] Some investigatory work has been done for Defra comparing satellite air quality maps with the emission maps generated as part of this work, but the data in these maps are not directly comparable.

[66] Interactive monitoring networks map - DEFRA UK Air - GOV.UK

the fit suggests improved understanding of the scale and distribution of emissions from domestic wood combustion first introduced in the NAEI 2015 emission maps.

Figure 5-3 Calibration of area source model for B(a)P for the year 2023, where the solid regression line and y_1 refer to Great Britain only, and the dashed line and y_2 refer to Great Britain and Northern Ireland.



Further information about the comparison of monitoring and mapped area sources is described in the report Technical report on UK supplementary modelling assessment under the Air Quality Standards Regulations 2010 for 2023 (Pugsley K. , et al., 2025).

The UK inventory uses an inverse modelling approach to help verify estimates of emissions for a selection of GHGs. The approach is described in Annex 6 of Brown, et al (2025). This modelling approach is not spatially resolved. Work is planned to expand this analysis to verify the NAEI maps against atmospheric concentrations from the UK DECC network (UK Deriving Emissions related to Climate Change network[67]).

[67] UK DECC Network | School of Chemistry | University of Bristol

5.3 EARTH OBSERVATION BASED VERIFICATION

Remote sensing measurements using satellites provide a unique opportunity to verify ground-up emissions estimates from the NAEI against an independently derived dataset. Satellite observations represent a good complement of surface observations since surface observations are not homogenously distributed over the UK. For some pollutants, satellite observations provide better coverage than current ground-based monitoring and thus enable improved spatial distributions of the pollutants. On the other hand, satellite observations may have a coarser horizontal resolution compared to ground-based measurements, and only provide one or two observations per day over the same location. The satellite observations can be influenced by weather effects such as cloud coverage, which may reduce the accuracy of retrievals, and the wind speed, which can spread the pollution far from the source.

The studies on this topic, using satellite-derived data to infer emissions, are still the subject of discussions in the research community. Most of the studies use a complex modelling approach which requires a strong technical expertise and significant computing resources to derive the emissions.

Alternative approaches to estimate emissions over large source regions, which can be natural such as volcanoes (e.g. Fioletov et al., 2020) and anthropogenic, such as cities and industrial sites (e.g. Beirle et al., 2021), have been deployed during the last decades in the research community. These approaches are feasible with the satellite observations presented in this report, but it is beyond the scope of this document. It is worth noting recent studies have applied these methods over British conurbations[68] (Pommier, 2022; Pope et al., 2022). It is also important to highlight the European projects, such as the Sentinel EO-based Emission and Deposition Service (SEEDS)[69] and World Emission[70] comparing the methods and aiming to standardise the approaches on inferring emissions with satellite data.

A qualitative comparison of spatial patterns between the NAEI emission maps and vertical column density maps for the corresponding pollutants measured by the satellite can be made, even without directly estimating the emissions from satellite observations as shown in the previous reports (e.g., Tsagatakis et al., 2024[71] and Tsagatakis et al., 2023[72]). This type of approach helps to highlight the main source regions and provide an initial comparison between pollutant distributions. This report considers how well atmospheric measurements of the column densities of NO_2 and NH_3 made by satellite-based instruments compare with maps of these pollutant emissions compiled as part of the NAEI. Unlike previous reports, SO_2 has not been considered here. The previous reports showed the SO_2 products did not have a sufficient quality for the purpose of an emission inventory verification in the UK.

5.3.1 Methodology

The approach used in this report is to compare qualitatively the spatial distribution of emissions and the distribution of remotely sensed atmospheric columns of two NAEI pollutants: nitrogen oxides (NO_x), and ammonia (NH_3). This corresponds to a raw comparison and further analysis and development are necessary to fully derive emissions from these satellite observations. It is also worth noting that in the satellite observations, the natural sources cannot be distinguished from the anthropogenic sources, while the NAEI corresponds to the total anthropogenic emissions of each pollutant. In addition, the approach presented in this report follows the same method used in the report published last year (Tsagatakis et al., 2024).

Qualitative assessment is the preferred approach because a number of issues need to be overcome to provide a quantitative assessment of bottom-up NAEI and top-down satellite data. Emissions inventory maps use reported or inferred evidence of activity to spatially represent the amount of a given pollutant produced at source. Satellite instruments measure the spectrum emitted by the Earth's atmosphere or the backscattered solar light from the atmosphere into space. The concentrations are then retrieved from these measured spectra by algorithms. The retrieval algorithms take into account different parameters, depending on the characteristics

[68] large urban area that results from the merging of several cities, towns, or other urban settlements, which have grown and expanded to the point where they form a continuous, interconnected urban region

[69] SEEDS - Sentinel EO-based Emission and Deposition Service | SEEDS

[70] https://www.world-emission.com/

[71] UK Spatial Emissions Methodology - A report of the National Atmospheric Emission Inventory 2022 | National Atmospheric Emissions Inventory

[72] UK Spatial Emissions Methodology - A report of the National Atmospheric Emission Inventory 2021 | National Atmospheric Emissions Inventory

of the instruments (e.g. angle of atmospheric sounding, instrumental noise) and of the retrieved species such as the influence of the stratosphere, the interference of other absorbing atmospheric species etc.

In principle, atmospheric measurements of relatively short-lived species such as NO_2 (typical lifetime: 2 to 12 hours), and NH_3 (typical lifetime: from 2 hours to 2 days in exceedance conditions) should roughly correspond to the emissions sources. However, the relationship between primary emissions and atmospheric concentrations is more complex. The pollutants can be transported and so well mixed in the atmosphere, and chemical reactions through the atmosphere disrupt the connection between emissions and atmospheric composition. Inverse modelling can be used to reconstruct a source emission from remotely-sensed data, but such analysis is beyond the scope of this report.

Despite these differences, atmospheric composition measured by satellite instruments can still be used to check mapped emission sources by estimating the correlations between both distributions and analysing the differences.

Units of measurements are not directly comparable with the NAEI emissions, but spatial patterns of pollutant distributions (atmospheric column densities) are indicative.

5.3.2 Satellite data

In terms of data processing, satellite products and data are generally provided at different levels. The Level 0 corresponds to the unprocessed instrument data, the Level 1 corresponds to the calibrated spectra measured by the instrument and Level 3 products are the averaged data. For this report, we have used the Level 2 products, corresponding to the satellite observation per pixel.

The tropospheric NO_2 satellite product from the European Space Agency (ESA) and the NH_3 from the joint team of the Free University of Brussels (ULB) and the Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS) have been used.

The NO_2 are measured by TROPOspheric Monitoring Instrument (TROPOMI) and NH_3 by the Infrared Atmospheric Sounding Interferometer (IASI).

5.3.2.1 TROPOMI: NO_2

TROPOMI was launched on the ESA’s Sentinel-5 Precursor mission on 13 October 2017. It measures the concentrations at ~13:00-14:00 UK time every day.

Earth observation data appropriate for mapping atmospheric concentrations of NO_2 and SO_2 were freely available from the Copernicus Data Space Ecosystem[73]. The corresponding data set (per orbit) was downloaded over the region covering the latitudes 48°-62°N and longitudes 12°W-4°E for the available dates in 2023. Data comes as a density measured within the troposphere. The “OFFL” (offline) version of NO_2 tropospheric columns have been used.

5.3.2.2 IASI: NH_3

IASI was launched onboard the EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) MetOp platforms, IASI-A on MetOp-A in 2006, IASI-B on MetOp-B in 2012 and IASI-C in 2018. We have used v4.0.0R (reanalysed) of the IASI L2 ammonia product (total column), which are freely available on the Aeris data infrastructure[74]. Since the year of interest for this report is 2023, only data from IASI-B and IASI-C have been used. Indeed, IASI-A stopped providing data after 2020. The instruments measure the vertical columns at ~09:00-12:00 UK time every day. We have downloaded the data covering the region within the latitudes 48°-62°N and longitudes 12°W-4°E.

5.3.2.3 Quality of the data

Table 5-2 summarizes the data sets presented in this report with the filters used, as recommended by the data providers.

[73] Copernicus Data Space Ecosystem | Europe's eyes on Earth
[74] NH3 – IASI portal

Table 5-2 Earth observation datasets used for emission comparisons in this report

Pollutant	Dataset	Recommended filters	Period used	Measurement unit
NO_2	TROPOMI/Sentinel-5P NO_2 Tropospheric Column L2 OFFL dataset	quality flag ≥ 0.75[75]	01.01.2023 - 31.12.2023	Molecules.cm^{-2}
NH_3	IASI/Metop B and C reanalysis ANNI-NH3-v4.0.0	- postfilter = 1[76] - morning orbit[77]	01.01.2023 - 31.12.2023	Molecules.cm^{-2}

In our analysis, we have used the recommended filters as listed by the data provider (i.e. the post processed filter and the orbit).

5.3.2.4 High resolution maps

To derive high resolution maps of satellite data, the pixel-averaging approach was applied. This approach slices each satellite pixel into multiple sub-pixels, which are mapped onto a high-resolution grid. This technique was used in previous NAEI spatial emissions methodology reports (e.g. Tsagatakis et al.) and helps to artificially increase the resolution of the spatial distribution.

This method relies on the original resolution of the satellite pixel. Thus, 1x1 km maps could be calculated with the TROPOMI data (original ground pixel of 3.5 × 7 km), while a 2x2 km map was prepared with IASI data (original ground pixel of 12 km of diameter at the nadir).

5.3.3 Comparison of NO_2

It is worth reminding that space-based data from TROPOMI measure NO_2 and not NO_x, which is mapped by the NAEI. However, NO_2 data from TROPOMI shows general agreement with regional-level spatial patterns present in the NAEI total NO_x emissions map (Figure 5-4).

Even with the differences between both distributions in terms of quantity represented, i.e. a mean tropospheric column with the satellite observations for 2023 (in molec.cm^2), and the total NAEI emissions in 2023 (in tonnes), clear similarities are visible in both maps.

In the NO_2 mean calculated from the TROPOMI observations, large urban areas in the UK are well distinguishable, especially London but other conurbations are also seen, such as Glasgow, Manchester, Birmingham, Leeds, Hull, and Leicester to cite few examples. Smaller cities are also visible, such as the coastal cities of Bristol and Southampton. These NO_2 “hotspots” are similar to those shown for the year 2019 (see

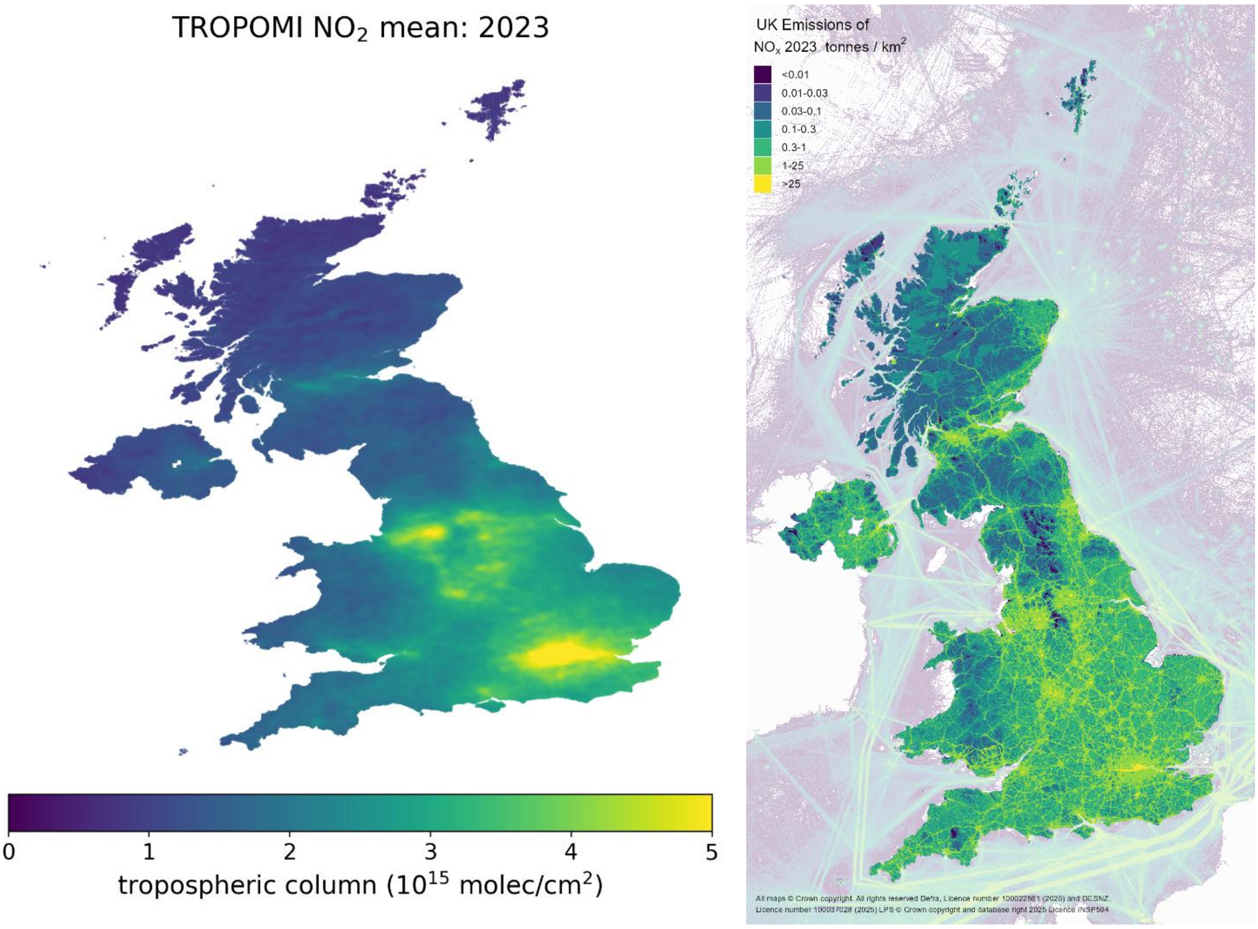
[75] S5P MPC Product Readme Nitrogen Dioxide
[76] NH3R-ERA5_readme – IASI portal
[77] Van Damme et al. (2021), Global, regional and national trends of atmospheric ammonia derived from a decadal (2008–2018) satellite record - IOPscience

Figure 5-5 in Tsagatakis et al., 2021[78]) and more pronounced compared to 2020 (see Figure 5-4 in Tsagatakis et al., 2022[79]).

The satellite map also confirms the lower NO_2 values, and therefore lower emissions regions such as in Northern Scotland and Wales.

Differences are also noticeable, such as the main roads which are not detected by the satellite observations and some larger values near the Scottish Northern coast. It is also worth noting only the TROPOMI data over land have been used so the NO_2 emissions from shipping are not present on the map.

Figure 5-4 NO_2 tropospheric column mean in molecules/cm^2 in 2023 (Left). Total NAEI NO_x emissions in tonnes for 2023 (Right). Both maps are plotted in 1x1 km



5.3.4 Comparison of NH_3

It is worth noting that the IASI map is plotted in a 2x2 km grid, while the resolution of the NAEI map is 1x1 km (see 5.3.2.4).

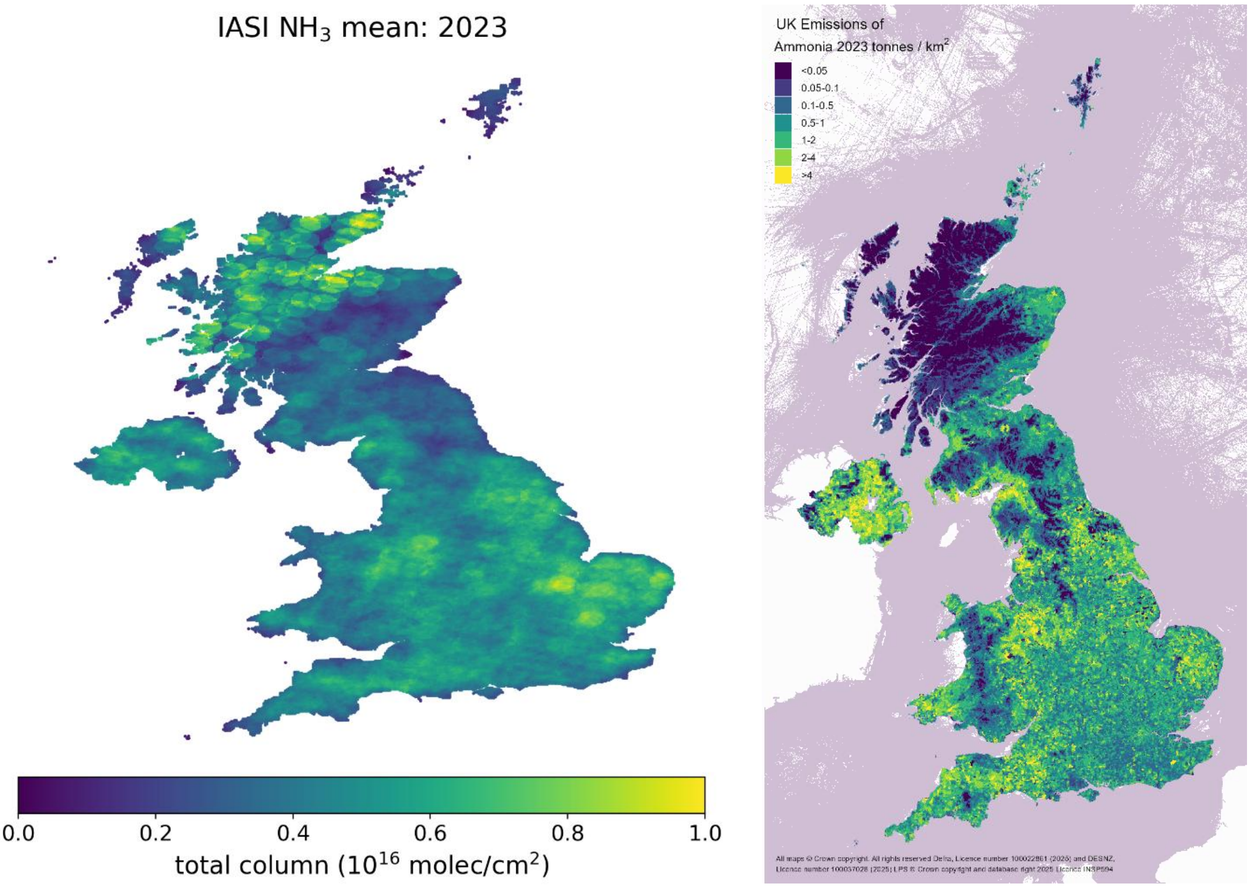
The calculated NH_3 distribution is rather homogeneous, however, we can still observe larger total columns in Northern Ireland, Cambridgeshire, and Staffordshire, which also present in the emission map (Figure 5-5). It is worth noting a limited number of observations in the North of Scotland causes the circle shapes visible in the IASI derived map which are probably not representative of an annual picture, and thus these higher values of NH_3 are likely not the result of larger emissions.

[78] UK Spatial Emissions Methodology - A report of the National Atmospheric Emission Inventory 2019 | National Atmospheric Emissions Inventory

[79] UK Spatial Emissions Methodology - A report of the National Atmospheric Emission Inventory 2020 | National Atmospheric Emissions Inventory

However, regions such as Dumfries and Galloway, and North Yorkshire do not experience as high NH_3 columns as the NAEI emission map could suggest.

Figure 5-5 NH_3 total column mean in molecules/cm^2 in 2023 (Left). Total NAEI NH_3 emissions in tonnes in 2022 (Right). The IASI map is plotted in 2x2 km while the NAEI map is plotted in 1x1 km



5.3.5 Summary

This section has presented a qualitative comparison between the vertical density maps from TROPOMI (NO_2) and IASI (NH_3) measurements and the NAEI emission maps in 2023.

The comparison between the NO_2 measurements and the NO_x emission map has shown better agreement compared to NH_3. The more consistent results for NO_2 were expected since the majority of UK NO_2 emissions originate from anthropogenic sources, which are well represented in the NAEI. Furthermore, NO_2 is the more mature product among the different pollutants retrieved from TROPOMI. The larger urban areas exhibit the highest NO_2 tropospheric columns, and the distribution is in general agreement with the NAEI emission map. However, the larger values related to road traffic are still challenging to observe from space on the actual road network, compared to the NAEI maps, where the spatial pattern of the roads is noticeable. This is due to the limited horizontal resolution of the satellite observation and the impact that the other large sources have in the area.

The satellite NH_3 distribution has highlighted regions with larger columns in 2023 in Northern Ireland, Cambridgeshire, and Staffordshire which are more consistent with the distribution of NH_3 emissions in the NAEI maps. However, other source regions shown in the NAEI maps, such as Dumfries and Galloway, and North Yorkshire did not experience as high NH_3 columns in 2023 and hence contrast with the distribution that the NAEI emission map suggests. Differences in NH_3 distribution that are also noted in other years will require more investigation, for example by distinguishing any weather effects (wind, surface temperature), changes in the satellite observations (e.g. changes in data version), impact of emissions or changes in atmospheric chemical reactions with other pollutants.

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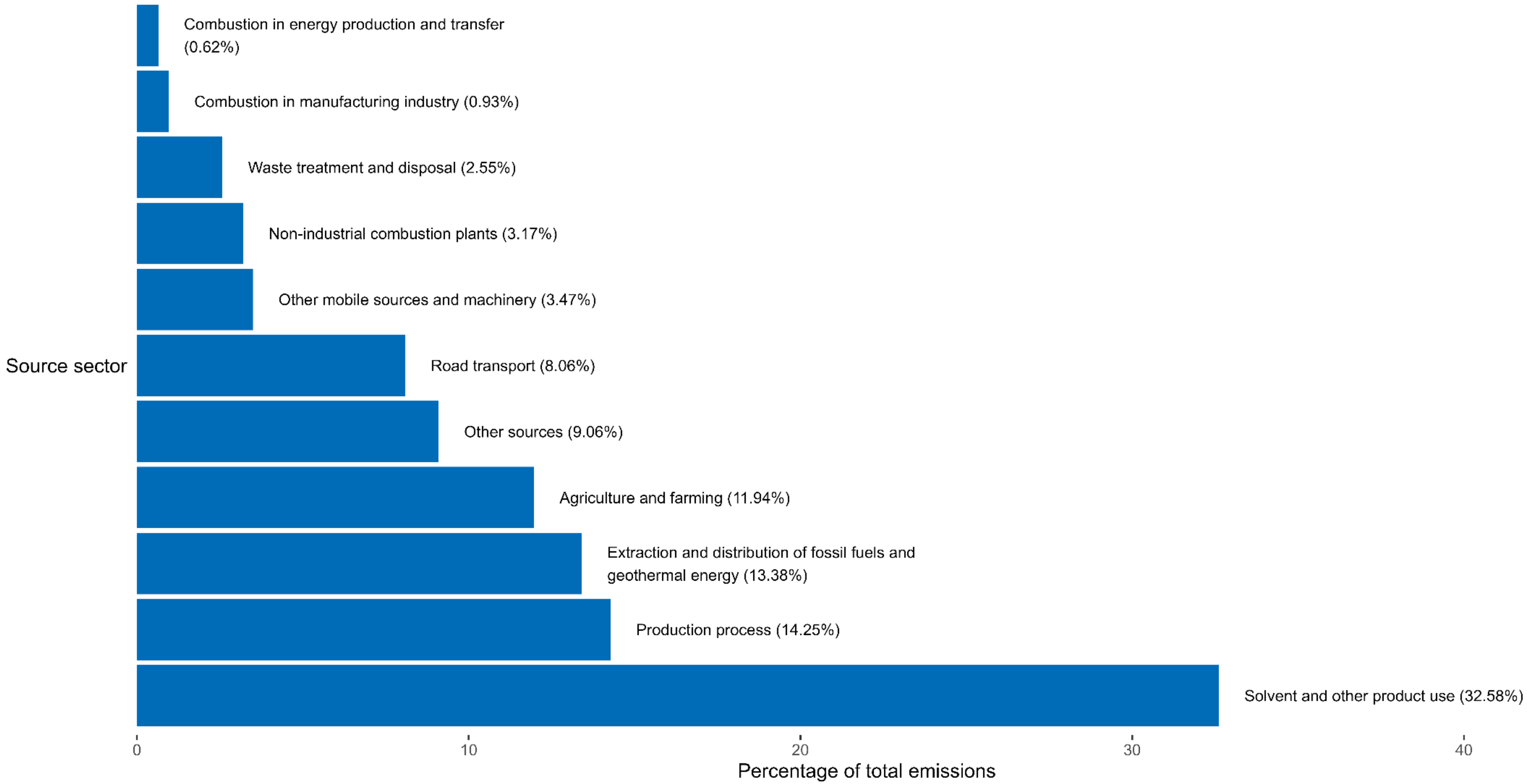
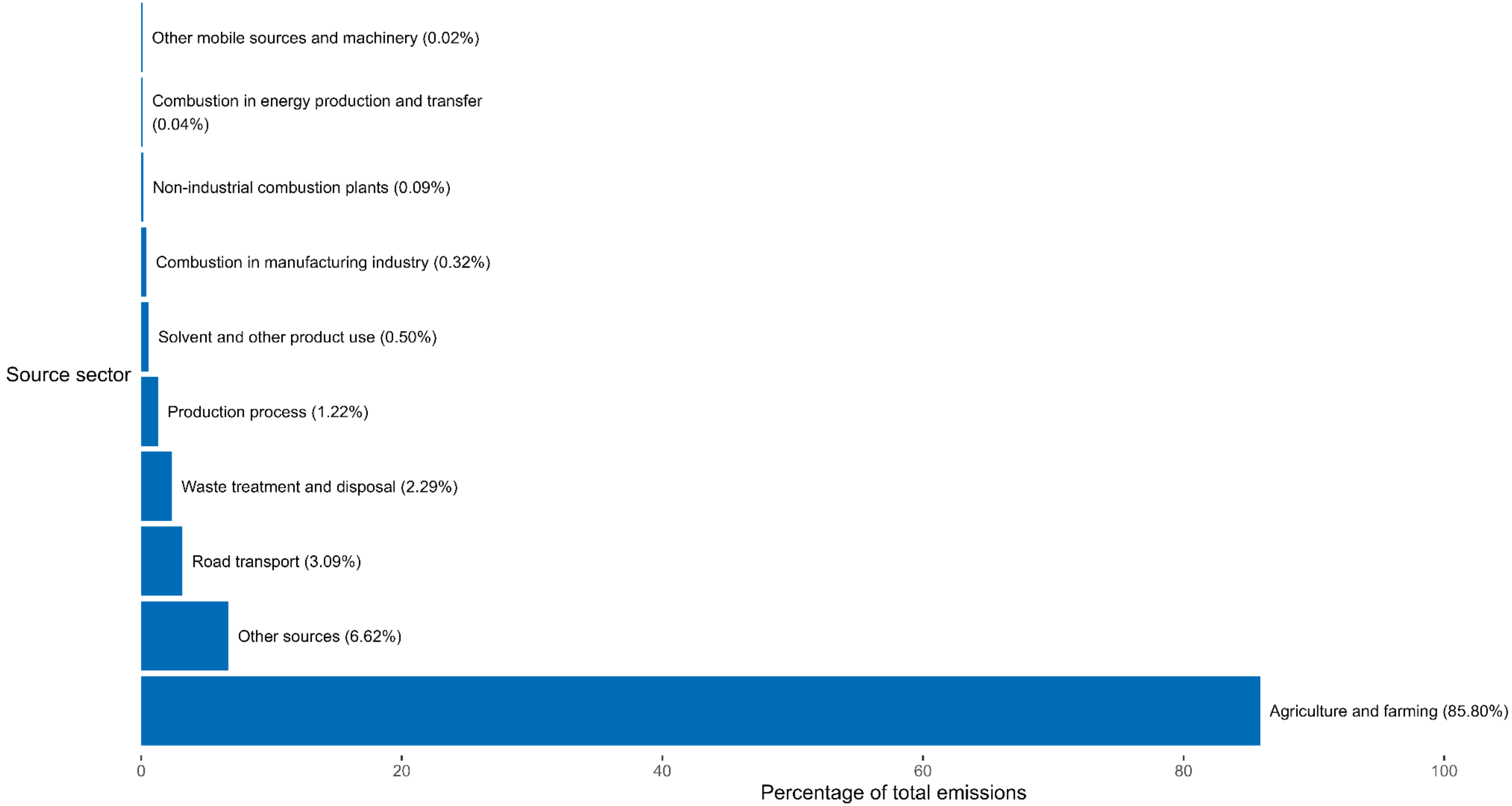
APPENDICES

APPENDIX 1 BAR CHARTS OF UK EMISSIONS SPLIT BY UNECE SECTOR

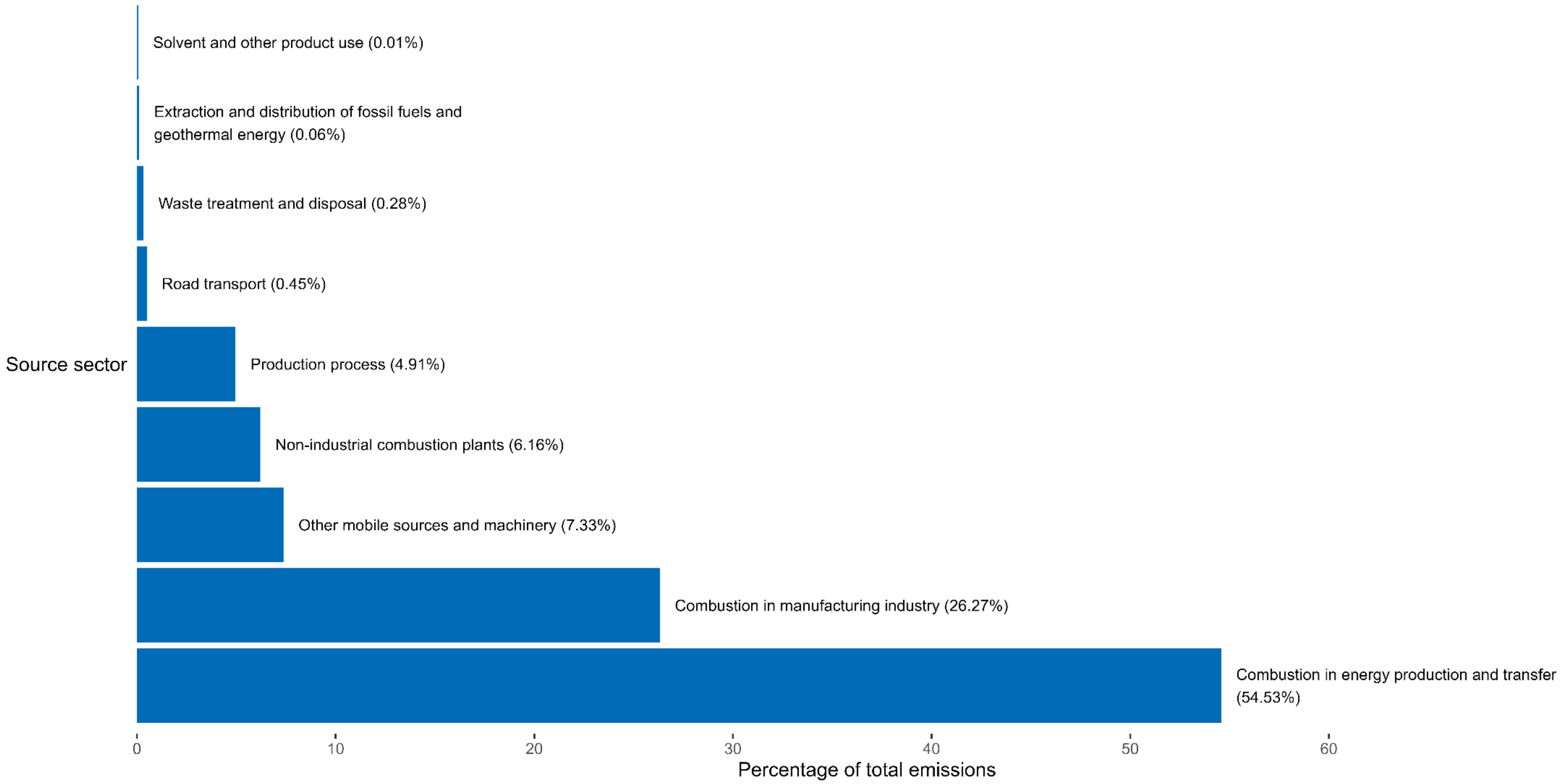
UNECE Source Sector contribution to the total NMVOC emissions in 2023 as shown on the NAEI 1x1km maps



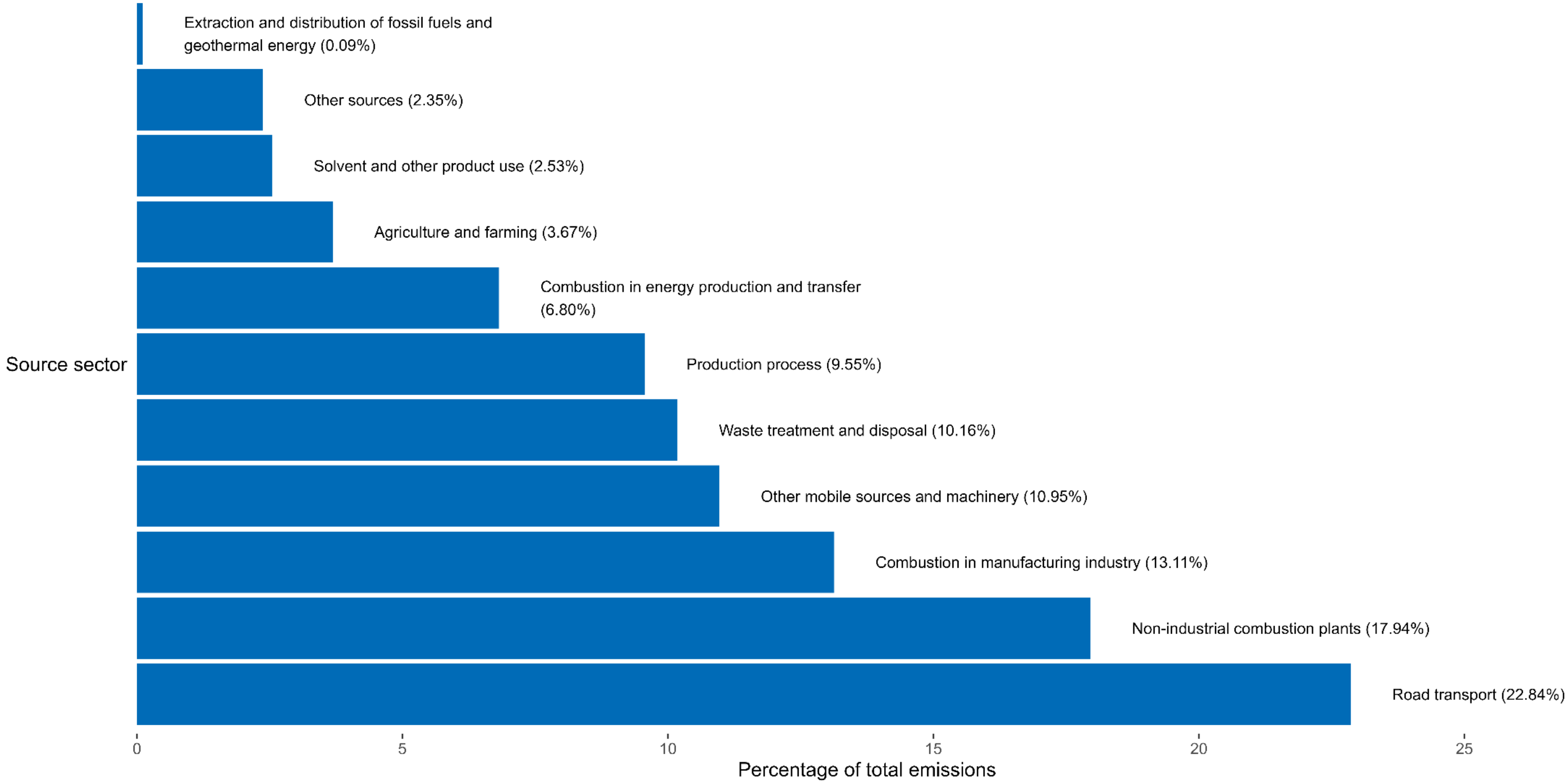
UNECE Source Sector contribution to the total Ammonia emissions in 2023 as shown on the NAEI 1x1km maps



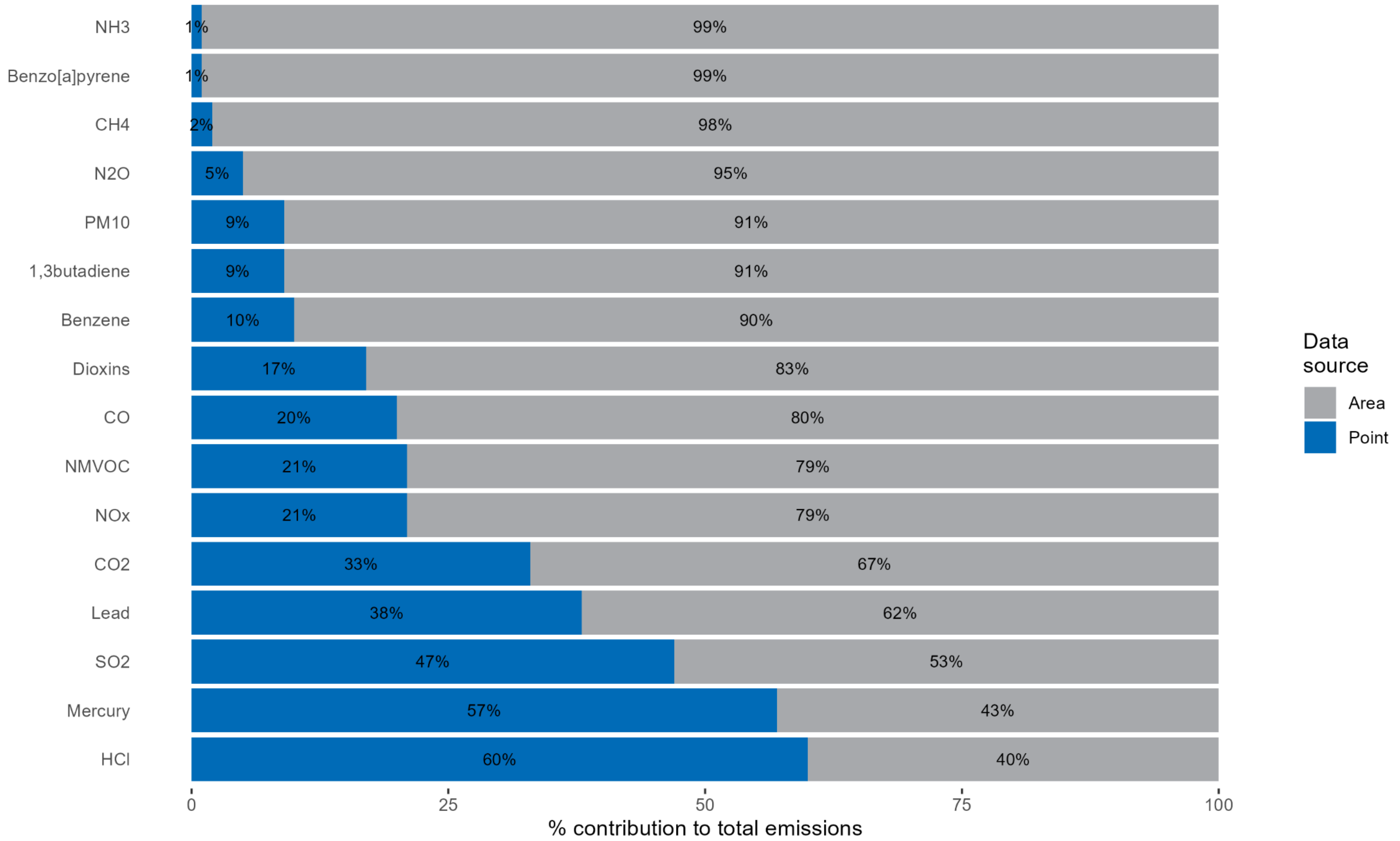
UNECE Source Sector contribution to the total Sulphur Dioxide emissions in 2023 as shown on the NAEI 1x1km maps



UNECE Source Sector contribution to the total PM2.5 emissions in 2023 as shown on the NAEI 1x1km maps



APPENDIX 2 CONTRIBUTION OF POINT SOURCES TO MAPPED EMISSIONS TOTALS (2005)



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