UK Informative Inventory Report (1990 to 2022)

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Executive Summary

This is the 19th Informative Inventory Report (IIR) from the UK National Atmospheric Emissions Inventory (NAEI) Programme. The report accompanies the UK's 2024 data submission under the UK National Emissions Ceilings Regulation 2018 (NECR)[1] and the Gothenburg Protocol under the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP). It contains detailed information on annual emission estimates of air pollutants by source in the UK from 1990 onwards. Emission estimates are presented in this report for a large number of pollutants, focusing on the pollutants that must be reported under the NECR and the CLRTAP.

The UK submission under the NECR and the CLRTAP comprises annual emission estimates presented in Nomenclature for Reporting (NFR19) format, for:

Nitrogen oxides (NO_X), carbon monoxide (CO), ammonia (NH_3), sulphur dioxide (SO_X), non-methane volatile organic compounds (NMVOCs), particulate matter (PM), persistent organic pollutants (POPs), and heavy metals, (1990 to 2022).

The geographical scope of emissions under both CLRTAP and NECR is UK and Gibraltar. The emissions scope is anthropogenic emissions for sources as defined under the CLRTAP.

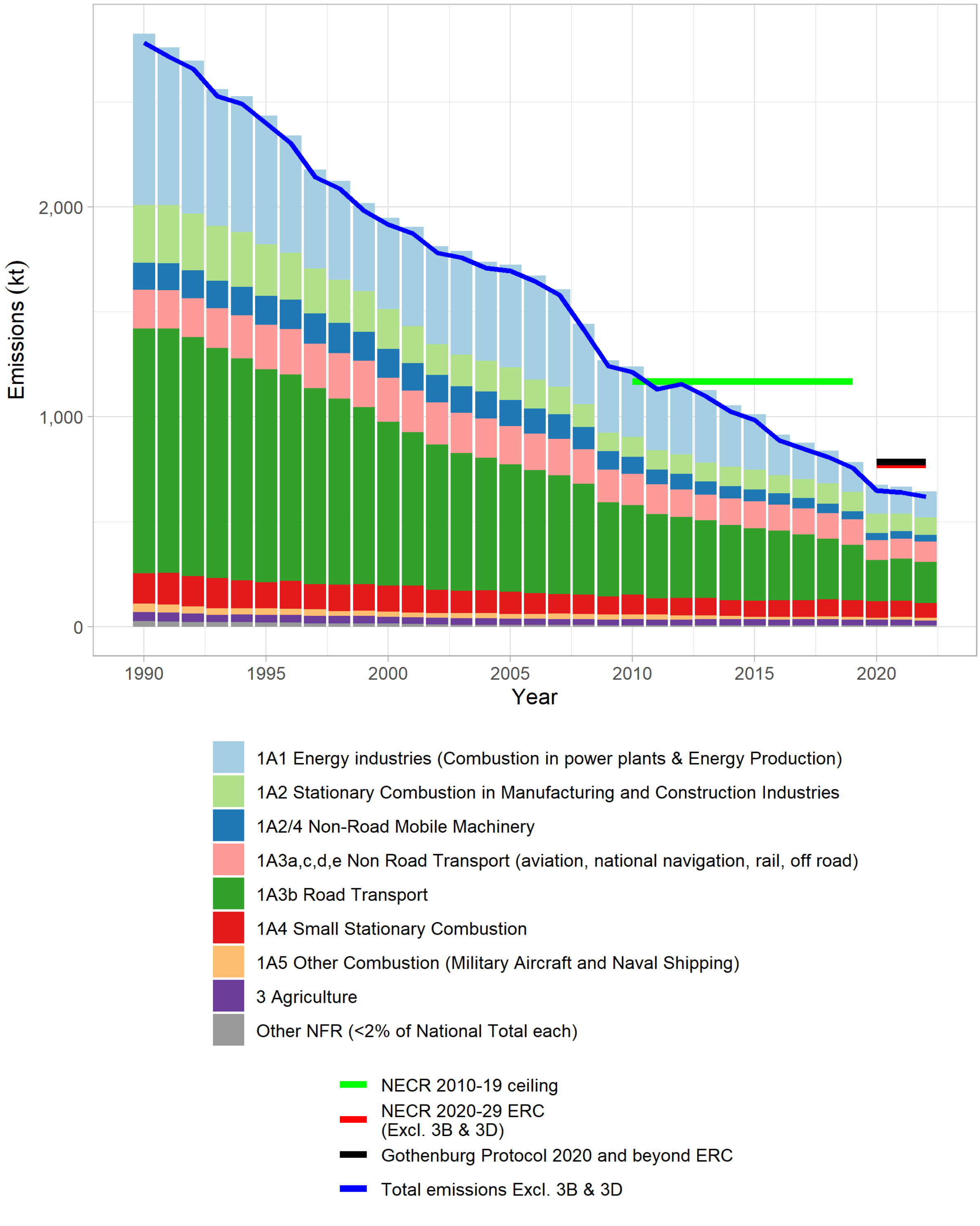
Both the NECR and the Gothenburg Protocol to the UNECE CLRTAP set 2020 emission reduction commitments (ERCs) for NO_X, SO_X, NMVOCs, NH_3 and $PM_{2.5}$. In addition, the NECR sets more ambitious 2030 ERCs for the same five pollutants. The 2010 emission ceilings for NO_X, NMVOCs, NH_3 and SO_X as agreed in the NECR and Gothenburg Protocol apply up to the end of 2019 and are then superseded by the 2020 ERCs.

The emission projections follow the EMEP/EEA Guidebook criteria for 'with existing measures' projections and therefore only take account of firm and funded measures that are already in place where data is available, with the exception of some notable circumstances as described within the documentation.

An overview of emissions from 1990-2022 by source sector for each of these pollutants is provided in Figure ES.1-1 through to Figure ES.1-5 The codes accompanying the definition of each source category in these figures refer to the NFR19, hereafter referred to as 'NFR', codes for the source sectors shown.

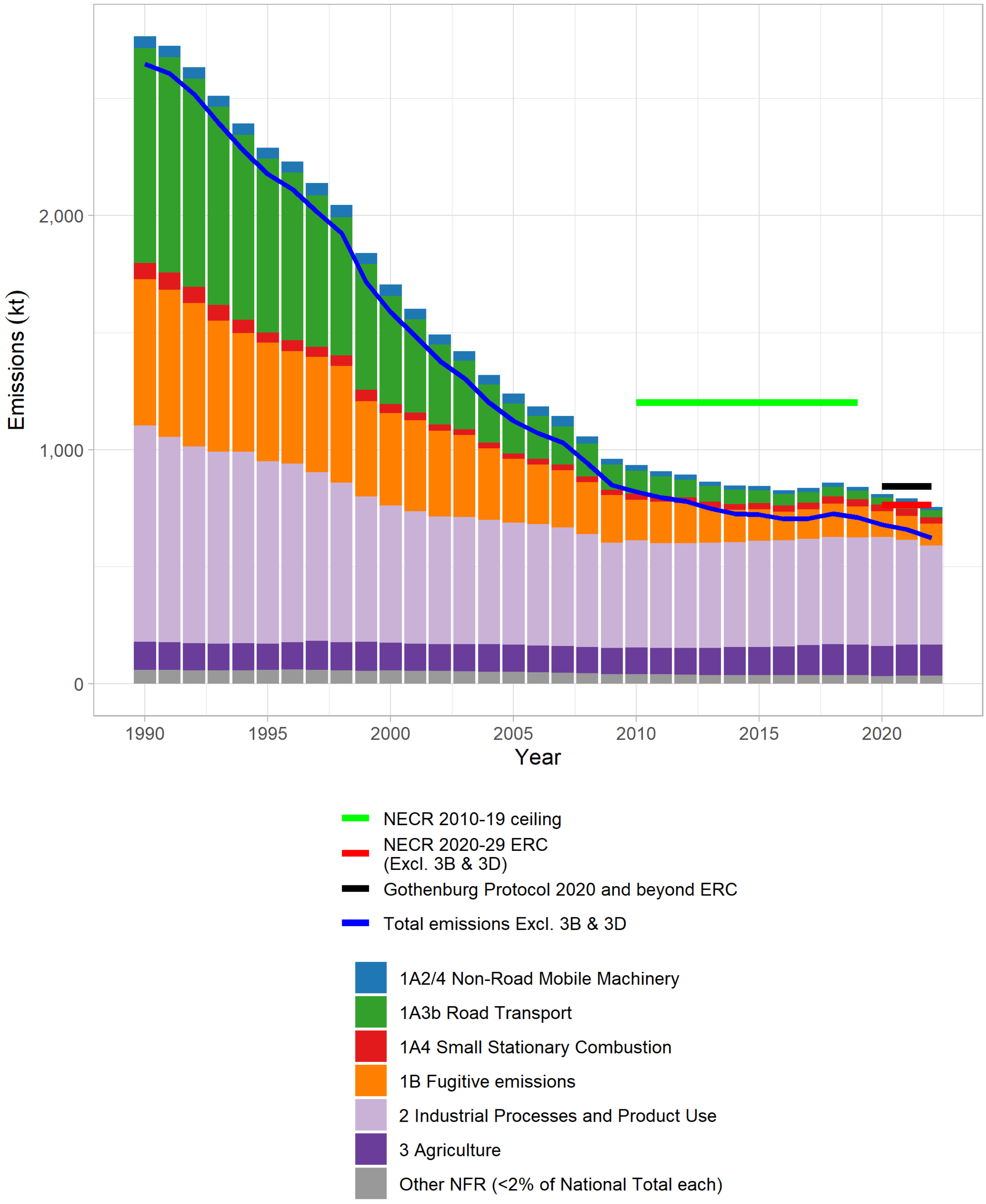
[1] The NECD has been transposed into UK law via the 232/2018 - European Union (National Emission Ceilings) Regulations 2018, see The National Emission Ceilings Regulations 2018 (legislation.gov.uk) https://www.legislation.gov.uk/uksi/2018/129/contents/made

Figure ES.1-1 Total UK Emissions by Source Sectors of Oxides of Nitrogen (NO_X), 1990-2022.



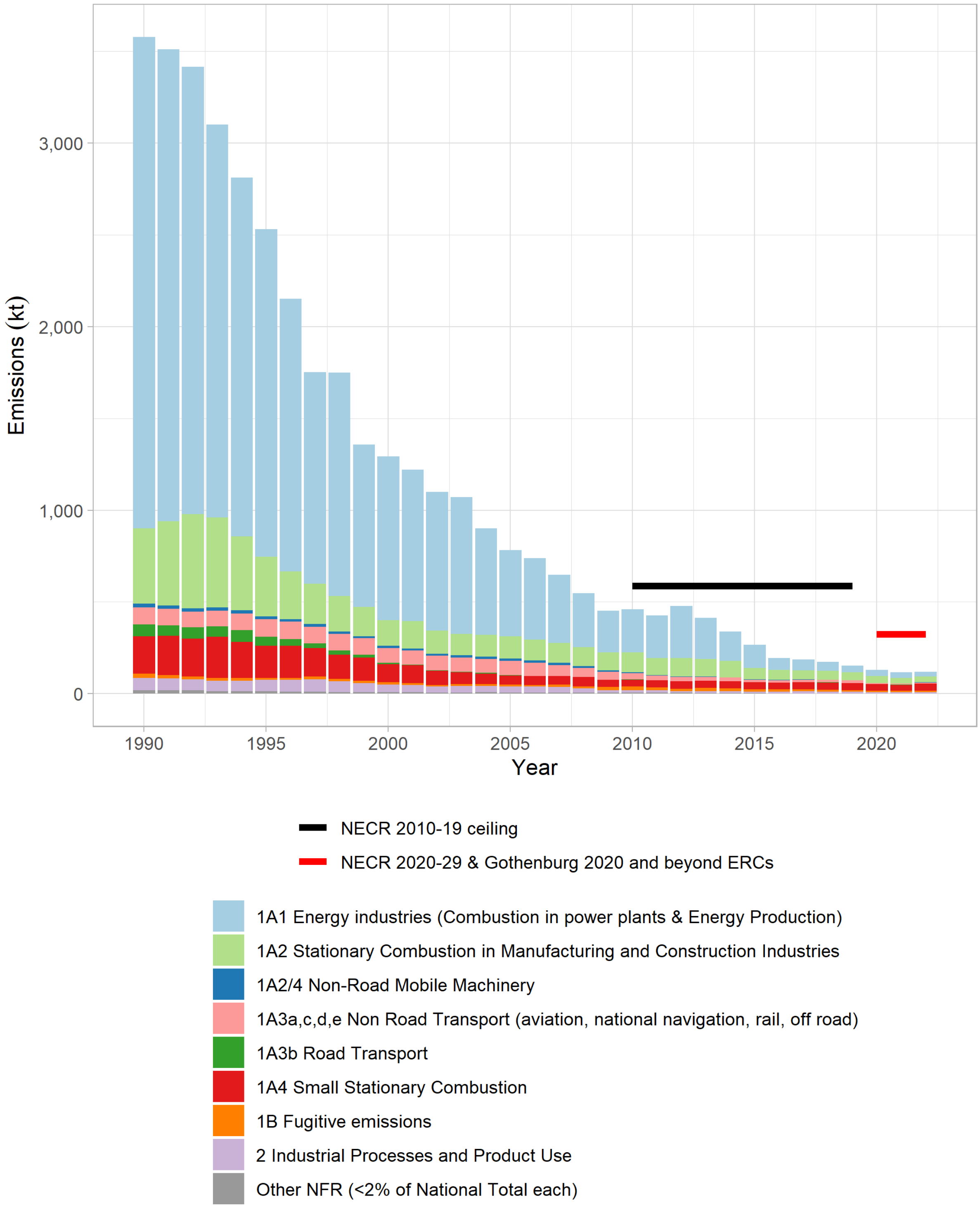
Other NFR includes: 1B Fugitive emissions, 2 Industrial Processes and Product Use
5 Waste, 6 Other (included in national total for entire territory)

Figure ES.1-2 Total UK Emissions by Source Sectors of Non-Methane Volatile Organic Compounds (NMVOCs), 1990-2022.



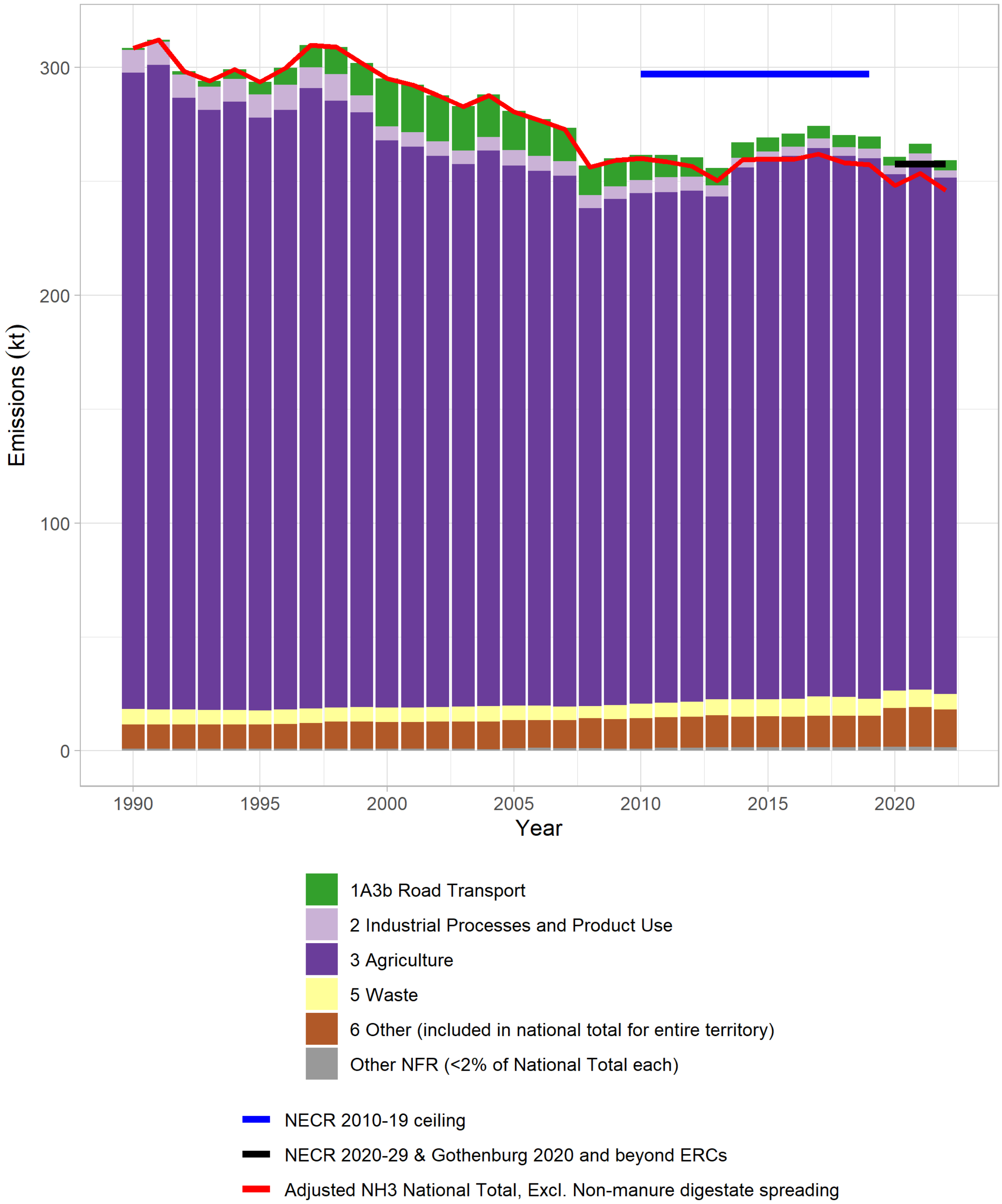
Other NFR includes: 1A1 Energy industries (Combustion in power plants & Energy Production), 1A2 Stationary Combustion in Manufacturing and Construction Industries
1A3a,c,d,e Non Road Transport (aviation, national navigation, rail, off road), 1A5 Other Combustion (Military Aircraft and Naval Shipping)
5 Waste, 6 Other (included in national total for entire territory)

Figure ES.1-3 Total UK Emissions by Source Sectors of Sulphur Dioxide (SO_X), 1990-2022.



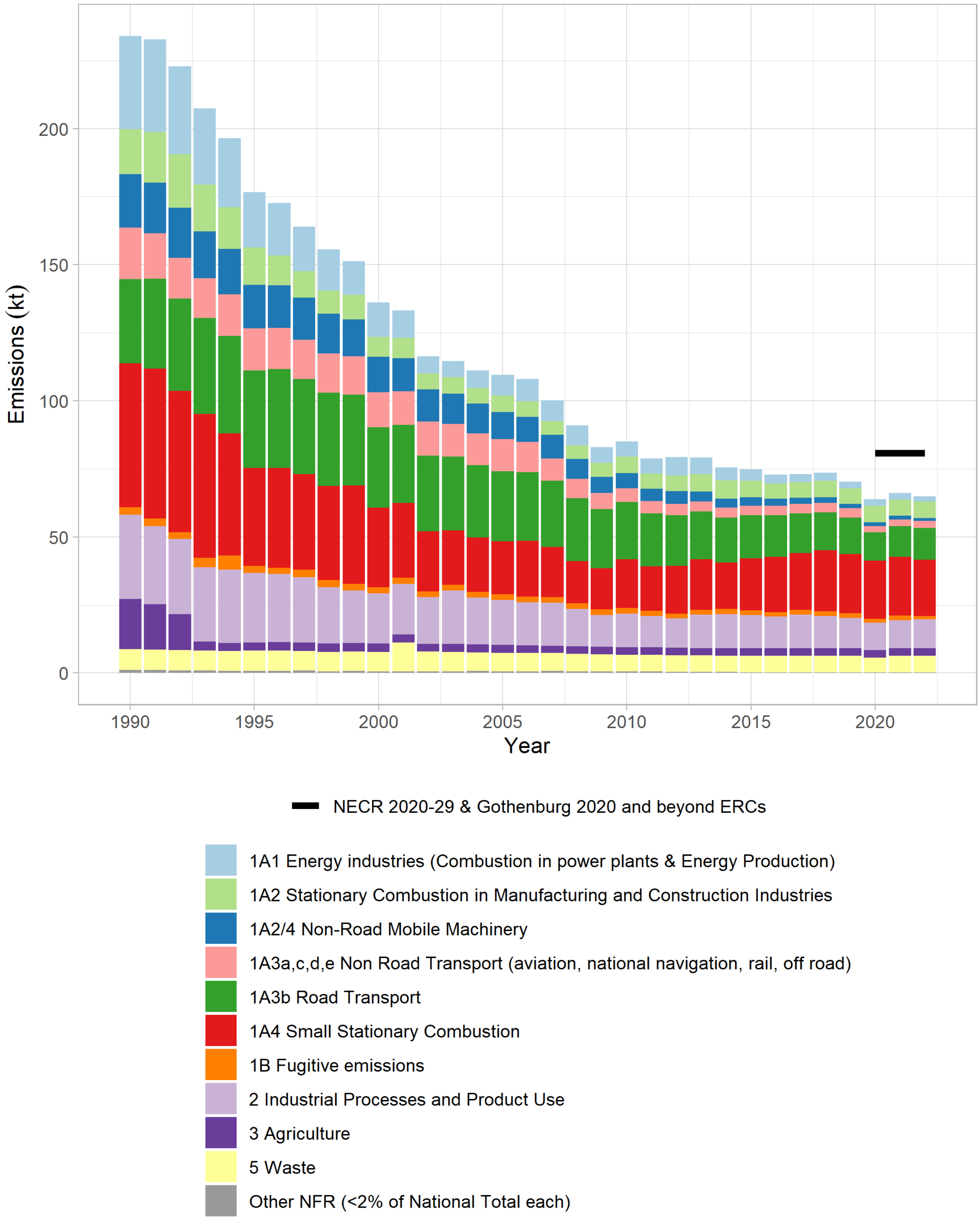
Other NFR includes: 1A5 Other Combustion (Military Aircraft and Naval Shipping), 3 Agriculture
5 Waste, 6 Other (included in national total for entire territory)

Figure ES.1-4 Total UK Emissions by Source Sectors of Ammonia (NH_3), 1990-2022.



Other NFR includes: 1A1 Energy industries (Combustion in power plants & Energy Production), 1A2 Stationary Combustion in Manufacturing and Construction Industries
1A2/4 Non-Road Mobile Machinery, 1A3a,c,d,e Non Road Transport (aviation, national navigation, rail, off road)
1A4 Small Stationary Combustion, 1A5 Other Combustion (Military Aircraft and Naval Shipping)
1B Fugitive emissions

Figure ES.1-5 Total UK Emissions by Source Sectors of Particulate Matter < 2.5 µm ($PM_{2.5}$), 1990-2022.



Other NFR includes: 1A5 Other Combustion (Military Aircraft and Naval Shipping), 6 Other (included in national total for entire territory)

Total percentage changes in emissions of these pollutants from 1990-2022 and from 2005-2022 are summarised in Table ES 1-1.

Table ES 1-1 Air Quality Pollutant Emission Reductions between 1990 and 2022, and 2005 and 2022

Pollutant	% Change from 1990 to 2022	% Change from 2005 to 2022
NO_X (as NO_2)	-69	-54
SO_X (as SO_2)	-96	-84
NH_3	-15	-7
NMVOC	-70	-36
CO	-83	-57
PM_{10}	-64	-34
$PM_{2.5}$	-72	-44

The emissions inventory makes estimates of all anthropogenic emissions to the atmosphere, at the highest level of source sector disaggregation possible. Estimated emissions are allocated to the corresponding NFR codes. However, in accordance with international guidelines[2] on emissions inventory reporting, there are a number of known sources that are excluded from the inventory emission estimates:

- Natural sources are not included in the national totals (although estimates of some sources are made).
- The inventory refers only to primary emission sources (as per international guidelines). Consequently, sources such as re-suspension of particulate matter from road dust or data on secondary pollutants formed by atmospheric transformation of primary air pollutants (such as tropospheric ozone) are not included in the national totals (although estimates for some re-suspension terms are made).
- Cruise emissions from civil and international aviation journeys are not included in the national totals.
- Estimates of "International" emissions such as from shipping are made and reported as memo items (excluded from the UK national totals).

National totals reported for the UK in the CLRTAP and the United Nations Framework Convention on Climate Change (UNFCCC) submissions, where there are overlaps in pollutant coverage, differ because the sources included in the national totals differ under the CLRTAP[3] and the UNFCCC reporting guidelines. For example, under the UNFCCC, total emissions from domestic aviation are included, and total emissions from international aviation are excluded, differing from the CLRTAP distinction between cruise and take-off and landing.

The UK's submission template under CLRTAP also forms the data set used for NECR reporting. The historical time series of emissions data from the 2024 inventory submissions under the CLRTAP and the NECR are identical.

The purpose of this report is to:

1. Present an overview of the institutional arrangements and emission inventory compilation process in the UK;

[2] https://www.ceip.at/reporting-instructions/reporting-programme
[3] Includes the United Kingdom (England, Scotland, Wales, Northern Ireland) and Gibraltar only

2. Present the emission estimates for each pollutant up to 2022 with analysis of the time series trends for each pollutant;
3. Explain the methodologies for key pollutants and key sectors used to compile the inventories, including a brief summary of estimates for future projections;
4. Provide other supporting information pertinent to the NECR and CLRTAP data submissions.

Information contained in this report is derived from the UK National Atmospheric Emissions Inventory (NAEI) programme, which includes the UK Greenhouse Gas Inventory, used for reporting to the UNFCCC. The compilation of the inventories for the pollutants reported under the NECR, the CLRTAP and the UNFCCC are strongly linked and share many common data sources, data management, data analysis, QA/QC and reporting procedures. This report summarises the data sources and emission estimation methodologies used to compile the inventories for each pollutant covered by the NECR and CLRTAP submission. The latest emission factors used to compile emissions estimates and the estimates themselves will be made available at https://naei.beis.gov.uk/data/ef-all in Spring 2024. The complete 2024 UK NECR and CLRTAP submission templates are available from the NAEI website under https://naei.beis.gov.uk/data/.

Emission trends for key source sectors are presented and discussed in Chapter 2, whilst revisions in source data or estimation methodology are summarised for each NFR source sector in the respective chapters. The NAEI is subject to methodology revisions on an annual basis with the aim of improving overall completeness and accuracy of the inventory. Some of the planned improvements that were outlined within the previous Informative Inventory Report (1990 to 2021) have been addressed in the 2024 submission. Planned improvements for future national inventory compilation cycles are discussed at the end of each chapter on each NFR source sector.

Table ES 1-2 compares overall emission estimates for each pollutant between the 2023 (previous) and 2024 (current) submissions. The table summarises and explains differences in emissions for the calendar year 2021 between the two submissions that are associated with methodological improvements or source data revisions.

Table ES 1-2 UK Inventory Recalculations, comparing emissions data for calendar year 2021 between the 2023 and 2024 CLRTAP/NECR Submissions. (Values have been rounded).

Pollutant	2023 Submission	2024 Submission		Units	% Change in 2021 values	Reason for Change
	2021	2021	2022			
NO_X	677.1	666.8	643.3	kt	-1.5%	Annual totals for 2005-2021 are mainly lower than in the previous version of the inventory (higher in 2011-2015 only). The size of the change varies from year to year and is highest in absolute terms for 2005. The change for 2021 is smaller in absolute terms but is proportionally larger than the previous inventory. These relatively minor changes mask some significant changes on an NFR level - these include re-allocations between sectors, and revisions to estimates in sectors which largely cancel out each other. These include improvements in emission estimates for residential combustion, paper production and road transport with the latter being due to use of factors from COPERT 5.6.
CO	1,274.8	1,291.2	1,235.7	kt	1.3%	The increase in emissions is driven by changes as a result of incorporating COPERT 5.6, particularly regarding cold starts in petrol cars (1A3bi). This is offset through the inclusion of CO in the Tier 2 Industrial Scale Combustion model (1A2).
NMVOC	781.2	792.2	755.6	kt	1.4%	The increases are driven by changes implemented COPERT 5.6 within the road transport sector, and further added to by increases in large (1A2) and small scale combustion (1A4).
SO_X	125.6	117.8	120.2	kt	-6.2%	The main reason for change across the time series is the improved methodology for paper production (2H1), which disaggregates data into specific processes and applies appropriate EFs. In more recent years, particularly 2021, this reduction is made larger by revisions to fuel use, predominantly coal, in DUKES.
NH_3	265.0	266.5	259.3	kt	0.6%	The changes are predominantly driven by changes made in the agriculture and waste sectors.
TSP	252.6	226.6	231.8	kt	-10.3%	The decrease in emissions is driven by using updated construction statistics (2A5b), and through improvements made to the PM estimation in the Tier 2 Industrial Scale Combustion model (1A2).

Pollutant	2023 Submission	2024 Submission		Units	% Change in 2021 values	Reason for Change
	2021	2021	2022			
PM_{10}	144.0	125.8	126.7	kt	-12.6%	Changes are mostly due to a move from a Tier 1 to Tier 2 method for industrial combustion of biomass i.e. use of technology-specific factors. Improvements to the residential combustion model and methods for paper production also contribute, as do numerous other smaller changes across the inventory.
$PM_{2.5}$	83.2	66.0	64.9	kt	-20.6%	Changes are mostly due to a move from a Tier 1 to Tier 2 method for industrial combustion of biomass i.e. use of technology-specific factors. Improvements to the residential combustion model and methods for paper production also contribute, as do numerous other smaller changes across the inventory.
Black Carbon	16.3	12.5	11.9	kt	-23.5%	The decrease in emissions is predominantly due to the inclusion of Black Carbon in the T2 Industrial Scale Combustion model (1A2).
Pb	114.9	131.8	147.0	tonnes	14.7%	The increase in emissions is predominantly due to implementing updated factors from COPERT 5.6 for brake and tyre wear (1A3bvi).
Cd	5.0	4.9	5.1	tonnes	-1.8%	The decrease in emissions is due to the removal of a double count for the combustion of industrial wood, which was included both based on the energy statistics and an emission factor, as well as through Tier 3 operator reporting for the chipboard sector (2I). This change was made as part of a wider review of reporting for industrial wood which also included some reallocations from 1A2gviii to 1A4ai. This is offset by an increase in emissions for brake and tyre wear due to incorporating COPERT 5.6 (1A3bvi).
Hg	3.73	3.89	3.49	tonnes	4.5%	The increase in emissions is driven by the inclusion of metal EFs for natural gas use, particularly impacting Other Industrial Combustion (1A2gviii) and miscellaneous/public (1A4ai). Mercury EFs are also included from the combustion of the petroleum coke fraction in SSF (1A4bi). Emissions are offset by reductions to the cremation sector by accounting for up-to-date figures on crematoria abatement (5C1bv).
As	14.2	14.5	13.9	tonnes	2.1%	The increase in emissions is predominantly due to implementing updated factors from COPERT 5.6 for brake and tyre wear (1A3bvi), as well as including emissions of arsenic from the combustion of the petroleum coke

Pollutant	2023 Submission 2021	2024 Submission 2021	2024 Submission 2022	Units	% Change in 2021 values	Reason for Change
						proportion in SSF (1A4bi) and natural gas used in public and miscellaneous sector combustion (1A4ai).
Cr	42.6	48.0	51.0	tonnes	12.9%	The increase in emissions is predominantly due to implementing updated factors from COPERT 5.6 for brake and tyre wear (1A3bvi).
Cu	548.8	667.7	712.6	tonnes	21.7%	The increase in emissions is predominantly due to implementing updated factors from COPERT 5.6 for brake and tyre wear (1A3bvi).
Ni	74.5	94.3	103.5	tonnes	26.6%	The increase in emissions is predominantly due to including emissions from the combustion of the petroleum coke proportion in SSF (1A4bi).
Se	8.9	9.1	7.9	tonnes	2.2%	The increase in emissions is predominantly due to including emissions from the combustion of the petroleum coke proportion in SSF (1A4bi).
Zn	509.7	522.9	535.7	tonnes	2.6%	The increase in emissions is predominantly due to implementing updated factors from COPERT 5.6 for brake and tyre wear (1A3bvi). This is offset by a decrease in emissions is due to the partial reallocation of other industrial wood (1A2gviii) to miscellaneous (1A4ai), with the rest removed as a double count with a Tier 3 operator reporting method used for the chipboard sector (2I).
PCBs	420.3	420.5	396.9	kg	0.1%	Minor recalculations driven by DUKES.
PCDD/PCDF (dioxins /furans)	115.7	114.2	131.3	grams TEQ	-1.3%	The decrease in emissions is driven my migrating the calculation of emissions of Dioxins from industrial combustion (1A2) to a more detailed Tier 2 model. This is offset by revisions to DUKES to the residential sector (1A4bi).
Benzo(a)-Pyrene	6.3	6.5	7.0	tonnes	3.2%	The increase in emissions largely driven by revisions to DUKES for the residential sector (1A4bi), as well as the improvement to assign a proportion of the increased wood activity to newer appliances, consistent with the DUKES methodology used for scaling activity from the Domestic Burning Survey.
Benzo(b)-Fluoranthene	7.5	7.8	8.5	tonnes	3.7%	The increase in emissions largely driven by revisions to DUKES for the residential sector (1A4bi), as well as the improvement to assign a more reliable figure for increased wood use to newer appliances.

Pollutant	2023 Submission	2024 Submission		Units	% Change in 2021 values	Reason for Change
	2021	2021	2022			
Benzo(k)-Fluoranthene	3.8	4.0	4.2	tonnes	3.1%	The increase in emissions largely driven by revisions to DUKES for the residential sector (1A4bi), as well as the improvement to assign a more reliable figure for increased wood use to newer appliances.
Indeno (1,2,3-cd) Pyrene	3.4	3.5	3.8	tonnes	3.4%	The increase in emissions largely driven by revisions to DUKES for the residential sector (1A4bi), as well as the improvement to assign a more reliable figure for increased wood use to newer appliances.
HCB	38.1	39.1	38.7	kg	2.5%	The increase in emissions is driven by DUKES recalculations for MSW use in power generation (1A1a).

Reporting Emissions

A summary of the statutory reporting requirements, their timescales, and the UK provision, is included in Table ES 1-3 below.

Table ES 1-3 Summary of statutory reporting requirements for estimating and reporting emissions under the CLRTAP and the NECR

Group	Pollutant	Required reporting years starting in 2017	Required in the 2024 UK submission
Historic Emissions (Annex I)	SO_X, NO_X, NH_3, NMVOCs, CO, PM_{10}, $PM_{2.5}$, Heavy Metals, POPs	Every year	Required - Reported
Informative Inventory Report	SO_X, NO_X, NH_3, NMVOCs, CO, PM_{10}, $PM_{2.5}$, Heavy Metals, POPs	Every year	Required - Reported
Adjustment (Annex IIA)	NH_3	Every year, depending on compliance status	Required - Reported
Projected emissions (Annex IV)	SO_X, NO_X, NH_3, NMVOCs, $PM_{2.5}$, BC (voluntary)	**NECR**: report every two years from 2017 onwards, for years 2020, 2025, 2030, (2040 and 2050 if available) **CLRTAP**: report every four years from 2015 onwards, for years 2020, 2025, 2030, (2040 and 2050 if available)	Not Required - Reported
Gridded data in the new EMEP grid (0.1° × 0.1° long-lat) (Annex V)	SO_X, NO_X, NH_3, NMVOCs, CO, PM_{10}, $PM_{2.5}$, Pb, Cd, Hg, PCDD/PCDFs, PAHs, HCB, PCBs	Every four years for reporting year minus 2 (X-2) as from 2017	Not Required – Not Reported[4]
Emissions from large-point sources (LPS) (Annex VI)	SO_X, NO_X, NH_3, NMVOCs, CO, PM_{10}, $PM_{2.5}$, Pb, Cd, Hg, PCDD/PCDFs, PAHs, HCB, PCBs	Every four years for reporting year minus 2 (X-2) as from 2017	Not Required – Not Reported[5]

There are some differences between the scope of emissions that must be reported for each of the NECR/CLRTAP and UNFCCC. The major differences between the source sector coverage are highlighted in Table ES 1-4, although there are also differences in the geographical coverage (see Section 1.1.4).

[4] Detailed gridded data will be available from Summer 2024, from here: https://naei.beis.gov.uk/data/map-uk-das
[5] Detailed point source data will be available from Summer 2024, from here: https://naei.beis.gov.uk/data/map-large-source

Table ES 1-4 Scope of UK Emissions Inventory Reporting under the CLRTAP, NECR and UNFCCC

Sector category	CLRTAP/NECR (included)	UNFCCC (included)
Domestic aviation (cruise)	No	Yes
International aviation (LTO)	Yes	No

Historic Emissions

Table ES 1-5 below shows the comparison of 2022 national emissions for the pollutants with the 2020-2029 NECR and Gothenburg Emission Reduction Commitments for the UK. Table ES 1-6 shows the comparison of 2022 national emissions with 2030 NECR emission reduction commitments.

Table ES 1-5 Comparison of UK 2022 national emissions with 2020-29 NECR and Gothenburg Emission Reduction Commitments for UK

Pollutant	NH_3[b]	NO_X (excludes 3B and 3D)[c]	NO_X[c]	SO_X	NMVOCs (excludes 3B and 3D)[c]	NMVOC[c]	$PM_{2.5}$
2005 National Compliance Total, kilotonnes	280.48	1,695.70	1724.94	781.83	1,123.42	1,239.20	109.48
2022 National Compliance Total, kilotonnes	246.14	619.21	643.30	120.23	623.66	755.59	64.89
Emission reduction commitment (ERC)	8%	55%	55%	59%	32%	32%	30%
2020 – 2029 ceiling, kilotonnes[a]	258.04	763.06	776.22	321.12	763.93	842.66	76.64
Progress to date towards 2020 – 2029 ERCs	153%	115%	114%	143%	139%	122%	136%
Emission reduction required to date from 2022 onwards	0	0	0	0	0	0	0

[a] **The 2020-29 and 2030 emission reduction commitment ceilings have been calculated using the 2005 emissions from the current inventory submission as the base year.**

[b] NH_3 **emissions are in compliance with the 2020-29 emission reduction commitment when adjustments outlined in Chapter 10: Adjustment are taken into account.**

[c] **Under the NECR, NMVOCs and** NO_X **emissions from 3B and 3D are not accounted in the National Total for the purpose of complying with the 2020-29 (or 2030) emission reduction commitments.**

Table ES 1-6 Comparison of UK 2022 national emissions with 2030 NECR emission reduction commitments (Emission values have been rounded)

Pollutant	NH_3[b]	NO_X (excludes 3B and 3D)[c]	SO_X	NMVOCs (excludes 3B and 3D)[c]	$PM_{2.5}$
2005 National Compliance Total, kilotonnes	280.48	1,695.7	781.83	1,123.42	109.48
2022 National Compliance Total, kilotonnes	246.14	619.21	120.23	623.66	64.89
Emission reduction commitment	16%	73%	88%	39%	46%
2030 ceiling, kilotonnes[a]	235.60	457.84	93.82	685.29	59.12
Progress to date towards 2030 ERCs	77%	87%	96%	114%	89%
Emission reduction required from 2022	10.54	161.37	26.41	0.00	5.77

[a] The 2020 and 2030 emission reduction commitment ceilings have been calculated using the 2005 emissions from the 2024 inventory submission as the base year.

[b] NH_3 emissions are in compliance with the 2020-29 emission reduction commitment when adjustments outlined in Chapter 10: Adjustment are taken into account.

[c] Under the NECR, NMVOCs and NO_X emissions from 3B and 3D are not accounted in the National Total for the purpose of complying with the 2020-29 (or 2030) emission reduction commitments.

In addition to reporting historic AQ emissions under the NECR and the CLRTAP, the NAEI reports GHG emissions to the United Nations Framework Convention on Climate Change (UNFCCC). This is to comply with UNFCCC reporting requirements and Kyoto Protocol (up to 2022) and Paris Agreement Enhanced Transparency Framework (from 2024) commitments on behalf of the UK Government. Furthermore, the NAEI reports projected emissions through to 2050 for the five key pollutants.

Adjustments

An adjustment is permitted under the National Emissions Ceilings Regulations 2018 and the 2012 amendment to the Gothenburg Protocol. Where non-compliance with national emission reduction commitments would result from applying improved inventory methods updated in accordance with new scientific knowledge that was not available at the time when the ERCs were agreed; countries can prepare an adjusted inventory to reflect this. Compliance with national emission reduction commitments is then assessed by reference to the adjusted inventory. For the 2022 submission, the UK submitted an inventory adjustment application for NH_3 which was approved (see further details in Chapter 10, Adjustment) and has been applied from the 2022 submission onwards. This adjustment reduced NH_3 emissions to below the 2020-29 emission reduction commitment ceiling for the latest submission.

Projected Emissions

Since 2019 there is a requirement for biennial reporting of projections under the NECR. Projections must be reported for the key pollutants, SO_X, NO_X, NMVOCs, NH_3, $PM_{2.5}$, for the years 2025 and 2030. Where available, projections for black carbon, and for the years 2040 and 2050 should also be reported. Separately, projections for the same pollutants and years must be reported to the CLRTAP every four years (starting in 2015). The UK voluntarily reports the emission projections on an annual basis. The emission projections take account of measures in place as far as is possible, given the data available, but do not reflect measures that are still in development.

The UK Government published a revised National Air Pollution Control Programme (NAPCP) in February 2023, which sets out measures to be considered further to meet its emission reduction commitments for 2020-29 and 2030.

Figure ES 1-6 shows a summary of the UK's projected emissions through to 2050 based on the 2024 submission and the projected compliance of emission reduction commitments under the NECR.

Table ES 1-7 shows the 2024 projections submission compared to the 2020-29 emissions reduction commitments for both the NECR and Gothenburg Protocol, for 2030, 2040 and 2050. It provides a summary of the 2030 emission reduction commitments set under the NECR. Based on the current 2024 submission - with only the existing 'firm and funded' measures in place together with taking into account the proposed transition from blast furnaces to electric arc furnaces at the Port Talbot[6] and Scunthorpe[7] integrated steelworks - the UK will meet its 2030 emission reduction commitments for NO_X and NMVOCs only.

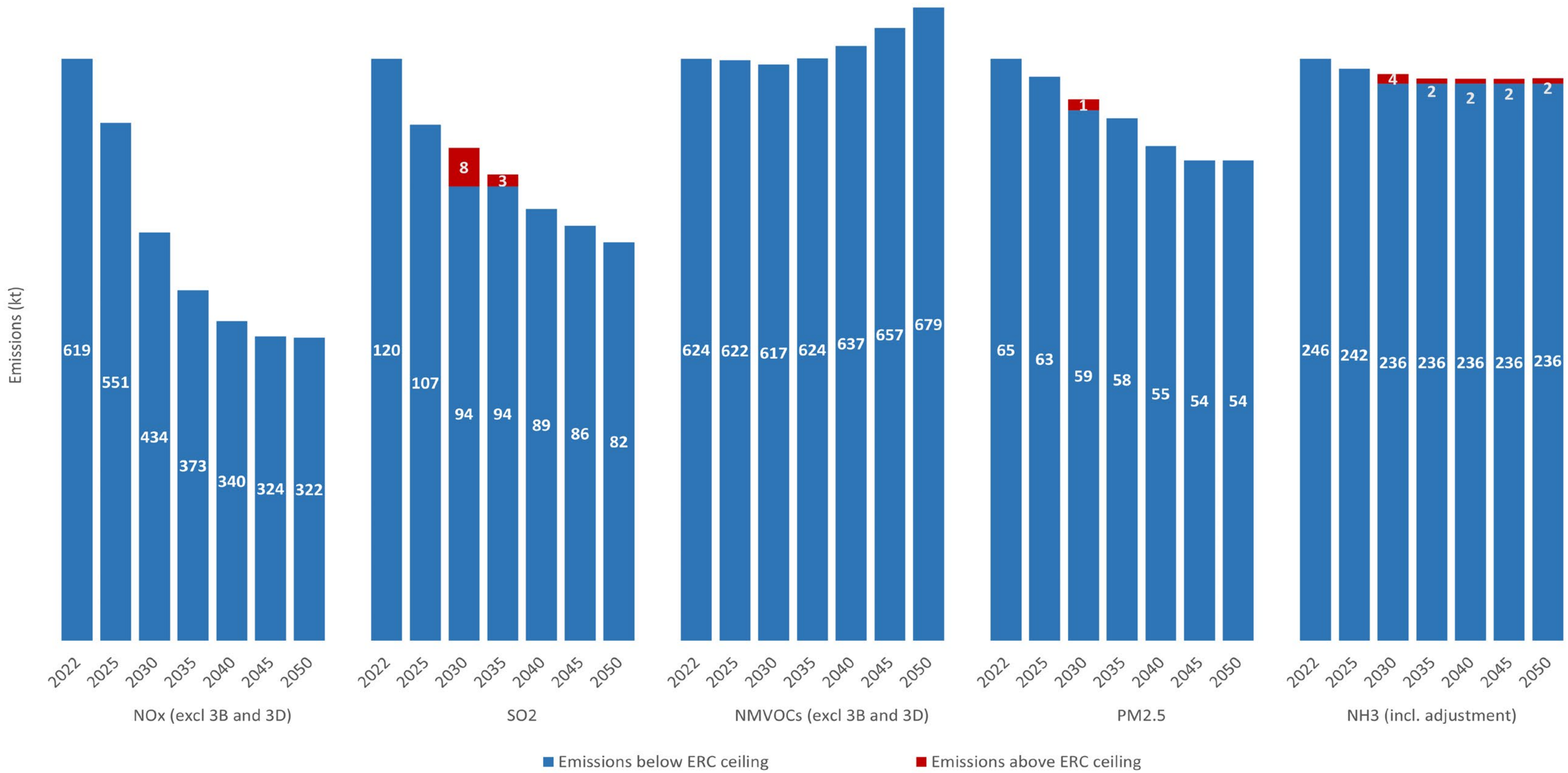
The projections are subject to uncertainty from a combination of sources, including but not limited to:

- Uncertainties in the historic emissions data;
- Uncertainties in the projections of future activities and technologies.
- Uncertainties in the future emission factors, particularly from stationary sources, e.g. industry

The emission projections therefore show a best estimate of the likely trajectories for UK emissions to 2050, if no further action is taken, beyond the measures already in place.

[6] https://britishsteel.co.uk/media/mwnp344v/british-steel-proposals.pdf
[7] https://apps.northlincs.gov.uk/application/pa-2024-123, accessed on 16/02/2024

Figure ES 1-6 Comparison of UK 2022 national emissions and projected emission estimates for years 2025- 2050 against NECR ERCs



Total bar heights are BAU projections, red areas are distances above relevant NECR ERC ceilings ('2020-29' (for 2022 and 2025) and '2030 (and each subsequent year)' for 2030-2050).

Table ES 1-7 Comparison of UK 2030 National Emission Reduction Commitments with projected 2030, 2040 and 2050 emissions

Pollutant	NH_3[b]	NO_X (excludes 3B and 3D)[c]	SO_X	NMVOCs (excludes 3B and 3D)[c]	$PM_{2.5}$
2005 Emissions, kilotonnes	280.48	1,695.7	781.83	1,123.42	109.48
Emission Reduction commitment (ERC)	8%	55%	59%	32%	30%
2030 ceiling, kilotonnes[a]	235.60	457.84	93.82	685.29	59.12
Projected 2030 Emissions, kilotonnes	239.64	434.34	101.85	617.37	60.38
Projected 2040 Emissions, kilotonnes	237.68	339.91	89.22	637.25	55.14
Projected 2050 Emissions, kilotonnes	237.94	322.36	82.34	678.53	53.55

Emission values presented have been rounded.

[a] The 2020 and 2030 emission reduction commitment ceilings have been calculated using the 2005 emissions from the 2024 inventory submission as the base year.

[b] NH_3 emissions are in compliance with the 2020-29 emission reduction commitment when adjustments outlined in Chapter 10: Adjustment are taken into account.

[c] Under the NECR, NMVOCs and NO_X emissions from 3B and 3D are not accounted in the National Total for the purpose of complying with the 2020-29 (or 2030) emission reduction commitments.

Spatially referenced data

Starting in 2017, the UK must report spatially allocated emissions (gridded data) and emissions from large point sources every four years as defined in Section A of Annex VI to the CLRTAP Reporting Guidelines. As requested by the Centre on Emission Inventories and Projections (CEIP) the gridded emissions do not include emissions from large-point sources, which are reported separately. The UK last submitted gridded data and emissions from large point sources in the 2021 submission, summarised in Chapter 11: Reporting of Gridded Emissions and Large Point Sources. The UK publishes annual updates of spatially disaggregated data[8], and associated methodology[9] reporting on the NAEI website.

[8] https://naei.beis.gov.uk/data/mapping
[9] https://naei.beis.gov.uk/reports/reports?section_id=6

I Contacts and Acknowledgements

The National Atmospheric Emission Inventory is prepared by a Ricardo-led consortium under the National Atmospheric Emissions Inventory contract to the Department for Energy Security and Net Zero (DESNZ).

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For non-agricultural and non-combustion emission sources, NH_3 emission estimates and NH_3 mapping information are provided by the Centre for Ecology and Hydrology (UK CEH) Edinburgh.

Emissions from agriculture are provided to Defra under a separate contract by a consortium led by ADAS in Helsby, Cheshire.

Emissions from rail are provided by Aether, Oxford.

A copy of this report and related documentation may be found on the NAEI website maintained by Ricardo on behalf of DESNZ and Defra: https://naei.beis.gov.uk/

Ricardo is a trading name of Ricardo-AEA Ltd.

Report to be referenced as:

Elliott, M., Ingledew, D., Richmond, B., *et. al*. (2024). *UK Informative Inventory Report (1990-2022)*. Available at: [https://naei.beis.gov.uk/data/]

II Glossary

Emission Units

Pollutant emissions are presented using a number of different mass and/or toxicity units, according to convenience, with specific reporting protocols including:

NO_X emissions are quoted in terms of NO_X as mass of NO_2.

SO_X emissions are quoted in terms of SO_X as mass of SO_2.

PCDD and PCDF are quoted in terms of mass but accounting for toxicity of the mixtures of congeners. This is the International Toxic Equivalents for dioxins and furans only (I-TEQ). The concept of TEQ is explained further in the UNEP Toolkit (UNEP, 2013). Pollutant emissions are quoted as mass of the full pollutant unless otherwise stated, e.g. NH_3 emissions are mass of NH_3 and not mass of the N content of the NH_3 (NH_3-N).

Table ES 1-8 Abbreviations for Chemical Compounds covered in the NAEI

Chemical Name	Abbreviation
Nitrogen Oxides	NO_X*
Sulphur Dioxide	SO_X**
Carbon Monoxide	CO
Non-Methane Volatile Organic Compounds	NMVOC
Black Smoke	BS
Black Carbon	BC
Particulates < 10 µm	PM_{10}
Particulates < 2.5 µm	$PM_{2.5}$
Particulates < 1 µm	$PM_{1.0}$
Particulates < 0.1 µm	$PM_{0.1}$
Total Suspended Particulates	TSP
Ammonia	NH_3
Hydrogen Chloride	HCl
Hydrogen Fluoride	HF
Lead	Pb
Cadmium	Cd
Mercury	Hg
Copper	Cu
Zinc	Zn
Nickel	Ni
Chromium	Cr
Arsenic	As
Selenium	Se
Vanadium	V
Beryllium	Be
Manganese	Mn
Tin	Sn
Polycyclic Aromatic Hydrocarbons	PAH
Benzo[a]pyrene	B[a]P
Benzo[b]fluoranthene	B[b]F
Benzo[k]fluoranthene	B[k]F
Indeno(1,2,3-cd)pyrene	I[123-cd]P
Polychlorinated dibenzo-p-dioxins/Polychlorinated dibenzofurans	PCDD/PCDF
Polychlorinated Biphenyls	PCBs

Chemical Name	Abbreviation
Hexachlorocyclohexane	HCH
Pentachlorophenol	PCP
Hexachlorobenzene	HCB
Short-chain chlorinated paraffins	SCCP
Polychlorinated Naphthalene	PCN
Polybrominated diphenyl ethers	PBDE
Sodium	Na
Potassium	K
Calcium	Ca
Magnesium	Mg

*NO_X **as NO_2**
SO_X **as SO_2

Table ES 1-9 Abbreviations for Units covered in the NAEI

Unit	Abbreviation
acre	acre
atmosphere	atm
bar	bar
British thermal unit	Btu
calorie	cal
centimetre	cm
square foot	ft^2
gram	g
gallon (UK)	gal
gigajoule	GJ
gigawatt	GW
gigawatt-hour	GWh
hectare	Ha
horsepower	hp
hour	hr
joule	J
kilometre per second	k/s
kilo-calorie (Calorie)	kcal
kilogram	kg
kilogram-kilometre	kgkm
kilogram-metre	kgm
kilojoule	kJ
kilometre	km
square kilometre	km^2
kilopascal	kPa
kilometre per hour	kph
kilotonne	kt
kilotonne-kilometre	ktkm
kilowatt	kW
kilowatt-hour	kWh
litre	l
pound	lb
metre	m
square metre	m^2
square metre-annum	m^2a
cubic metre	m^3
megalitre	Mega-l
milligram	mg
mile	mile

Unit	Abbreviation
mile per second	mile/s
square mile	$mile^2$
minute	min
megajoule	MJ
millilitre	ml
millimetre	mm
megapascal	MPa
mile per hour	mph
megatonne	Mt
megatherm	Mth
megawatt	MW
megawatt-hour	MWh
pint (UK)	p
pascal	Pa
parts per million	ppm
second	s
tonne	t
therm	therm
terajoule	TJ
tonne-kilometre	tkm
tonne-metre	tm
tonne of oil equivalent	toe
terawatt	TW
terawatt-hour	TWh
vehicle kilometre	vkm
watt-hour	Wh
square yard	yd2
year	yr
microgram	µg

III Contents

IV Figures

V Tables

VI Acronyms and Definitions

AADF	Annual Average Daily Flow
AG	Acid Gas
ACEA	European Automobile Manufacturers' Association
AD	Activity Data
AE	Adjusted national Emissions total
AEAT	AEA Technology
AER	Adjusted Emission Reduction
AFBINI	Agri-Food and Biosciences Institute
AFRC	Agriculture and Food Research Council
AIS	Automatic Identification System
AnD	Anaerobic Digestion
AmPI	American Petroleum Industry
ANPR	Automatic Number Plate Recognition
AP-42	Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors
APC	Air Pollution Control
APU	Auxiliary Power Unit
AQ	Air Quality
AQEG	Air Quality Expert Group
AQISG	Air Quality Inventory Steering Group
AQPI	Air Quality Pollutant Inventory
AR	Activity Rate
ARTEMIS	Assessment and Reliability of Transport Emission Models and Inventory Systems
AS	Aviation Spirit
ATF	Aviation Turbine Fuel
ATM	Air Transport Movement
BAMA	British Aerosol Manufacturers Association
BASA	British Adhesives & Sealants Association
BAT	Best Available Techniques
BCF	British Coatings Federation
BEIS	Department for Business, Energy and Industrial Strategy (now DESNZ)
BGS	British Geological Survey

BREF	Best Available Technology Reference
BRES	Business Register and Employment Survey
CAA	Civil Aviation Authority
CAMEO	Crematoria Abatement of Mercury Emissions Organisation
CAR	Cambridge Architectural Research
CBP	Chorleywood Bread Process
CCGT	Combined Cycle Gas Turbine
CD	Crown Dependency
CE	Consumer Evolution
CEIP	Centre on Emissions Inventories and Projections
CEPI	Confederation of European Paper Industries
CET	Central England Temperature
CFC	ChloroFluoroCarbon
CHP	Combined Heat and Power
CI	Confidence Interval
CLRTAP	Convention on Long-Range Transboundary Air Pollution
COD	Chemical Oxygen Demand
COPERT	Computer Programme to calculate Emissions from Road Transport
CPA	Construction Products Association
CRF	Common Reporting Format
CSRGT	Continuing Survey of Road Goods Transport
CVs	Calorific Values
DA	Devolved Administration
DAERA	Northern Ireland's Department of Agriculture, Environment and Rural Affairs
DARDNI	Northern Ireland's Department of Agriculture and Rural Development
DECC	Department of Energy & Climate Change
DEFRA	Department for Environment, Food and Rural Affairs
DERV	Road diesel fuel
DETR	Department of the Environment, Transport and the Regions
DESNZ	Department for Energy Security and Net Zero (formerly BEIS)
DfT	Department for Transport
DG ENV	Directorate-General for Environment

DOI	Digital object identifier
DM	Dry Matter
DPFs	Diesel Particulate Filters
DRDNI	Department for Regional Development Northern Ireland
DTI	Department for Trade and Industry
DUKES	Digest of UK Energy Statistics
DVLA	UK Driver and Vehicle Licencing Agency
EA	Environment Agency
EAGER	European Agricultural Gaseous Emissions Research
EC	European Commission
ECUK	Energy Consumption in the UK
EEA	European Environment Agency
EEMS	Environmental Emissions Monitoring System
EF	Emission Factor
EfW	Energy from Waste
EGR	Exhaust Gas Recirculation
EIONET	European Environment Information and Observation Network
EIPPCB	European Integrated Pollution Prevention and Control Bureau
ELV	Emission Limit Values
EMEP/CORINAIR	After 1999 called EMEP/EEA
EMEP/EEA	European Monitoring and Evaluation Program Emission Inventory Guidebook
EN	European Standard
EO	Earth Observation
EPR	Environmental Permitting Regulations
ERCs	Emission Reduction Commitments
ESIG	European Solvents Industry Group
EU	European Union
EU ETS	European Union Emissions Trading System (succeeded by the UK ETS)
EUMM	European Union Monitoring Mechanism
EWC	European Waste Category
FAOSTAT	The Food and Agriculture Organization Statistical Databases
FBCA	Federation of Burial and Cremation Authorities

FERA	Food and Environmental Research Agency
FOCA	Federal Office of Civil Aviation
FPSO	Floating production storage and offloading
FR	Forest Research
FYM	Farmyard Manure
gITEQ	Grams International Toxic Equivalent
GB	Great Britain
GDP	Gross Domestic Product
GEMIS	Global Emission Model for Integrated Systems
GEN	General
GHG	Greenhouse gases
GHGI	Greenhouse gas inventory
GHGISC	National Inventory Steering Committee
GIS	Geographic Information System
GPG	IPCC Guidelines or Good Practice Guide
GNFR	Gridded Nomenclature For Reporting
GPS	Global Positioning System
GVW	Gross Vehicle Weight
GWh	Giga Watt Hour (unit of energy)
HFO	Heavy Fuel Oil
HGV	Heavy Goods Vehicles
HMIP	His Majesty's Inspectorate of Pollution (former name for regulatory agency in England and Wales, its functions are now carried out by the Environment Agency and Natural Resources Wales)
HMRC	His Majesty's Revenue and Customs
ICAO	International Civil Aviation Organisation
IDBR	Office for National Statistics Inter-Departmental Business Register
IE	Included Elsewhere
IED	Industrial Emissions Directive
IEF	Implied Emission Factor
IIR	Informative Inventory Report
IMO	International Maritime Organization
IPCC	International Panel on Climate Change

IPPC	Integrated Pollution Prevention and Control
IPPU	Industrial Process and Product Use
ITEQ	International Toxic Equivalent
ISSB	Iron and Steel Statistics Bureau
LAPC	Local air pollution control
LCP	Large Combustion Plant
LCPD	Large Combustion Plant Directive
LEZ	Low Emission Zone
LF	typical Load Factor
LFG	Landfill Gas
LGV	Light Goods Vehicles
LOSP	Light Organic Solvent Preservative
LPG	Liquefied Petroleum Gas
LPS	Large Point Source
LRC	London Research Centre
LRQA	Lloyds Register Quality Assurance
LSOA	Lower Super Output Area
LTO	Landing & Take Off
LULUCF	Land Use, Land-Use Change and Forestry
MANDE	Manure Analysis Database
MBT	Mechanical Biological Treatment
MCGA	Maritime and Coastguard Agency
MCP	Medium Combustion Plant
MDO	Marine Diesel Oil
ME	Metabolisable energy
MoD	Ministry of Defence
MMO	Marine Management Organisation
MMR	Monitoring Mechanism Regulation
MPA	Mineral Products Association
MSDS	Material Safety Data Sheets
MSOA	Middle layer Super Output Area
MSW	Municipal Solid Waste

N	Nitrogen
NA	Not Applicable
NAEI	National Atmospheric Emissions Inventory
NAPCP	National Air Pollutant Control Programme
NAQS	National Air Quality Standard
NCSC	National Center for Climate Change Strategy and International Cooperation
NCV	Net Calorific Value
NE	Not Estimated
NECD	National Emission Ceilings Directive
NECR	National Emission Ceilings Regulations
NFR19	2019 Reporting Guidelines Nomenclature For Reporting
NFR	Nomenclature For Reporting
NGL	Natural Gas Liquid
NH_3-N	Ammonia concentration as nitrogen
NHN	National Household Model
NHS	National Health Service
NIEA	Northern Ireland Environment Agency
NIPI	Northern Ireland Pollution Inventory
NIR	National Inventory Report
NR	Not Reported
NRMM	Non-Road Mobile Machinery
NRTY	National Rail Trends Yearbook
NRW	Natural Resources Wales
NSTA	North Sea Transition Authority
NT	National Totals
OECD	Organisation for Economic Co-operation and Development
OEUK	Offshore Energies UK
OFWAT	The Water Industry Regulator for England and Wales
OGA	Oil and Gas Authority
OGUK	Oil and Gas UK
ONS	Office for National Statistics
OPG	Other petroleum Gases

OPRED	Offshore Petroleum Regulator for Environment and Decommissioning
OPTIS	Offshore Platform and Terminal Inventory System
ORR	Office of Rail and Road
OT(s)	Overseas Territories
PCM	Pollution Climate Mapping
PI	Pollution Inventory (of the Environment Agency and Natural Resources Wales)
POC	Port of Call
POPs	Persistent Organic Pollutants
PPC	Pollution Prevention and Control
PPRS	Petroleum Production Reporting System
PRODCOM	Production Communautaire
PSDH	Project for the Sustainable Development of Heathrow
Q	Quarter of the year
QA/QC	Quality Assurance and Quality Control
RASCO	Regional Air Services Co-Ordination
RCEP	Royal Commission on Environmental Pollution
RDF	Refuse-Derived Fuel
RE	Revised Estimates
REM	Rail Emissions Model
RESTATS	Renewable Energy Statistics (published by DESNZ)
RFT	Robust Farm Type
RSSB	Rail Safety and Standards Board
RVP	Reid Vapour Pressure
SCP	Small Combustion Plant
SCR	Selective Catalytic Reduction
SECA	Sulphur Emission Control Area
SED	Solvent Emissions Directive
SEPA	Scottish Environmental Protection Agency
SICE	Science and Innovation Climate and Energy
SMMT	Society of Motor Manufacturers and Traders
SPRI	Scottish Pollutant Release Inventory
SSF	Solid Smokeless Fuel

SWA	Scotch Whisky Association
TAN	Total ammoniacal nitrogen
TCCCA	Transparency, Completeness, Consistency, Comparability and Accuracy
TERT	Technical Expert Review Team
TFEIP	Task Force on Emission Inventories and Projections
TfL	Transport for London
THC	Total Hydrocarbons
TSP	Total Suspended Particulate
TRL	Transport Research Laboratory
U	Urea
UK	United Kingdom
UK ETS	United Kingdom Emissions Trading System
UK-PRTR	Pollutant Release and Transfer Register
UKCEH	United Kingdom Centre for Ecology and Hydrology
UKOOA	UK Offshore Operators Association
UKPIA	UK Petroleum Industries Association
ULEZ	Ultra-Low Emission Zone
ULSD	Ultra-low Sulphur Diesel
ULSP	Ultra-low Sulphur Petrol
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
US EPA	United States Environment Protection Agency
WEI	Welsh Emissions Inventory
WWT	Wastewater treatment

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1. Introduction

This chapter provides an overview of the management and delivery of the UK National Atmospheric Emissions Inventory (NAEI) programme, including:

- Section 1.1 summarises the scope of the inventory and the reporting requirements.
- Section 1.2 describes the institutional arrangements that underpin the inventory activities.
- Section 1.3 summarises the process of inventory preparation, providing an overview of data management throughout the annual inventory cycle.
- Section 1.4 provides a summary of compilation methods and inventory input data.
- Section 1.5 provides the results from a key category analysis. This identifies the sources which make the most important contributions to the emissions totals and trends.
- Section 1.6 summarises the inventory QA/QC system, including insight into inventory data quality objectives, key QA/QC activities and the roles and responsibilities within the inventory team.
- Section 1.7 summarises the results from the uncertainty analysis across a range of the pollutants in the NAEI.
- Section 1.8 gives an overview of the completeness assessment that is conducted every year.

1.1. National Inventory Background

1.1.1. UK Inventory Reporting Scope: Pollutants & Time Series

The UK NAEI compiles long running time series of annual pollutant emissions, starting from 1970 for many pollutants. The Convention on Long-Range Transboundary Air Pollution (CLRTAP) and National Emissions Ceilings Regulations (NECR[10]) 2018 (which transposed the EU National Emission Ceilings Directive 2016/2284/EU into UK law) both require emissions to be reported from 1990 for most pollutants. The NAEI produces a complete time series of emissions where required for reporting under these requirements. The pollutants that are reported under CLRTAP and NECR are highlighted in Table 1-2. Black Carbon and nine heavy metals are reported on a voluntary basis.

Inclusion of additional pollutants in the inventory is usually a result of new legislation that sets limits on total emissions and/or requires the reporting of quantitative information on pollutant emissions. Further, the UK government takes a proactive approach to review and enhance where necessary the scope of the NAEI, in order to support research and UK policy development (see Section 1.2 on the Institutional Arrangements for Inventory Preparation).

As a result, the NAEI data set includes emission estimates of pollutants which are not currently required by international or national reporting obligations, but which are of use to the research community. For example, the UK compiles emission inventories for base cations (sodium, potassium, calcium and magnesium), to enable air pollution modellers to better recreate real-world atmospheric processes, and to generate more accurate estimates for the impact of acidic gases on human health and the environment. The scope of pollutants that are compiled in the NAEI is listed in Table 1-1.

[10] The National Emission Ceilings Regulations 2018 (legislation.gov.uk) https://www.legislation.gov.uk/uksi/2018/129/contents/made

The NAEI is subject to continuous improvement. Potential improvements to data sources, method options and reporting outputs are identified through QA activities such as peer, bilateral and expert reviews, or are identified and logged by the UK Inventory Agency experts as part of the routine annual compilation process. A list of potential improvements is then compiled and reviewed by the UK Government, the Inventory Agency and other stakeholders every six to twelve months to generate a prioritised list of improvement tasks. Improvements may then be implemented (depending on resources) in time for the next inventory cycle.

Table 1-1 Scope of NAEI Reporting for each pollutant.

Pollutant	Reported under CLRTAP/NECR	Inventory Time series[1]	Type of Pollutant[2]
Nitrogen Oxides	✓	1970-2022	NAQS, AG, IGHG, O, E
Sulphur Dioxide	✓	1970-2022	NAQS, AG, IGHG
Carbon monoxide	✓	1970-2022	NAQS, O, IGHG
Non-Methane Volatile Organic Compounds *	✓	1970-2022	NAQS, O, IGHG
Black Smoke		1970-2022	NAQS
Black Carbon	✓	1970-2022	-
Particulates < 10 μm	✓	1970-2022	NAQS
Particulates < 2.5 μm	✓	1970-2022	NAQS
Particulates < 1 μm		1970-2022	-
Particulates < 0.1 μm		1970-2022	-
Total Suspended Particulates	✓	1970-2022	-
Ammonia	✓	1980-2022	AG, E
Hydrogen Chloride		1970-2022	AG
Hydrogen Fluoride		1970-2022	AG
Lead	✓	1970-2022	NAQS, TP
Cadmium	✓	1970-2022	TP
Mercury **	✓	1970-2022	TP
Copper	✓	1970-2022	TP
Zinc	✓	1970-2022	TP
Nickel **	✓	1970-2022	TP
Chromium **	✓	1970-2022	TP
Arsenic	✓	1970-2022	TP
Selenium	✓	1970-2022	TP
Vanadium		1970-2022	TP
Beryllium		2000-2022	TP
Manganese		2000-2022	TP
Tin		2000-2022	TP
Polycyclic Aromatic Hydrocarbons *	✓	1990-2022	TP
PCDDs and PCDFs	✓	1990-2022	TP
Polychlorinated Biphenyls *	✓	1990-2022	TP
Hexachlorocyclo-hexane (HCH)[3]		1990-2022	TP
Pentachlorophenol		1990-2022	TP
Hexachlorobenzene	✓	1990-2022	TP
Short-chain chlorinated paraffins		1990-2022	TP
Polychlorinated Naphthalene		NE	TP

Pollutant	Reported under CLRTAP/NECR	Inventory Time series[1]	Type of Pollutant[2]
Polybrominated diphenyl ethers		SE	TP
Sodium		1990-2022	BC
Potassium		1990-2022	BC
Calcium		1990-2022	BC
Magnesium		1990-2022	BC

[1] An explanation of the codes used for time series:

SE A "Single Emission" not attributed to a specific year

NE "Not Estimated"

[2] An explanation of the codes used for pollutant types:

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

[3] Total HCH is dominated by lindane, an organochlorine chemical variant of HCH that has been used as an agricultural insecticide.

*** The inventory also makes emission estimates of the individual compounds within this group of compounds.**

**** Metals for which the inventory makes emission estimates for each of the chemical form of the emissions**

1.1.2. International and Domestic Reporting Requirements: NECR and CLRTAP

The UK Air Pollutant Inventory programme (which is part of the NAEI programme), managed by the Department for Environment, Food and Rural Affairs (Defra), is responsible for submitting the official UK emissions datasets to the public under the NECR and to the UNECE Secretariat under the CLRTAP.

The NECR sets emission reduction commitments (ERCs) for the total emissions of NO_X, SO_X, NMVOCs, NH_3 and $PM_{2.5}$ in 2020-29 and 2030. The 2010 emission ceilings for NO_X, NMVOCs, NH_3 and SO_X, in the NECR and Gothenburg Protocol, apply up to the end of 2019 and are then superseded by the 2020-29 ERCs. The NECR pollutants contribute to acidification and eutrophication of ecosystems whilst also playing a major role in the formation of ground-level ozone. Under the NECR and Gothenburg Protocol, the UK is required to prepare and annually update national emissions inventories for these and a number of other air pollutants.

The 2024 NAEI submission shows the UK is compliant with all 2020-29 domestic and international emission reduction commitments for NECR pollutants (NO_X, NMVOCs, SO_X, NH_3 and $PM_{2.5}$) in 2020, 2021 and 2022.

The UK prepared an adjusted inventory for ammonia (NH_3) in the 2022 inventory submission, which was approved by the UNECE, and will be applied in all subsequent submissions, bringing the emissions total for 2020, 2021 and 2022 below the 2020-29 emission reduction commitment ceiling. More detail on the adjustment is set out in Chapter 10.

NECR ERC for 2020-29 requires the UK annual emissions of $PM_{2.5}$ to be 30% lower than emissions in 2005. In the previous submission, $PM_{2.5}$ emissions were 28% lower than in 2005 and so the UK emissions were greater than the emissions reduction commitment for 2021. Due to the combined impact of multiple revisions made across the latest inventory timeseries, estimated $PM_{2.5}$ emissions are now 40% lower in 2021 than in 2005 and so the UK is now compliant for 2021. These revisions are discussed in detail in chapter 8 however, the key improvements are:

- Updated road transport emission factors to align with COPERT 5.6.
- Updated methodology for industrial biomass boiler emissions enabling use of more technology specific emission factors.

- Updated assumptions on domestic wood consumption, including the types of appliances being used, to better align with how the Digest of UK Energy Statistics (a key data source for the NAEI) models wood consumption.

The 2024 NECR submission uses the latest CLRTAP reporting templates (as per international reporting guidelines), including a common scope of reporting of pollutant inventories and similar reporting timeframe, as shown in Table 1-2.

The deadlines for NECR and CLRTAP are as follows:

- Emission inventories - 15th February 2017 and every year thereafter;
- Informative Inventory Report (IIR) - 15th March 2017 and every year thereafter;
- Emission projections - 15th March 2017 and every two years thereafter;
- Spatially-disaggregated emissions (gridded emissions) - 1st May 2017 and every four years thereafter;
- Large point source (LPS) emissions - 1st May 2017 and every four years thereafter.

CLRTAP

There are several protocols under the CLRTAP, which require national emission estimates to be reported on an annual basis. The most extensive commitments are specified in the 'multi-pollutant' protocol (the so-called Gothenburg Protocol agreed in November 1999 and revised in 2014), but there are also reporting requirements included in the Heavy Metals Protocol and Persistent Organic Pollutants Protocol. The 2024 NAEI submission under the NECR and Gothenburg Protocol has been compiled in line with the revised Gothenburg Protocol Guidance[11].

The pollutants required for reporting under the CLRTAP and the NECR are listed in Table 1-2 below.

[11] https://unece.org/sites/default/files/2021-10/ECE.EB_.AIR_.114_ENG.pdf

Table 1-2 Summary of annual reporting requirements for estimating and reporting emissions under the CLRTAP and NECR

Group	Pollutant	Required reporting years	Reported years in 2024 UK submission
Main Pollutants	Nitrogen Oxides	1990 - reporting year minus 2	1990-2022
	Sulphur Dioxide		
	Carbon monoxide		
	Non-Methane Volatile Organic Compounds		
	Ammonia		
Particulate Matter	Particulates < 10 µm	2000 - reporting year minus 2	1990-2022
	Particulates < 2.5 µm		
	Total Suspended Particulates		
	Black Carbon (voluntary)		
Priority Heavy Metals	Lead	1990 - reporting years minus 2	1990-2022
	Cadmium		
	Mercury		
Other Heavy Metals	Copper (voluntary)	1990 - reporting year minus 2	1990-2022
	Zinc (voluntary)		
	Nickel (voluntary)		
	Chromium (voluntary)		
	Arsenic (voluntary)		
	Selenium (voluntary)		
Persistent Organic Pollutants	Benzo[a]pyrene	1990 - reporting year minus 2	1990-2022
	Benzo[b]fluoranthene		
	Benzo[k]fluoranthene		
	Indeno(1,2,3-cd)pyrene		
	PCDD/PCDFs		
	Polychlorinated Biphenyls		
	Hexachlorobenzene		
Activity data by source category		1990 - reporting year minus 2	1990-2022

1.1.3. Emission Sources Reported in the NAEI

In principle, the NAEI makes estimates of all GHG and air pollutant emissions to the atmosphere at the highest level of disaggregation possible where suitable information exists to calculate an estimate. However, in accordance with international guidelines[12] on emissions inventory reporting, there are several known sources that are excluded from the inventory emission estimates:

- Natural sources are not included in the national totals (although estimates of some sources are made). Only anthropogenic emission sources are reported.
- The NAEI reports only primary source emissions to atmosphere (as per international guidelines). Consequently, re-suspension of particulate matter is not included in the national totals (although estimates for some re-suspension terms are made) or any secondary pollutants, such as tropospheric ozone.

[12] https://unece.org/sites/default/files/2021-10/ECE.EB_.AIR_.114_ENG.pdf

- Cruise emissions from civil and international aviation are not included in the national totals (only estimates from landing and take-off (LTO) for civil and international aviation are included in the national totals).
- Estimates of "International" emissions such as shipping are made and reported as memo items (i.e. excluded from the UK national totals).

Assessing the completeness of the emissions inventory, and the use of validation studies are explained under the Quality Assurance and Quality Control sections of this report (Section 1.6).

1.1.4. Geographical Scope

The geographical coverage of the emissions data in this report is the UK plus Gibraltar. Emissions from any other UK Overseas Territories (OTs), and Crown Dependencies (CDs) are excluded.

Under the UNFCCC[13], GHG emissions from the UK CDs and OTs who have chosen to opt in to the "UK umbrella agreement" are included in the national totals. This is one reason for differences in the NO_X, SO_X, NMVOCs and CO emissions reported under the NECR/CLRTAP and the UNFCCC, where they are reported as indirect GHGs.

1.2. Institutional Arrangements for Inventory Preparation

The NAEI is maintained under contract to the Science and Innovation for Climate and Energy (SICE) Division at the Department for Energy Security and Net Zero (DESNZ) and the Air Quality and Industrial Emissions Evidence Team of the Department for Environment, Food and Rural Affairs (Defra).

The NAEI is also co-funded by the Scottish Government (SG), the Welsh Government (WG) and the Northern Ireland Department of Agriculture, Environment and Rural Affairs (DAERA).

The UK emission inventories are compiled and maintained by the NAEI consortium, led by Ricardo (the Inventory Agency).

ADAS compiles emissions of air quality pollutants and GHGs from agricultural emission sources under a separate contract to Defra. ADAS provides the agriculture inventory data and supporting documentation to Ricardo for inclusion within the NAEI submissions.

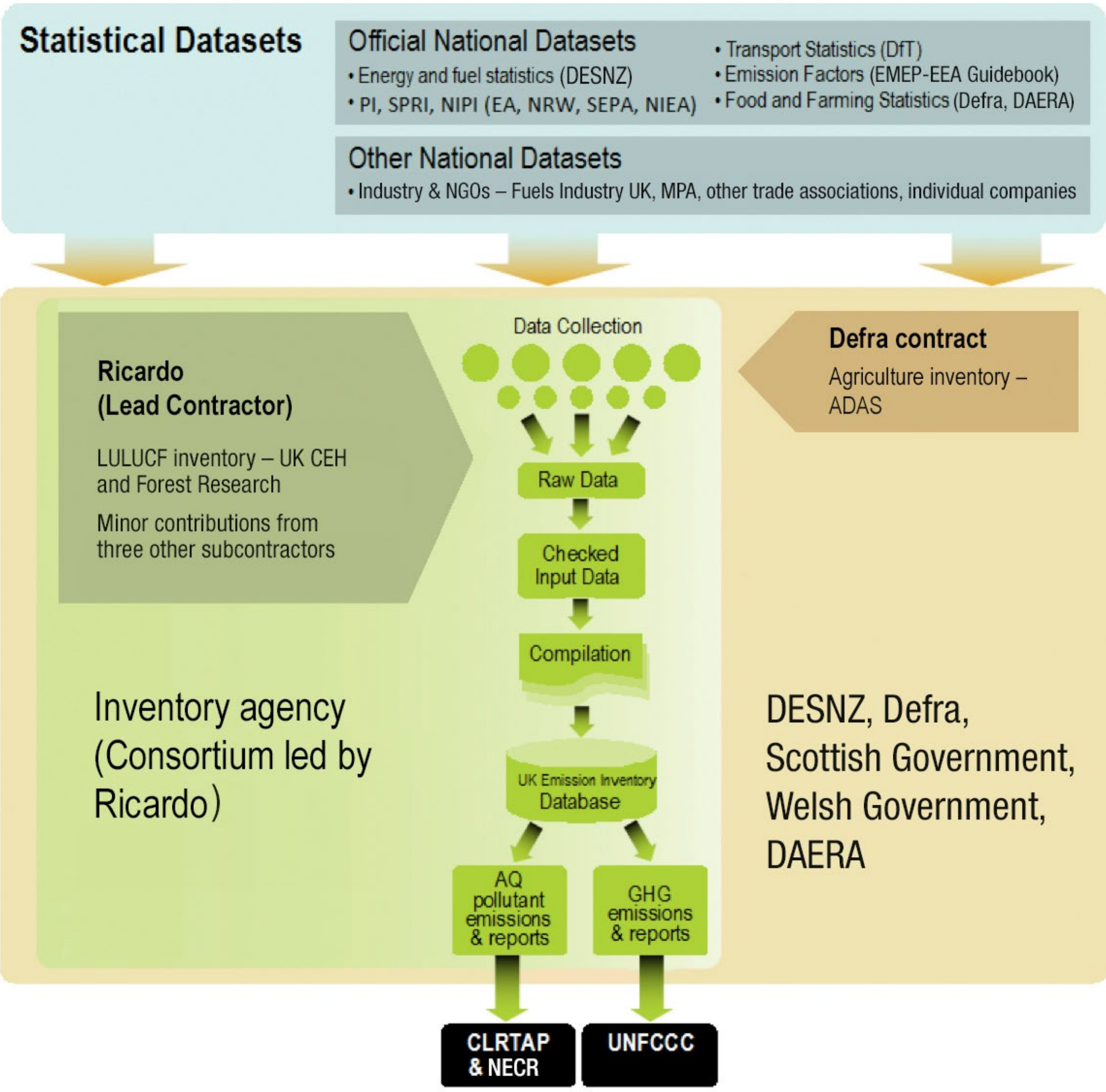
An overview of the organisational structures, roles and responsibilities within the NAEI is provided in

Figure 1-1 below. The figure also illustrates the data flow from official statistical datasets, other data provider organisations through the inventory compilation system and NAEI database to the main international reporting outputs.

For a summary of Key Data Providers to the NAEI work programme, see section 1.3.4.2

[13] Under the EU Monitoring Mechanism Regulation emissions are reported for the United Kingdom and Gibraltar only.

Figure 1-1 Overview of the Roles within the NAEI



1.2.1. Defra

Defra is the Department responsible for meeting the UK Government's commitments to international reporting on air quality pollutant emissions. Defra has the following roles and responsibilities:

- National level management and planning;
- Overall control of the inventory programme development and function;

- Procurement and management of contracts which deliver and report emissions inventories;
- Development of legal and contractual Infrastructure;
- Review and evolution of legal and organisational structure;
- Implementation of legal instruments and contractual developments as required, to meet guidelines.

1.2.2. Ricardo

As the UK's Inventory Agency, Ricardo is responsible for compiling the emission inventories and submitting them on behalf of Defra. Other roles and responsibilities include the following:

Planning

- Co-ordination with Defra and DESNZ to compile and deliver the NAEI to meet international reporting requirements and standards;
- Review of current performance and assessment of required development action;
- Scheduling of tasks and responsibilities of the range of inventory stakeholders to ensure timely and accurate delivery of emissions inventory outputs.

Preparation

- Drafting of data supply agreements with key data providers;
- Review of source data and identification of developments required to improve the inventory data quality.

Management

- Documentation and secure archiving of data and relevant information;
- Dissemination of information to NAEI stakeholders, including data providers;
- Management of inventory QA/QC plans, programmes and activities across all aspects of the inventory;
- Archiving of historic datasets (and ensuring the security of historic electronic data), maintaining a library of reference material. The NAEI database is backed up whenever the database has been changed.

Inventory Compilation

- Data acquisition, analysis, processing and reporting;
- Delivery of the Informative Inventory Report (IIR) and associated datasets to time and quality.

Ricardo is the lead contractor in the consortium responsible for compiling and maintaining the NAEI and has direct responsibility for the items listed above, as well as managing the inputs from sub-contractors, and incorporating the inputs from other contracts directly held by other organisations with Defra:

- Agricultural emissions of air quality pollutants are prepared by a consortium led by ADAS, under contract to Defra.

Information Dissemination

Data from the NAEI are made available to national and international bodies in a number of different formats and publications, including being published as Accredited Official Statistics[14]. The NAEI team also liaise regularly with representatives from industry, trade associations, UK Government and the Devolved Governments in Scotland, Wales, and Northern Ireland.

In addition, there is a continuous drive to enhance the information made available and accessible to the public. The NAEI website is updated annually, providing the most recent emissions data and other information such as temporal trends, new pollutants and methodology changes.

The NAEI web pages may be found at http://naei.beis.gov.uk/.

The web pages are arranged to allow easy and intuitive access to the detailed emissions data, as well as providing general overview information on air pollutants and emissions inventories for non-experts. Information resources available on the NAEI web pages include:

- Data Selector - Emissions data, spanning all pollutants and the entire time series are made available in numerous formats through a database. This allows extraction of overview summary tables, or highly detailed emissions data. The data can also be downloaded and manipulated via Excel based pivot tables.
- Emissions Maps - Emissions of pollutants are generated as maps covering the whole UK and are updated annually. These are interactive maps illustrating emissions of various pollutants on a 1 x 1 km resolution. The maps are available as images, but in addition the data behind the maps can also be accessed directly from the website. An interactive interface to the maps may be found at http://naei.beis.gov.uk/emissionsapp/.
- Reports- The most recent reports compiled by the inventory team, covering a range of topics and tasks undertaken as part of the NAEI programme.
- Methodology- An overview of the approach used for the compilation of the NAEI is included on the website.

In addition, the NAEI website provides links to webpages that explain technical terms, provide ambient pollutant concentration data and to sites that outline the scientific interest in specific pollutants and emission sources. In particular, there are links to the various Defra pages containing comprehensive measurement data on ambient concentrations of various pollutants. The Defra air quality website can be found at http://uk-air.defra.gov.uk/.

Information Archiving and Electronic Back-ups

The UK emissions inventory team are responsible for maintaining an archive of reference material and previously conducted work. This archive include both paper records (held on site at the Ricardo office in Oxfordshire), and electronic records.

Electronic information is held on networked servers. This allows efficient access and maintains good version control. The data on the servers are mirrored to a second server situated at a different location to ensure data security, with incremental tape backups performed to maintain currency. The data files (in particular the compilation data and central database) are automatically backed up whenever the files are changed.

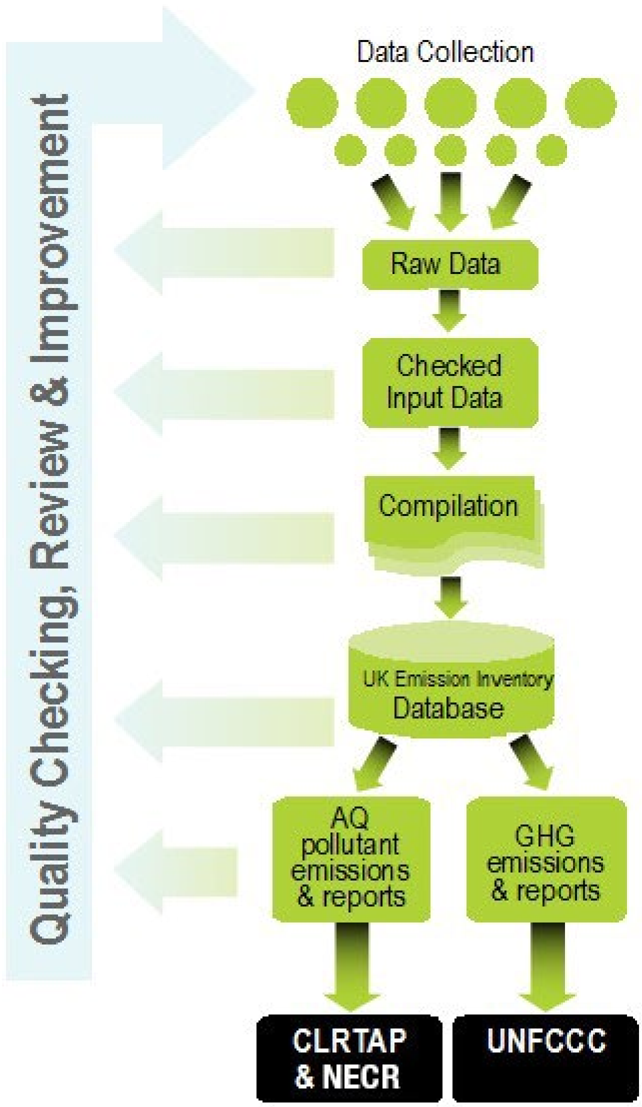
[14] https://www.gov.uk/government/statistical-data-sets/env01-emissions-of-air-pollutants

1.3. Inventory Preparation

1.3.1. Introduction

Figure 1-2 shows the main elements of the NAEI system, from collection of source data from UK organisations through to provision of data to international organisations. Further details of these elements are discussed in Section 1.3.4 to Section 1.3.8.

Figure 1-2 Overview of the Inventory Preparation Process



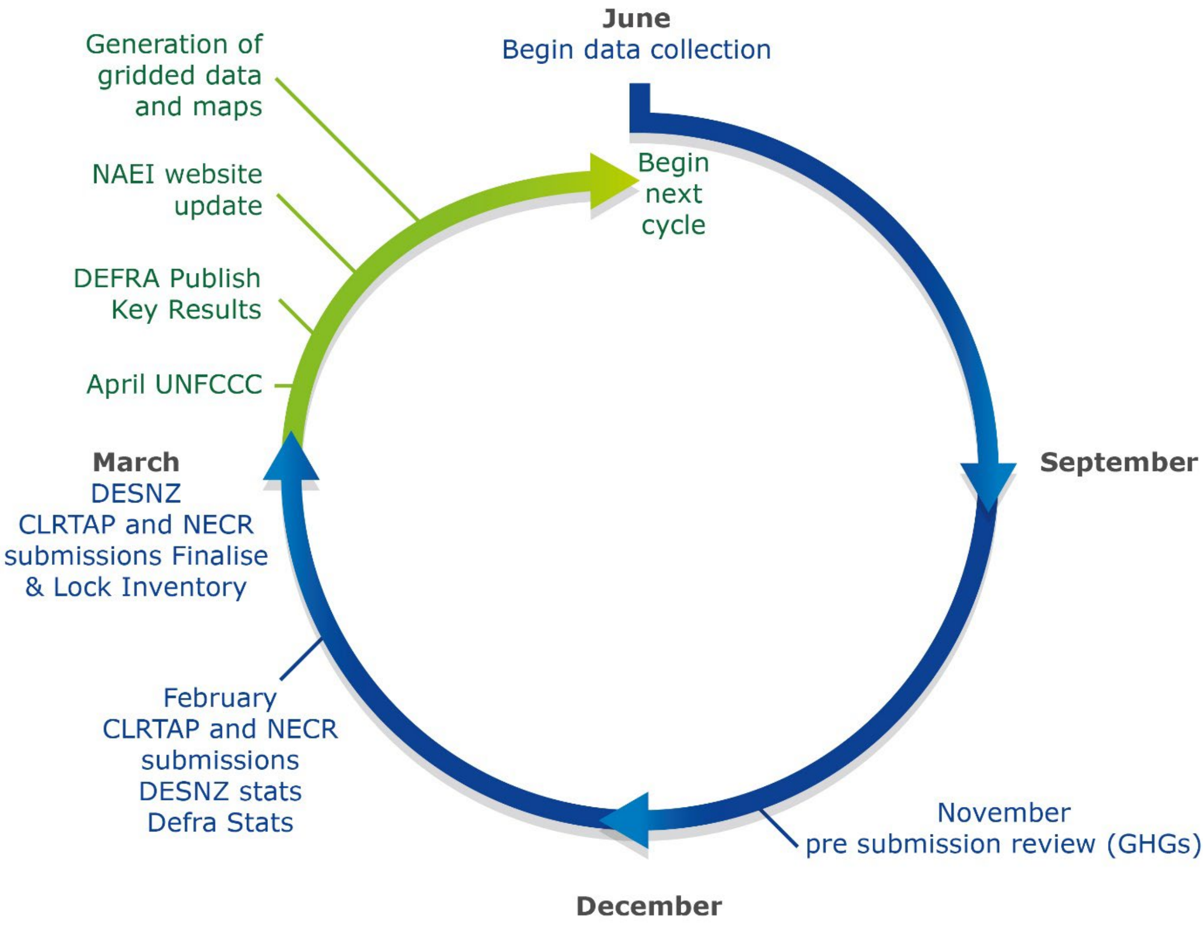
1.3.2. The Annual Cycle of Inventory Compilation

The activities outlined above in Figure 1-2 comprise the annual cycle of NAEI delivery from data acquisition, method selection and development through to reporting. Each year the latest data are added to the NAEI and the time series from 1990 is updated to take account of improved data and any advances in the methodology used to estimate the emissions. Updating the time series, and making re-calculations where necessary, is an important process as it ensures that:

- The post-1990 NAEI dataset/time series is based on the latest available data, using the most recent research, inventory guidance, methods and estimation models available in the UK;
- The NAEI estimates for a given source are calculated using a consistent approach across the time series and the full scope of pollutants;
- All the NAEI data are subject to an annual review, and findings of all internal and external reviews and audit recommendations are integrated into the latest dataset.

This annual cycle of activity is represented schematically in Figure 1-3. It is designed to ensure that the NAEI data are compiled and reported to meet all quality requirements and reporting timescales of the UNECE, other international forums and for UK and Devolved Government publications of inventory data.

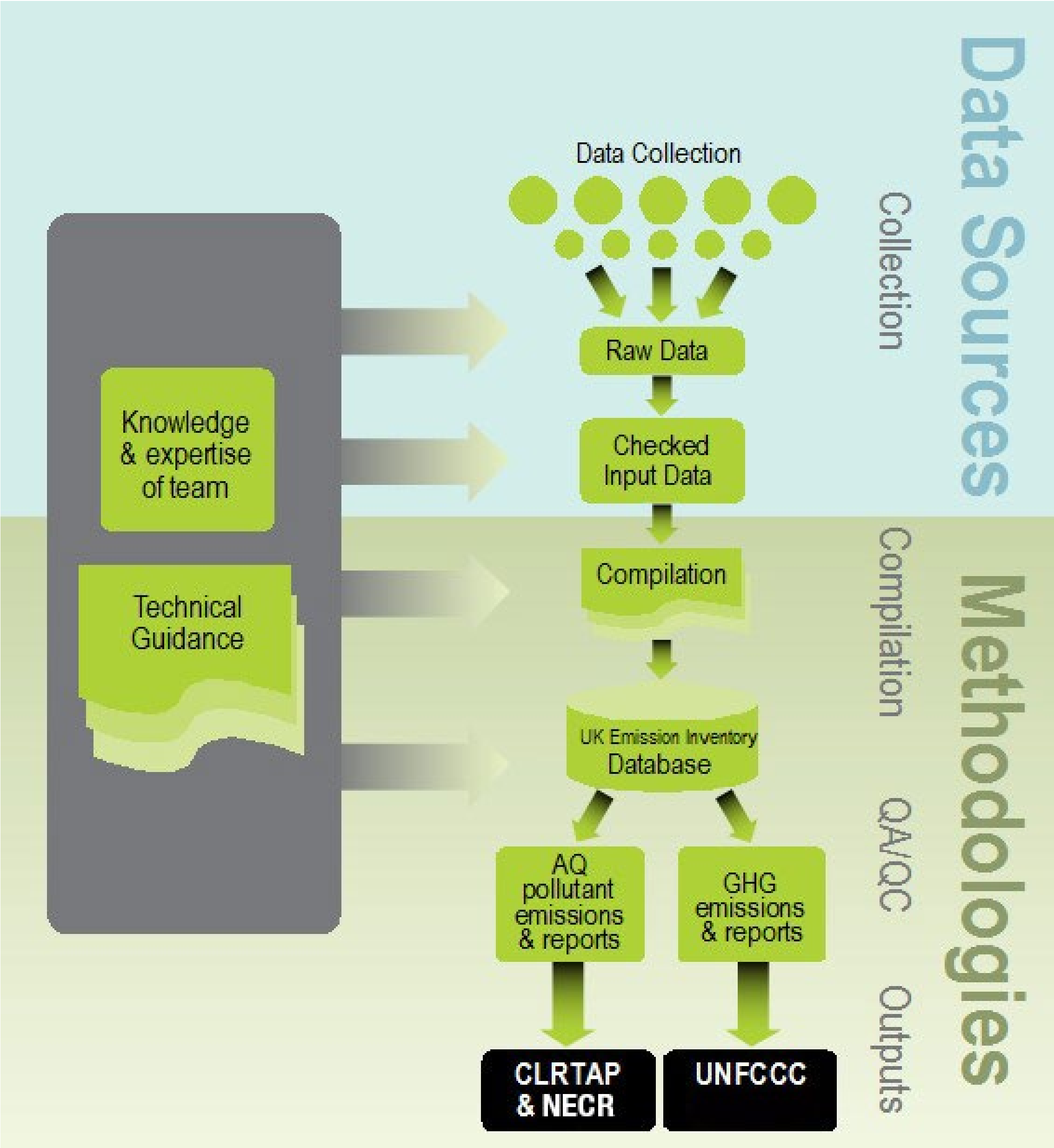
Figure 1-3 The Annual NAEI Cycle in the UK



1.3.3. The NAEI Compilation System

The compilation of the NAEI requires a systematic approach to the collection and collation of statistical and source emission measurement information, and the subsequent calculation of comprehensive, coherent and comparable air emissions data to a range of users as illustrated in Figure 1-4.

Figure 1-4 Summary of NAEI data flows



The compilation method can be summarised as follows:

1. **Method Review and Data Collection** - Findings from inventory reviews and previous NAEI compilation cycles are reviewed, method improvements are planned / implemented and the source data that will be required for all NAEI methods are requested, collected and logged, from a wide variety of data providers.
2. **Raw Data Processing** - The raw data received from data provider organisations are reviewed, and where necessary formatted for use in the NAEI system of data processing. This may include checking the completeness and accuracy of data, reviewing associated QA/QC documentation and filling data gaps in the time series using a range of robust methods.
3. **Inventory Compilation** - Formatted input data are used in calculations within bespoke spreadsheets and coded models to generate all required emission factors, activity data, data references and recalculation references that are all required for use in the NAEI

database. The models include many QA/QC features to ensure that the processed data meet the inventory data quality objectives.

4. **Database Population** - All emission factors, activity data, references and recalculation references are uploaded to the central NAEI database, and QA/QC routines are run across the NAEI data to ensure that data are complete, internally consistent and accurate.
5. **Reporting Emissions Datasets** - Emissions data are extracted from the database and formatted to generate a variety of datasets used for national or international reporting requirements. These NAEI output datasets serve a range of national and international reporting requirements, and may vary in their level of detail, geographical coverage and spatial resolution.

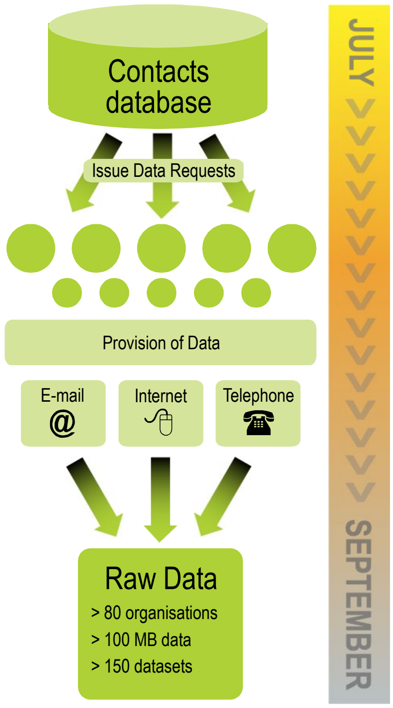
Each of these stages are explained in more detail in the following sections and the QA/QC programme that operates across the inventory programme is explained in Section 1.6. After finalisation, all different aspects of the compilation process are reviewed for improvement e.g. quality of the input data, the emissions calculation methods, the thoroughness of the QA/QC checks, efficiency of data handling etc. All review findings then feed into stage 1 of the next NAEI cycle.

1.3.4. Stage 1: Data Collection

1.3.4.1. Data Management

Figure 1-5 describes the data collection process for core NAEI compilation. Requests to data providers are made by e-mail, telephone and via internet-based queries. The process is managed by the NAEI Data Acquisition Manager who follows-up on the initial data requests, keeps a detailed record of all data received and ensures initial QC of data by sector or pollutant experts. The primary tool used to monitor requests for, and collection of data is a Contacts Database, which holds contact details of all data providers, and references to the data provided in the past. All data requests and details of incoming data are logged and tracked through the database. All incoming data (and all outgoing data) are given a unique reference number to allow effective data tracking.

Figure 1-5 Data collection for core NAEI compilation



A wide variety of organisations provide data that is essential for the NAEI, to deliver complete, accurate emission estimates. Much of the data is available from statistical agencies or from Government Departments and agencies. Other essential data is provided voluntarily by private companies and trade associations. Secure data provision is aided by the development of strong working relationships with these data providers and a programme of stakeholder consultation to enable the Inventory Agency to address any emerging data requirements, for example for any new emission sources evident in the UK.

1.3.4.2. Key Data Providers

For installations that report their emissions under UK ETS, there is a statutory basis[15] for the reporting of information for the purpose of preparing and publishing national energy and emissions statistics, including the national inventory; data from the UK ETS are therefore used to inform the activity data for many high-emitting emission sources in the NAEI. Aside from this, there is currently no obligation for organisations to provide data pertinent specifically to the Air Pollutant Inventories. However, the key data providers to the NAEI are encouraged to undertake the following commitments relating to data quality, data formats, timeliness of provision and data security:

- Delivery of source data in an appropriate format and in time for NAEI compilation;
- Undertake and provide an assessment of their data acquisition and processing and reporting systems;
- Application and documentation of QA/QC processes;
- Identification of any organisational or legal requirements and resources to meet more stringent data requirements, notably the security of data provision in the future;
- Communication with Defra or DESNZ, the Inventory Agency and their peers/members to help to disseminate information.

[15] See The Greenhouse Gas Emissions Trading Scheme Order 2020, available at: https://www.legislation.gov.uk/uksi/2020/1265/contents

Energy statistics required for compilation of the NAEI are obtained from the Digest of UK Energy Statistics (DUKES), which is compiled and published annually by a team of energy statisticians within DESNZ.

Information on industrial processes is provided either directly to the Inventory Agency by the individual plant operators or from:

- The Environment Agency's Pollution Inventory (PI) for England;
- Natural Resources Wales's Welsh Emissions Inventory (WEI);
- The Scottish Environment Protection Agency's Scottish Pollutant Release Inventory (SPRI);
- The Northern Ireland Environment Agency Pollution Inventory (NIPI);
- The Offshore Petroleum Regulator for Environment and Decommissioning (OPRED) Environmental and Emissions Monitoring System (EEMS); and
- UK Emissions Trading System (UK ETS) data are provided by DESNZ.

Reporting to these UK inventories for the purposes of environmental regulation is a statutory requirement for industries covered by the Industrial Emissions Directive (IED) and the UK Environmental Permitting Regulations (EPR) that transposes this. The data from these inventory sources is also used to quality check data provided voluntarily by companies directly to the Inventory Agency.

Other Government Departments and agencies provide essential inputs ranging from annual statistics to periodic research and analysis, including:

- DfT provides annual transport statistics for different modes of transport;
- The Department for Levelling Up, Housing and Communities provides housing statistics;
- Defra provides waste management annual statistics;
- ONS provides economic activity data.

Other key data providers or inventory compilers that feed into the NAEI include:

- ADAS compiles the inventory for agricultural emissions using agricultural statistics from Defra and the Northern Ireland Department of Agriculture Environment and Rural Affairs (DAERA).
- The UK Centre of Ecology and Hydrology (UKCEH) compiles NH_3 emission estimates for sources in the natural and waste sectors and provides information for mapping NH_3 emissions.

Trade associations, statistical agencies and individual companies such as, but not limited to:

- Tata Steel and British Steel;
- Fuels Industry UK;
- Iron and Steel Statistics Bureau (ISSB);
- Mineral Products Association (MPA);
- Civil Aviation Authority (CAA);
- British Geological Survey (BGS);

- British Aerosols Manufacturing Association (BAMA).

The NAEI is also subject to a continuous improvement programme to incorporate the latest available evidence. For example, an improvement to the domestic combustion model to integrate research carried out on wood burning in the residential sector in the UK, by reallocating 'new' wood use to more modern stoves, improving the accuracy of emission estimates of key pollutants (notably $PM_{2.5}$) from this source, has been implemented in this submission (see section 3.4.5 for further details).

1.3.5. Stage 2: Raw Data Processing

The data received from the data providers are stored in a file structure according to the provider. All data is traceable back to the original source via the Contacts Database

The majority of data received is used directly in the compilation spreadsheets (Stage 3 below). However, for some datasets further processing is required before it is possible to use in Stage 3. For example, extensive data pre-processing is conducted to convert installation-level energy and/or emissions data from the UK ETS, PI, WEI, SPRI and NIPI into data that are in the correct units and format for use within the NAEI model suite.

The data checking, and QA/QC procedures associated with this stage of the work are detailed in Section 1.6.

1.3.6. Stage 3: Inventory Compilation

Raw data are compiled into a series of data processing spreadsheets and coded models. These models are used to perform the bespoke calculations, analysis and data manipulations necessary to compile appropriate and consistent component statistics or emission factors for use in the NAEI emissions database. The models also record the source of any originating data and the assumptions and calculations conducted to create the data necessary for the emissions database. There are thorough checks on the compilation models as detailed in Section 1.6. All processed data are ultimately transferred into the central NAEI database.

1.3.7. Stage 4: Database Population

A core MySQL database is maintained containing all the activity data and emission factors. Annually, this core database is updated with activity data for the latest year, updated data for earlier years and with revised emission factors and methods. The transfer of data to the database from the compilation spreadsheets is automated via a Microsoft Access front-end to increase efficiency and reduce the possibility of human error.

The core database system calculates all the emissions for all the sectors required by the NAEI and greenhouse gas inventory (GHGI) to ensure consistency.

All activity data and emission factors in the database are referenced with data origin, a text reference/description and the literature reference.

Once populated there are numerous checks on the data held in the database before use. These checks are detailed in Section 1.6.

1.3.8. Stage 5: Reporting Emissions Data

There are numerous queries in the database to allow the data to be output in a variety of different formats. Database forms allow data output handling to be conducted more efficiently and consistently.

For the CLRTAP and NECR submissions, data for the relevant pollutants and years are extracted from the database in NFR format, with post-processing then conducted in a spreadsheet which is set-up to enable automated population of reporting forms. The NFR reporting templates are then populated automatically, and manual amendments to specific sections e.g. adjustments are carried out before the data are thoroughly checked and submitted.

1.4. Methods and Data Sources

The NAEI (AQPI – Air Quality Pollutant Inventory and GHGI) is compiled according to international good practice guidance for national inventories; for air quality pollutant inventories the inventory methodological guidance is the 2019 EMEP/EEA Air Pollutant Emission Inventory Guidebook[16]. As recommended by the EEA, we have used the 2019 guidebook where possible and appropriate for UK circumstances for the 2024 submission. For Greenhouse Gas inventories, the latest mandatory guidance is the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories[17]. In a number of cases, the NAEI is supplemented with guidance from the 2019 Refinement to the 2006 IPCC Guidelines.[18] Additionally, the most recent 2023 version of the EMEP/EEA Guidebook is used in some areas. A more complete integration is anticipated to take place for the 2025 submission.

Each year, the NAEI is updated to include the latest data available and any new research to improve the emission estimation methods. Improvements to the NAEI methodology are made and backdated to 1990 to ensure a consistent time series for emissions reporting. Emission estimates in years prior to 1990 were locked down following the 2021 submission to allow resources to be focussed on recent emissions. Methodological changes are made to take account of new data sources, or new guidance from EMEP/EEA, relevant work by IPCC, new research, or specific research programmes sponsored by Defra or DESNZ. Information on improvements and recalculations can be found throughout this report, in Chapters 2 to 7, which describe the methods used in the different source sectors.

This section provides an overview of the NAEI data and methods and provides further details for the two most significant data sources: (i) the UK energy statistics, and (ii) industrial emissions reported via the UK environmental regulatory agencies. Finally, the planned improvements are summarised.

1.4.1. NAEI Data and Methods Overview

Overview information on primary data providers and methodologies has been included in the above sections. Table 1-3 indicates where UK-specific data are used in the NAEI, and where methodologies that are more generic are used (i.e. where UK specific information is not available). Please note that this table presents an overview only, by NFR category. Further details (e.g. of EF sources from literature or UK research) are provided in the individual chapter sections, presenting methodological information for each NAEI source within each NFR category.

Table 1-3 NAEI Compilation Methodologies by NFR Category

NFR Category	Activity Data	Emission Factors
1A1a Public Electricity & Heat Production	UK statistics (DUKES), UK ETS/EU ETS	Operator reporting to regulators for PRTR; default EFs (UK research, EMEP/EEA, US EPA)
1A1b Petroleum refining	UK statistics (DUKES), UK ETS/EU ETS	Operator reporting to regulators for PRTR; default EFs (UK research, EMEP/EEA, US EPA)
1A1c Manufacture of Solid Fuels etc.	UK statistics (DUKES), UK ETS/EU ETS, EEMS	Operator reporting to regulators for PRTR and EEMS; default EFs (UK research, EMEP/EEA, US EPA)

[16] https://www.eea.europa.eu/publications/emep-eea-guidebook-2019
[17] http://www.ipcc-nggip.iges.or.jp/public/2006gl
[18] https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

NFR Category	Activity Data	Emission Factors
1A2a Iron & Steel	UK statistics (DUKES), ISSB, UK ETS/EU ETS	Operator - Majority of EFs reported from Tata Steel and British Steel; several EFs from fuel analysis or default EFs (UK research, EMEP/EEA, US EPA)
1A2b Non-ferrous Metals	UK statistics (DUKES), UK ETS/EU ETS	Fuel analysis or default EFs (US EPA, EMEP/EEA, UK-specific research).
1A2c Chemicals	UK statistics (DUKES), UK ETS/EU ETS	Fuel analysis or default EFs (US EPA, EMEP/EEA, UK-specific research); Operator reporting to regulators for PRTR
1A2d Pulp, Paper & Print	UK statistics (DUKES)	Fuel analysis or default EFs (US EPA, EMEP/EEA, UK-specific research).
1A2e Food Processing, Beverages & Tobacco	UK statistics (DUKES)	Fuel analysis or default EFs (US EPA, EMEP/EEA, UK-specific research).
1A2f Non-metallic minerals	UK statistics (DUKES), UK ETS/EU ETS, MPA	Operator reporting to regulators for PRTR; fuel analysis or default EFs (US EPA, EMEP/EEA, UK-specific research).
1A2g Other	UK statistics (DUKES)	Fuel analysis or default EFs (US EPA, EMEP/EEA, UK-specific research).
1A3ai(i) International Aviation (LTO)	UK statistics (CAA)	Calculated based on information from the ICAO database
1A3aii(i) Civil Aviation (Domestic, LTO)	UK statistics (CAA)	Calculated based on information from the ICAO database
1A3b Road Transportation	UK statistics (DfT, DAERA)	Literature sources and UK factors
1A3c Railways	UK statistics (ORR) and estimated	UK factors
1A3di (ii) International inland waterways	NA	NA
1A3dii National Navigation	UK statistics and sector research	Literature sources and UK factors
1A3e Pipeline compressors	IE (Emissions are reported under 1A1c)	
1A4a Commercial / Institutional	UK statistics (DUKES)	Literature sources and UK factors
1A4bi Residential	UK statistics (DUKES)	Literature sources and UK factors
1A4bii Household & gardening (mobile)	Estimated	Literature sources
1A4ci Agriculture/Forestry/Fishing: Stationary	UK statistics (DUKES)	Literature sources and UK factors
1A4c ii/iii Off-road Vehicles & Other Machinery	Estimated	Literature sources and UK factors
1A5a Other, Stationary (including Military)	IE (Emissions are reported under 1A5b)	
1A5b Other, Mobile (Including military)	UK statistics	Literature sources and UK factors
1B1a Coal Mining & Handling	UK statistics (DUKES, UK Coal)	Literature sources
1B1b Solid fuel transformation	UK statistics (DUKES), UK ETS/EU ETS	Operator reporting to regulators for PRTR, literature sources
1B1c Other	IE (Emissions are reported under 1B1b)	
1B2 Oil & natural gas	UK statistics & Industry, UK ETS/EU ETS, EEMS.	Operator reporting to regulators for PRTR and via EEMS, data from Fuels Industry UK, data from UK gas network operators and from DESNZ

NFR Category	Activity Data	Emission Factors
2A Mineral Products	Industry & Estimated, UK ETS/EU ETS	US EPA factors for slag cement grinding; UK and literature factors for glass and brick/ceramics manufacture; EMEP/EEA Guidebook for construction and quarrying
2B Chemical Industry	Industry & Estimated, UK ETS/EU ETS	Operator reporting to regulators for PRTR and literature factors for some specialist chemical processes
2C Metal Production	UK statistics & Industry, ISSB, UK ETS/EU ETS	Industry & Operator reporting to regulators for PRTR; literature factors, including EMEP/EEA Guidebook for some processes
2D Solvents	UK statistics & Industry	Mostly UK-specific emissions data from trade bodies, individual operators, and regulators. Some use of EMEP/EEA Guidebook factors for minor sources.
2G Other product use	UK statistics	EMEP/EEA Guidebook
2H Pulp and paper industry, Food and beverages industry	UK statistics & Industry	EMEP/EEA Guidebook and UK-specific factors for food & drink manufacture, many of which are consistent with those presented in the EMEP/EEA Guidebook. Data from regulators used for some minor sources. EMEP/ EEA Guidebook factors for pulp and paper production.
2I Wood processing	UK statistics & Industry	Literature sources, EMEP/EEA Guidebook and operator reporting to regulators for PRTR.
2J Production of POPs	NA	NA
2K Consumption of POPs and heavy metals	Industry	Literature sources and UK-specific methods
2L Other production, consumption, storage, transportation or handling of bulk products	NA	NA
3B Manure Management	UK statistics	UK factors
3D Agricultural Soils	Majority based on UK farm surveys and fertiliser sales data	Literature sources
3F Field Burning of Agricultural Wastes	Majority based on UK farm surveys and fertiliser sales data, Estimates used for foot and mouth pyres	Literature sources
3I Other	UK Statistics & Estimated	UK factors
5A Solid Waste Disposal on Land	UK waste and disposal statistics	UK model and assumptions
5B Biological treatment of waste	UK statistics	UK factors
5C Waste Incineration	UK Statistics & Estimated	Operator reporting to regulators for PRTR and EMEP/EEA Guidebook and UK factors
5D Waste-Water Handling	UK statistics	UK factors
5E Other Waste	Estimated	UK factors
6A Other	Estimated	UK factors

NFR Category	Activity Data	Emission Factors
1A3aii(ii) Civil Aviation (Domestic, Cruise)	UK statistics (CAA)	UK Literature sources
6B Other (Memo)	UK statistics	UK factors
11 Other (Memo)	Estimated	UK factors
z_1A3ai(ii) International Aviation (Cruise)	UK statistics (CAA)	UK Literature sources
z_1A3di(i) International maritime Navigation	UK statistics and sector research	Literature sources and UK factors

The terms used to summarise the data and methods in Table 1-3 above are defined as follows:
For activity data:

- **UK Statistics**: UK statistics, including energy statistics published annually in DUKES. Almost all statistics are provided by UK Government, but the NAEI also relies on some data from other organisations, such as: iron and steel energy consumption and production statistical data provided by the ISSB, the UK Minerals Yearbook provided by the BGS, and energy use data from the UK ETS.
- **Industry**: Process operators or trade associations provide activity data directly, for example from Fuels Industry UK, Mineral Products Association (MPA), and the British Coatings Federation (BCF).
- **Estimated:** Activity data may need to be estimated by the Inventory Agency (or other external organisations) where UK statistics are not available or are available only for a limited number of years or sites. The modelled activity data estimates are commonly derived from published data or the best available proxy information such as UK production, site-specific production, plant capacity etc.

For emission factors:

- **Operator**: emissions data reported by operators is used as the basis of emission estimates and emission factors.
- **Industry:** Process operators or trade associations have provided emissions data or emission factors directly
- **UK factors:** Country-specific emissions factors based on UK research and literature sources from UK analysis.
- **Modelled:** Emissions and/or emission factors may need to be estimated by the Inventory Agency, based on parameters such as: plant design and abatement systems, reported solvent use, plant-specific operational data. Furthermore, to address data gaps and time series consistency, either emissions or emission factors may be modelled based on emissions (or emission trends) of other pollutants or activity data.
- **Literature Sources:** For many UK emission sources there may not be any specific data from UK sources or research, and in these cases the Inventory Agency refers to literature sources for emission factors that best characterise the emissions. These literature sources are mainly from international guidance for inventory reporting such as the latest EMEP/EEA Guidebook, the US EPA AP-42 and IPCC. Other useful resources are sector-specific operator reporting guidance such as best available techniques reference (BREF) documents produced by the EU IPPC bureau, or the American Petroleum Institute (AmPI) Compendium for oil and gas emission estimates.

The specific emission factors used in the calculation for all sources and pollutants for the latest inventory will be made available at the data selector on the NAEI website in Spring 2024[19].

1.4.2. Methodology Tiers

The method selected for each emission source is determined by the significance of that source in the overall NAEI context, and the availability of UK-specific data or models. A tiered approach is taken, as follows:

- **Tier 1** methods are the most simplistic. UK activity data are combined with default EFs to generate emission estimates. The default EFs from EMEP/EEA are selected to be representative of typical global average performance (e.g. of a combustion unit). Hence the Tier 1 estimates are associated with higher uncertainty, as the default EF may not accurately reflect UK circumstances, and are only used for minor sources (non-key sources).
- **Tier 2** methods combine UK activity data with EFs that are specific to the UK, usually derived from UK research, or derived from emissions reporting by plant operators that are based on emissions measurements to characterise the performance of their production or combustion process, which can then be extrapolated across all such sources (i.e. including where monitoring may not be feasible). As these EFs are more representative of the UK emission source, they are associated with lower uncertainty than Tier 1 and are suitable for application for key source categories.
- **Tier 3** methods typically apply more complex modelling approaches that are developed to generate more accurate estimates than Tier 2, often through research to better understand high-emitting emission sources. For example, Tier 3 methods in the NAEI include:
    - Aggregation of all operator-reported emissions reported to the UK environmental regulators across all high-emitting installations such as power stations, refineries, cement kilns, iron and steel works, upstream oil and gas facilities, and chemical works;
    - Road transport emissions modelling from tailpipe and tyre and brake wear sources, that combine many parameters to characterise the performance across the UK fleet, including: fuel sales, vehicle kilometre data by vehicle type (from surveys), UK fleet statistics, and average speeds on different road types (e.g. motorway, urban, rural);
    - Nitrogen balance modelling to synthesise the flow of N through different UK farming systems, to assess the fate of N and emissions of pollutants such as ammonia and nitrous oxide (a greenhouse gas).
    - The agriculture sector model to estimate emissions from major livestock categories (e.g. cattle) also take consideration of a wide range of parameters that influence emissions, including soil and climate, livestock numbers by age and breed, feed, fertiliser use, housing and waste management practices;
    - First order decay modelling of waste degradation and elution of pollutants (including NMVOCs and methane) from waste disposed in UK landfills, incorporating assessment of waste compositional analysis surveys, waste arisings and fate activity data from across the UK, by waste type, modelling of

[19] https://naei.beis.gov.uk/data/ef-all

performance in different landfill designs, and consideration of landfill gas capture and utilisation in flares and engines.

1.4.3. Accredited Official Statistics

DESNZ provides the majority of the energy statistics required for compilation of the NAEI and the GHGI. These statistics are obtained from the publication - *The Digest of UK Energy Statistics* (DUKES) (DESNZ, 2023a)[20] - which is produced in accordance with QA/QC requirements stipulated within the UK Government's - *National Statistics Code of Practice (ONS, 2002)* - and as such is subject to regular QA audits and reviews.

The DUKES team follows a number of steps to ensure the energy statistics are reliable. At an aggregate level, the energy balances are the key quality check with large statistical differences used to highlight areas for further investigation. Prior to this, DESNZ tries to ensure that individual returns within DUKES are as accurate as possible. A two-stage process is used to achieve this. Initially the latest data returns are compared with those from previous months or quarters to highlight any anomalies. Where data are seasonal, comparison is also made with corresponding data for the same month or quarter in the previous year. An energy balance approach is also used to verify that individual returns are sensible. Any queries are followed up with the reporting companies. DUKES is dependent on receiving data from a range of companies and work closely with them to ensure returns are completed as accurately as possible and in good time for the annual publications of statistics.

The activity data used to derive emission estimates in the NAEI does not always exactly match the fuel consumption figures given in DUKES and other Accredited Official Statistics. This may occur for various reasons:

- Data in DUKES and other Accredited Official Statistics are not always available to the level of detail required for inventory reporting. For example, activity data within DUKES does not distinguish between fuel used in stationary and mobile combustion units. Emissions from these different types of appliances have to be separately reported in the inventory and furthermore they exhibit very different combustion characteristics and therefore require application of different emission factors in the NAEI.
- Data in DUKES and other Accredited Official Statistics are subject to varying levels of uncertainty, especially at the sector-specific level, and in some cases more accurate data are available from other sources. For example, the UK ETS provides more accurate fuel use data for several high-emitting industrial sectors and is used in preference to DUKES data.
- DUKES and other Accredited Official Statistics do not include any data for a given source. For example, DUKES does not provide any information on secondary fuels such as process off-gases that are derived from petroleum feedstocks and are commonly used as fuels in petrochemical and chemical industries.
- Where the DUKES team makes improvements to Accredited Official Statistics, they typically do not revise the whole time series of data; usually the DUKES data are retrospectively revised for up to the 5 most recent years. This can lead to step changes in the DUKES time series that are due to methodological differences rather than reflecting real changes in fuel use. Therefore, to ensure time series consistency of reported emissions, the Inventory Agency works with the energy statistics team to derive a defensible historic time series back to at least 1990 for use in the NAEI.

[20] https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

There is a high degree of confidence in the overall fuel commodity balance data in DUKES, with the statistics for production, imports, exports, and final demand for fuels across the UK economy believed to be complete and accurate. However, fuel use allocations within DUKES *to* specific economic sectors are considered subject to greater uncertainty due to the difficulties in obtaining comprehensive survey or sales data by sector. Based on this understanding of uncertainty within DUKES, the Inventory Agency assumes in most cases that where an alternative source indicates DUKES data for a sector is inaccurate, there is no reason that this implies any inaccuracy in overall fuel usage in DUKES. Therefore, introducing a deviation from DUKES in one area of the inventory should be accompanied by an equal and opposite deviation in another area of the inventory. As a result, there are very few instances where the total amount of fuel used to underpin inventory estimates differs from the total fuel consumption data presented in DUKES; in most cases the inventory deviations from DUKES data are *re-allocations* of fuel use between source sectors across the UK economy, whilst retaining consistency with the total DUKES consumption of that fuel.

Deviations from sector-specific allocations in DUKES are most notable in the case of gas oil and fuel oil, especially for fuel use in the shipping sector. Gas oil is also widely used in off-road machinery engines (e.g. agricultural and construction machinery), railway locomotives, marine engines, stationary engines and other stationary combustion plant such as furnaces. DUKES relies on data provided by fuel suppliers and importers / exporters but data on industrial use of gas oil is very uncertain. The distribution chain for refinery products is complex, and the gas oil producers and importers have very little knowledge of where their product is used once sold into the marketplace. Furthermore, the Inventory Agency needs to distinguish between gas oil burnt in mobile machinery and gas oil burnt in stationary combustion plants and this information is not available from fuel suppliers and importers.

As a result of these data limitations, the Inventory Agency makes estimates of gas oil consumption for many sectors using alternative bottom-up methods (e.g. for off-road machinery based on estimates of population and usage of different types of equipment) or gathers data from other sources (e.g. the Office of Rail and Road and power station operators). DUKES data are not used directly; however, estimates of gas oil consumption by other sectors are then adjusted in the inventory in order to maintain consistency with the total DUKES gas oil consumption. The approach to reconciling bottom-up estimates of gas oil consumption with the UK energy statistics is detailed in section 3.3.9.

Other fuels with notable deviations from the sector-specific allocations presented in DUKES include fuel oil, aviation turbine fuel, petroleum coke, wood, other petroleum gases (OPG) and coal. Minor reallocations are also made for natural gas and burning oil.

There are, however, a small number of exceptions where the inventory estimates are based on data that lead to a deviation from the reported DUKES total consumption for a specific fuel, including:

- Energy consumption data and process-related activity data are available for installations that operate within the UK ETS. The operator-reported UK ETS activity and emissions data undergo third party verification as part of the UK ETS regulatory system, and hence are regarded as being a low uncertainty dataset that is provided to the Inventory Agency for the purposes of inventory compilation. Where the UK ETS data provides complete coverage of fuel use within a specific economic sector, the UK ETS data by installation are aggregated and applied within the NAEI.
- Natural gas consumption at a number of compressor sites operating international import-export pipelines are known to be omitted from the DUKES data, and thus estimates of activity are obtained from the UK ETS dataset;
- Restructuring of the data supply systems to the DUKES team in the early 2000s identified that throughout the 1990s there were omissions in reported gas use from

upstream oil and gas terminals; the inventory therefore estimates the gas used by these installations based on oil and gas production data from DUKES as a proxy indicator of activity;

- DUKES has no mechanism to collect data on the use of process off-gases, for example once petroleum feedstocks have been delivered for petrochemical and chemical production processes (and therefore are rightly, within DUKES, allocated to “Non Energy Use”) but are subsequently used as a secondary fuel. The inventory totals for Other Petroleum Gases (OPG) includes an estimate for consumption of these secondary fuels based on data from the UK ETS;
- Estimates for the consumption of petroleum coke in various energy and non-energy applications are made based on UK ETS and other data, In the years 1990, 1991, 1999-2001, 2005-2007, 2015, and 2019 onwards, there is insufficient petroleum coke reported in DUKES to cover all of these uses and so the inventory activity total deviates from DUKES. Note that the comparison between DUKES and inventory data also indicates certain years (most notably 1992-1997, 2004, 2010 and 2014) where there is a large surplus in DUKES compared with the uses identified in the inventory, and this petroleum coke is then assumed to be used in various unidentified non-energy uses. It is conceivable, however that there is actually some stockpiling of petroleum coke, with increases in stocks in those years of surplus, and reduction in stocks in those years where there is a deviation from DUKES. Note that the Inventory Agency assumes that the unidentified non-energy use of petroleum coke does not lead to any emissions of air pollutants other than CO_2.
- A new methodology for estimating emissions from national navigation was developed and adopted by the inventory for the first time in the 2018 submission based on a bottom-up estimate of domestic shipping fuel consumption using high resolution Automatic Identification System (AIS) vessel movement data. The fuel consumption estimates exceed the amount of fuel allocated in DUKES for national navigation in all years in the time series. The DUKES team acknowledged that the allocation of fuel to national navigation in DUKES is uncertain. The new approach based on vessel movement data is able to identify with greater confidence the allocation of fuel consumption to UK domestic navigation separately from international navigation consistent with the definition of domestic navigation in the latest EMEP/EEA Guidebook and IPCC (2006) GHG inventory guidelines. The DUKES team has greater confidence in the fuel consumption figures for international navigation in DUKES and these data are used in the inventory for this source in the International Bunkers 1A3di Memo Item category.

1.4.4. Industrial Process Emissions Data

Information on industrial process emissions is provided either directly to the Inventory Agency by the individual plant operators or from:

The Environment Agency- Pollution Inventory and Natural Resources Wales - Welsh Emissions Inventory

Both the Environment Agency (England) and Natural Resources Wales compile an emissions inventory (“PI” for sites in England; “WEI” for sites in Wales) based on operator returns of annual mass emissions from around 2,000 major point sources in England and Wales. For most years of the time series, this is one combined dataset, but in recent years the WEI data has been compiled in a separate (parallel) system from the PI data for sites in England. These inventories require the extensive compilation of data from a large number of different source sectors. This valuable source of information is incorporated into the inventory wherever possible, as either emissions data, or surrogate data for particular source sectors. The information held in the PI and WEI are also extensively used in the generation of the emissions maps, as the locations of individual point sources are known. The Inventory Agency, the EA and the NRW work closely to maximise the exchange of useful information.

The Scottish Environment Protection Agency - SPRI Inventory

The Scottish Environment Protection Agency (SEPA) compiles an emissions inventory for emissions reporting under the EPR in order to report to the PRTR. Industrial process emissions are reported to the Scottish Pollutant Releases Inventory (SPRI), and the data covers emissions in 2002 and from 2004 onwards. As with the equivalent industrial emissions inventory data from the EA and NRW, the point source emissions data provided via the SPRI are used within the NAEI in the generation of emission totals, emission factors and mapping data. The SEPA inventory can be found at:

http://www.sepa.org.uk/air/process_industry_regulation/pollutant_release_inventory.aspx

The Northern Ireland Environment Agency - Pollution Inventory

The Northern Ireland Environment Agency compiles a Pollution Inventory of industrial emissions for the purposes of PRTR. This point source data, although not yet available via the web, is readily available to the public via the Department itself. The NAEI utilises this valuable point source emissions data for the development of emissions totals, factors and mapping data.

1.4.5. Improvements to Inventory Data and Methods

As noted above, each year the inventory is updated to include the latest data available; improvements to the methodology are made and are backdated to ensure a consistent time series. The NAEI has been developed and improved over many years and for most emission sources the methodologies used are well-established and cannot be improved upon without committing significant resources to the task. However, the inventory improvement programme (described in section 1.6.6.4) enables research to be undertaken aimed at improving the inventory, for example to address any new / emerging emission sources and to take account of any changes and additions to the following:

- UK Government energy, transport and production statistics used in the inventory;
- UK ETS data;
- emissions data given in the PI/WEI/SPRI/NIPI;
- emissions data from the EEMS data set;
- data sets routinely supplied by industry to the Inventory Agency as part of the annual data collection process.

The NAEI improvement plan is constantly under review by Defra and DESNZ, to take account of expert and peer review findings as well as issues identified by the Inventory Agency in the post-submission review, which collates findings from the latest inventory cycle.

In addition to formal reviews of the inventory, the Inventory Agency seeks new information and accesses new data sources through an annual programme of consultation with industrial trade associations, specific organisations, government departments and agencies, and other stakeholders. These meetings, phone calls and email exchanges often highlight areas of the inventory for which new or updated data is available, where further refinements could be made - for example where new industry-specific research or investment highlights an improvement in emissions performance or understanding of emission sources on existing UK plant.

Sector-specific planned improvements are detailed throughout this report in the relevant sections.

1.5. Key Source Analysis

Table 1-4 provides an overview of the most important sources for selected pollutants, for the year 2022, reported under the CLRTAP in the 2024 inventory submission. The key source analysis is calculated based on emissions from fuel used and hence differs to the KCA generated by CEIP's RepDab tool.

Key sources are those which, when summed up in descending order of magnitude, cumulatively add up to 80% of the national total, as per reporting guidance[21]. Due to rounding, the sum of the % emissions by row may not equal the value given in the "Total (%)" column in Table 1-4.

For NO_X, the dominant source is 1A3b Road transport (including cars, light and heavy-duty vehicles and buses) contributing collectively 30% of emissions. Six of the seven key sources for NH_3 are from the agriculture sector, with 23% of the emissions from livestock manures applied to soils (3Da2a). The largest source of NMVOC emissions, 22% of the national total, is from the use of domestic solvents including fungicides (2D3a). 1A4bi (residential stationary combustion) remains as the dominant source of SO_X, $PM_{2.5}$, and PAH emissions. 1A1a (electricity and heat production) is one of the dominant sources of SO_X, NO_X, CO, $PM_{2.5}$, Hg and HCB emissions, although this should be viewed against a substantially reduced national total over the time series. TSP and PM_{10} are dominated by 2A5b (construction).

The iron and steel sector (2C1) is a dominant source for Pb emissions in 2022, contributing 31% of the UK's total emissions of this pollutant. There are only two key source categories for HCBs, which are public electricity and heat production (1A1a) and the use of pesticides in the agriculture sector (3Df).

[21]https://www.ceip.at/fileadmin/inhalte/ceip/1_reporting_guidelines2014/annex_ii_informative_inventory_report_issue2021_final.pdf

Table 1-4 Key NFR Sources of Air Quality Pollutants in the UK in 2022 (that together contribute at least 80% to the pollutant emissions totals, based on fuel used data). Different colours are used to highlight NFR sectors (1A1, 1A2, 1A3, 1A4, 1B, 2, 3, 5, and 6).

Component	Key categories (Sorted from high to low from left to right)															Total (%)
SOx	1A4bi 31%	1A1b 14%	1A2gviii 14%	1A1a 7%	1A2a 6%	1B1b 5%	1A3dii 5%									81.6%
NOx	1A3bi 16%	1A3dii 11%	1A3bii 10%	1A1a 10%	1A2gviii 8%	1A1c 7%	1A4ai 6%	1A3biii 4%	1A4bi 4%	1A5b 2%	1A2f 2%					80.9%
NH_3	3Da2a 23%	3B1a 14%	3Da1 13%	3B1b 13%	3Da3 7%	3Da2c 6%	6A 6%									82.5%
NMVOC	2D3a 22%	2H2 16%	2D3d 7%	3Da2a 6%	2D3i 4%	3B1a 4%	3B1b 4%	1B2ai 3%	1A4bi 3%	1B2av 3%	1B2b 3%	2D3g 2%	1A3bv 2%	1A3bi 2%		80.3%
CO	1A2gvii 24%	1A4bi 19%	1A3bi 15%	1A4bii 6%	2C1 5%	1A2a 4%	1A3dii 4%	1A2gviii 4%	1A1a 3%							82.3%
TSP	2A5b 40%	1A4bi 9%	1A3bvi 7%	2A5a 8%	1A3bvii 4%	3Dc 3%	2C1 3%	3B4gi 3%	3B4giv 2%	3B4gii 2%						80.7%
PM_{10}	2A5b 22%	1A4bi 15%	1A3bvi 10%	2A5a 7%	3Dc 5%	1A3bvii 4%	1A2gviii 4%	5C2 3%	2C1 3%	3B4gii 2%	2G 2%	2A6 2%	3B4giv 2%			80.2%
$PM_{2.5}$	1A4bi 29%	1A3bvi 11%	1A2gviii 7%	5C2 6%	1A3bvii 4%	2A5b 4%	2C1 3%	5E 3%	1A3dii 3%	2G 2%	2A6 2%	1A4ai 2%	1A3bi 2%	1A1a 2%	2A5a 1%	80.1%
Pb	1A3bvi 35%	2C1 31%	1A3aii(i) 7%	2G 7%	1A2gviii 5%											83.5%
Hg	1A1a 19%	5C1bv 10%	1A2gviii 10%	5A 9%	1A2f 9%	1A4bi 8%	2C1 7%	2C7c 5%	1A3bi 4%							80.8%
Cd	2G 34%	1A2gviii 19%	2C1 14%	1A4bi 10%	1A3bvi 4%											81.1%
PCDD/F	5C2 21%	5E 16%	2C1 16%	1A4bi 16%	1A2gviii 14%											83.0%
PAH	1A4bi 88%															87.6%
HCB	1A1a 78%	3Df 19%														97.2%

1.6. Quality Assurance and Quality Control

This section provides details of the QA/QC system for the UK NAEI, including verification and treatment of confidentiality issues. QA/QC activities comprise:

- **Quality Control** (e.g. raw data checks, calculation checks, output checks) to minimise the risk of errors within the available resources to deliver the inventory.
- **Quality Assurance** (e.g. peer reviews, bilateral reviews, expert reviews) whereby independent experts periodically review all or part of the inventory to identify potential areas for improvement.
- **Verification** where alternate independent datasets are available to compare against inventory data and trends).

The NAEI QA/QC system complies with the guidance published in the latest EMEP/EEA Guidebook and the more comprehensive guidance on GHG emissions inventories (Tier 1 procedures outlined in the 2006 IPCC Guidelines). The QA/QC plan sets out a timeline for QA/QC checks, designed to fit in with compilation and reporting requirements for all UK Air Pollutant and GHG inventory reporting commitments.

Ricardo (the Inventory Agency) is fully certified to ISO 9001:2015 and ISO 14001: 2015 (see Box 1 below). This certification provides assurance that through application of the ISO 9001 standard by Ricardo, a consistent quality approach across all aspects of the inventory project is maintained, including conforming to good practice in project management.

Box 1: ISO 9001:2015 and ISO 14001: 2015 Accreditation

In addition to the UK's AQPI-specific QA/QC system, through Ricardo, the Inventory has been subject to ISO 9000 since 1994 and is now subject to ISO 9001:2015. It is audited by Lloyds Register Quality Assurance (LRQA) and the Ricardo internal QA auditors. The NAEI has been audited favourably by LRQA on five occasions in the last 15 years. The emphasis of these audits was placed on authorisation of personnel to work on inventories, document control, data tracking and spreadsheet checking and project management. As part of the Inventory management structure there is a nominated officer responsible for the QA/QC system - the QA/QC Co-ordinator. As part of the Ricardo group certification, Ricardo is currently accredited to ISO 9001:2015. Lloyds Register Quality Assurance carried out a three-yearly recertification audit of Ricardo which was completed in October 2022. Ricardo successfully passed the recertification, with no major non-compliances, and a new Ricardo Group certificate was issued in February 2023. Under the Ricardo Group certification Ricardo is currently certificated both for the Quality Assurance ISO 9001:2015, Environmental Management System ISO 14001: 2015 standards and Health & Safety ISO 4500:2018 standards.

The main elements of the Tier 1 QA system requirements are:

- There is an Inventory Agency (consortium managed by Ricardo)
- A QA/QC plan
- A QA/QC manager
- Reporting documentation and archiving procedures
- General QC (checking) procedures
- Checks for data calculation errors and completeness
- Reviews of methods, data sources and assumptions
- Review of internal documentation
- Documentation of methodologies and underlying assumptions
- Documentation of QA/QC activities

The NAEI QA/QC system complies with all of the above Tier 1 requirements and in addition, there are a range of source-specific (Tier 2) QA/QC measures within the UK system that are typically applied to the most important "key categories" and/or where complex estimation methods (Tier 2-3) are applied. Details of source-specific QA/QC activities are presented in the relevant sections within Chapters 2 to 7 of this report.

1.6.1. Description of the Current Inventory QA/QC System

The NAEI and the UK Greenhouse Gas Inventory are compiled and maintained together by a consortium led by Ricardo (the Inventory Agency), on behalf of the UK Department for Energy Security and Net Zero (DESNZ) and the Department for Food and Rural Affairs (Defra).

ADAS manages the compilation of emission estimates for the agriculture sector under contract to Defra, working with a team of contractors that are agriculture sector experts from several other organisations: Rothamsted Research, Cranfield University, the UK Centre of Ecology and Hydrology (UKCEH) and Scotland's Rural College (SRUC).

Many of the statistical datasets received by Ricardo and ADAS for the UK AQPI compilation come from data provider organisations that are UK government departments, agencies, research establishments or consultants working on behalf of UK government or for trade associations. Several of these data provider organisations (e.g. DESNZ, the Department for Transport, Defra, the Office for National Statistics and British Geological Survey) qualify as UK National Statistical Agencies (as defined in UN Guidance[22]) and abide by strict statistical QA/QC standards.

Other organisations (e.g. the UK environmental regulatory agencies that provide installation-level emissions data) supply important datasets for the NAEI and have their own QA/QC systems that govern data quality. Regulatory agencies for industry and commerce have developed QA/QC systems to support their specific regulatory functions, including to regulate operator environmental performance (such as to underpin atmospheric emissions reporting under UK ETS or the PRTR) and to regulate other activity performance that is relevant for the national inventory (such as annual reporting against industry performance standards for water companies, gas suppliers, electricity suppliers). In some cases, data for the national inventory are provided by individual companies or organisations (e.g. trade associations) and in those instances the Inventory Agency requests information annually regarding

[22] See: https://unstats.un.org/unsd/methods/statorg/

QA/QC systems that underpin the data, as well as seeking information on estimated uncertainties of the data provided.

Ricardo is responsible for co-ordinating inventory-wide QA/QC activities relating to inventory submissions, across all inventory stakeholders. In addition, Ricardo works with organisations supplying data to the GHG inventory to encourage them to demonstrate their own levels of QA/QC that comply with either 2006 IPCC Guidelines or the UK's Accredited Official Statistics standards, through stakeholder consultation meetings and annual information requests.

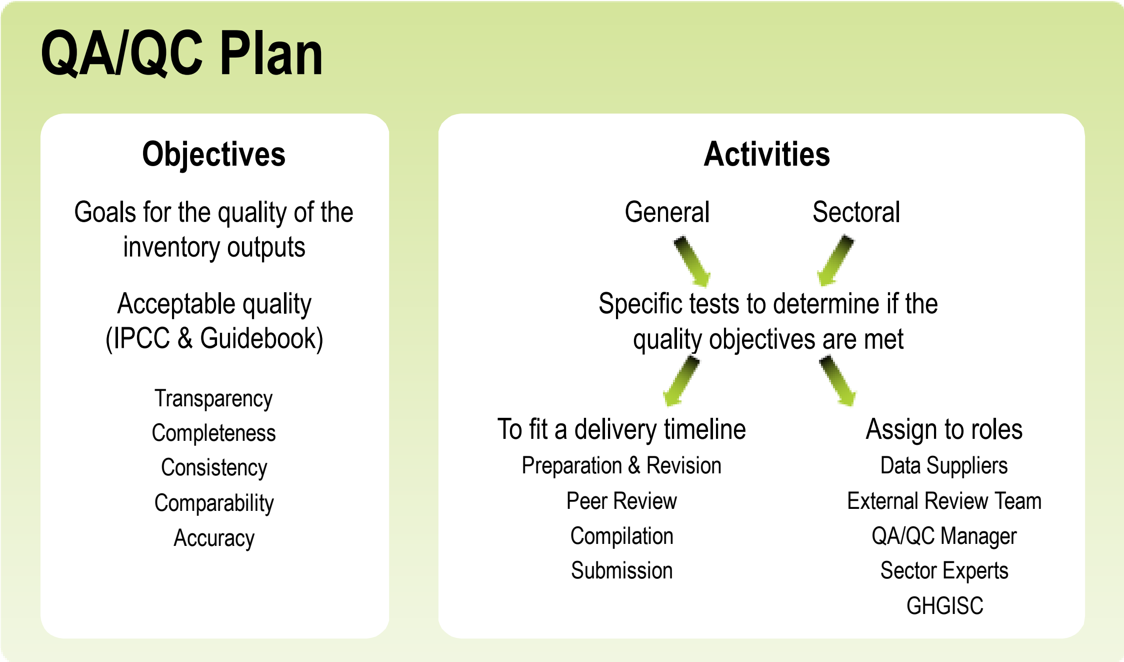
The NAEI QA/QC system encompasses a wide range of activities to cover:

- planning tasks, including review of historic data and methods, identification of improvement priorities, data and method selection, and inventory team training and development;
- compilation and reporting tasks, including; management and documentation of data flows from raw data through calculation of emission estimates to reporting, input data requests/acquisition, management of compilation processes and quality checking systems, documentation of data, methods and assumptions, assessment of key source categories and uncertainties, and reporting of inventory outputs;
- checking tasks, including raw data checks, inventory model/calculation checks, source-specific and cross-cutting output checks, checking reasons for changes compared to previous inventory estimates, emission trend checks, and emission factor checks;
- QA review tasks, including pre-submission reviews, post-submission reviews, peer reviews, bilateral reviews, and expert reviews.

To control and deliver across all these tasks, the inventory QA/QC system includes three core components:

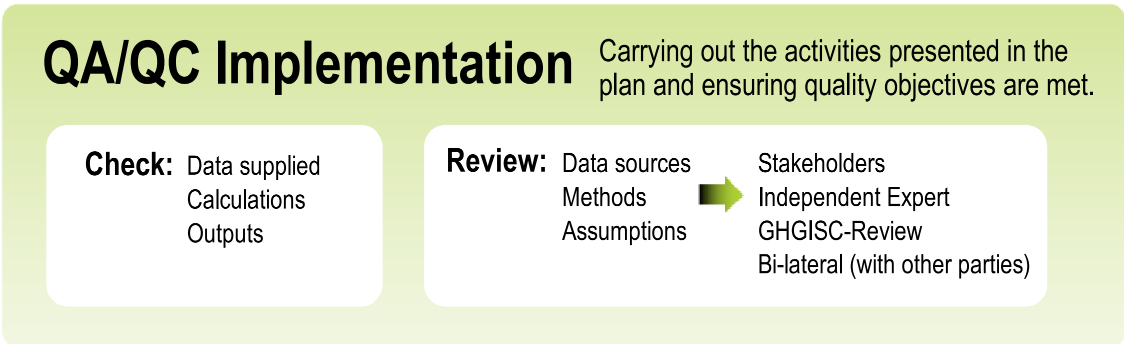
1. A QA/QC Plan is maintained by the Inventory Agency's QA/QC manager and defines the specific quality objectives and QA/QC activities required in undertaking the compilation and reporting of the inventory estimates. The plan sets out source-specific and general (cross-cutting) activities to ensure that quality objectives are met within the required inventory reporting timeframe. The QA/QC plan also assigns roles and responsibilities for the Inventory Agency team and records the key outcomes from inventory QA activities in order to underpin a programme of continuous improvement.

Figure 1-6 QA/QC Plan



2. QA/QC implementation includes the physical undertaking of the QA/QC activities throughout the data gathering, compilation and reporting phases of the annual emission estimation cycle and in accordance with the QA/QC plan, and as agreed with Defra. The systems and tools for QA/QC implementation are described in the sections that follow.

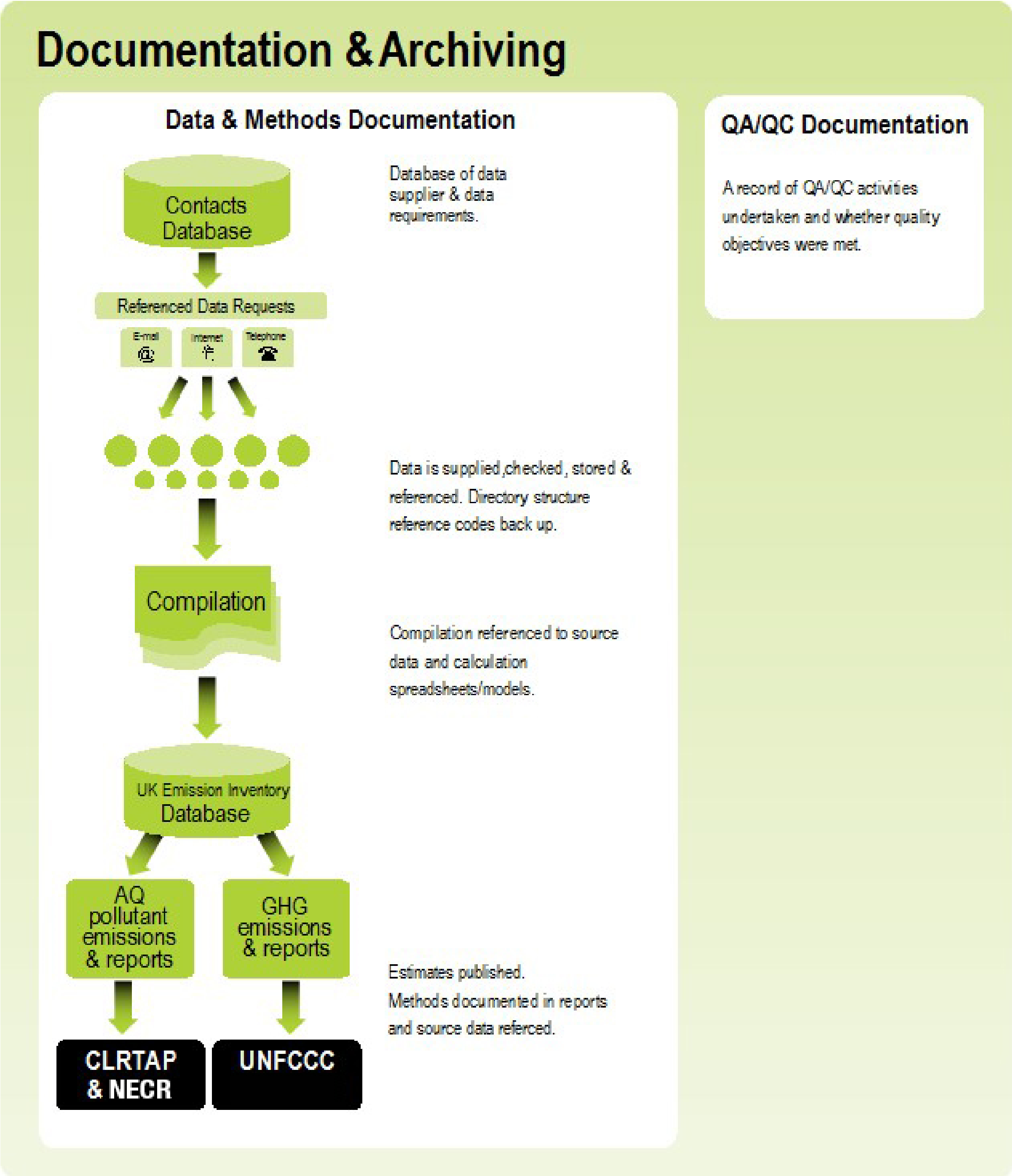
Figure 1-7 QA/QC Implementation



GHGISC refers to the National Inventory Steering Committee, responsible for the review and sign off of the UK Greenhouse Gas Inventory.

3. Documentation and archiving which includes a) transparent documentation of all data sources, methods, and assumptions used in estimating and reporting the NAEI. These are included in the calculation tools used for calculating the estimates and in the GHG National Inventory Report (NIR) (Brown et al., 2024) and Air Quality Pollutants (IIR) informative inventory reports; b) transparent documentation of all QA/QC implementation including records of activities undertaken, findings, recommendations and any necessary actions taken or planned; and c) archiving.

Figure 1-8 Documentation and Archiving



The QA/QC plan and procedures are subject to continuous review and improvement. In 2014, BEIS (now DESNZ) and Defra commissioned an independent review of the NAEI QA architecture, through a series of audits focussed on fifteen NAEI models. The review was conducted by Hartley McMaster (HM), and was aimed at assessing the NAEI QA systems against the requirements of IPCC guidance, BEIS model QA guidance and the wider Government guidelines for model integrity (HMT Aqua Book[23]). Further to this review, BEIS commissioned in late 2016 a review of a further sample of NAEI models by Cambridge Architectural Research (CAR). During 2016, HM also reviewed a representative sample of the models operated by Forest Research (FR) and UKCEH to generate the land use, land-use change and forestry (LULUCF) estimates, and during 2017 HM reviewed a sample of models used to process

23 https://www.gov.uk/government/publications/the-aqua-book-guidance-on-producing-quality-analysis-for-government

point source data for the national inventory. The findings of these reviews have underpinned QA system improvements over recent submission cycles; further model-specific QA improvements may be implemented in future, subject to priorities and resources available.

From 2021, DESNZ have commissioned DNV to conduct a further independent review of the NAEI models and QA processes. DNV have reviewed around nine model streams per year. The headline outcome from DNV's review of the Model streams over the last three years is that there were no errors identified. DNV is reviewing the UK inventory models against the UK Government (DESNZ) QA Guidance for Models. Areas noted for improvement for some of the models reviewed are predominantly regarding: (i) the documentation of the scope and specification of the individual models, and (ii) the documentation and analysis of the areas of risk to model outputs that arise from key data inputs and assumptions within the model calculations. In response to these findings, a number of improvements to the models and documentation have been carried out. These improvements include:

- Standardised documentation of data sources as part of a data log.
- Standardised documentation of assumptions and the impact of these.
- Improvements to the structure of the calculations to remove hard coded values, in older models and pre-processing workbooks.
- Crosscutting scope, specification documentation, technical and user guide for the NAEI model suite.

Improvements made to the NAEI QA/QC system are summarised below. This list includes improvements made for the 2022 submission, and improvements that have been implemented and have fed into the 2024 submission.

- Migration of pollutant-specific checking templates to an R-shiny application to enable checking to be carried out in a more efficient manner. The application calculates the most contributing sources to recalculations or trends at an NFR level, such that the sector lead can easily disseminate the key areas to check and provide comments on. Recalculations can also be easily viewed as the percentage contribution with respect to the national total, as a result, the largest and most important overall changes can be more easily identified compared to the previous spreadsheet-based system. Sector leads can also provide a comment on a specific recalculation or trend and upload this to the central NAEI database. This has been in use for two submission cycles and a database of trend commentary is being built up to facilitate the annual checking routines.
- Two major improvements have been made to the suite of inventory mastersheets, following the outcomes from DNV's year 1 review. These were to:
    - Remove hard coded values from within calculations
    - Fully populate the data log for each of the models
- The actions following DNV's year 2 review are to:
    - Produce a crosscutting scope document for the NAEI.
    - Produce a crosscutting specification document for the NAEI.
    - Produce a technical guide for the NAEI.

- A number of areas in the compilation process of the NAEI have been adjusted to allow the UK team to minimise time spent on lower-priority areas, and maximise resources available for the QA/QC of high emitting sources and sectors. These changes include:
    - Locking down the pre-1990 data to be in line with the data provided on the NAEI website in 2021, it should be noted that the submissions under the NECR and CLRTAP do not contain emissions data prior to 1990;
    - Migrating no-longer occurring sources e.g. Animal incineration as a result of Foot and Mouth, and Adipic acid manufacture from a spreadsheet system to a database-to-database transfer;
    - Continued migration of constant emission factors to the Emission Factor Database – this is an ongoing process to move emission factors into this system, which standardises conversions and assumptions across the inventory.

1.6.2. Quality Objectives

The key objectives of the QA/QC plan are to ensure that the estimates in the air pollutant and greenhouse gas (GHG) inventories are of a suitably high quality and will meet the methodological and reporting requirements for UK submissions to the UNECE and UNFCCC, as set out within national inventory reporting guidance from the IPCC[24] and CLRTAP[25]. The inventory data quality objectives are to achieve the principles of Transparency, Completeness, Consistency, Comparability and Accuracy (TCCCA):

- **Transparent in:**
    - The description of methods, assumptions, data sources used to compile estimates in internal (spreadsheets and other calculation tools) and published material (e.g. the IIR) and on the inclusion of national and international assumptions (e.g. source category detail and the split between UK ETS and non-UK ETS sources, implementation of policies and measures, carbon contents of fuels, site specific estimates, Accredited Official Statistics such as population, GDP, energy prices, carbon prices etc.).
    - The documentation of QA/QC activities and their implementation using internal checklists and summarised in relevant public material (e.g. the IIR).
- **Complete**: and include all relevant (anthropogenic) emission/removal activities, using representative data for the national territory for socio-economic assumptions and policies and measures for all required years, categories, pollutants and scenarios.
- **Consistent**: across trends in emissions/removals for all years (especially where applicable between the historic and projected estimates) and that there is internal consistency in aggregation of emissions/removals. Where possible, the same methodologies are used for the base year and all subsequent years and consistent data sets are used to estimate emissions or removals from sources or sinks.
- **Comparable**: with reported emission/removal estimates compiled for other countries through use of the latest reporting templates and nomenclature consistent with reporting requirements. Using the correct NFR or IPCC category level and consistent units for expressing mass of emissions/removals by gas, split between UK ETS and

[24] 2006 IPCC Guidelines for National Greenhouse Gas Inventories: http://www.ipcc-nggip.iges.or.jp/public/2006gl/
[25] Guidelines for reporting emissions and projections data under the Convention (2013 EB Decision: ECE/EB.AIR/122/Add.1, 2013/3 and 2013/4): https://www.ceip.at/reporting-instructions

non-UK ETS sources, scenarios, units for parameters and of input parameters with international assumptions (e.g. energy prices, carbon price, population etc.).

- **Accurate**: ensuring the most accurate methods and data are used in the application of methods, minimising the uncertainty in assumptions and in use of data sources used for the estimates and inclusion of national and international assumptions.

The overall aim of the NAEI QA/QC system is to meet the above objectives, and to minimise the risk of errors in the NAEI data such that emission estimates are not knowingly over- or under-estimated as far as can reasonably be judged.

The NAEI QA/QC system also reflects that quality is one of three often competing attributes for a given project scope. These are quality, time, and resources. Noting that the complete set of UK GHGI and AQPI estimates contain a large number of large and small contributors to emissions/removals, key category analysis is used to prioritise the most important categories (i.e. the highest-emitting source categories in the UK and/or the most uncertain sources). More resources and time are typically directed towards method development, compilation, reporting and associated QA/QC activities for these key source categories, with simpler methods and less rigorous approaches typically applied to lower emitting/more certain (non-key) source categories.

1.6.3. Roles and Responsibilities

The QA/QC plan sets out specific responsibilities for the different QA (review) and QC (data controls, checking) activities and to different roles within the NAEI compilation and reporting team. These are embedded within compilation and processing spreadsheets and databases. Training and project management communication across the Inventory Agency ensures that these responsibilities are clear, with specific tasks and checks signed-off at appropriate stages throughout the inventory process.

The following responsibilities are outlined in the NAEI QA/QC plan:

- **QA/QC Manager**: Co-ordinates all QA/QC activities and manages contributions from data suppliers, sector experts and independent experts and undertakes cross cutting QA/QC activities. Maintains the QA/QC plan, co-ordinates action across the team to set quality objectives, communicate and implement QA/QC activities, and identify training and development needs (individual, systematic).

- **Technical Directors/Knowledge Leaders**: Lead the technical development and implementation of the NAEI programme, supporting the QA manager and Project management team in delivering the project to meet technical requirements of international reporting as well as UK-specific and other output quality expectations. Manage periodic review and perform final checking activities on data and report submissions.

- **Project Manager**: Lead all key management activities including management of the project finances, commercial issues, liaison with Defra and DESNZ, manage and attend project meetings, communicating project tasks and requirements to the team and oversee the day-to-day running of the project. Manage team resources and support QA Manager, Technical Director and Knowledge Leaders in identifying and resolving resource limitations (e.g. skills gaps, continuity planning).

- **Sector Experts**: Perform and oversee sector-specific and/or output-specific QA/QC activities and report to the QA/QC Manager. Sector Experts should also collaborate with data suppliers and other key stakeholders to review data quality (input data and outputs), perform quality checks on supplied information, assess and report on uncertainties associated with NAEI outputs. Identify improvement requirements for their tasks/ sectors and promote/ implement cross-cutting QA/QC improvements by sharing best practice and engaging in team communication activities.

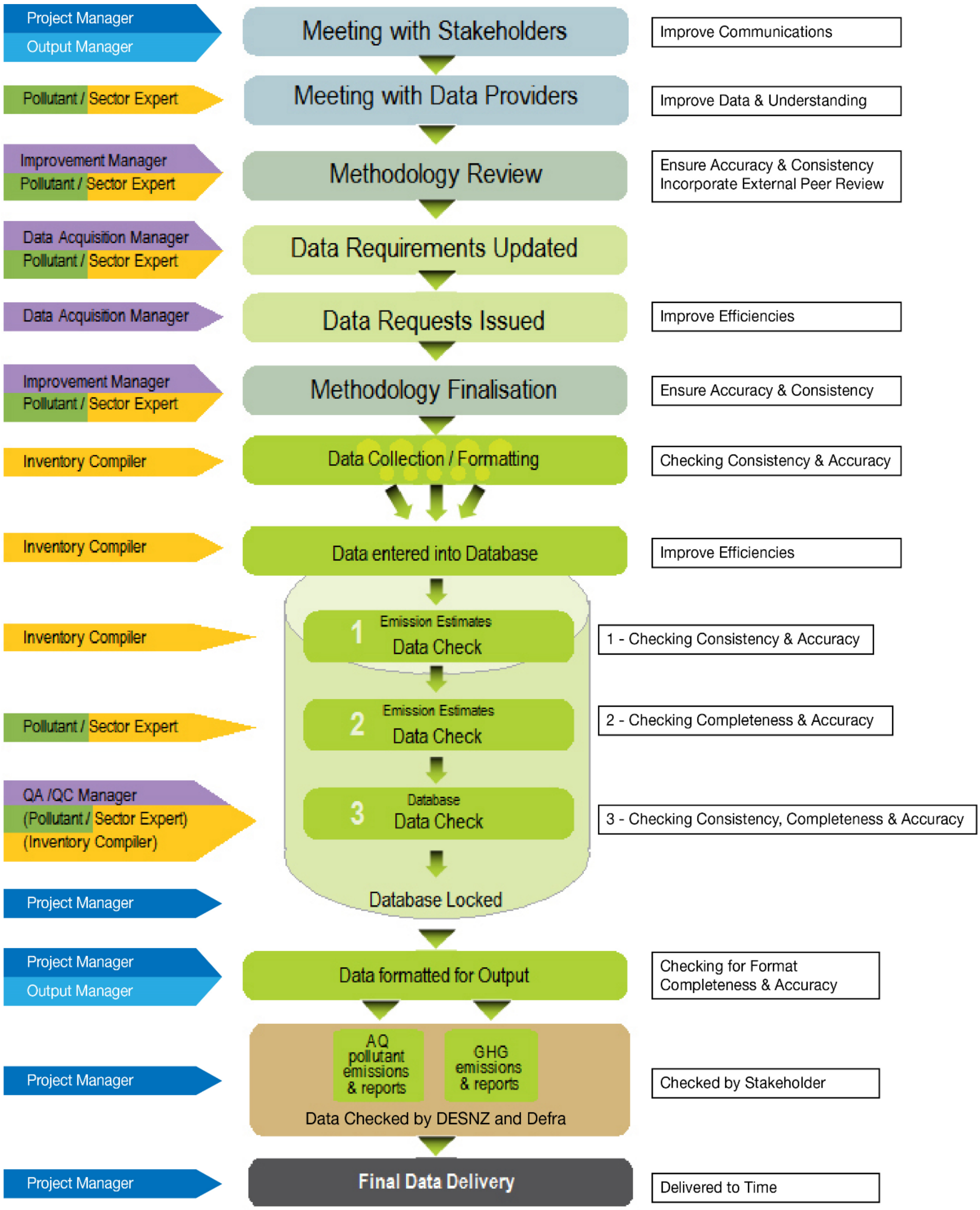
- **External Review Experts**: Provide expert/ peer review of emission estimates and methods for specific sectors, identify key findings and inventory improvement recommendations, and report to the QA/QC Manager.

The QA/QC plan sets out a detailed timeline for QA/QC checks. The timeline is designed to fit in with compilation and reporting requirements for all UK GHG and Air Pollutant reporting commitments.

1.6.4. Implementation of the QA/QC Plan

Figure 1-9 gives an overview of the inventory compilation process and associated QA/QC activities. The process is based on the "plan, action, monitor and review" improvement cycle. The important QA/QC elements throughout the cycle are presented for each step.

Figure 1-9 QA/QC Activities throughout the NAEI Cycle



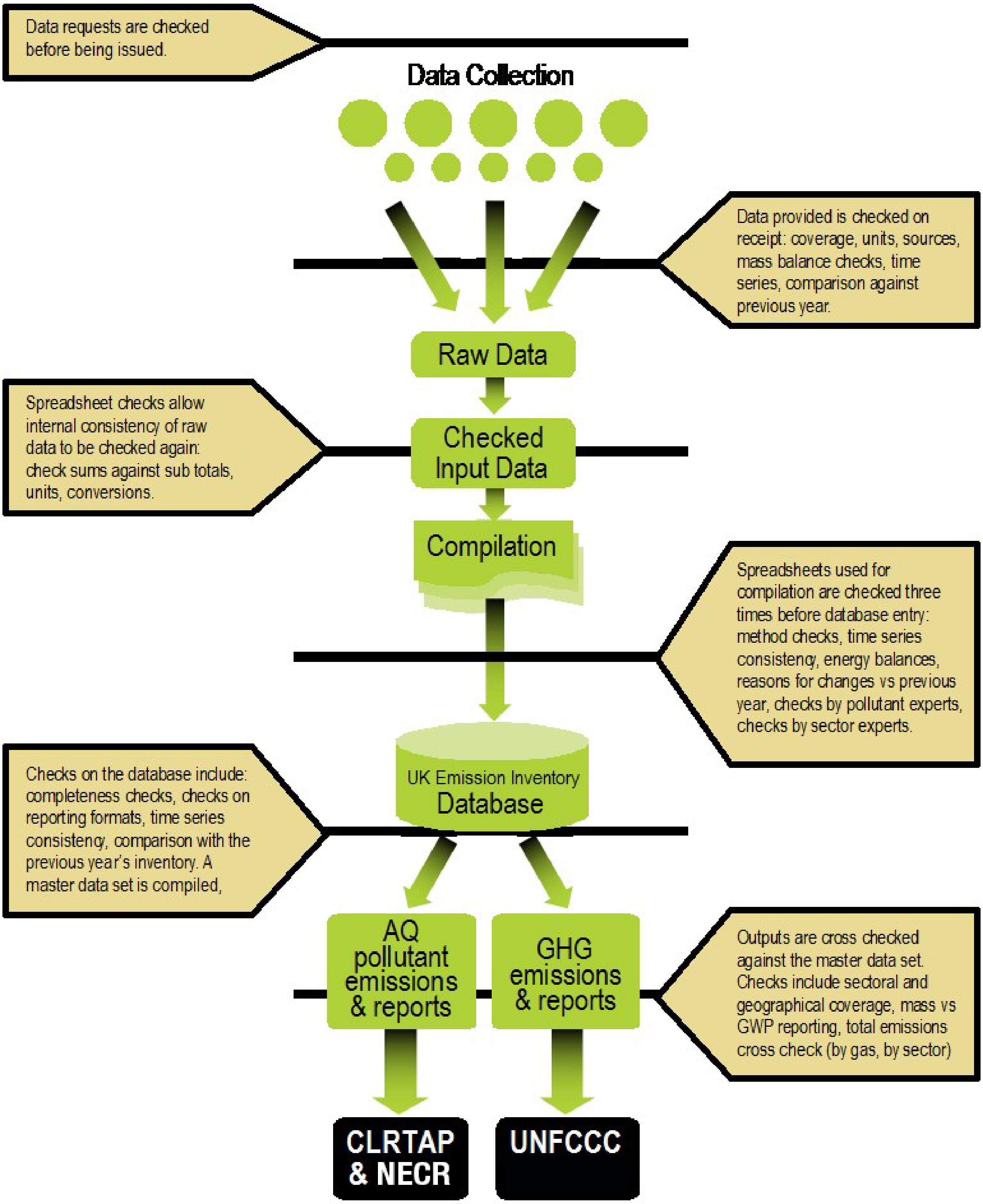
1.6.5. Quality Control and Documentation

The NAEI Quality Control (checking, documentation and archiving) occurs throughout the data gathering, compilation and reporting cycle and illustrates the process of data checks used within the NAEI compilation cycle. The horizontal bars in Figure 1-10 symbolise 'gates' through which data does not pass until it meets the quality criteria and the appropriate checks have been performed. The key activities that are undertaken and documented to check the estimates include:

1. **Checking of input data for scope, completeness, consistency with data from previous years and (where available) verification against other independent datasets.** Compilers check the incoming data from data providers to assess whether the data are complete and consistent with data from previous years. In some cases, checks are performed to compare data between individual operators (e.g. gas composition data from multiple UK gas transporters) and between different reporting mechanisms (such as comparisons of operator-reported activity and emissions data between IED/PRTR and UK ETS). For several sources, production-based emission estimates can be compared with other data (e.g. sales data, plant capacity data) to check that the trends and values are reasonable.
2. **Analysis of internal inventory energy and mass balances** and other statistics assumptions against Accredited Official Statistics input data (e.g. DUKES and ONS). Mass or energy balances are performed for each major fuel in the UK economy and any deviations from UK energy statistics are checked and documented. Several sector methods for key categories also have Tier 2 checks to assess internal consistency, such as carbon balance checks for the carbon flows through integrated iron and steel works.
3. **Completeness checks**. The database is checked for completeness and consistency of entry across the different pollutants and gases. For example, combustion sources are checked for inclusion of all relevant pollutants and the database checked for any missing estimates and appropriate use of notation keys.
4. **Recalculation checks**. The latest inventory dataset is compared against the previous inventory submission. Any recalculations are documented by inventory compilers and signed off by checkers. Reasons for the recalculations are documented, e.g. method improvements, revisions to input data or assumptions. These recalculation notes are referenced within the inventory database to facilitate reporting and transparency of recalculations.
5. **Time series checks and benchmarking checks.** The time series of emissions are checked for step changes, trends and any outlier data (e.g. outlier EFs or peaks/dips in activity data trends). Any unusual features are checked and explained, with reasons for notable trends and outliers documented in the method sections of the IIR. Implied Emission Factors (IEFs) are checked against previous estimates and for key categories against defaults (from EMEP/EEA, IPCC guidance) to identify any notable UK-specific EF outliers.
6. **Method implementation checks**. A range of common checks are performed across inventory calculation models, such as: checking that units are correct for input parameters; checking that selection of Net Calorific Values (NCVs) or default EFs is consistent across years / pollutants; checking for either new emission estimates (e.g. due to new UK data or new methodological guidance or the provision of EFs for more pollutants within the latest EMEP/EEA Guidebook) or for any missing emission sources compared to previous submissions; and EF sense-checks such as PM_{10} > $PM_{2.5}$ > BC.

7. **Reporting checks**. Inventory submissions are checked to ensure correct allocation into the NFR and common reporting format (CRF) categories. Emission totals at national and sub-category level are checked against the "master" dataset derived from the NAEI database outputs, to minimise risks of data transcription errors into reporting templates.

Figure 1-10 Quality checks throughout the NAEI compilation process



Checking and documentation is facilitated by specific custom data storage and handling systems alongside procedures developed for the NAEI compilation that include:

1. **<u>A database of contacts</u>** (the "contacts database") Containing uniquely referenced data suppliers and data users, detailed data requirement specifications (including requirements for supplier QA/QC and uncertainty information) and data supplied to and delivered from the inventory. This database tracks all data sources and suppliers used for the estimation of emissions with unique references allocated to datasets through the inventory compilation process. The contacts database also tracks all outputs from the AQPI including formal submissions and data supplied in response to informal and ad-hoc data requests.
2. **<u>Individual data processing tools</u>** are used to prepare the majority of source data into suitable activity data and EFs for NAEI estimates. These data processing tools (spreadsheets and database models) include QC procedures, summaries and source data referencing within them. The QC procedures include embedded (in the tools) sector specific checks (e.g., energy/mass balance and default EF checks for country specific EFs, and IEF checking). The QC procedures, within each tool/spreadsheet, include calculation input/output checking cells and flags to identify calculation errors. The QC summary sheets in each tool/spreadsheet provides an intuitive mechanism for documenting and summarising all checking undertaken on a model. It includes links to QC activities that need to be performed, flags for the QC activities, their status and sign off; details of source data; key assumptions, methods, data processing activities and progress; the scope of activities, gases and years included; relationships with other processing spreadsheets (where inter-dependencies exist); records of authorship; version control and checking. All relevant cells in the data processing spreadsheets are colour coded for ease of reference indicating whether the cells are calculation cells, output cells, checking cells or data input cells. All input cells carry a reference to the unique data source and data supplier held in the contacts database so all source data can be traced back to its originator and date of supply. All spreadsheets are subject to second-person checking prior to data uploading to the NAEI database.
3. **<u>A Core Database (NAEI Database) of Activity Data and Emission Factors</u>** with embedded Tier 1 QC routines (as defined at the start of Section 1.6), data source and data processing referencing. The database provides the quality assured dataset of emission/removal estimates used for reporting (including NFR population), responding to ad-hoc queries or deriving other downstream estimates (e.g. emissions by Devolved Government and emissions by Local Authority). The detailed activity data and EF components for each source category are held within the NAEI database and include all sources, activities, gases/pollutants (AQPI and GHGI), territories and years. The majority of data in the database is imported directly from the individual data processing tools and spreadsheets (as described above). To ensure data source transparency, all data points in the database carry a reference that pinpoints either the upstream data processing tools used to derive the data, the external data source and supplier or both. It also includes details of the date entered, the person uploading the data, its units (to ensure correct calculation), and a revision or recalculation code (which ensures that recalculations of historic data can be easily traced and summarised in reports). Automated data import routines used to populate the database minimise transcription errors and errors resulting from importing data that still itself contains errors even after previous checking. This process extracts output data from the upstream data processing tools and spreadsheets and can be controlled by the Inventory Agency via a data import dashboard. The automated system ensures that data is only uploaded to the database once it meets specified QA/QC criteria of data checking, completion and consistency. A number of detailed QC checking queries are embedded within the database that facilitate annual QC activities, as defined in the QA/QC Plan, including:

   a. Checks with previous submissions for changes due to recalculations or errors at a detailed level, by source-activity-pollutant (a designated auditor identifies sources where there have been notable changes or new sources. Inventory compilers are then required to explain these changes to satisfy the auditor);
   b. Assessment of trends and time series consistency for selected key sources, including QC of activity data and emissions of high priority pollutants;
   c. Mass balance checks for all major fuels to ensure that the total fuel consumptions in the AQPI and GHGI are in accordance with those published in the official UK Energy Statistics in DUKES, and that any exceptions or deviations are documented and understood;
   d. Input-output checks for key UK models to conduct "implementation" checks on the processing of data from upstream models, such as for the agriculture sector;
   e. Industry-specific checks, to compare NAEI output data against operator-reported data via other mechanisms, such as UK ETS or PRTR. These checks enable high-level checks on the data consistency for high-emitting source categories (e.g. power stations, refineries, cement kilns, iron and steel works) for priority pollutants (e.g. CO_2, NO_X);
   f. Other activity data checks e.g. production and consumption with Accredited Official Statistics;
   g. Implied Emission Factor checks (assessing trends in IEF and comparison with previous submissions);
   h. A consistency check between NFR output and IPCC CRF formatted output.
4. **Data extraction checking routines and procedures**: Data exported from the NAEI database and entered into reporting tools (e.g. the CRF Reporter tool for reporting GHG emissions to the UNFCCC, and for Air Quality reporting into the UNECE reporting templates) are checked against the direct database output totals to ensure that any inconsistencies are identified and rectified prior to submission. This includes interrogating the output datasets and comparing this against a series of queries from the NAEI database to compare both emissions and activity data.
5. **Official annual reports to UNFCCC and UNECE** provide full documentation of inventory estimation methodologies, data sources and assumptions by source sector, key data sources and notable revisions to methods and historic data, where appropriate. In addition, the annual reports include details of planned prioritised improvements identified by the Inventory Agency and agreed by the Air Quality Inventory Steering Group (AQISG) or National Inventory Steering Committee (a cross-Government body focussed on the UK GHG inventory work programme), and from Expert and Peer Reviews. Any data presented in reports are checked against accompanying submission datasets and the NAEI database.
6. **Archiving**: At the end of each reporting cycle, all the database files, spreadsheets, online manuals, electronic source data, records of communications, paper source data, output files representing all calculations for the whole time series are frozen and archived on a central server. Electronic information is stored on secure and separately located servers (with one acting purely as a back-up) that are regularly backed up. Paper information is archived in a Roller Racking system with a simple electronic database of all items references in the archive.
   a. The model and database supporting the agriculture Inventory (compiled by a consortium of RSK ADAS Ltd, Rothamsted Research, UKCEH, Cranfield University and Ricardo) is located on an RSK ADAS Ltd server at the Bristol site and is backed up daily on a 3-day cycle onto the server file storage, on a weekly basis onto a tape system and with off-site tape storage on a monthly basis. At the conclusion of each

submission the entire Inventory is archived to a network-attached long-term storage device. The model and database are mirrored on an RSK ADAS Ltd server at the Wolverhampton site. All input annual activity tables and model outputs including database files, spreadsheet analyses, written reports on the entire reporting time-series and the final data submissions to the National Atmospheric Emissions Inventory are archived on a private Share-Point hosted by Ricardo.

1.6.6. Quality Assurance and Verification

Quality assurance and verification activities provide an objective, independent review of inventory source data, methods and assumptions. These activities are primarily conducted to assess compliance with reporting requirements (e.g. comparing NAEI methods against international guidelines) and also to identify areas for future inventory improvement. QA and verification activities include:

1. Assessment of improvements against recommendations and the Inventory Improvement Programme lists of required improvements.
2. Official annual review of changes to estimates and trends, prior to submission, by stakeholders supplying key datasets and by UK government departments responsible for the inventory reporting.
3. Peer/Expert review of methods, assumptions and data sources for new/revised estimates and on a periodic basis for key categories to determine whether methods should be improved due to the availability of new datasets and assumptions (focussing on key categories).
4. Documentation of recalculations and changes to the estimates.
5. Verification analysis (e.g. comparison of trends with trends in ambient measurements).

This section describes a number of specific QA activities and procedures.

1.6.6.1. External Peer and Bilateral reviews

The Inventory Agency may draw upon a team of air quality and emissions experts (from outside of the core NAEI team) in order to conduct periodic peer reviews or validation on sections of the inventory. These peer review experts are typically knowledge leaders from the emissions inventory, Air Quality (AQ) modelling and research communities who use inventory data as part of their wider studies. From 2021, these peer review experts have formed part of the Air Quality Inventory Steering Group (AQISG). Individual reviews may be commissioned, but also many of the peer review team conduct studies funded from other sources which give direct feedback on the robustness of the emissions inventory estimates.

In addition, the Air Quality Expert Group (AQEG) regularly utilises and analyses NAEI data whilst assessing policy and science questions related to air quality. AQEG are the Expert Committee to Defra that provides independent scientific advice on air quality. Specifically, AQEG gives advice on levels, sources and characteristics of air pollutants in the UK and as such regularly utilises and scrutinises AQPI data. A senior member of the Inventory Agency is a member of the AQEG and can answer questions, provide advice and address issues associated with the use of AQPI data to the inventory team.

The UK also undertakes bilateral and external peer reviews that are managed as part of the NAEI improvement programme. Bilateral reviews are initiated with other countries to share good practice and to provide independent expertise to review estimates. The UK has participated in several bilateral exchanges and the current contract makes allowances for biennial bilateral reviews (see Table 1-5).

Table 1-5 Summary of Recent Inventory Reviews

Review description	Summary
2023: CLRTAP agriculture review	A review took place on the agriculture sector. Through this review, no revised estimates or technical corrections were calculated for the UK.
2022-2023: Bilateral review of the solvent sector for NMVOCs	In March 2022, the UK began a bilateral review of NFR sector 2D with the German inventory team. Several useful meetings have taken place several useful meetings took place and provide a basis for further discussions in future.
2022: CLRTAP condensables review	There was a review[26] on the road transport and domestic combustion sectors, focusing on the methods and whether the condensable component of PM emissions are included or not within the inventory methods for these sectors. Through this review, no revised estimates or technical corrections were calculated for the UK.
2017-2020: Annual National Emission Ceilings Directive (NECD) review	In-depth review of the NAEI under the EU NECD conducted by an expert team on behalf of the European Commission. Every year the main NECD pollutants (SO_X, NO_X, NMVOCs, NH_3, $PM_{2.5}$) were reviewed as well as reviewing of the action taken to address previous review findings. On top of this each year the review focused on different sections: 2017 - Main pollutants (NO_X, SO_X, NH_3, NMVOCs, NH_3, $PM_{2.5}$ covered in this first review) 2018 - Metals and POPs 2019 - Second phase of the in-depth review of national emission inventories of POPs and HM 2019 - NECD projection review 2020 - Gridded data and point sources Recommendations made in these reviews were considered in the NAEI improvement programme.
Annual (semi-automated) Stage 1 and Stage 2 CLRTAP reviews	The EMEP emission centre CEIP uses semi-automated routines to carry out annual initial check of submissions for timeliness, completeness and formats (the so-called Stage 1 review). CEIP also compile an annual synthesis and assessment of all national submissions with respect to consistency, comparability, key category analysis, trends of emissions data (the so-called Stage 2 review). Results are published in March/April on the CEIP website[27], and review findings were considered for action within the NAEI improvement programme.
2018: Expert review of the agriculture sector	Following the major change in the UK methodology for most agriculture sources, implemented in the 2018 submission, to move to higher-tier methods, the UK invited an experienced UNECE and UNFCCC reviewer to conduct a focussed expert review of the new UK methods. This was conducted during autumn 2018 and the findings from the review were fed into plans for improvements for the 2020 submission.

[26] https://webdab01.umweltbundesamt.at/download/review/GB/2022/GB_2022_Stage3RR_FINAL.pdf?cgiproxy_skip=1
[27] https://www.ceip.at/review-of-emission-inventories/technical-review-reports

Review description	Summary
2016: Stage 3 UNECE Review	In-depth review of the UK AQPI inventory submitted under the UNECE CLRTAP and EU NECD. The review was coordinated by the EMEP emission centre CEIP acting as review Secretariat. This review concentrated on SO_X, NO_X, NMVOCs, NH_3 plus PM_{10} and $PM_{2.5}$ for the time series years 1990-2014 reflecting priorities from the EMEP Steering Body and the Task Force on Emission Inventories and Projections (TFEIP). Heavy metals and persistent organic pollutants (POPs) have been reviewed to the extent possible. Recommendations made in the Stage 3 review were considered in the NAEI improvement programme.
2015: Bilateral review of the Energy and Industrial Process Sectors	Bilateral review with Denmark, focusing on the energy balance, refineries, Reference Approach, mobile and fugitive sources and industrial processes. The recommendations from this review were fed into the NAEI improvement programme.
2015: Multi-lateral review on QA/QC.	Hosted by Germany and including QA experts from UK, Denmark, France and the Netherlands, the review compared Member State approaches to QA/QC, reviewing the requirements of the 2006 IPCC Guidelines, to identify common approaches, areas of uncertainty and interpretation of the Guidelines. The aim was to exchange good practice and identify where the guidelines were open to interpretation in order to derive a common approach for EU Member States.
2006 - 2015: Annual UNFCCC review	Annual review by the UNFCCC expert review team. The reviews highlighted reporting issues of transparency, completeness, consistency, comparability or accuracy that need to be resolved by the UK. *These reviews were focussed on the GHG inventory rather than the AQPI, but nevertheless identify areas for improvement that apply across all of the NAEI programme.*
2014: Bilateral review of the energy and waste sectors	Bilateral review with Germany, focusing on the energy balance, iron and steel, refineries, the chemical industry and waste and biofuels. The recommendations from this review were fed into the NAEI improvement programme.
2012: Peer review of all sectors (excluding Sector 5). Conducted by EC Technical Expert Review Team	The review focussed on non LULUCF sectors and provided a report for each Member State (including the UK) highlighting recommendations for improvements as well as documentation of any revised estimates as a result of the review. The UK made 3 minor revisions as recommended by this review for lime production and burning of biomass for energy to address underestimates, and for dairy cattle to address an overestimate. The review also presented another 20 recommendations for the UK to consider.
2008: Bilateral review of Agriculture (4) with the French inventory team	The objectives of the review were to develop emissions inventory capacity in collaboration with France, and to provide elements of expert peer review to meet quality assurance requirements under national inventory systems e.g. Article 5, paragraph 1, of the Kyoto Protocol and European Union Monitoring Mechanism (EUMM) e.g. 280/2004/EC. Specific activities undertaken included sharing good practice between the UK and France and the development of ideas for efficient future technical collaboration.

1.6.6.2. Stakeholder Consultation and User Feedback

The Inventory Agency consults with a wide range of stakeholders to ensure that the NAEI uses the best available data and research, interprets information from data providers correctly and improves outputs to address user requirements.

The inventory data are used by a wide range of UK air quality researchers and decision-makers including users of data for air pollution modelling and air quality review and assessment work undertaken by local authorities; these users provide regular feedback regarding possible improvements to source-specific or spatially-resolved air quality emission estimates. The Inventory Agency also manages an annual programme of stakeholder engagement meetings and engages in detailed discussions with key data providers to help ensure that the inventory is using the best available data. The stakeholder engagement plan encompasses a programme of face-to-face meetings with data providers, research organisations, government departments and agencies, regulators and academia, as well as numerous emails and phone calls each year. The programme of meetings, calls and emails is aimed at raising the profile of the NAEI work programme and identifying new research that may lead to new data for the NAEI. Importantly it enables targeted discussions to seek resolution of inventory improvements or to obtain data clarifications (e.g. regarding the scope or quality of source data provided to the Inventory Agency). Regular and important stakeholder consultations include:

Department for Energy Security and Net Zero (DESNZ)

- The Inventory Agency met with the DESNZ energy statistics team that produces the Digest of UK Energy Statistics (DUKES) to discuss changes (to both activity and methodology) in the 2023 publication of the statistics, in order to ensure correct interpretation of the new statistics in the 2024 inventory submission. The Inventory Agency has regular contact with the DUKES team and works to ensure that any revisions in the DUKES data are reflected accurately in the inventory, and where necessary that time series recalculations are made in consultation with the DUKES team.
- Consultation with OPRED to request clarifications on the scope and completeness of EEMS reported data for several individual installations, to ensure correct interpretation of the available data.

Environmental Regulators

- Meetings, teleconferences and emails with sector experts and emission inventory analysts from the environmental regulatory agencies in the UK (Environment Agency (EA), National Resources Wales (NRW), Scottish Environment Protection Agency (SEPA), and Northern Ireland Environment Agency (NIEA)) and plant operators. These were undertaken to address source-specific EF uncertainties and obtain up to date information regarding site-specific activities, abatement and changes to plant design or scope of reporting. In some instances, this has led to corrections to previous estimates.
- Consultation with industry regulators such as OFGEM and UREGNI has helped to improve the quality of data used for gas use and fugitive emission estimates from the gas network.

Other data providers

- Consultation with British Aerosols Manufacturing Association (BAMA) to access more detailed and up-to-date statistics for the aerosol industry, allowing us to remove a long-standing double count with the adhesives and paint sectors;
- Consultation with the Scotch Whisky Association to access more recent data for this sector, which is to be incorporated into the inventory in the 2025 submission;
- Consultation with the Iron and Steel Statistics Bureau (ISSB) to access more detailed statistics than are available through publications and to confirm the reporting of energy units;
- Consultation with the Department for Transport (DfT) to discuss the potential use of MOT data for improving the relative mileage with age assumption for road transport and to discuss the methodological approach applied for the analysis of ANPR data to develop the fleet composition;
- Discussions with the Environmental Analysis team at DfT about fleet modelling assumptions are ongoing, which may lead to changes in the fleet turnover assumptions in future submissions;
- Consultation with Tata Chemical (soda ash producer) and trade bodies representing soda ash users in order to gather data so that emissions from soda ash use could be estimated for inclusion in the 2020 submission of the UK inventory. Previously the inventory only included emissions from soda ash used to produce glass; this consultation enabled us to quantify soda ash consumption by other industries and related emissions;
- Consultation with Environmental Compliance team of the Ministry of Defence (MoD) to seek improved understanding of the fuels data the MoD provides for military aviation and naval shipping. Of particular interest was understanding the source of the MoD fuels data and how it is derived, how fuel supplied for overseas operations is accounted for, understanding the different types of fuels used for military aviation, emphasising the need for time series consistency and getting information on ground-based machinery and military transport. The MoD was given a better understanding of the inventory requirements, and whilst it was unable to provide new, more granular data for this year’s inventory submission, it agreed to work with its data providers to determine what may be possible for future submissions.

1.6.6.3. Verification

Verification activities provide an objective, independent review of inventory source data, methods and assumptions. Verification can seldom demonstrate that an inventory is “correct” at the national scale, but comparisons between NAEI emissions estimates and real-world data can indicate whether pollutant trends and ratios are consistent, whether spatial distributions are accurate, and may highlight missing sources or identify more uncertain data or models. For some sources, it is possible to compare emission factors from direct real-world measurements to those applied in the NAEI.

The UK’s Inventory program includes an annual program of verification activities undertaken each year involving experts from the air pollution science and modelling communities who use specific inventory information to analyse and interpret ambient measurements. The activities usually focus on specific sources or pollutants and require use of the spatially resolved inventory.

Defra has an ongoing air pollution mapping and dispersion modelling programme which maps concentrations of pollutants using emissions data from the NAEI and concentration data at fixed sites from national air quality monitoring stations. A valuable output from this work is the calibration factors which are used to scale emissions data for road transport to match the model with roadside concentration measurements. Recent work has shown that improvements to the emission inventory for domestic wood burning, including the spatial distribution of PM and benzo(a)pyrene emissions from these sources, has reduced the model calibration coefficients closer to unity, indicating that changes to the NAEI emission estimates and spatial distributions help to improve agreement with ambient modelling.

Recent NAEI improvement work has focussed on improving the representation of traffic speeds in the road transport emissions model. The impact of changing the speed assumptions within the NAEI is a small reduction in the calibration coefficient for the model roadside increment for NO_X, indicative that the changes to traffic speed tend to improve the agreement between modelled and measured concentrations of NO_X. Changes in the Pollution Climate Mapping (PCM) calibration coefficients will continue to be monitored, particularly when notable changes to the activity data and EFs used in the NAEI have an impact on emissions totals and mapped emissions. The NAEI inventory verification program is ongoing, and the availability of independent measurement data continues to be reviewed to inform the next steps in the program.

Other verification activities can use Earth Observation (EO) data, vehicle emissions remote sensing data, or measurements supported by research council programmes or university groups. Recent work demonstrated a methodology to estimate city level emissions of NO_X from satellite observations and the methodology was demonstrated for cites in England (Rose *et al*., 2022). With further refinement and extension to other air quality pollutants, the methodology has the potential to be used to provide verification of NAEI emissions. Evidence from UK on-road vehicle emissions remote sensing data has been reviewed to evaluate recent updates to vehicle, fuel and Euro standard specific emissions degradation functions in COPERT and applied in road transport emissions calculations. Furthermore, evidence from vehicle emissions remote sensing, which suggests a possible underestimate of emissions of ammonia from road transport sources in urban areas, is under review.

A member of the Inventory Agency is represented on Defra's AQEG where there are opportunities to bring important research findings and inventory information together and discussed in relation to important air quality policy issues. The NAEI inventory verification program is ongoing, and the availability of independent measurement data continues to be reviewed to inform the next steps in the program.

1.6.6.4. Inventory Improvement Programme

New information needs to be regularly assessed to ensure the inventory is accurate and up-to-date. The AQPI and GHGI estimates are updated annually and incorporate as many improvements to methods, data and assumptions as possible. This annual revision of the full time series ensures that the inventory reflects the latest scientific understanding of emission sources and removals, and that a consistent estimation methodology is used across the full time series. Continuous improvement of the inventory is delivered through a process of reviewing inventory data followed by a programme of targeted research, data gathering and/or revisions to methods and data sources. Improved understanding of the science and policy relating to GHGI and AQPI is also greatly enhanced through participation in related international activities. The improvement programme is managed through maintenance of an on-going "live" list of comments, improvements and problems that the inventory team find at any time of the inventory cycle or through external review or international activities.

Internal, external and international review findings as well as uncertainty analysis provide the means for justifying and prioritising improvements. Defra are responsible for the management of improvement tasks to the AQPI and DESNZ for the GHGI. Improvements to activity data that improve the accuracy of both AQ and GHG emissions are jointly owned but can be led by either of the departments. Specific activities that feed into the improvement programme include:

- Participation in technical national and international projects, workshops, conferences and meetings (including TFEIP/CLRTAP meetings, working groups and guidance writing, authorship and review of IPCC Guidelines and EMEP/EEA Guidebook chapters, UNFCCC negotiations, provision of expertise to the UNFCCC and UNECE inventory review.
- On-going data collection and inventory compilation.
- Stakeholder consultation including specific improvement feedback from the wider user community including users of data for modelling and Local Authority review and assessment work.
- Assessment of results from the annual uncertainty assessments.
- Recommendations from external and internal reviews.
- Potential issues identified through inventory verification projects.

In recent years, the improvement programme implemented specific consultations, bilateral reviews, research projects and analysis to improve the inventory estimates reporting for the NAEI. These include:

Domestic Combustion of Solid fuels improvement (2023-ongoing) The following improvements relating to the residential combustion sector have been implemented in recent years, or will be implemented in future years:

2023 submission:

- The methods used to calculate emissions from the use of solid, liquid and gaseous fuels were consolidated from four separate systems into one flexible, integrated system. During this upgrade, many pollutants were migrated to a Tier 2 method.
- New, UK-specific EFs relating to the combustion of wet, dry and seasoned wood in fireplaces and a range of stoves for all pollutants other than PM have been included in the NAEI.
- The results from the first Defra Burning Survey were included.

2024 submission:

- A refined approach was implemented which aligns the trend in wood use with the methodology used in Accredited Official Energy Statistics to separate year to year changes in heating demand (heating degree days) and new appliance installations.

2025 submission:

- It is anticipated that, further EFs for PM from wood, and all pollutants from solid mineral fuels will also be updated.
- The results from the second Defra Burning Survey are anticipated to be included.

- **Road Transport Model (2024)** Improvements have been made to the Road Transport Model to take account of the latest version of the EMEP/EEA Guidebook, based on COPERT 5.6 emission factors (previously COPERT 5.4); which includes new emission factors and methodologies for non-exhaust, cold start and degradation processes.
- **Industrial Scale Combustion Model (2024)** The model used to help calculate emissions from Industrial Scale Combustion (which previously only covered NO_X and PM_{10}) has been extended to cover NMVOCs, $PM_{2.5}$, Black Carbon, and a range of POPs/PAHs. This ensures that technology specific (Tier 2) emission factors are used and applied to calculate an appropriate overall weighted emission factor for that sector.
- **Paper Production (2024)** Previously only Tier 1 factors from the EMEP/EEA Guidebook (2019 edition) were available which assumed chemical paper pulp production via the Kraft process. This did not accurately represent the mechanical pulping and neutral sulphite semi-chemical (NSSC) pulping processes used in the UK. Feedback from the UK inventory during the preparation of the 2023 edition of the EMEP/EEA Guidebook, led to the inclusion of Tier 2 emission factors for the mechanical pulping and the NSSC processes which are now incorporated into the inventory.
- **NRMM (2023)** Defra commissioned Ricardo to conduct a detailed Government-supported machinery population and usage survey with industry stakeholders, including evaluating the findings for their use in the inventory. As such, there are now two models, the previous approach covering house and garden machinery, and the new model for all other off-road machinery. In contrast to the previous approach, in the new off-road model, machinery can be grouped into more than one of eight sector types, based on stakeholder feedback. When there is not enough fuel to allocate to bottom-up estimates, the new approach now adjusts all bottom-up off-road estimates, including agricultural off-road depending on the degree to which those bottom-up estimates agree with DUKES.
- **Hand Sanitiser (2022)** Data were supplied by ESIG, which included total ethanol use for the UK. This was used in conjunction with known ethanol use to derive an estimate for hand sanitiser use.
- **Road Transport model improvements (2021).** Extensive improvement work was carried out on the Road Transport emissions model to: i) Implement new basemap speeds; ii) implement a revised fleet turnover model; iii) adopt the COPERT 5.4 factors in the model.
- NO_X **and PM_{10} emissions from industrial-scale combustion (2020).** A major improvement has been made to the methodology used to estimate NO_X and PM_{10} emissions from industrial-scale combustion (reported in 1A1c, 1A2, 1A4a and 1A4c). The new method uses a Tier 2 approach (i.e. technology-specific factors) with some elements of Tier 3 also (i.e. use of site-specific emissions data as reported by operators to UK regulators). While this is an important improvement in the quality of the UK inventory, it has had relatively little impact on emission totals for NO_X and PM_{10}.
- **NMVOCs in Consumer Products (2020).** Estimates of NMVOC emissions from the use of solvents and other NMVOCs in consumer products have been reviewed following research to gather new information. Emission estimates

for aerosol and non-aerosol consumer products were revised to reflect new data provided by the UK Cleaning Products Industry Association and the British Aerosols Manufacturing Association. The estimates for consumer products were extended to include scented candles for the first time. The European Solvent Industry Group (ESIG) also supplied new data which was used to revise emission estimates for a number of industrial solvent use categories. Finally, both the British Coatings Federation (BCF), and the British Adhesives and Sealants Association provided updated data and estimates also took account of new site-specific emissions data from the PRTR. Overall emission estimates for the 2D3 (solvent use) sector were revised up across the time series.

For improvements made before 2020 please see previous versions of the IIR report.

1.6.6.5. Capacity Building and Knowledge Sharing

The UK actively participates in capacity building and knowledge sharing activities with other countries. The list below highlights some recent examples of these activities. The focus has mainly been on the GHG Inventory, which has in turn helped the AQPI.

1. Knowledge sharing with Chinese energy statisticians on GHG emissions trading and statistics.
2. Capacity building activities in South Africa in the agricultural sector.
3. Knowledge sharing with the Romanian GHG inventory team during December 2011 to support the improvement of energy sector reporting.
4. Knowledge sharing with the Chinese Energy Research Institute regarding the UK experience of integrating facility-level data into the national inventory and outlining all of the QA procedures that govern energy and emissions data from facility to sector to national level within the UK, to support their efforts in developing a national system of data management to account for GHG emissions, working from provincial and facility-level data.
5. Capacity building in Spain - invited to present the UK agricultural inventory improvements and further conversations with Spanish government representatives.
6. Knowledge sharing with French inventory team.
7. UK CEH participation in twice yearly knowledge sharing with European LULUCF inventory compilers at EU Joint Research Council LULUCF meetings.
8. Knowledge sharing with and technical assistance to the Vietnam inventory team to help develop the national inventory system.
9. Capacity building workshop with Balkan EU accession countries on National System development.
10. Study visit by delegation from the Chinese National Centre for Climate Change Strategy and International Cooperation (NCSC) as part of their week-long visit to the UK arranged by BEIS. Ricardo hosted representatives from NCSC, BEIS and Welsh Government, presenting on compilation and usage of national, devolved, local and city inventories.
11. The UK experts on inventory verification, including the InTEM model, have engaged with verification experts from other countries and across other research institutes through workshops managed by WMO, IG3IS and the AGAGE network, in order to share knowledge and experience from the UK programme and explore options for further development of these techniques to underpin emissions inventory verification at a range of spatial scales, and/or targeted at specific industries/sources.

12. UK experts participate as lead reviewers and sector experts in annual inventory review processes, including those for the CLRTAP, NECR and UNFCCC transparency processes.
13. Liaised with the Norwegian Pollution Directorate and Environment Agency in 2022 regarding emissions factors and abatement technologies in the offshore oil and gas sector.
14. Discussions with the German inventory team who have transposed their IIR into a wiki format (2023).
15. The NAEI team has met with delegations from Oman and Malaysia to share knowledge on national systems and inventory reporting.
16. UK experts have liaised with peers within the Norwegian Pollution Directorate and Environment Agency to share research and evidence regarding technological developments, emissions factors and abatement technologies in the offshore oil and gas sector, for example relating to fugitive NMVOCs and methane (2022, 2023).
17. UK experts have shared knowledge regarding recent developments in the UK road transport model with other countries, for example via a recent (2023) remote workshop with experts in South Africa.
18. UK experts have shared knowledge regarding the interactions and development of evidence in conjunction with (predominantly UK-based) academic measurement experts with our peers in Australia at CSIRO Aspendale (2024), focusing on the usefulness of modelling to generate comparators to inventory evidence from atmospheric measurements and meteorological data targeting specific sources and locations (e.g. landfill sites, gas pipelines, production facilities).
19. As part of the inventory improvement programme for road transport, the NAEI team have received information and consulted with the Technical University Graz in Austria about alternative methods and emission factors for modelling road transport emissions using the Handbook Emission Factors for Road Transport (HBEFA) approach as used in some other countries. This approach may allow more detailed modelling of air quality in urban areas.
20. Knowledge sharing of activity data on non-road mobile machinery (NRMM) with the transport sector expert in Denmark.

The UK Informative Inventory Reports from the 2008 IIR onwards[28], and estimates of emissions of air quality pollutants, are all publicly available from https://naei.beis.gov.uk/

1.6.7. Treatment of Confidentiality

NAEI input data from some sources are subject to commercial confidentiality, notably where the production data and/or activity data for a specific installation or company are identifiable. For example, there are confidential data indicating the plant production capacity for specific industrial plant (e.g. cement kilns, chemical plant), annual sales data of specific commodities (e.g. sporting goods) and also details of fuel use for specific installations (e.g. plant-level data from UK ETS-regulated installations).

It is important therefore that in the management of these data within the NAEI system, and in the publication of emission estimates (and other data) relating to these data sources, that the NAEI does not disclose such commercially sensitive information.

[28] Earlier versions of the IIR can be found on EIONET (http://cdr.eionet.europa.eu/gb)

There are several mechanisms that the Inventory Agency and the wider inventory compilation teams (e.g. ADAS) deploy to ensure that disclosure of confidential data does not occur:

- The provision of sensitive raw data to the Inventory Agency, if not through direct communication with the data source organisations, is managed via Defra or DESNZ using file encryption with password protection.
- Confidential data, such as the UK ETS dataset, is managed by the Inventory Agency on a password-protected secure server which has limited access rights, i.e. access is limited to the relevant compilers and checkers only.
- Within the NAEI database tables, there are specific data fields to identify confidential data. These are applied to cover all of the associated data, such as emissions, AD and EFs, in order to minimise the risk of mistakenly releasing sufficient information that the confidential data can be inferred. These database data fields then enable ease of identification of risk of data disclosure in any NAEI database output (e.g. data at different spatial scales, such as for a specific Local Authority or in mapping outputs).
- Confidential data assignations are periodically reviewed, and in every routine data request for input data for the NAEI the organisation providing the data is given an opportunity to identify confidential data.
- Where data outputs use the confidential data, the data are reported at an aggregated level - either with other sources (e.g. in the case of sporting goods), or over a larger geographical area (e.g. in the case of emissions mapping outputs which are usually at 1 km x 1 km resolution, data for some sources are aggregated and smeared over a larger area, typically 10 km x 10 km). This may mean that the UK cannot report exactly in line with the expected level of sectoral resolution as defined in the NFR format for air pollutants, but this is considered an acceptable trade-off that is necessary to protect sensitive data.

1.6.8. Uncertainty Assessments

An uncertainty analysis for national estimates of NAEI pollutants has been undertaken using the Tier 1 uncertainty aggregation method for the latest inventory submission. A more complex and comprehensive Monte-Carlo analysis, as described in chapter 5 of the latest EMEP/EEA Guidebook, was last carried out for earlier inventory submissions.

The Tier 1 methodology investigates the impact of the assumed uncertainty of individual parameters (such as emission factors and activity statistics) upon the uncertainty in the total emission of each pollutant. Uncertainties are assessed for the NECR and Gothenburg Protocol base year (2005) and the most recently reported year by source sector and by pollutant.

Results from both the Tier 1 methodology and the Monte-Carlo analysis are presented in Section 1.7. These results are used to plan the programme of inventory improvement.

1.7. Uncertainty Evaluation

According to the 2006 IPCC guidelines, “An uncertainty analysis should be seen, first and foremost, as a means to help prioritise national efforts to reduce the uncertainty of inventories in the future, and guide decisions on methodological choice”. Therefore, uncertainty information is not intended to dispute the validity of the inventory estimates, but to provide an indication of where future improvements may be best made. The EMEP/EEA Guidebook requires countries to undertake an uncertainty assessment of the national totals of each pollutant reported under the CLRTAP.

Evaluation of uncertainty is undertaken by a Tier 1 uncertainty aggregation assessment as indicated in Section 1.6.8. Uncertainty estimates are shown in

Table **1-6**. These estimated uncertainties are one of the indicators used to guide the NAEI improvement programme, which aims to reduce uncertainties in the NAEI. More information on the analysis for some of the key pollutants are given in the subsequent sections including details on a sectoral basis for each of these pollutants.

Table 1-6 Uncertainty of the NAEI for a sample of key air quality pollutants[29]

Pollutant	Emissions[a]			Estimated Uncertainty[b]		
	2005	2022	Trend	2005	2022	Trend[c]
PM_{10}	190	127	-33%	32%	44%	13%
$PM_{2.5}$	109	65	-41%	23%	39%	16%
SO_X	782	120	-85%	6.6%	24%	3.1%
NO_X	1725	643	-63%	6.2%	8%	2.6%
NMVOC	1239	756	-39%	13%	21%	8.3%
NH_3	281	259	-7.7%	21%	17%	12%
Pb	0.21	0.15	-32%	58%	72%	22%
B[a]p	8416	7024	-17%	54%	78%	63%

[a] Emissions data are presented in kg for B[a]p and kt otherwise, and are to the nearest integer, or to 2 decimal places
[b] the range of +- the percentages given represents a 95% confidence interval. Because the Tier 1 approach used does not account for asymmetric distributions these values can be greater than 100%. This does not indicate that emissions could be negative, but that the values are very uncertain, and a skewed distribution is expected. Data are presented to 2 significant figures
[c] This is the 95% confidence interval from the central estimate of the trend, e.g. if the trend in emissions is a decrease of 50% and the trend uncertainty is 5%, then the 95% confidence interval would be a decrease of between 45 and 55%.

This Tier 1 assessment has been undertaken for several key pollutants - analysis of a more comprehensive list of pollutants will be considered in the future if resources allow.

Table 1-7 presents a summary of uncertainties determined previously using a Tier 2 Monte Carlo approach.

The uncertainty ranges derived previously are not comparable with those from the current Tier 1 methodology. This is because there have been changes to the inventory since the figures in Table 1-7 were derived, and because the assumptions used in the current uncertainty analysis have been improved since this earlier uncertainty analysis.

The uncertainties shown in Table 1-7 are presented to indicate the relative uncertainty of pollutant inventories, for example the results suggest that the inventory for CO (-20% to +30%) is slightly less uncertain than the inventory for HCl (-30% to +>50%) etc.

The uncertainty figures derived from the Tier 1 uncertainty analysis are all higher than the figures derived previously from the Tier 2 Monte Carlo analysis e.g. SO_X was +/- 4%, NMVOCs were +/- 10%, ammonia was +/- 20%. No analysis has been undertaken using the Tier 1 methodology with the same inventory data as used for the Tier 2 approach (2012 NAEI data). It is therefore not possible to conclude how much the observed increase in inventory uncertainty is due to changes in methodologies and how much is due to changes in the inventory data itself.

[29] Emissions are expressed on a fuel used basis, i.e. the LRTAP compliance totals in the Annex 1 Emission reporting template.

Whilst the Tier 1 method has generated notably different estimates of uncertainty for some pollutants (SO_X, NMVOCs, B[a]P in particular), the ranking of pollutants is generally similar to that obtained previously.

Table 1-7 Uncertainty of the Emission Inventories determined previously (pre-2015) using a Tier 2 Monte Carlo approach for pollutants covered under the NAEI, but not covered by the recent Tier 1 assessment.

Pollutant	Estimated Uncertainty (%)
Carbon monoxide	-20 to +30
Benzene	-20 to +30
1,3-butadiene	-20 to +30
$PM_{1.0}$	-20 to +50
$PM_{0.1}$	-20 to +50
Black Carbon	-20 to +50
Black smoke	-30 to +50
Hydrogen chloride	-30 to +>50
Hydrogen fluoride[a]	-30 to +>50
Arsenic	+/- >50
Cadmium	-30 to +>50
Chromium	-50 to +>50
Copper	+/- >50
Mercury	-30 to +50
Nickel	-40 to + >50
Selenium	-30 to +40
Vanadium	-30 to +30
Zinc	-40 to + >50
Beryllium	+/- >50
Manganese	+/- >50
PCDD/PCDFs	+/- >50
Polychlorinated biphenyls	+/- >50
Pentachlorophenol	+/- >50
Hexachlorocyclohexane	+/- >50
Hexachlorobenzene	+/- >50
Short-chain chlorinated paraffins	+/- >50
Pentabromodiphenyl ether	+/- >50
Polychlorinated naphthalenes	not estimated

[a]Assumed to be same as for hydrogen chloride

1.7.1. Ammonia

Ammonia emission estimates are dominated by uncertainties in the estimates of emissions from agricultural sources, which represent the majority of the national total ammonia emissions. Although the UK uses a detailed (largely Tier 3) approach to estimating emissions from agriculture, which accounts for different animal sub-categories and management systems, it is not possible to fully represent the many factors influencing emissions from what are often diffuse emission sources including, for example, animal stocking densities, daily weather, soil type and conditions, etc. These are therefore reflected in the uncertainties associated with individual emission factors. The uncertainty parameters for agriculture have been updated to reflect the latest understanding in the 2024 submission.

Table 1-8 Assessment of Ammonia uncertainty

NFR Code	2005			2022			
	Emissions (kt)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Emissions (kt)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Uncertainty introduced into the trend in total national emissions
1A	18.0	110%	6.8%	6.07	62%	1.4%	5.3%
1B	0.36	38%	0.0%	0.15	47%	0.0%	0.0%
2A	0.51	33%	0.1%	0.45	33%	0.1%	0.0%
2B	4.06	25%	0.4%	0.74	53%	0.2%	0.2%
2C	0.00	91%	0.0%	0.00	91%	0.0%	0.0%
2D	1.21	140%	0.6%	1.21	140%	0.7%	0.3%
2G	0.23	72%	0.1%	0.13	72%	0.0%	0.0%
2H	0.87	140%	0.4%	0.60	140%	0.3%	0.1%
3B	106	45%	17%	93.8	38%	14%	9.3%
3D	131	16%	7.6%	133	16%	8.2%	3.8%
5A	1.40	62%	0.3%	0.17	62%	0.0%	0.2%
5C	0.05	79%	0.0%	0.02	89%	0.0%	0.0%
5B	3.17	32%	0.4%	5.19	19%	0.4%	0.3%
5D	1.74	95%	0.6%	1.48	92%	0.5%	0.1%
6A	12.3	130%	5.6%	16.5	100%	6.4%	3.2%
Total	281	21%	21%	259	17%	17%	12%

1.7.2. Carbon Monoxide

Carbon monoxide emissions occur almost exclusively from combustion of fuels, particularly by road transport. Emission estimates for road transport are moderately uncertain, as measurements are quite limited on some vehicle types and emissions are highly variable between vehicles and for different traffic conditions.

Emissions from stationary combustion processes are also variable and depend on the technology employed and the specific combustion conditions. Emission estimates from small and medium-sized installations are derived from emission factors based on relatively few measurements of emissions from different types of boilers. As a result of the high uncertainty in emission data for major sources, emission estimates for CO are much more uncertain than other pollutants such as NO_X and SO_X which are also emitted mainly from major combustion processes. Unlike the case of NO_X and NMVOCs, a few sources dominate the inventory and there is limited potential for error compensation.

1.7.3. Nitrogen Oxides

Uncertainty of NO_X emission estimates are driven by uncertainty in emissions from fuel combustion (sector 1A). The estimates for 1A are subject to relatively low uncertainty compared with the estimates for other sectors and because 1A dominates the inventory so much, the higher uncertainties for the other sectors make very little impact on the overall uncertainty. Sources within 1A that drive the uncertainty include:

- Road transport: There is a high level of confidence in the activity data, and hence uncertainty is driven by uncertainty in the emission factors for different vehicles. The emission factors vary depending on vehicle type, catalyst technology and driving conditions amongst other factors. There is some uncertainty in choosing how the emission factors are applied to UK data, but also in the emission factors themselves, which are based on measurements that are associated with significant variation even when keeping the conditions constant.

- Off-road machinery: While this is a relatively small source (compared to road transport or power generation), the emission factors have similar issues to that of road transport. Additionally, activity data is believed to be less reliable and therefore uncertainty in the activity data is considered to be significant.

The estimates for large stationary combustion plant are assumed to be substantially less uncertain than the estimates for mobile sources or small stationary combustion. The large combustion plant consist of a large number of sites for which independent emission estimates are available, and these emission sources are broadly of similar size, with none dominating. This leads to a large potential for error compensation, where an underestimate in emissions for one site or sector is very likely to be compensated by an overestimate in emissions in another site or sector. Many of the larger point-sources make up the bulk of the UK estimates, and these are commonly derived from continuous emission measurement data and hence are regarded to be good quality.

Table 1-9 Assessment of Nitrogen Oxides uncertainty

NFR Code	2005			2022			
	Emissions (kt)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Emissions (kt)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Uncertainty introduced into the trend in total national emissions
1A	1687	6.2%	6.1%	614	8.1%	7.7%	2.6%
1B	3.29	37%	0.1%	1.82	30%	0.1%	0.0%
2B	1.29	27%	0.0%	0.65	51%	0.1%	0.0%
2C	1.62	21%	0.0%	0.51	25%	0.0%	0.0%
2G	0.10	90%	0.0%	0.06	91%	0.0%	0.0%
2H	0.03	65%	0.0%	N/A	N/A	N/A	0.0%
3B	1.69	68%	0.1%	1.47	73%	0.2%	0.0%
3D	27.6	59%	0.9%	22.6	60%	2.1%	0.4%
5C	1.89	35%	0.0%	1.64	36%	0.1%	0.0%
5E	0.32	88%	0.0%	0.11	83%	0.0%	0.0%
6A	0.35	100%	0.0%	0.35	100%	0.1%	0.0%
Total	1725	6.2%	6.2%	643	8.0%	8.0%	2.6%

N/A used where emissions are 0

1.7.4. Non-Methane Volatile Organic Compounds

The NMVOC inventory is more uncertain than those for SO_X and NO_X. This is due in part to the difficulty in obtaining good emission factors or emission estimates for many sectors (e.g. for solvent use and industrial processes) and partly due to the absence of good activity data for some sources. Given the broad range of independent sources of NMVOCs, as with NO_X, there is a high potential for error compensation, and this is responsible for the relatively low level of uncertainty compared with most other pollutants in the NAEI. Compared with many of the other pollutants analysed, the uncertainty in the NMVOC inventory is quite variable with time, reflecting the fact that the NMVOC inventory has been subject to phases of significant investment. Much improvement work was done in the late 1990s and early 2000s, resulting in the acquisition of much data at that time so that the estimates for that period are less uncertain. Similarly, considerable work has been done in recent years to update the data held on emissions from solvent use and so uncertainty for that part of the inventory, having increased after the early 2000s, is now decreasing again.

Table 1-10 Assessment of NMVOC uncertainty

NFR Code	2005			2022			
	Emissions (kt)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Emissions (kt)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Uncertainty introduced into the trend in total national emissions
1A	313	17%	4.3%	96.4	17%	2.1%	2.2%
1B	274	25%	5.5%	93.5	19%	2.3%	2.5%
2A	1.95	37%	0.1%	0.75	34%	0.0%	0.0%
2B	39.8	59%	1.9%	10.4	100%	1.4%	0.7%
2C	1.64	82%	0.1%	0.76	84%	0.1%	0.0%
2D	388	12%	3.7%	290	20%	7.6%	4.3%
2G	0.26	200%	0.0%	0.15	200%	0.0%	0.0%
2H	87.3	67%	4.7%	120	59%	9.4%	3.1%
2I	1.55	120%	0.1%	1.39	120%	0.2%	0.1%
3B	74.8	140%	8.4%	75.4	140%	14%	4.2%
3D	41.0	110%	3.5%	56.6	110%	8.4%	3.4%
5A	6.30	34%	0.2%	1.73	34%	0.1%	0.1%
5C	6.22	190%	0.9%	6.02	190%	1.5%	0.5%
5D	0.36	460%	0.1%	0.51	470%	0.3%	0.3%
5E	1.60	88%	0.1%	0.56	84%	0.1%	0.0%
6A	1.52	97%	0.1%	1.53	97%	0.2%	0.1%
Total	1239	13%	13%	756	21%	21%	8.3%

1.7.5. Particulate Matter Estimates

The emission inventory for PM_{10} and $PM_{2.5}$ is subject to high uncertainty. This stems from both uncertainties in the emission factors and the activity data. For many source categories, emissions data and/or emission factors are available for total particulate matter only and emissions of PM_{10} must be estimated based on assumptions about the size distribution of particle emissions from that source. This adds a further level of uncertainty for estimates of PM_{10} and in some cases to an even greater extent for $PM_{2.5}$ and other fine particulate matter.

Many sources of particulate matter are diffuse or fugitive in nature e.g. emissions from coke ovens, metal processing, or quarries. These emissions are difficult to measure, and in some cases, it is likely that no entirely satisfactory measurements have ever been made, so emission estimates for these fugitive sources are particularly uncertain.

Emission estimates for combustion of fuels are generally considered more reliable than those for industrial processes, quarrying and construction. All parts of the inventory would need to be substantially improved before the overall uncertainty in PM could be reduced to the levels seen for SO_X, NO_X or NMVOCs.

Table 1-11 Assessment of PM_{10} uncertainty

NFR Code	2005			2022			
	Emissions (kt)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Emissions (kt)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Uncertainty introduced into the trend in total national emissions
1A	96.7	21%	11%	54.4	41%	17%	7.8%
1B	2.96	120%	1.8%	1.35	67%	0.7%	1.1%
2A	52.5	70%	19%	39.1	76%	24%	5.4%
2B	0.65	62%	0.2%	0.14	61%	0.1%	0.1%
2C	6.51	110%	3.7%	3.67	100%	2.9%	0.7%
2D	1.48	270%	2.1%	1.35	230%	2.4%	0.3%
2G	3.44	280%	5.1%	2.06	300%	4.8%	0.4%
2H	1.87	490%	4.8%	1.33	500%	5.2%	0.2%
2I	1.17	140%	0.9%	1.02	140%	1.2%	0.4%
3B	9.12	390%	19%	8.80	390%	27%	6.8%
3D	6.33	290%	9.7%	6.77	290%	16%	4.2%
5A	0.02	62%	0.0%	0.01	62%	0.0%	0.0%
5C	4.54	150%	3.5%	4.64	150%	5.5%	3.1%
5E	2.81	290%	4.2%	1.94	370%	5.6%	1.4%
6A	0.04	1200%	0.3%	0.04	1200%	0.4%	0.1%
Total	190	32%	32%	127	44%	44%	13%

Table 1-12 Assessment of $PM_{2.5}$ **uncertainty**

NFR Code	2005			2022			
	Emissions (kt)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Emissions (kt)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Uncertainty introduced into the trend in total national emissions
1A	81.2	23%	17%	44.1	49%	33%	15%
1B	2.05	160%	3.0%	1.26	250%	4.8%	1.2%
2A	7.71	100%	7.2%	5.25	120%	9.5%	1.6%
2B	0.45	67%	0.3%	0.09	54%	0.1%	0.1%
2C	3.91	130%	4.7%	2.21	120%	4.2%	0.9%
2D	0.51	230%	1.1%	0.47	200%	1.4%	0.3%
2G	2.50	200%	4.7%	1.47	220%	4.9%	0.4%
2H	0.57	480%	2.5%	0.40	500%	3.0%	0.3%
2I	0.93	250%	2.1%	0.82	250%	3.1%	0.8%
3B	2.19	260%	5.1%	2.02	250%	7.9%	2.1%
3D	0.68	500%	3.1%	0.73	500%	5.6%	1.4%
5A	0.00	62%	0.0%	0.00	62%	0.0%	0.0%
5C	4.14	150%	5.7%	4.27	150%	10%	5.1%
5E	2.61	290%	6.8%	1.80	370%	10%	2.6%
6A	0.03	1200%	0.3%	0.03	1200%	0.5%	0.1%
Total	109	23%	23%	64.9	39%	39%	16%

1.7.6. Sulphur Dioxide

Sulphur dioxide emissions are related largely to the level of sulphur in solid and liquid fuels. Hence, the inventory, which is based upon comprehensive analysis of UK produced coals and fuel oils consumed by power stations and the agriculture, industry and domestic sectors, contains accurate emission estimates for the most important sources.

It should be noted, that the uncertainty in emissions for the most recent year is much higher than the uncertainty in 2005 emissions. Between these years, regulations have been tightened to control the sulphur content of various fuels and it has become a requirement for SO_X emissions to be reported by large emitters such as power stations, refineries and steelworks. As a result, it has been possible to reduce the uncertainty in the assumptions relating to the sulphur content of many fuels, and more confidence in the emission estimates for many sectors. However, the contribution of those fuels and sectors to the national total has reduced. Further, the proportion of coal used that is UK produced is much smaller, as such a greater proportion of the estimate for certain sectors is based on default emission factors. The result is that fuels burnt by sectors for which there are less regulation and less data (e.g. petroleum coke and coal used as a domestic fuel) now dominate the estimate of total sulphur emissions and, as these sources have a much higher uncertainty, they drive up the overall uncertainty when expressed as a percentage.

Table 1-13 Assessment of SO_X uncertainty

NFR Code	2005			2022			
	Emissions (kt)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Emissions (kt)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Uncertainty introduced into the trend in total national emissions
1A	739	7.0%	6.6%	105	27%	24%	3.1%
1B	9.18	21%	0.2%	6.49	23%	1.3%	0.2%
2A	17.2	14%	0.3%	5.34	14%	0.6%	0.1%
2B	7.38	23%	0.2%	0.37	34%	0.1%	0.0%
2C	7.51	12%	0.1%	1.86	27%	0.4%	0.1%
2G	0.81	71%	0.1%	0.81	69%	0.5%	0.1%
2H	0.06	97%	0.0%	N/A	N/A	N/A	N/A
5C	0.88	110%	0.1%	0.52	160%	0.7%	0.1%
Total	782	6.6%	6.6%	120	24%	24%	3.1%

N/A used where emissions are 0

1.7.7. Heavy Metals

Among the metal inventories, those for selenium, vanadium and lead are currently judged as least uncertain, followed by the inventories for cadmium, mercury, nickel, manganese and zinc. Those for chromium, arsenic, copper, beryllium and tin are the most uncertain. This ranking of the inventories reflects the relative contributions made by sources that can be estimated with more certainty, such as emissions from fuel combustion (very well characterised activity data, although determining the metal content of the fuel can be challenging) and chemicals manufacture. This is in contrast to the contributions made by sources for which estimates are very uncertain, such as burning of impregnated wood.

Below is the detailed assessment for lead. Many of the other heavy metals are expected to have a similar order of magnitude uncertainty to lead, and some of the same relative uncertainties between sectors. Most of the metal emissions estimates are based on similar data and methodologies. They all share certain important emission sources such as the combustion of coal and oils, and metal production processes. However, some metals have specific sources from which emissions of that one metal are particularly abundant e.g. mercury emissions from crematoria, or selenium emissions from glassmaking. These unique features of each metal inventory mean that the uncertainty in the lead inventory can only be indicative and not an accurate reflection of uncertainties for other heavy metals.

Table 1-14 Assessment of lead uncertainty

NFR Code	2005			2022			
	Emissions (t)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Emissions (t)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Uncertainty introduced into the trend in total national emissions
1A	126	86%	51%	81.0	110%	59%	18%
1B	2.32	100%	1.1%	0.65	120%	0.5%	0.6%
2A	0.67	71%	0.2%	0.19	95%	0.1%	0.2%
2B	13.8	52%	3.4%	1.79	59%	0.7%	2.9%
2C	53.0	100%	25%	49.8	110%	38%	13%
2G	15.4	180%	13%	9.71	180%	12%	2.1%
2I	2.54	90%	1.1%	3.53	90%	2.2%	1.3%
5C	0.39	94%	0.2%	0.29	120%	0.2%	0.1%
Total	215	58%	58%	147	72%	72%	22%

1.7.8. Persistent Organic Pollutants

Inventories for persistent organic pollutants (POPs) are more uncertain than those for gaseous pollutants, PM_{10}, and metals. This is largely due to the paucity of emission factor measurements on which to base emission estimates and the complexity of dealing with POPs as families of congeners (PCDD/PCDFs, PCBs, PAHs). The issue is further exacerbated by a lack of good activity data for some important sources, for example small scale waste burning. The inventories for polychlorinated biphenyls and hexachlorobenzene are less uncertain than those for other persistent organic pollutants, however the overall uncertainty is still high.

Below is the detailed assessment for benzo[a]pyrene. In general, it is expected that the other polycyclic aromatic hydrocarbon (PAH) emissions estimates would be at least as uncertain and, in some cases, much more uncertain. Benzo[a]pyrene uncertainty estimates are not indicative of uncertainties in PCDD/PCDF emissions.

Table 1-15 Assessment of Benzo[a]pyrene uncertainty

NFR Code	2005			2022			
	Emissions (kg)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Emissions (kg)	Combined uncertainty for sector	Combined uncertainty as % of total national emissions	Uncertainty introduced into the trend in total national emissions
1A	7042	36%	30%	6606	81%	77%	52%
1B	77.8	90%	0.8%	58.0	90%	0.7%	0.1%
2B	17.9	92%	0.2%	10.6	110%	0.2%	0.1%
2C	162	150%	2.9%	35.2	280%	1.4%	1.3%
2D	10.5	130%	0.2%	8.64	130%	0.2%	0.1%
2G	6.07	130%	0.1%	3.39	130%	0.1%	0.0%
2I	15.4	140%	0.3%	12.1	140%	0.2%	0.1%
5C	745	490%	44%	38.2	360%	1.9%	34%
5E	339	330%	13%	252	410%	15%	3.6%
Total	8416	54%	54%	7024	78%	78%	63%

1.8. Notation Keys in the UK Inventories

In the compilation and reporting of inventories, it is not always possible to report emissions for all pollutants for all sources and at the level of resolution defined in the inventory guidance and reporting templates. This may be for a range of reasons, but is typically due to insufficient input data, or insufficient source-specific detail in the input data. In these instances, common with other reporting parties, the UK applies inventory good practice and uses appropriate notation keys, in order to ensure that the NAEI submissions are transparent and comparable to those of other countries, and to facilitate an assessment of completeness of UK inventories.

The two main uses of Notation Keys in the NAEI submissions are:

- NE ('Not Estimated'): where there are methodological or data gaps in pollutant inventories;
- IE ('Included Elsewhere'): where emissions are estimated but are not reported within the expected source category but are included in other source estimates.

The use of these notation keys in the NAEI is summarised in the sections below.

1.8.1. Not Estimated

Emissions of sources that are not estimated in the NAEI are reported as NE and are listed in Table 1-16.

Table 1-16 Pollutant Emissions Reported NE in the NAEI

NFR code	Substance(s)	Further details
1A2a to 1A2b	NH_3	Operator estimates of ammonia emissions from industrial fuel combustion are not reported routinely in the UK, and no other reliable UK-specific data exits. Further, there are no default EFs in the latest EMEP/EEA Guidebook for the coal, oil or gas used in these source categories; hence the UK does not estimate ammonia emissions for these fuels in the NAEI.
1A3aii(i)	NH_3	Aviation spirit (or also referred to as aviation gasoline) is used for civil aviation in the UK. However, NH_3 emissions are not estimated for this source as there are no EFs available in the latest EMEP/EEA Guidebook; the guidebook states that ammonia emissions are 'NE' for this source.
2C5	BC	The latest EMEP/EEA Guidebook does not have an EF for Black Carbon for this source.
2C7c	BC	The latest EMEP/EEA Guidebook does not have an EF for Black Carbon for this source.
2C7d	Metals	Emissions from the storage, handling and transport of metal products are not routinely reported separately by UK operators to environmental regulators. In the latest EMEP/EEA Guidebook, only EFs for particulate matter, PM_{10} and $PM_{2.5}$ are presented, with all other pollutants states as ‘NE’ for this source.
2D3c	NMVOC	Emissions from asphalt roofing are NE, as there are no activity data available in the UK. We note that activity is not widespread in the UK and hence this is expected to be a very minor source in the UK.
2D3g	PAHs	Oxidised bitumen is produced at two sites that do not report PAH emissions. Hence it is assumed that emissions are negligible.
3F	All	Emissions from field burning of agricultural residues are reported as ‘NE’ from 1994 onwards as EU legislation led to widespread bans of this practice. In the UK it is illegal to burn cereal straw and stubble and the residues of oilseed rape, peas and beans in the field, unless: • It is for education or research purposes • It is in compliance with a notice served under the Plant Health (Great Britain) Order 1993 (e.g. to eliminate pests) • It is to dispose of broken bales and the remains of straw stacks. The burning of linseed residues is exempted from the ban, but there are no EFs for burning of linseed residues in the latest EMEP/EEA Guidebook, and no UK activity data are available. It is assumed therefore that only very small amounts of residues are burned in the UK, that emissions are a minor source; it may be considered that 'relevant emissions are considered never to occur'.

1.8.2. Included Elsewhere

Emissions of sources that are unspecified within the NFR code disaggregation for a specific sector are reported as IE. Table 1-17 lists all sources included in these categories.

Table 1-17 Pollutant Emissions Reported ‘IE’ in the NAEI

NFR	Substance(s)	Included in NFR	Further Details
1A1b	NH_3	1B2aiv	Emissions of ammonia from UK refineries are reported in 1B2aiv. Estimates are based on total site emissions as reported by site operators to the UK regulators, which include emissions from fuel combustion, fugitives and process sources. Operators report one emission value for all sources on site and therefore all emissions are reported in 1B2aiv.
1A1c	NH_3	1B1b	Ammonia emissions from coke ovens are reported in 1B1b since these are based on total site emissions as reported by site operators to the UK regulators. These site emissions will include combustion-related as well as fugitive and process-related emissions, however, no split is provided and thus all emissions are reported in 1B1b.
1A3ei	All	1A1ciii	Within the UK energy balance the fuel use at gas compressors on the gas supply network are included in "Other Energy Industry" which also covers a range of other energy users (e.g. nuclear power stations use of support fuels, colliery use of fuels etc.). Data are not available specific to fuel use in pipelines, hence emissions from 1A3ei are included in 1A1ciii.
1A5a	All	1A4ai	Fuel use for stationary combustion for military purposes is not reported separately in the UK energy statistics and hence emissions are included under 1A4ai (Commercial/institutional: Stationary).
1B1c	All	1B1b	1B1c is cited in the guidance as a “catch all” category for anything that does not fit into other parts of 1B, and it is only to be used as a last resort. The UK includes all fugitive emissions from solid fuel manufacturing within 1B1b, and hence 1B1c is ‘IE’. Arguably the UK could report ‘Not Occurring’ here.
1B2aiv	SO_X, Pb, Cd, Hg, PCDD/PCDF	1A1b	Fugitive emissions from petroleum refineries of pollutants such as SO_X and metals are reported together with fuel combustion emissions in 1A1b. There is no separate reporting by operators of combustion and fugitive emissions, and as the combustion component is by far the highest contributing, all operator emissions are allocated to 1A1b.

NFR	Substance(s)	Included in NFR	Further Details
1B2av	SO_X	1B2ai	Emissions of SO_X from the distribution of oil products is cited as 'NE' throughout the latest EMEP/EEA guidance, i.e. there are no EFs presented for any emission sources in this category. In the UK, upstream oil and gas operators report emissions of SO_X from "process sources" which may include emissions from distribution activities (e.g. oil loading / unloading, storage); these are reported under 1B2ai, as the predominant process source of SO_X is the upstream treatment of oil and gas products.
2A5c	PM	2A5a, 2A5b, 2A6 & 2H3	Dust emissions from storage, handling and treatment of mineral products are reported in the UK under the quarrying sector (2A5a), construction (2A5b), cement batching (2A6) and other industrial processes (2H3).
2B1	NO_X	1A2c	Emissions of NO_X from ammonia production are reported by operators, but it is not practicable to distinguish between emissions from combustion (1A2c) or process sources (2B1) and hence all emissions are reported under 1A2c, with 'IE' reported for 2B1.
2B1	NH_3, NMVOC	2B10a	Operator-reported emissions of ammonia and NMVOCs from most chemical production processes are very minor emissions, but they are reported to regulators. Given the integration of chemical complexes, in the NAEI we aggregate these emissions across chemical process types and report all within 2B10a.
2B2	NH_3, NMVOC	2B10a	
2B10b	All (except NMVOCs)	2B10a	Emissions from handling and transport of chemicals are reported within operator submissions to regulators, together with estimates of other emission sources. These are all reported together within 2B10a.
2C2	All	1A2a and 2C1	Emissions from ferroalloys may arise from use of reductants, fuels or limestone and dolomite. In all cases, the activity data for UK activities are not available separately from other iron and steel sector production. Hence, they are reported within 1A2a and 2C1.
2C7d	PM	2C1	Dust emissions from storage, handling and treatment of metal products are reported in the UK under the iron and steel sector (2C1). The emissions are very minor.
2D3a	Hg	1A1a and 5A	Emissions of Hg from fluorescent tubes are reported in 1A1a as part of emissions from municipal solid waste incinerations (since energy is recovered at these sites, they are treated as power stations), as well as under 5A (in from of mercury emissions from waste disposal of fluorescent lighting tubes).

NFR	Substance(s)	Included in NFR	Further Details
3B4f	NO_X, NMVOCs, PM and NH_3	3B4e	Manure management from "mules and asses" are arguably 'Not Occurring' in the UK. However, it is feasible that some of the data on horses (3B4e) includes livestock that could be allocated to 3B4f; hence we report 'IE'.
5C1bi	All	5C1a and 5C1bii	Emissions from industrial waste incinerators are arguably 'Not Occurring' in the UK. In some cases, it may be that the general industrial waste feedstock envisaged for reporting in 5C1bi are incinerated in either MSW plant (5C1a) or are reported as chemical waste incinerators (5C1bii) in the UK, and hence we report 'IE'.
1A2gvii, 1A3c, 1A4bii, 1A4cii, 1A5a and 1A5b	Activity data: Biomass	1A3b	The UK currently has no statistics on the amount of biofuels used by the various non-road mobile machinery sources or the rail sector, so total consumption of these fuels are reported under 1A3b road transport where the large majority of these fuels are believed to be used.

1.8.3. Other Notation Keys

"NA" (not applicable), and "NO" (not occurring) notation keys are used where appropriate.

2. Explanation of Key Trends

2.1. Introduction

This chapter discusses the latest emission estimates for selected pollutants and analyses the time series across the main source sectors. The pollutants considered are pollutants which under the NECR have Emission Reduction Commitments for the UK to achieve (SO_X, NO_X, NMVOCs, NH_3 and $PM_{2.5}$), the priority metals (Lead, Cadmium and Mercury), Dioxins and Furans (PCDD/PCDF) and Benzo[a]pyrene as an indicator for PAHs.

The geographical coverage of the emissions reported to the CLRTAP and NECR is the United Kingdom and Gibraltar, and this has been used for all data presented in this chapter.

The emission source categories considered are the following:

- **1A1 Energy Industries** – primarily emissions from combustion in power stations
- **1A2 Stationary Combustion in Manufacturing and Construction Industries**
- **1A2/4 Non-Road Mobile Machinery –** covers sectors 1A2gvii, 1A4aii, 1A4bii, 1A4cii, 1A4ciii
- **1A3a,c,d,e Non-Road Transport** - aviation, rail, national shipping, and non-road mobile machinery used in the aforemention sectors.
- **1A3b Road Transport**
- **1A4 Small Stationary Combustion** – stationary combustion in the public, commercial, residential and agriculture sectors
- **1A5 Other Mobile Combustion** - military aircraft and naval shipping
- **1B Fugitive Emissions** - for example sources associated with the extraction, refining and distribution of fossil fuels
- **2 Industrial Processes and Product Use**
- **3 Agriculture**
- **5 Waste**
- **6 Other** - other sources that are included within the national total.

Section 2.2 considers each of the pollutants in turn and explains the main features of the time series of emissions. The text highlights where there have been noteworthy changes in emissions between 1990 and 2022. A wide range of legislation and activities has affected emissions of these pollutants, and these are listed and discussed. The chapter starts with a general discussion of the trends in emissions of NECR pollutants, and then moves on to discuss the emissions and trends for each of the major source categories.

The percentage changes presented in this chapter are calculated from emission estimates held at full precision within a database and so they may differ slightly from percentages that could be calculated from the rounded figures presented in this report.

Further information and analysis on the emission trends of all pollutants reported under the CLRTAP and NECR are available on the NAEI website (http://naei.beis.gov.uk). The website also provides access to more detailed NAEI data, including emission factors and emission maps for key pollutants.

Section 2.3 considers some of the trends on a sector-by-sector basis. This sector breakdown used in Section 2.3 differs slightly to that used for the pollutant analysis. This is because the sector breakdown used in Section 2.2 has been selected to best present the main sources on a pollutant-by-pollutant basis. The sector breakdown used in Section 2.3 is more closely aligned to a simple aggregation of the NFR reporting structure.

Section 2.3 includes not only the main features of the time series on a sector by sector basis, but also includes some more detailed consideration of time series features which are not necessarily apparent from the figures included in Section 2.2.

2.2. UK Emission Trends for Key Pollutants

The following sections show trends in emissions for a geographical area covering the UK and Gibraltar.

2.2.1. Trends in Emissions of NO_X

Emissions of nitrogen oxides have declined substantially since 1990, Figure 2-1 shows the time series of UK emissions of NO_X.

Figure 2-1 Total UK emissions of NO_X for 1990-2022

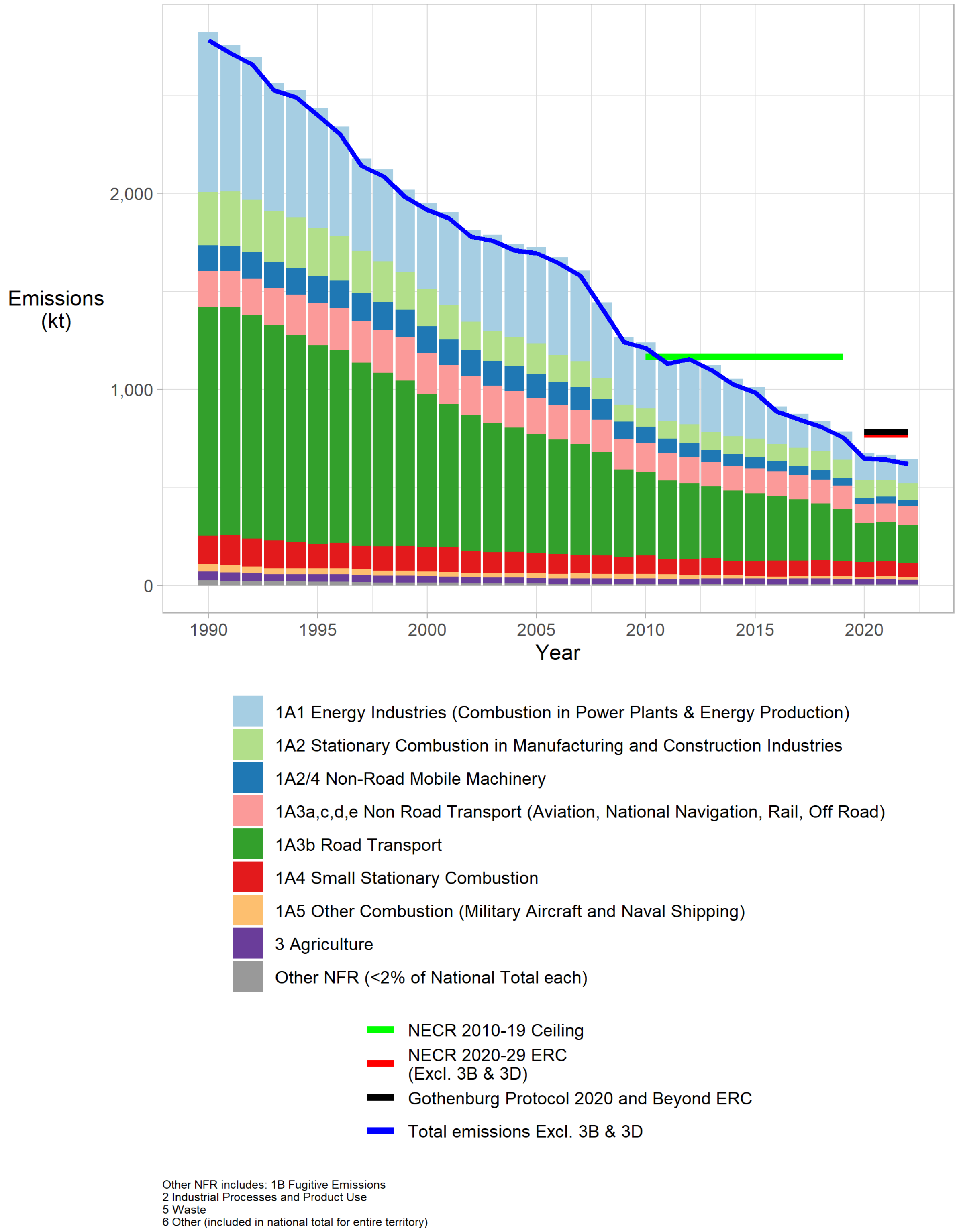


Table 2-1 shows the percentage changes in the emissions of NO_X since 1990 and summarises the key factors and legislation responsible for the reductions in emissions.

Table 2-1 Changes in emissions of NO_X since 1990

Key data relating to the emissions trend	
Total emission (1990): 2,825 kt Total emission (2022): 643 kt Emission reduction 1990-2022: 77%	Largest source category (1990): Road Transport (41%) Largest source category (2022): Road Transport (30%) Emissions reduction 1990-2022, Road Transport: (83%)
Key factors and legislation driving the decline in emissions	
• UK legislation has transposed Directive (EU) 2015/2193 on the limitation of emissions of certain pollutants into the air from medium combustion plant (Medium Combustion Plant (MCP) Directive) • National legislation has been introduced in England, Wales and Northern Ireland to control emissions from small power plant use for short periods (some of which would be captured by MCP Directive, but most fell below operating hours threshold for application of MCPD limits) • Ecodesign Directive which controls NO_X (and other pollutants) from small scale oil, gas and solid fuel boilers and room heaters; • Updates to BAT (Best Available Techniques) under national controls on sub-IED 'Part B' installations[30] • Directive on Industrial Emissions 2010/75/EU (IED) • UK Pollution Prevention and Control (PPC) regulations • New air quality directive (Directive 2008/50/EC) • Implementation of the large combustion plant directive (LCPD, 2001/80/EC) • Series of Euro standards to limit vehicle tailpipe emissions, e.g. Euro 5 standards in Regulation (EC) No 715/2007 and previous Directives • Implementation of various stages of the EU Non-Road Mobile Machinery Directives 97/68/EC and subsequent amendments • CLRTAP which arose from the 2012 amendment of the Gothenburg Protocol, includes measures to combat the effects of NO_X • Reductions in the quantities of solid and liquid fuels burnt • Improvements in combustion technology of solid, liquid and gaseous fuels leading to reductions in emissions, most notably trends in the power sector to fit low-NO_X burners, increase the use of nuclear and CCGT generation in the UK fuel mix, and retrofitting coal-fired power stations with Boosted Over-Fire Air systems to reduce NO_X formation.	

In the UK, the sectors which contribute most to the NO_X emissions total are the energy industries (primarily power stations) and road transport (see Figure 2-1). Road transport has accounted for over a quarter of UK NO_X emissions in recent years.

As well as being a pollutant regulated under the Gothenburg Protocol and the NECR, there is a great deal of legislation that is specific to key sources of NO_X emissions, such as electricity generation and other large-scale industrial combustion (e.g. the provisions of the EPR, which is primarily related to

[30] http://eippcb.jrc.ec.europa.eu/reference/

large combustion plant) and road transport (e.g. Euro Standards in vehicle regulation). Figure 2-1 shows how emissions from the transport sector (particularly from passenger cars), have decreased greatly since 1990. This is a result of vehicle emission regulations coming into force in the form of Euro Standards and important technological improvements, such as the three-way catalytic converter in petrol cars, and more recently, the uptake of electric vehicles.

Large decreases from the 1990s onwards have been due to factors such as the fitting of low NO_X burners and other NO_X reduction technology to power stations along with a phasing out of coal-fired power stations and a general decline in coal consumption in other sectors in favour of natural gas. Whilst these general trends are evident across the whole time series, there are occasions where coal consumption in power stations increases - for example, in 2012 coal consumption in power stations increased and rose above that of natural gas for the first time since 2007, contributing to an increase in emissions from the sector as a whole. However, since 2012, a return to the previous trend of decreasing coal consumption and reducing NO_X emissions is evident, although, this trend has slowed from 2020 onwards as fewer coal-fired power stations continue to operate.

2.2.2. Trends in Emissions of SO_X

Figure 2-2 shows the time series of UK emissions of SO_X. Emissions have declined substantially since 1990.

Figure 2-2 Total UK emissions of SO_X for 1990-2022

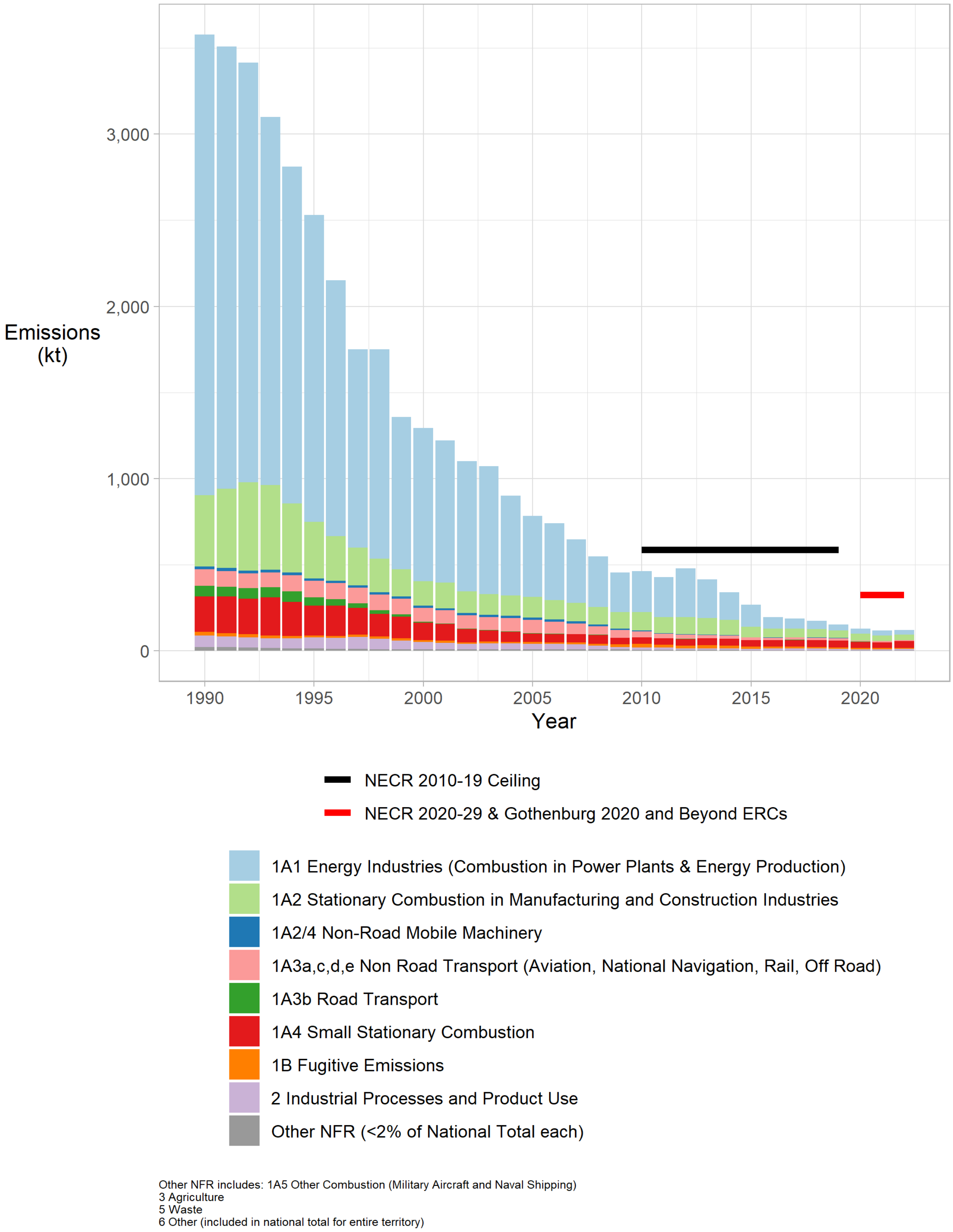


Table 2-2 shows the percentage changes in the emissions of SO_X since 1990 and summarises the key factors and legislation responsible for the reductions in emissions.

Table 2-2 Changes in emissions of SO_X since 1990

Key data relating to the emissions trend	
Total emission (1990): 3,578 kt Total emission (2022): 120 kt Emission reduction 1990-2022: 97%	Largest source category (1990): Energy Industries (75%) Largest source category (2022): Other Combustion (e.g. residential) (33%) Emissions reduction 1990-2022, Other Combustion: (82%)
Key factors and legislation driving the decline in emissions	
• UK legislation has transposed Directive (EU) 2015/2193 on the limitation of emissions of certain pollutants into the air from medium combustion plant (Medium Combustion Plant (MCP) Directive) • Updates to BAT (Best Available Techniques) under national controls on sub-IED 'Part B' installations[31] • Directive on Integrated Pollution Prevention and Control (IPPC) (Directive 2008/1/EC) • Directive on Industrial Emissions 2010/75/EU (IED) • UK Pollution Prevention and Control (PPC) regulations • Large combustion plant directive (LCPD, 2001/80/EC) • Limiting sulphur emissions from the combustion of certain liquid fuels by controlling their sulphur content (Directive 1999/32/EC) • CLRTAP which arose from the 2012 amendment of the Gothenburg Protocol, includes measures to combat the effects of SO_2 • Reductions in the quantities of coal burnt • Introduction of CCGT power stations • Implementation of flue gas desulphurisation at some power stations • Annex VI of the MARPOL agreement for ship emissions, augmented by the Sulphur Content of Marine Fuels Directive 2005/33/EC and the introduction of Sulphur Emission Control Areas	

In the UK, 'Other Combustion' sources (NFR 1A4) contribute most to the SO_X emissions total this year, with Residential Combustion (NFR 1A4bi) being the dominant source within this (approximately a third of UK emissions). A large proportion of the SO_X emissions also come from combustion in petroleum refineries (NFR 1A1b) and in manufacturing industries and construction (NFR 1A2).

Of all the air quality pollutants controlled under the NECR and Gothenburg Protocol, SO_X emissions show the most marked decrease over time: since 1990, emissions have declined by 97%. This is directly linked to an economy-wide shift away from sulphur-containing fuels, as natural gas has largely replaced coal as the main fuel for electricity producers, industry and for residential heating. Over 100 Mt of coal were used in the UK in 1990, falling to less than 10 Mt in recent years. Where coal use is still prevalent, such as in electricity generation, the introduction of emissions abatement (such as flue gas desulphurisation) has reduced emissions further. Use of heavy fuel oil, another fuel which can contain

[31] http://eippcb.jrc.ec.europa.eu/reference/

high levels of sulphur, has also fallen - from approximately 20 Mt in 1990 to less than 5 Mt in recent years. The sulphur content of liquid fuels has also been greatly reduced, although the impact of this is fairly small compared with the changes related to coal use.

Legislation such as the Environmental Protection Act (1990), the Large Combustion Plant Directive (2001) and the Industrial Emissions Directive (2010) have all contributed to the regulation and mitigation of SO_X emissions across energy and industrial sources since 1990, for example resulting in the fitting of flue-gas desulphurisation to eight power stations between 1997 and 2009. In addition, several high-emitting industry sectors (such as steel-making, non-ferrous metal production, oil refining) have been in decline in the UK as production has increasingly moved overseas during the 1990s and 2000s. The increase in emissions from energy industries from 2011 to 2012 was due to increased coal consumption. However, the downwards trend returns in subsequent years, resulting in decreasing emissions.

Emissions from transport and non-road mobile machinery have declined due to the lowering of the sulphur contents of liquid fuels. In addition, legislation has been introduced that impacts some specific sources, such as the Sulphur Content of Marine Fuels Directive 2005/33/EC and the introduction of Sulphur Emission Control Areas.

2.2.3. Trends in Emissions of NMVOCs

Figure 2-3 shows the time series of UK emissions of NMVOCs. Emissions have declined substantially since 1990 but since 2013 have remained at a more constant level. In the graph below, the Gothenburg Protocol ERC relates to the commitment when taking into account all UK emissions, as displayed by the bars. The NECR ERC however, corresponds to total emissions, excluding sectors 3D and 3B (i.e. agricultural soils and manure management), and this is represented by the blue line.

Figure 2-3 Total UK emissions of NMVOCs for 1990-2022

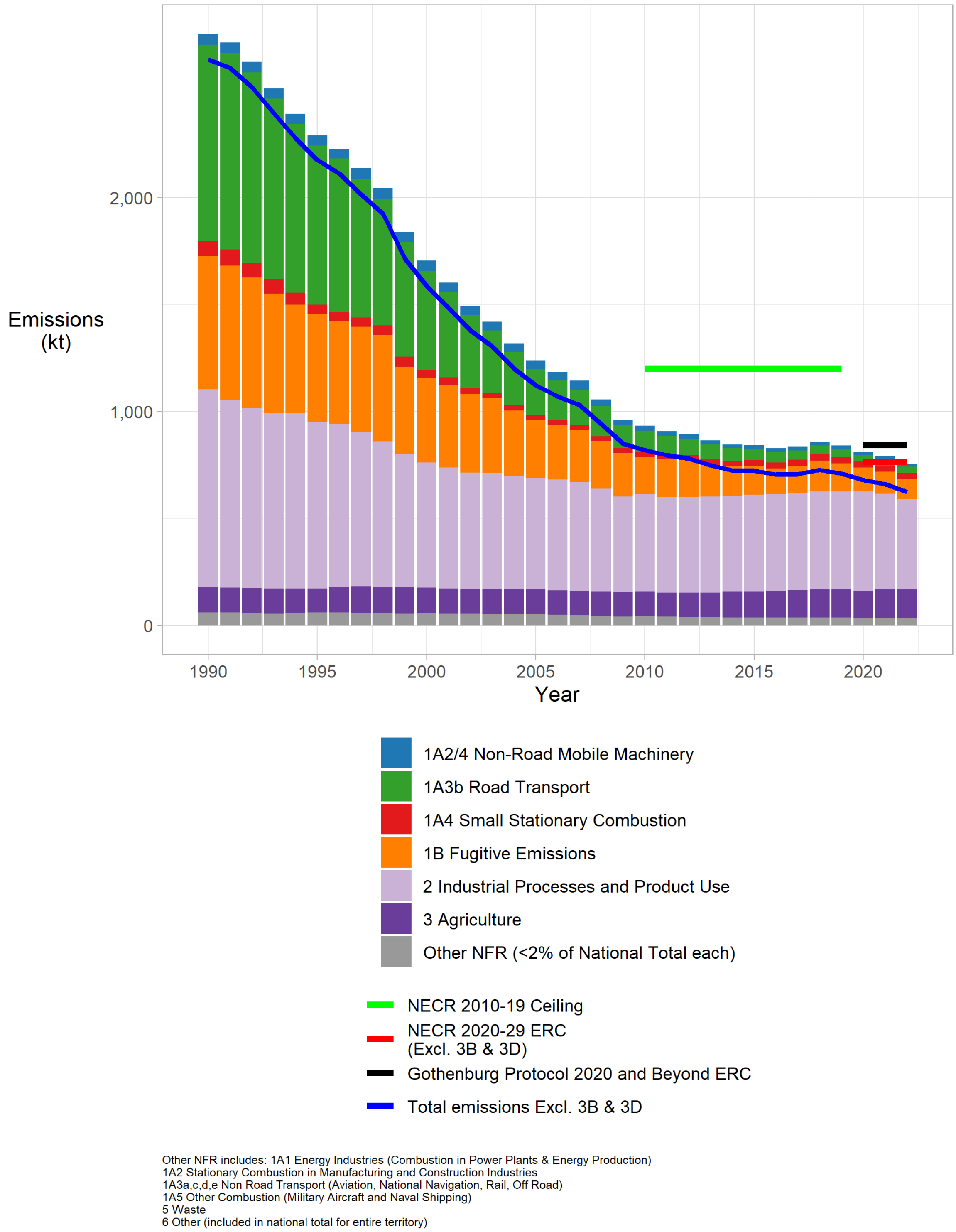


Table 2-3 shows the percentage changes in the emissions of NMVOCs since 1990 and summarises the key factors and legislation responsible for the reductions in emissions.

Table 2-3 Changes in emissions of NMVOCs since 1990

Key data relating to the emissions trend	
Total emission (1990): 2,764 kt Total emission (2022): 756 kt Emission reduction 1990-2022: 73%	Largest source category (1990): Industrial Processes (33%) Largest source category (2022): Industrial Processes (56%) Emissions reduction 1990-2022, Industrial Processes: (54%)
Key factors and legislation driving the decline in emissions	
• 1991 Protocol concerning the Control of Emissions of Volatile Organic Compounds and their Transboundary Fluxes (*Geneva Protocol* under the CLRTAP), which committed the UK to a 30% reduction in emissions of NMVOCs by 1999 from a 1988 base year. That was achieved through UK legislation such as the Environmental Protection Act 1990, and through implementation of EU directives, such as on road vehicle emissions. • Updates to BAT (Best Available Techniques) under national controls on sub-IED ‘Part B’ installations[32] • UK Pollution Prevention and Control (PPC) regulations • Directive on Integrated Pollution Prevention and Control (IPPC) (Directive 2008/1/EC) • Directive on Industrial Emissions 2010/75/EU (IED) • Solvents Directive (99/13/EC) • New air quality directive (Directive 2008/50/EC) • Series of Euro standards to limit vehicle tailpipe and evaporative emissions, e.g. Euro 5 standards in Regulation (EC) No 715/2007 and previous Directives • EU Fuel Quality Directive 98/70/EC limiting vapour pressure of petrol to reduce evaporative emissions • Implementation of various stages of the EU Non-Road Mobile Machinery Directives 97/68/EC and subsequent amendments • Reductions in the quantity of petrol consumed • Declining production of crude oil after reaching a peak in 1999 • Ecodesign Directive which controls NO_X (and other pollutants) from small scale oil, gas and solid fuel boilers and room heaters.	

In 1990, the largest contributions to the total emissions were from industrial processes and product use, road transport and fugitive emissions from fuels. Since 1990, emissions from all major sources have decreased, which is generally attributed to the introduction of wide-ranging legislative controls, and changes in industrial activity in the UK.

[32] http://eippcb.jrc.ec.europa.eu/reference/

Emissions from road transport have seen a dramatic decrease since 1990 due to the introduction of three-way catalytic converters and controls on evaporative emissions from vehicles, and, to a lesser degree, a switch away from petrol to diesel cars, and improved fuel economy.

The Industrial Processes and Product Use category, shown in Figure 2-3, is the largest source sector. However, it is a very diverse category, and includes emissions from the use of domestic products that contain solvents, the use of solvents by industry, for example in industrial coating and printing processes, and industrial processes such as the manufacture of chemicals, timber products, metal products, food, alcoholic drinks and hand sanitisers. Reductions in emissions have been driven by legislation that has, for example, reduced the solvent content of paints and other products and also required industries using solvents to implement better control or recovery of solvent releases, thus substantially reducing the NMVOC emissions. However, emissions from some sources have increased. For example, it is assumed that the consumption of some domestic products that contain solvents have increased in-line with UK population and the production of alcoholic drinks such as whisky has increased, so emissions from both sources are estimated to have increased.

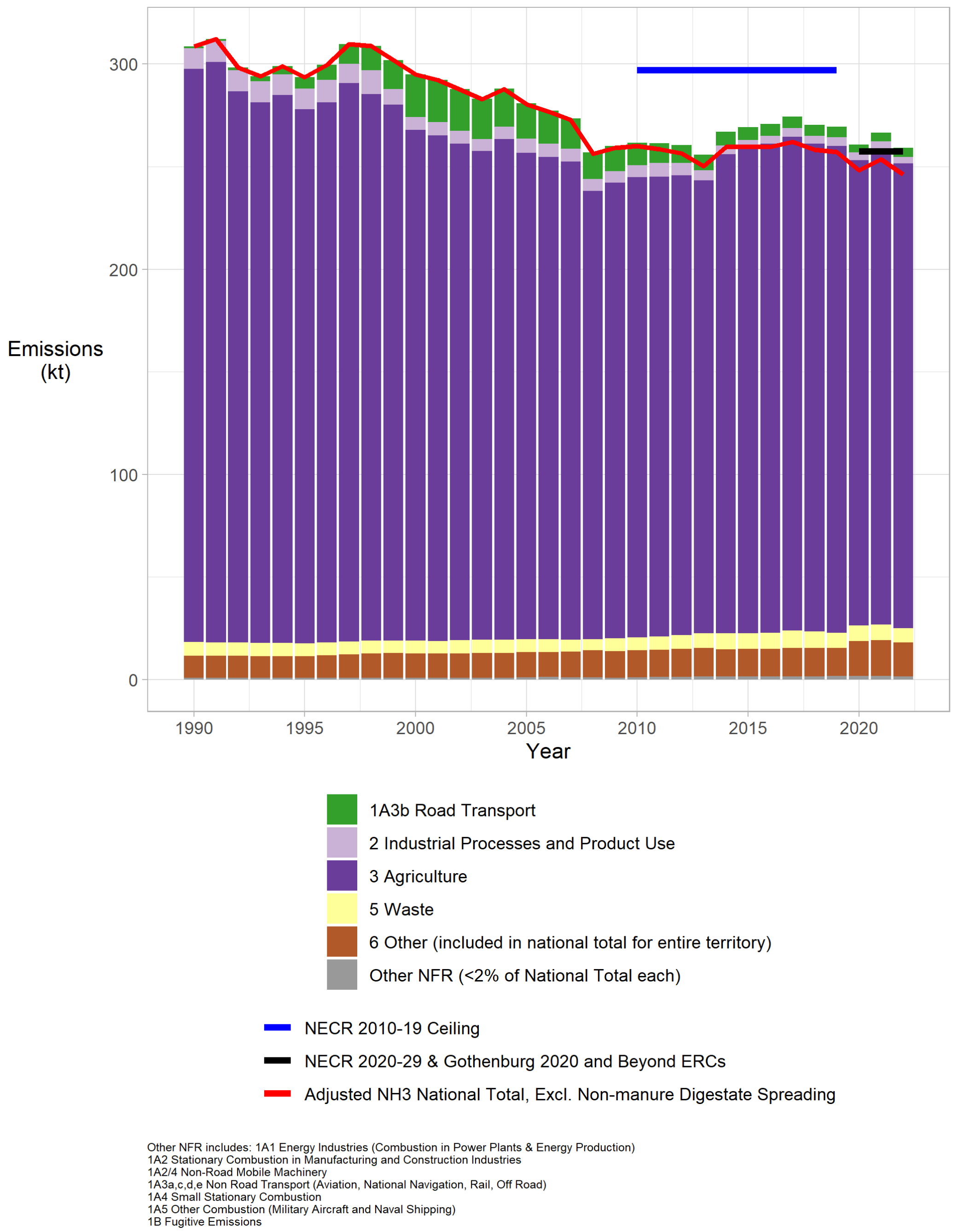
The Fugitive Emissions source category includes emission sources associated with the extraction, refining and distribution of fossil fuels. More stringent controls on emissions from extraction and refining operations, programmes to replace older gas main pipes, and improved emission controls at petrol stations have all contributed to the reduction in emissions from this source sector across the time series. Coal mining (1B1a) was an important source in 1990, but emissions have decreased almost to zero since then, as the deep mining of coal has practically ceased in the UK.

Emissions remained relatively consistent between 2014 and 2018, before reducing in the following years as a result of reduced venting in the upstream oil and gas sector, followed by reductions in activity in many sectors, which coincided with the COVID-19 pandemic. 2021 and 2022 saw further reductions, predominantly due to reduced usage of hand sanitiser when compared to the peak in 2020.

2.2.4. Trends in Emissions of NH_3

Overall ammonia emissions have been in decline since 1990. The majority of the decline has occurred between 1990 and 2008, following which emissions have remained relatively stable. Annual emissions achieved their lowest level in 2013, and following this emissions have been higher, but remained below the levels seen prior to the mid - 2000s. Figure 2-4 shows the time series of UK emissions of NH_3. The recent peak seen in 2021 is as a result of poor weather in Autumn 2019, meaning that winter wheat could not be planted, hence fertiliser was not used on this crop in 2020. 2022 emissions are reduced from 2021 due to a reduction in nitrogen fertiliser use.

Figure 2-4 Total UK emissions of NH_3 for 1990-2022[33]



[33] The UK has an approved adjustment NH_3 emissions from NFR 3Da2c, as a result, the UK is in compliance with NH_3 NECR and Gothenburg ERC ceilings for 2020-2022. Please see chapter 10 for more information

Table 2-4 shows the percentage changes in the emissions of NH_3 since 1990 and summarises the key factors and legislation responsible for the reductions in emissions.

Table 2-4 Changes in emissions of NH_3 since 1990

Key data relating to the emissions trend	
Total emission (1990): 309 kt Total emission (2022): 259 kt Emission reduction 1990-2022: 16%	Largest source category (1990): Agriculture (91%) Largest source category (2022): Agriculture (87%) Emissions reduction 1990-2022, Agriculture: (19%)
Key factors and legislation driving the decline in emissions	
• Changes in agricultural practices and reductions in numbers of some types of agricultural animals • UK Pollution Prevention and Control (PPC) regulations • Directive on Integrated Pollution Prevention and Control (IPPC) (Directive 2008/1/EC) • Directive on Industrial Emissions 2010/75/EU (IED) • Water pollution by discharges of certain dangerous substances (Directive 76/464/EEC) • Revised Gothenburg UN/ECE Protocol to abate acidification, eutrophication and ground level ozone (ECE/EB.AIR/122/Add.1, decisions 2013/3 and 2013/4) • CLRTAP which arose from the 2012 amendment of the Gothenburg Protocol, includes measures to combat the effects of NH_3	

NH_3 emissions are difficult to measure and estimate because they are dominated by “diffuse” sources (i.e. wide geographical spread and large variety of emission sources, ranging from livestock and domestic pets to composting), rather than point sources (e.g. power stations and industrial installations). As a result, uncertainty in the UK inventory estimates are greater for NH_3 than for many other air quality pollutants (see Section 1.7).

Figure 2-4 shows that emissions from agriculture dominate the total NH_3 emissions. The largest source within agriculture is associated with livestock, specifically the decomposition of urea in animal wastes (and uric acid in poultry wastes). Of the livestock classes, cattle are the largest emitters of NH_3, accounting for approximately two thirds of all emissions from livestock. Emissions from soils are also an important source, caused by the application of manure, digestates from anaerobic digestion (AnD), and inorganic (manufactured) fertiliser, especially urea-based fertilisers. Emissions of ammonia dropped in the agriculture sector from 2019-2020 as poor weather in autumn meant that winter wheat could not be planted, due to this fertiliser was not used on this crop so the emissions are lower for this year.

Compared with other air quality pollutants, there has been relatively little reduction in total emissions over the time series (Figure 2-4). The reduction of NH_3 emissions over the time series is largely due to a decrease in numbers of some types of livestock such as beef cattle, pigs, and turkeys, leading to lower emissions from the wastes (excreta) of these types of animals. The implementation of regulations such as the Nitrate Sensitive Areas Order (1990), and subsequent designation of Nitrate Vulnerable Zones where the use of manufactured nitrogen fertilisers and organic manures is controlled, led to a reduction in fertiliser use and resultant NH_3 emissions from the late 1990s onwards. Overall, the combined effect of changes in animal numbers and the reductions in use of chemical fertilisers resulted in a gradual reduction in NH_3 emissions throughout the period from 1990 to 2008. However, since then, emissions have fluctuated slightly each year, due to slight changes in numbers of dairy cattle, but also due to increased use of urea-based fertilisers. The price of fertilisers varies and thus there is annual variation in the quantities applied and the balance between types of fertiliser.

A relatively recent development has been the use of digestates from AnD of non-agricultural wastes on agricultural land (3Da2c). This emission source was small before the mid-2000s but contributed 6% of emissions in 2022. The application of sewage sludge to agricultural land has also grown, particularly in the early 2000s, but this is a relatively small source.

NH_3 emissions from road transport increased in the 1990's as early generation catalyst systems were introduced to the vehicle fleet. However, from 2000, emissions fall as improved catalyst systems, which result in much lower emissions, become more prevalent in the fleet.

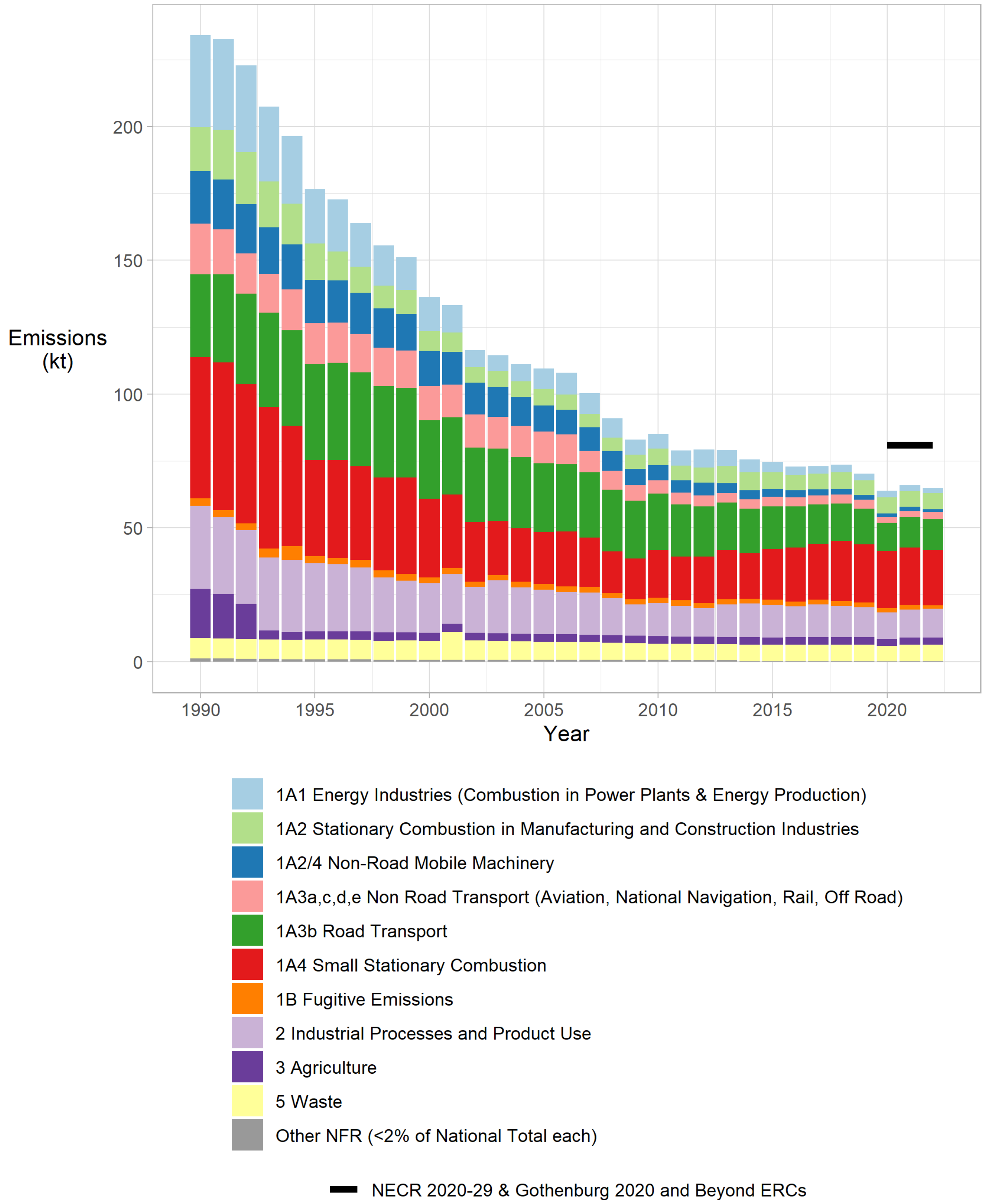
Since 2008, a rise in the use of AnD and composting for organic waste treatment has led to small increases of NH_3 emissions from the waste sector.

NH_3 emissions from NFR 6 covers miscellaneous sources such as domestic pets, professional and privately-owned horses, infant emissions from nappies, fertiliser use on parks, gardens and golf courses. These sources contribute to between 5 and 10% of total NH_3 emissions across the time series.

2.2.5. Trends in Emissions of $PM_{2.5}$

Figure 2-5 shows the time series of UK emissions of $PM_{2.5}$. Emissions have decreased by approximately two thirds since 1990. There was a slight increase in emissions from 2020 to 2021 but they have decreased again in 2022.

Figure 2-5 Total UK emissions of $PM_{2.5}$ for 1990-2022



Other NFR includes: 1A5 Other Combustion (Military Aircraft and Naval Shipping)
6 Other (included in national total for entire territory)

Table 2-5 shows the percentage changes in the emissions of $PM_{2.5}$ since 1990 and summarises the key factors and legislation responsible for the reductions in emissions.

Table 2-5 Changes in emissions of $PM_{2.5}$ **since 1990**

Key data relating to the emissions trend	
Total emission (1990): 234 kt Total emission (2022): 65 kt Emission reduction 1990-2022: 72%	Largest source category (1990): Other combustion (which includes residential combustion) (1A4) (27%) Largest source category (2022): Other combustion (1A4) (33%) Emissions reduction 1990-2022, Other combustion (1A4): (72%)
Key factors and legislation driving the decline in emissions	
• Directive on Industrial Emissions 2010/75/EU (IED) • UK Pollution Prevention and Control (PPC) regulations • Large Combustion Plant Directive (LCPD, 2001/80/EC) • CLRTAP which arose from the 2012 amendment of the Gothenburg Protocol, includes measures to combat the emissions of $PM_{2.5}$ • Reductions in the quantities of coal burnt • Series of Euro standards to limit vehicle tailpipe emissions, e.g. Euro 5 standards in Regulation (EC) No 715/2007 and previous Directives • Implementation of various stages of the EU Non-Road Mobile Machinery Directives 97/68/EC and subsequent amendments • Improvements in combustion technology and more extensive use of improved abatement equipment (such as electrostatic precipitators).	

The time series (Figure 2-5) shows steady reductions in total $PM_{2.5}$ emissions since 1990. However, despite continued decreases in emissions across transport sectors, the overall downward trend has slowed since 2002. This is because large decreases in emissions from important sources, such as coal use, have been partly offset in recent years by emissions from residential wood combustion.

Small Stationary Combustion (1A4ai, 1A4bi and 1A4ci) represents the largest emission source, representing fuel combustion in the residential, commercial and public sectors as well as in agriculture. Throughout the 1990s, emissions from this sector reduced, mostly due to the declining use of solid fuel (particularly coal) in favour of natural gas. However, since the mid-2000s, there has been an increase in emissions caused by the increased burning of wood in domestic appliances. Small stationary combustion was responsible for 32% of UK $PM_{2.5}$ emissions in 2022. The burning of wood accounts for the vast majority of this. $PM_{2.5}$ emissions increased in 2021 compared to 2020 due to a combination of increased activity following the relaxation of COVID-19 related restrictions, and an upward trend in biomass burning in both domestic and industrial settings. However, in 2022 emissions are lower than in 2021 due to reductions in emissions from power stations (NFR 1A1) and reduced coal and wood use in the residential sector (NFR 1A4bi), based on the modelling approach used.

The emissions trend for the Road Transport sector is influenced by a variety of factors. Regulation of vehicle emissions, such as through the introduction of Euro Standards on diesel vehicles has contributed to emissions reductions. However, the benefits have been countered by the growth in diesel vehicles, which despite contributing to fewer emissions for other pollutants (e.g. CO_2), contribute more PM emissions per vehicle kilometre than petrol vehicles. More stringent emissions legislation now means that the latest Euro standard diesel vehicles are fitted with diesel particulate filters which result in emissions of PM that are broadly comparable to petrol engines. However, further reductions in road transport emissions are now being restricted by increases in non-exhaust sources of PM from vehicles, through tyre and brake wear and road abrasion. Emissions from these sources are not currently regulated and emissions have grown with increases in traffic to the point where, overall, these now exceed PM emissions from vehicle exhausts.

The trend for Energy Industries dominates the total trend in the 1990s. Emissions from power stations follow a similar trend to that observed for SO_X, where reduced coal use has been a major factor in reducing PM emissions, as well as the impacts of more stringent emissions legislation and the resulting use of more sophisticated abatement equipment.

Decreases in coal consumption also impacts the emissions trend for the ‘Combustion in Manufacturing Industries and Construction’ source category. In recent years, the main sources of $PM_{2.5}$ in 1A2 is from the industrial combustion of biomass based-fuels. This relates to the combustion of biomass based-fuels to generate energy for industrial use, for example to drive mobile machinery or to create heat or electricity for industrial processes. We presume that most of these fuels will be burnt in boilers, furnaces, kilns etc to provide heat for industrial processes or other uses. Biomass based-fuels here covers solid biomass fuels such as wood, liquid biofuels such as biodiesel, and gaseous biofuels, and will include the use of those fuels in the various branches of manufacturing industry – such as the food and drink, paper, metal and chemical sectors.

2.2.6. Trends in Emissions of Lead, Cadmium, and Mercury

Lead

Figure 2-6 below shows the time series of UK emissions of Lead. Emissions of lead have declined dramatically since 1990 but have been largely consistent 2009, with a slight increase from 2020-2022.

Figure 2-6 Total UK emissions of Lead for 1990-2022

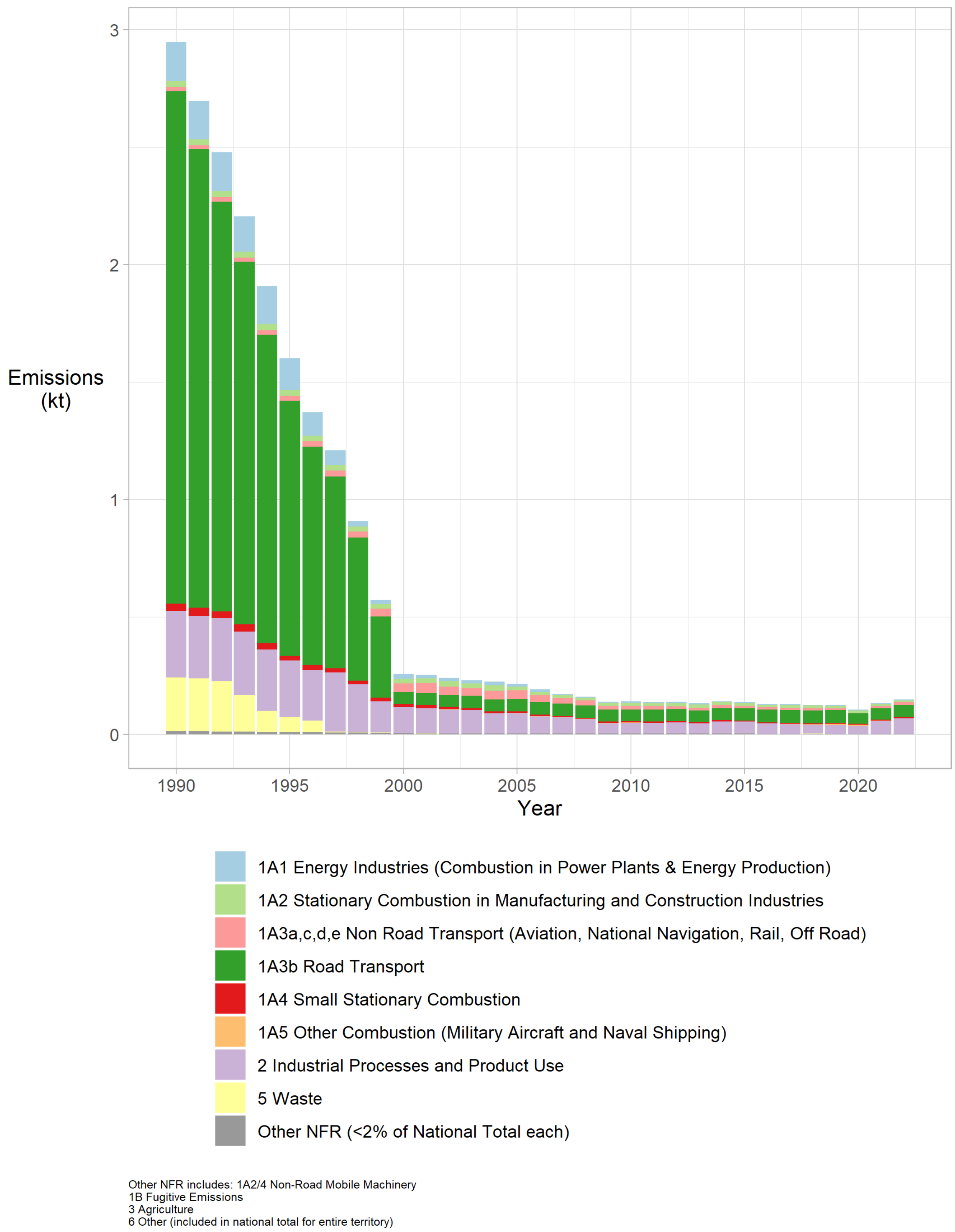


Table 2-6 shows the percentage changes in the emissions of Pb since 1990.

Table 2-6 Changes in emissions of Lead since 1990

Key data relating to the emissions trend	
Total emission (1990) : 2,948 tonnes Total emission (2022) : 147 tonnes Emission reduction 1990-2022: 95%	Largest source category (1990): Road Transport (74%) Largest source category (2022): Industrial Processes (44%) Emissions reduction 1990-2022, Industrial Processes: (77%)

Road Transport was the largest source sector of lead emissions until 1999 as lead was used as an anti-knocking additive in petrol. From 1990, the sales of unleaded petrol increased, particularly as a result of the increased use of cars fitted with three-way catalysts. Leaded petrol was then phased out from general sale at the end of 1999, giving rise to the large emissions reduction observable in Figure 2-6.

Industrial processes and Product Use (NFR 2) now represent the largest source sector. More specifically, emissions of lead arise from processes in metal production. There has been some reduction in emissions from iron and steel production processes across the timeseries due to the closure of some sites.

Emissions from Energy Industries (power stations) declined in the late 1990s. This was caused by the decline in the use of coal at power stations and the introduction of tighter emissions controls, and in particular substantial reductions in lead emissions from burning municipal solid waste in waste-to-energy plants. With many of the historically larger sources of lead emissions experiencing sharp declines across the time series, this increases the importance of smaller sources, for example, the use of leaded fuel in small aeroplanes. The increase in Lead emissions seen from 2021 to 2022 is due to increases in emissions from steel production and firework use. The transportation sector has also seen increases in emissions in 2022 due to domestic aviation and higher non-exhaust emissions from road transport (e.g. from brake wear).

Cadmium

Figure 2-7 shows the time series of UK emissions of Cadmium. Emissions of Cadmium have declined substantially since 1990 but since 2007 remained relatively constant. .

Figure 2-7 Total UK emissions of Cadmium for 1990-2022

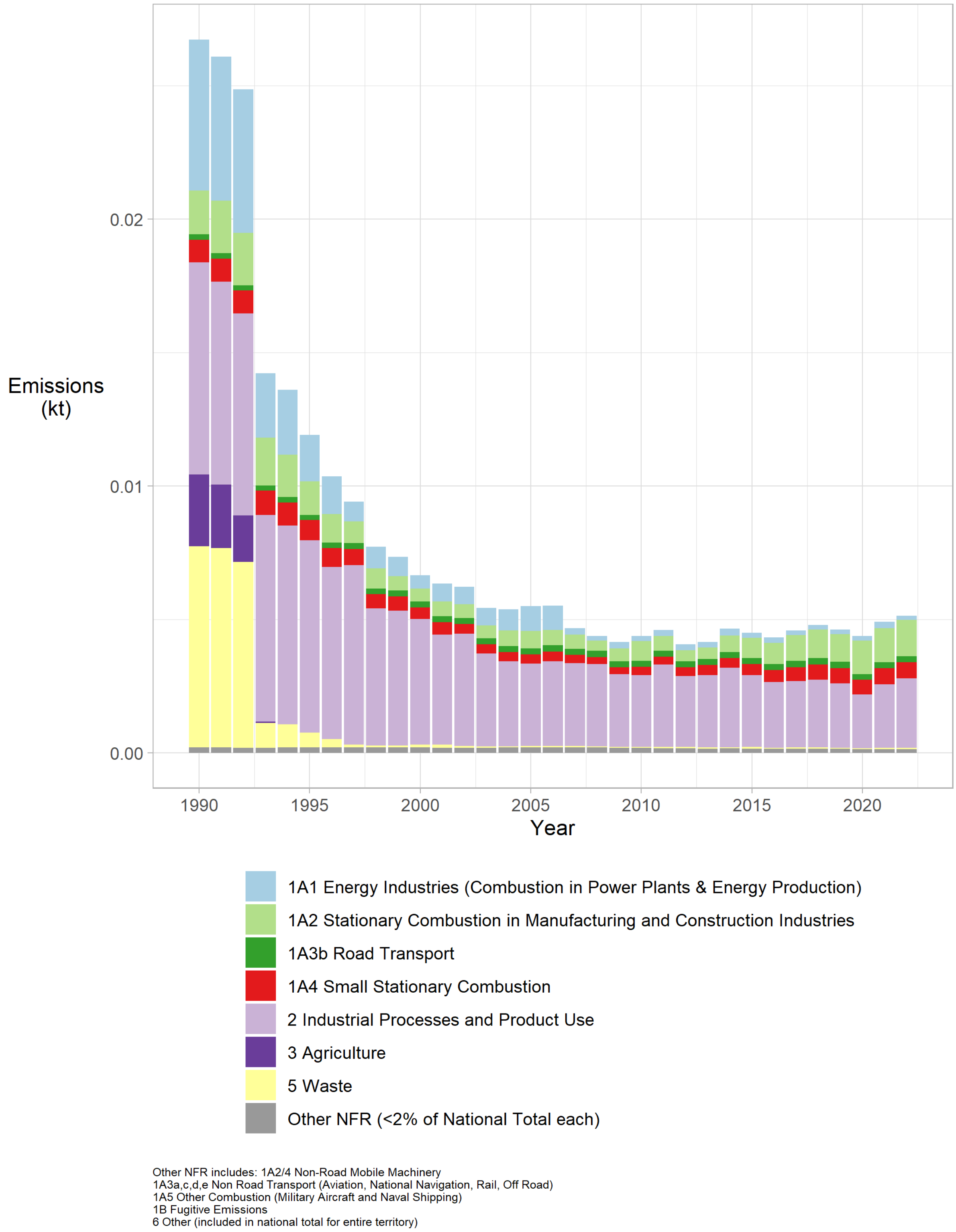


Table 2-7 shows the percentage changes in emissions of cadmium since 1990.

Table 2-7 Changes in emissions of Cadmium since 1990

Key data relating to the emissions trend	
Total emission (1990): 27 tonnes Total emission (2022): 5 tonnes Emission reduction 1990-2022: 81%	Largest source category (1990): Industrial Processes (30%) Largest source category (2022): Industrial Processes (51%) Emissions reduction 1990-2022, Industrial Processes: (67%)

In the early part of the time series, there are three source categories comprising the majority of emissions.

- Emissions from the Energy Industries sector are primarily from power stations.
- Emissions from Industrial Processes and Product use include those from non-ferrous metal production and iron and steel manufacture.
- Emissions within the Waste sector are from waste incinerators.

The large reduction in Waste sector emissions in the early-mid 1990's is due to improved controls on municipal solid waste (MSW) incinerators from 1993 onwards. In addition to tighter emissions controls being introduced, these plants also had energy and/or heat recovery installed, converting them to waste to energy plants. As a result, these installations were reassigned to the Energy Industries source sector. However, there is no increase to emissions from the Energy Industries sector observable in Figure 2-7, because emissions from these waste-from-energy plants were low, and also because emissions from other sources within the category (such as coal-fired power stations) were falling at this time. This was due to the decline in coal use for electricity generation and improved emissions control at the sites that remained in operation. Use of fuel oil for power generation also fell at this time. The notable reduction in emissions in the Energy Industries sector from 2006 to 2007 is due to reduced emissions from coal combustion.

Emissions from industrial processes have generally decreased with time. This is due to the decline in the levels of non-ferrous metal production and iron and steel manufacture across the time series. However, since 2020 process emissions from industrial sites have increased, due to greater emissions from iron and steel production.

Mercury

Mercury Emissions have declined dramatically since 1990, as shown in Figure 2-8, and continue to decline gradually overall in recent years.

Figure 2-8 Total UK emissions of Mercury for 1990-2022

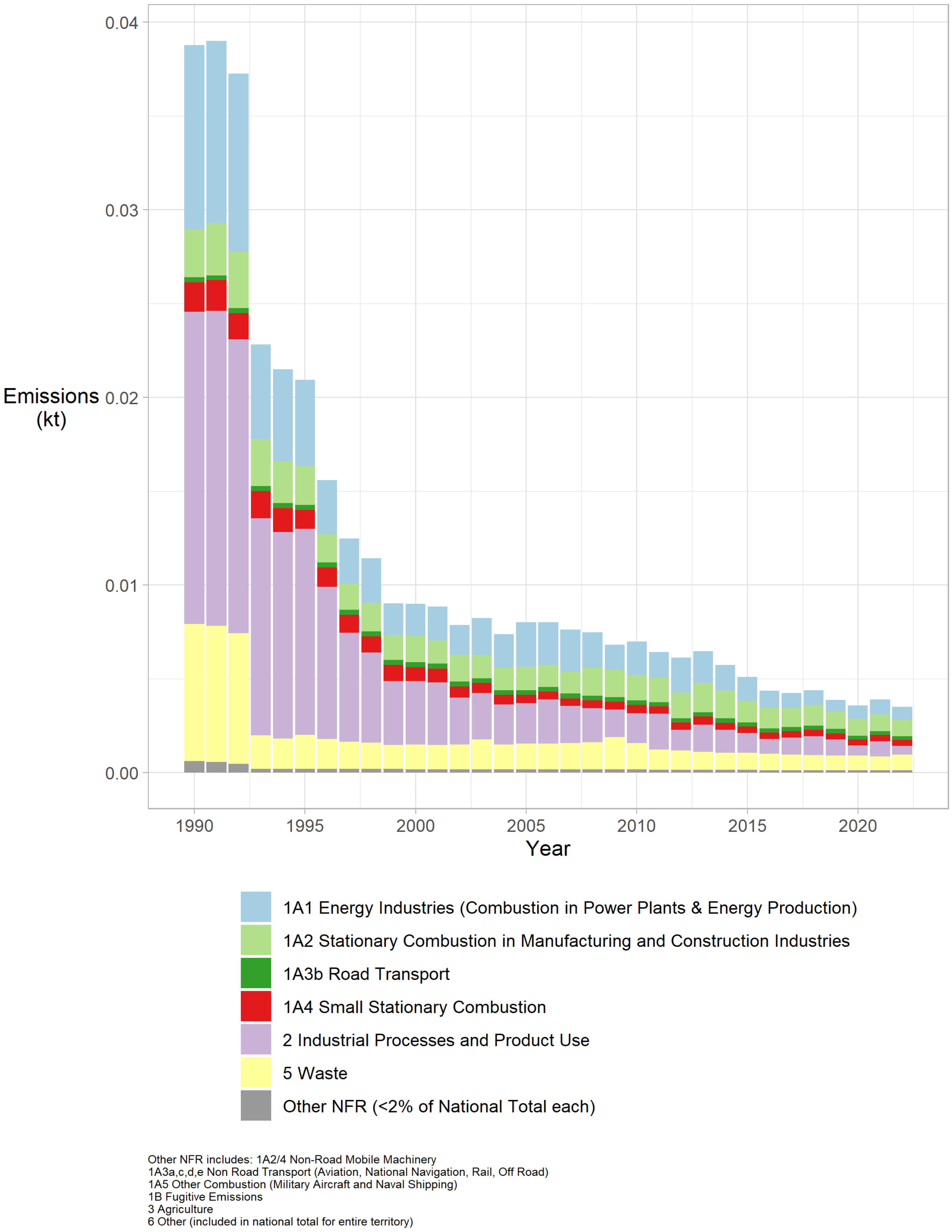


Table 2-8 shows the percentage changes in emissions of mercury since 1990.

Table 2-8 Changes in emissions of Mercury since 1990

Key data relating to the emissions trend	
Total emission (1990): 39 tonnes Total emission (2022): 3 tonnes Emission reduction 1990-2022: 91%	Largest source category (1990): Industrial Processes (43%) Largest source category (2022): Stationary Combustion in Manufacturing and Construction (25%) Emissions reduction 1990-2022, Stationary Combustion in Manufacturing and Construction: (66%)

The time series trend for mercury is very similar to that observed for cadmium. This is because the factors affecting mercury emissions are similar to those for cadmium - improved controls introduced for the incineration of waste, a general decline in ferrous and non-ferrous metal production, the decreasing use of coal as a fuel across all sectors. This explains the large reductions in emissions observed across the 1990's, and the continued general trend of decreasing emissions from 2000 onwards.

Emissions from the waste sector have decreased across the time series. This is due to improved recycling, and lower mercury content of products such as batteries. As a result, less mercury goes to landfill, and hence emissions reduce with time.

One source that is specific to mercury is the manufacture of chlorine in mercury cells. This is included within Industrial Processes and Product Use. Emissions have declined from the mid 2000's onwards as a result of improved controls on mercury cells and their replacement by diaphragm or membrane cells.

Although emissions increased slightly from 2020 to 2021, in 2022 there was a reduction in emissions driven by decreases in the Industrial Processes and Product Use sector (NFR 2) and from Combustion in Power Generation (NFR 1A1) and the Manufacturing Industries and Construction sector (1A2).

2.2.7. Trends in Emissions of Dioxins and Furans, Benzo[a]pyrene

Dioxins and Furans

Emissions of Dioxins and Furans have declined substantially since 1990 and then continue to generally gradually decrease from 2011 onwards. Figure 2-9 shows the time series of their emissions.

Figure 2-9 Total UK emissions of Dioxins and Furans for 1990-2022

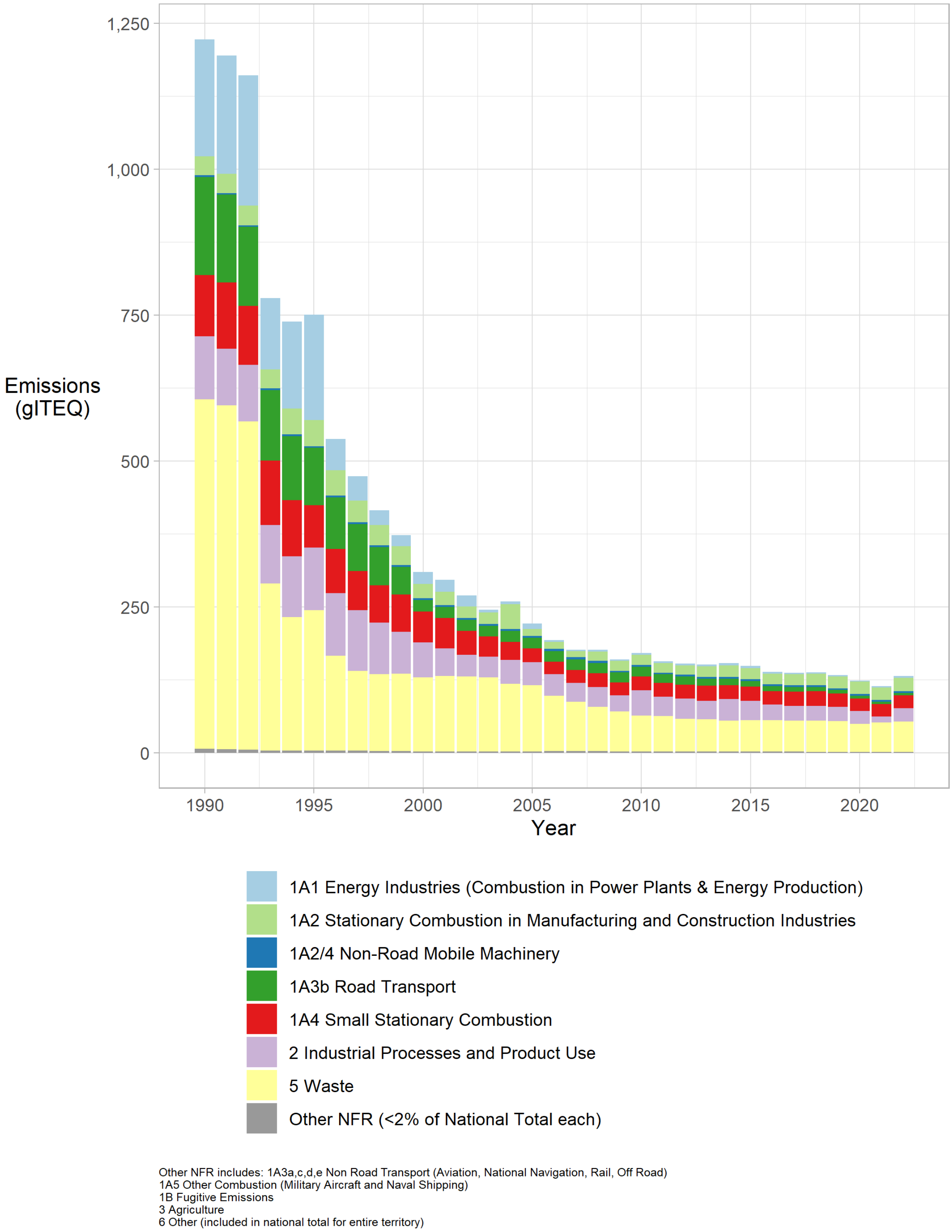


Table 2-9 shows the changes in dioxins and furans since 1990.

Table 2-9 Changes in emissions of Dioxins and Furans since 1990

Key data relating to the emissions trend	
Total emission (1990): 1,223 g- ITEQ Total emission (2022): 131 g-ITEQ Emission reduction 1990-2022: 89%	Largest source category (1990): Waste (49%) Largest source category (2022): Waste (39%) Emissions reduction 1990-2022, Waste: (91%)

Emissions from the Waste source sector have substantially reduced across the time series. This has been driven by the introduction of control measures. Municipal Solid Waste (MSW) incinerators not meeting the new standards closed in the period leading up to December 1996, and improved combustion and flue gas controls, and developments in abatement technology in modern MSW incinerator design, has resulted in greatly lowered levels of PCDD/F emissions in the later part of the time series. The relatively low emissions from chemical incinerators reflects the much lower quantities of waste burnt, and the use of different technologies and/or the use of more advanced abatement equipment. However, clinical waste incineration remains a large source. There is a long-term decrease in the burning of household waste on domestic open fires (because of the long-term decline in use of these open fires), also resulting in decreased emissions across the time series from the Waste source sector.

Emissions from Energy Industries have decreased with time. This is due to a general decrease in coal consumption across the time series, and also the substantial tightening of emissions control in the earlier part of the time series.

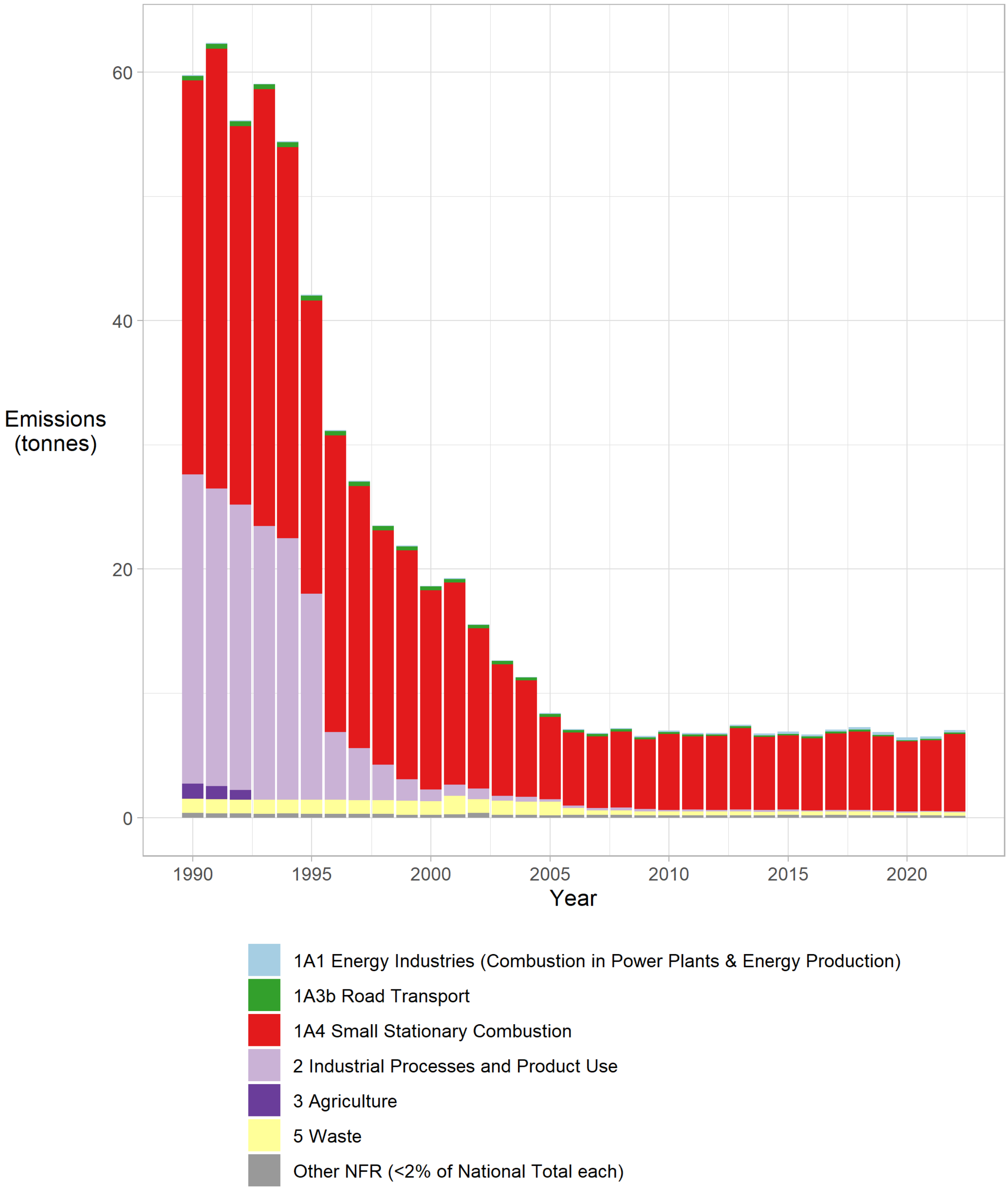
Emissions from the 'Other Combustion' sector are dominated by residential burning of coal and wood - the former generally decreasing with time, and the latter increasing substantially across the time series.

Emissions from road transport are associated with compounds previously added to leaded petrol. Consequently, the emissions of PCDD/F decrease in line with lead emissions from the Road Transport sector. Emissions in 2022 increase slightly from 2021 as a result of increased emissions from sinter production in the iron and steel sector.

Benzo[a]pyrene

Figure 2-10 shows the time series of UK emissions of B[a]P. Emissions of Benzo[a]pyrene (B[a]P) have declined substantially since 1990 and have remained consistent since 2006.

Figure 2-10 Total UK emissions of Benzo[a]pyrene for 1990-2022



Other NFR includes: 1A2 Stationary Combustion in Manufacturing and Construction Industries
1A2/4 Non-Road Mobile Machinery
1A3a,c,d,e Non Road Transport (Aviation, National Navigation, Rail, Off Road)
1A5 Other Combustion (Military Aircraft and Naval Shipping)
1B Fugitive Emissions
6 Other (included in national total for entire territory)

Table 2-10 shows the changes in benzo[a]pyrene since 1990.

Table 2-10 Changes in emissions of Benzo[a]pyrene since 1990

Key data relating to the emissions trend	
Total emission (1990): 60 tonnes Total emission (2022): 7 tonnes Emission reduction 1990-2022: 88%	Largest source category (1990): Small-scale Combustion (53%) Largest source category (2022): Small-scale Combustion (89%) Emissions reduction 1990-2022: Small-scale Combustion: (80%)

Emissions from the Industrial Processes and Product Use (NFR 2) source sector in the early part of the time series are dominated by aluminium production and the process of anode baking. Emissions from this source have substantially declined since the mid-1990s, and anode baking no longer takes place in the UK, as a result of plant closures.

Small Stationary Combustion source sectors dominate the total emission of B[a]P across the time series. Emissions in the early part of the time series were dominated by the use of coal in residential combustion. But as with other pollutants, coal use decreases, and wood use increases across the time series. As a result, emissions from residential wood burning are now the dominant emission source.

2.3. UK Emission Trends for Key Source Sectors

The following sections provide comment on the more notable trends at a sectoral level for key source categories.

2.3.1. Power Generation (NFR 1A1a)

Power generation (NFR 1A1a) is a key source for many pollutants. However, there has been a substantial reduction in the magnitude of emissions from this source since 1990. Table 2-11 summarises the major contributors to emissions from power generation and shows how emissions have changed from 1990 to 2022.

Table 2-11 Power Stations: Sector share of UK emissions total in 2022 and Trends from 1990 to 2022

Pollutant	NFR Code	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
NO_X (as NO_2)	1A1a	10%	-91%
Hg	1A1a	19%	-93%
SO_X (as SO_2)	1A1a	7%	-100%
HCB	1A1a	78%	+941%
CO	1A1a	3%	-68%
$PM_{2.5}$	1A1a	2%	-97%

Since 1988, electricity generators have adopted a programme of progressively fitting low NO_X burners to their 500 MWe (megawatt electric) or larger coal fired units, and since 2007 a programme of fitting over-fire-air burners has further reduced NO_X emissions from the sector. Since 1990, the increased use of nuclear generation, renewables and the introduction of CCGT (Combined Cycle Gas Turbine) plant burning natural gas, in place of older coal stations, have further reduced NO_X emissions. The emissions from the low NO_X turbines used are much lower than those of pulverised coal fired plant even when low NO_X burners are fitted. Moreover, CCGTs are more efficient than conventional coal and oil stations and have negligible SO_X emissions; this has accelerated the decline of SO_X emissions. The reduction of particulate emissions is also due to this switch from coal to natural gas, nuclear power and renewables for electricity generation, as well as improvement in the performance of particulate abatement plant at coal-fired power stations. The installation of flue gas desulphurisation at eight power stations has reduced SO_X and particulate emissions further. Emissions of CO, dust and metals are also much higher at coal-fired stations than at CCGTs, so emissions of these pollutants have also fallen sharply. In contrast, all of the HCB emissions from power stations arises from the burning of municipal solid waste, and emissions have grown greatly reflecting changes in the quantities of waste burnt.

There was a particularly large change in the use of coal between 2015 and 2016, with consumption approximately 50% lower in 2016, due to plant closure and low utilization rates at some of the remaining stations. This has continued to reduce since then.

The impacts of these changes are observable in Figure 2-1 and Figure 2-2, which present the emissions of NO_X and SO_X since 1990 respectively. Further detail in the estimation of emissions from this source sector are included in Section 3.

2.3.2. Industrial Combustion (NFR 1A1/1A2)

This category covers the use of fuels in combustion in crude oil refineries and other processes that manufacture or process fuels (NFR codes 1A1b and 1A1c) and Combustion in Manufacturing Industries and Construction (NFR codes 1A2a-1A2g). This category is a key source for many pollutants. There has been a substantial reduction in the magnitude of emissions from this source category since 1990 (although emissions in some sub-categories have increased in some years).

Table 2-12 Industrial Combustion: Sector share of UK emissions total in 2022 and Trends from 1990 to 2022

Pollutant	NFR Code	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
SO_X (as SO_2)	1A1b Petroleum refining	14%	-88%
NO_X (as NO_2)	1A1c Manufacture of solid fuels and other energy industries	7%	-24%
CO	1A2a Stationary combustion in manufacturing industries and construction: Iron and steel	4%	-84%
SO_X (as SO_2)	1A2a Stationary combustion in manufacturing industries and construction: Iron and steel	6%	-75%
Hg	1A2f Stationary combustion in manufacturing industries and construction: Non-metallic minerals	9%	58%
NO_X (as NO_2)	1A2f Stationary combustion in manufacturing industries and construction: Non-metallic minerals	2%	-87%
CO	1A2gvii Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)	24%	-5%

Pollutant	NFR Code	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
CO	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	4%	9%
NO_X (as NO_2)	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	8%	-43%
PM10	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	4%	-45%
$PM_{2.5}$	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	7%	-39%
Hg	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	10%	-63%
Cd	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	19%	50%
Pb	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	5%	-54%
PCDD/PCDF	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	14%	3%
SO_X (as SO_2)	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	14%	-87%

The industrial combustion category used here covers stationary plants, off-road vehicles, and mobile machinery, and these combustion processes burn a wide range of fuels in a wide range of combustion devices. The main fossil fuels used are coal, fuel oil, gas oil and natural gas - all of which have reduced across the time series (to very different extents). The most important non-fossil fuels are wood and other solid biomass fuels, which have seen their usage increase substantially across the time series, particularly in recent years. Other renewable fuels, such as bioliquids, biogas and waste-derived fuels have also seen their usage increase.

Table 2-12 above show the trends in the emissions from key industrial sources across the time series. The changes in fuel consumption are a major factor driving reductions in emissions of many pollutants. Coal and fuel oil contain high levels of sulphur and metals and so their use can result in emissions of SO_X and metals. Natural gas contains no metals other than traces of mercury, and also contains negligible quantities of sulphur. Light oils such as kerosene and gas oil/diesel contain relatively low levels of metals and sulphur, so the large reductions in the consumption of coal and fuel oil have resulted in big reductions in emissions of SO_X and metals. Solid and liquid fuels also typically emit more NO_X than a similar quantity of natural gas, so emissions of these pollutants have also fallen substantially. Emissions of NO_X from industrial off-road vehicles and mobile machinery have decreased due to the penetration of units with diesel engines that comply with tighter regulation under the UK Non-Road Mobile Machinery (NRMM) emission Directive.[34]

Emissions of NMVOCs and particulate matter (TPM, PM_{10}, $PM_{2.5}$) have not reduced to the same extent and this reflects the fact that combustion of coal and fuel oil are not the major source of these pollutants within the industrial combustion category. Instead, off-road vehicles and mobile machinery are the main source of NMVOCs, and the industrial combustion of biomass based-fuels is the main source of particulate matter. Emissions of NMVOCs from off-road vehicles and mobile machinery have substantially decreased due to the penetration of units with diesel engines that comply with tighter regulation under the UK Non-Road Mobile Machinery (NRMM) emission Directive. Emission rates for NMVOCs have decreased over time in the case of larger plant burning gas oil and diesel oil, resulting in the decrease for NMVOCs. Industrial use of biomass based-fuels is increasing, resulting in an increase over the time series in particulate matter from industrial combustion. Further detail in the estimation of emissions from this source sector are included in Section 3.2.

2.3.3. Transport (NFR 1A3)

The transport sector is a key source for many pollutants. Table 2-13 summarises key sources and emission trends for the transport sources.

Table 2-13 Transport: Sector share of UK emissions total in 2022 and Trends from 1990 to 2022

Pollutant	NFR Code	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
Pb	1A3aii(i) Domestic aviation LTO (civil)	7%	-38%
CO	1A3bi Road transport: Passenger cars	15%	-96%
NO_X (as NO_2)	1A3bi Road transport: Passenger cars	16%	-87%
$PM_{2.5}$	1A3bi Road transport: Passenger cars	2%	-80%
Hg	1A3bi Road transport: Passenger cars	4%	-30%
NO_X (as NO_2)	1A3bii Road transport: Light duty vehicles	10%	-35%
NO_X (as NO_2)	1A3biii Road transport: Heavy duty vehicles and buses	4%	-91%
TSP	1A3bvi Road transport: Automobile tyre and brake wear	7%	24%
PM_{10}	1A3bvi Road transport: Automobile tyre and brake wear	10%	22%
$PM_{2.5}$	1A3bvi Road transport: Automobile tyre and brake wear	11%	24%
Pb	1A3bvi Road transport: Automobile tyre and brake wear	35%	18%

[34] https://www.legislation.gov.uk/uksi/2018/764/made

Pollutant	NFR Code	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
TSP	1A3bvii Road transport: Automobile road abrasion	4%	24%
PM_{10}	1A3bvii Road transport: Automobile road abrasion	4%	24%
$PM_{2.5}$	1A3bvii Road transport: Automobile road abrasion	4%	24%
NO_X (as NO_2)	1A3dii National navigation (shipping)	11%	-50%
$PM_{2.5}$	1A3dii National navigation (shipping)	3%	-88%
SO_X (as SO_2)	1A3dii National navigation (shipping)	5%	-94%
CO	1A3dii National navigation (shipping)	4%	158%

Aviation spirit, which is often used in small aeroplanes, is a notable source of lead emissions in the UK, however has declined notably with respect to a 1990 baseline. With the phase out of lead emissions from historically large sources, such as road transport and coal-fired power stations, historically smaller sources of lead emissions now contribute an increasing amount to the national total.

Road traffic activity has grown since 1990 but there has been a decline in emissions for a number of reasons. Since 1992, the requirement for new petrol cars to be fitted with three-way catalysts has reduced emissions of NO_X, CO, and NMVOCs. European vehicle emission regulations have also required petrol cars to be fitted with evaporative control systems which have also contributed to reductions in NMVOC emissions since the early 1990s.

The further tightening of emission standards on petrol cars and all types of new diesel vehicles over the last decade has also contributed to the reduction in NO_X emissions. Evidence has shown however that Euro 4 and 5 diesel cars and light goods vehicles (LGVs) exceed their type approval limit for NO_X in real-world operation meaning that there has been little change in emission factors across the range of Euro standards for diesel cars and LGVs. This is reflected in the emissions factors provided in the European COPERT 5.6 source used in the NAEI, also showing only modest reduction in NO_X factors occurring for new Euro 6 diesel cars entering the fleet for the first time in 2015 (and Euro 6 diesel LGVs in 2016). Fuel switching from petrol cars to diesel cars has reduced CO and NMVOC emissions and limited the reduction in NO_X emissions. Further reductions in NO_X emissions have occurred for heavy goods vehicles (HGVs) and buses with the introduction of Euro VI standards since 2013.

Diesel engine vehicles emit a greater mass of particulate matter per vehicle kilometre than petrol engine vehicles. However, since around 1992, exhaust emissions from diesel vehicles (on a per vehicle kilometre travelled basis) have been decreasing due to the penetration of new vehicles meeting tighter PM emission regulations ("Euro standards" for diesel vehicles were first introduced in 1992). This has more than offset the increase in diesel vehicle activity so that overall PM_{10} emissions from road transport have been falling. Emissions of PM from non-exhaust sources such as tyre and brake wear and road abrasion are not regulated and so have generally been increasing over the time series in line with the growth in traffic and are becoming a more important source of traffic-related PM emissions compared with exhaust emissions. An exception is for brake wear where hybrid and electric vehicle emission factors are lower than conventional vehicles due to their use of regenerative braking.

Road transport is a relatively minor source of NH_3 emissions, however NH_3 emissions have increased from petrol cars in the 1990s with early generation three-way catalyst control systems. These have since declined with better catalyst technologies. However, these improvements are being offset by increases in NH_3 emissions from Euro 5/V and 6/VI diesel vehicles introduced since 2010 using selective catalytic reduction (SCR) with urea injection in the exhaust intended for controlling NO_X emissions.

Domestic shipping is a key category for CO, NO_X, SO_X, and $PM_{2.5}$. Emissions of SO_X and PM are showing a large decline over the time series due mainly to the reduction in the sulphur content of fuels used by shipping and the introduction of Sulphur Emission Control Areas in the North Sea and English Channel since 2007. Emissions of NO_X have declined to a lesser extent, the decline being partly due to a reduction in domestic vessel activities since 1990, particularly vessels serving the offshore oil and gas industry, and partly due to the continued turnover in the fleet leading to larger proportions of vessels with more recent engines which meet later (more stringent) NO_X emission tiers under the IMO MARPOL Annex VI NO_X Technical Code for ship engines. The increase in CO emissions is mainly due to an increase in activities of small inland waterway vessels with petrol engines Further detailed information on Transport is provided in section 3.3.

2.3.4. Residential, Public and Commercial Sectors (NFR 1A4)

This category covers the use of fuels by the residential sector and by the public and commercial sectors. For most pollutants, emissions in this category are dominated by those from residential combustion, which is a key source for many pollutants. There has been a substantial reduction in the magnitude of emissions for many of these pollutants since 1990.

The use of coal and other solid mineral fuels as domestic fuels has decreased greatly since 1990, whereas the consumption of wood has increased substantially. Emissions of Cd are particularly large from wood combustion and so, for the residential sector as a whole, emissions of these pollutants have not reduced in the same way as many other pollutants (see Figure 2-5 and Figure 2-10).

Table 2-14 summarises key sources and trends across the residential, public, and commercial sectors.

Table 2-14 Residential, Commercial and Public: Sector share of UK emissions total in 2022 and Trends from 1990 to 2022

Pollutant	NFR Code	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
NO_X (as NO_2)	1A4ai Commercial and Public Combustion: Stationary	6%	-34%
$PM_{2.5}$	1A4ai Commercial and Public Combustion: Stationary	2%	-79%
CO	1A4bi Domestic Combustion: Stationary	19%	-74%
NO_X (as NO_2)	1A4bi Domestic Combustion: Stationary	4%	-69%
NMVOC	1A4bi Domestic Combustion: Stationary	3%	-65%
TSP	1A4bi Domestic Combustion: Stationary	9%	-60%
PM_{10}	1A4bi Domestic Combustion: Stationary	15%	-60%
$PM_{2.5}$	1A4bi Domestic Combustion: Stationary	29%	-60%
Cd	1A4bi Domestic Combustion: Stationary	10%	10%
PCDD/PCDF	1A4bi Domestic Combustion: Stationary	16%	-79%
SO_X (as SO_2)	1A4bi Domestic Combustion: Stationary	31%	-69%
PAHs	1A4bi Domestic Combustion: Stationary	88%	-80%
Hg	1A4bi Domestic Combustion: Stationary	8%	-68%

Pollutant	NFR Code	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
CO	1A4bii Domestic Combustion: Mobile	6%	-34%

In the commercial and public sectors, most energy requirements are now met by natural gas and electricity and so emissions of all pollutants have fallen. However, the combined emission figures for domestic, commercial and public sector combustion are, for most pollutants, dominated by the contribution from the residential sector.

Emissions from house and garden machinery, agricultural machinery and fishing vessels are included in this sector. Emissions of NO_X, PM and NMVOCs have been decreasing with the penetration of units with diesel and petrol engines that comply with tighter regulation under the UK Non-Road Mobile Machinery (NRMM) emission Directive. A reduction in the maximum permitted sulphur content of gas oil fuels used by these machineries since 2011 has also reduced SO_X emissions.

Further details in the estimation of emissions from this source sector are included in Section 3.4.

2.3.5. Fugitive Emissions from fuels (NFR 1B)

Fugitive sources are minor emitters in the context of total UK emissions for most pollutants. However, they are a key source of NMVOCs as well as SO_X. Fugitive emissions (that is losses, leaks and other releases of gases) are associated with the extraction, refining and distribution of fossil fuels like oil and gas. Emissions from this sector show a strong decline from 1990, as shown in Table 2-15. There are several high-emitting regulated industrial sectors, for example, upstream oil and gas, and solid fuel production; in particular for hydrocarbon emissions. These sectors have shown a strong decline in emissions since 1990 due, in part, to reduced UK production (e.g. coal and smokeless solid fuel), but also due to improved abatement measures, most notably for loading, unloading, and storage of crude oil and petroleum products. Several of these regulated industries are still high emitters in the UK context, as a result of NMVOC emissions from many historic high emitters also decreasing substantially.

Table 2-15 Fugitive: Sector share of UK emissions total in 2022 and Trends from 1990 to 2022

Pollutant	NFR Code	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
SO_X (as SO_2)	1B1b Fugitive emission from solid fuels: Solid fuel transformation	5%	-70%
NMVOC	1B2ai Fugitive emissions oil: Exploration, production, transport	3%	-76%
NMVOC	1B2av Distribution of oil products	3%	-82%
NMVOC	1B2b Fugitive emissions from natural gas (exploration, production, processing, transmission, storage, distribution and other)	3%	-57%
NMVOC	1B2c Venting and flaring (oil, gas, combined oil and gas)	2%	-53%

2.3.6. Industrial Processes and Product Use (NFR 2)

Table 2-16 summarises key sources and emission trends for the industrial process and product use sector.

Quarrying and construction are important sources of particulate matter, but emissions have fallen by approximately half since 1990 due to decreased activity in these sectors. Both sectors emit relatively more coarse particulate matter and so their importance is much greater for total particulate matter than for $PM_{2.5}$. For example, the Construction Sector (2A5b) is estimated to have emitted 40% of UK particulate matter (Total suspended particulates, TSP) in 2022, but only 4% of $PM_{2.5}$.

The Chemical Industry (2B) is no longer a key source category for mercury, emissions from the sector accounted for approximately 20% of the National Total in 1990. Emissions are reported in NFR 2B10a, which is used for chemicals other than the few that are given their own category in the NFR system. Mercury emissions in this category are predominantly from manufacture of chlorine using mercury cell technology. The production of chlorine by this technology has decreased over time, and emissions have fallen as well. Emission reductions will also have been due to increasing emission controls, but with the current data availability, it is not possible to determine the separate impacts of changes in production and reductions in emission rates.

Iron and Steel Production (2C1) and Foundries (2C7c) are important sources of CO, Cd, Hg, Pb, PCDD/F and PM, with contributions ranging from a few percent to around 32% of UK emissions in 2022 in the case of Pb and 2C1. Emissions of all of these pollutants have decreased since 1990, most notably so for foundries where the estimates are based on the assumptions that emissions were uncontrolled during the early part of the time series and that abatement now ensures much lower emission rates. Emissions from steelmaking have not fallen consistently over the period; instead there have been periods when emissions have increased from year to year. Emissions decreased throughout the 1990s, at least in part because of the closure of many production sites. Emissions of many pollutants then increased in the period 2002-2008; these increases coinciding with increases in steel production. Emissions then decreased again in 2008-2011, due to a sharp fall in demand in steel which led to decreased production and the mothballing of one large steelworks. Between 2011 and 2014, production of steel increased again as demand recovered, and emissions of many pollutants also increased. In 2015, the Teesside steelworks closed, and steel production and emissions fell again. The trends are not identical for each pollutant, and even differ slightly for closely related pollutants such as TSP, PM_{10} and $PM_{2.5}$. Different emission sources within steelworks make different contributions to emissions of fine and coarse dust, and so trends will be slightly different for each pollutant.

Emissions of mercury from steelmaking have decreased since 1990. This pollutant is emitted mainly from the manufacture of steel in electric arc furnaces and the emissions reported by some operators of these furnaces in recent years have been higher than levels reported in the 1990s. Emissions across the time series fluctuate with frequent peaks and troughs. This may reflect a highly variable mercury content of the scrap metal melted in the furnaces, or perhaps instead indicate that the raw emissions data, taken from the UK's Pollution Inventory and similar sources and used as the basis of the NAEI estimates are highly uncertain.

Solvent use (NFR sectors 2D3) is a key source for NMVOCs, contributing approximately 40% of UK emissions of NMVOCs in 2022, and some industrial coating processes that use solvent will also give rise to PM emissions. Consumption of solvent in industrial coatings and decorative paints (2D3d, 7% of NMVOC emissions in 2022) and printing inks (2D3h, <2% of NMVOC emissions in 2022) has declined over time, driven by regulations and this, combined with increasing abatement of NMVOC emissions from industrial processes, has led to a downward trend in emissions. Emissions from the use of solvents for degreasing (2D3e) and dry cleaning (2D3f) have fallen due to technological improvements in equipment used to carry out the cleaning, and the use of one solvent (1,1,1-trichloroethane) has been phased out altogether, and emissions from cleaning solvents were <2% of UK NMVOC totals in

2022. NMVOC emissions from solvent use in consumer products such as Aerosols, Detergents and Fragrances (2D3a), on the other hand, are estimated to have increased slightly, in line with increasing population, and now make up almost a quarter of UK NMVOC emissions. Sector 2D3a also includes estimates of NMVOC emissions from the use of hand sanitiser. Emissions from 'other solvent use' (2D3i) contributed approximately 4% of the UK total for NMVOCs in 2022, and emissions from this sector are estimated to have increased in recent years due to strong growth in the use of adhesives, although emissions are still below their 1990 level. Solvent use in chemical products (2D3g) contributed around 2% of the UK emission of NMVOCs in 2022.

Food and drink production (2H2) is a key source category for NMVOC emissions, contributing 16% of UK emissions in 2022. The largest source is whisky maturation, which accounts for almost two-thirds of the food and drink sector emissions. The emission trends with time are primarily driven by production in 2H2, with large growth in Scotch whisky production, and slower growth or decreasing production for many other foods and beverages. Further detail in the estimation of emissions from this source sector are included in Chapter 4.

Table 2-16 Industrial Processes: Sector share of UK emissions total in 2022 and Trends from 1990 to 2022

Pollutant	NFR Code and Name	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
PM_{10}	2A5a Quarrying and mining of minerals other than coal	7%	-48%
$PM_{2.5}$	2A5a Quarrying and mining of minerals other than coal	1%	-48%
TSP	2A5a Quarrying and mining of minerals other than coal	8%	-48%
PM_{10}	2A5b Construction and demolition	22%	-42%
$PM_{2.5}$	2A5b Construction and demolition	4%	-42%
TSP	2A5b Construction and demolition	40%	-43%
PM_{10}	2A6 Other mineral products (please specify in the IIR)	2%	-35%
$PM_{2.5}$	2A6 Other mineral products (please specify in the IIR)	2%	-35%
Cd	2C1 Iron and steel production	14%	-48%
CO	2C1 Iron and steel production	5%	-56%
PCDD/PCDF	2C1 Iron and steel production	16%	-68%
Hg	2C1 Iron and steel production	7%	-56%
Pb	2C1 Iron and steel production	31%	-24%
PM_{10}	2C1 Iron and steel production	3%	-62%
$PM_{2.5}$	2C1 Iron and steel production	3%	-64%
TSP	2C1 Iron and steel production	3%	-57%
Hg	2C7c Other metal production (please specify in the IIR)	5%	-97%

Pollutant	NFR Code and Name	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
NMVOC	2D3a Domestic solvent use including fungicides	22%	10%
NMVOC	2D3d Coating applications	7%	-78%
NMVOC	2D3g Chemical products	2%	-52%
NMVOC	2D3i Other solvent use (please specify in the IIR)	4%	-55%
Cd	2G Other product use (please specify in the IIR)	34%	-6%
Pb	2G Other product use (please specify in the IIR)	7%	60%
PM_{10}	2G Other product use (please specify in the IIR)	2%	-45%
$PM_{2.5}$	2G Other product use (please specify in the IIR)	2%	-56%
NMVOC	2H2 Food and beverages industry	16%	44%

2.3.7. Agriculture (NFR 3)

The agriculture sector is a key source for NH_3, NMVOCs, PM_{10}, TSP, and HCB. Table 2-17 shows key sources and the trends in emissions from these sources.

Table 2-17 Agriculture: Sector share of UK emissions total in 2022 and Trends from 1990 to 2022

Pollutant	NFR Code	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
NMVOC	3B1a Manure management - Dairy cattle	4%	17%
NH_3	3B1a Manure management - Dairy cattle	14%	25%
NMVOC	3B1b Manure management - Non-dairy cattle	4%	-11%
NH_3	3B1b Manure management - Non-dairy cattle	13%	-9%
TSP	3B4gi Manure management - Laying hens	3%	-5%
PM_{10}	3B4gii Manure management - Broilers	2%	65%
TSP	3B4gii Manure management - Broilers	2%	65%
PM_{10}	3B4giv Manure management - Other poultry	2%	49%
TSP	3B4giv Manure management - Other poultry	2%	28%
NH_3	3Da1 Inorganic N-fertilizers (includes also urea application)	13%	-33%
NMVOC	3Da2a Animal manure applied to soils	6%	45%
NH_3	3Da2a Animal manure applied to soils	23%	-24%

Pollutant	NFR Code	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
NH_3	3Da2c Other organic fertilisers applied to soils (including compost)	6%	Not Defined[35]
NH_3	3Da3 Urine and dung deposited by grazing animals	7%	-19%
TSP	3Dc Farm-level agricultural operations including storage, handling and transport of agricultural products	3%	-7%
PM_{10}	3Dc Farm-level agricultural operations including storage, handling and transport of agricultural products	5%	-7%
HCB	3Df Use of pesticides	19%	-94%

Agricultural emissions from livestock and their wastes (NFR 3B) and emissions from agricultural soils due to use of chemical- and manure-fertilisers and sewage and other sludges (3D) are the major sources of NH_3 emissions. These emissions derive mainly from the decomposition of urea in animal wastes and uric acid in poultry wastes, and the decomposition of ammonium and urea-based fertilisers. Emissions of NH_3 from agricultural livestock were relatively steady prior to 1999. After that, emissions decreased with time to 2012, before increasing slightly again. These trends were driven predominantly by trends in animal numbers, in particular, decreases in beef cattle, pigs and turkeys. Emissions from use of chemical fertiliser (NFR 3Da1) mostly fell between 1990 and 2001, before fluctuating over the following 12 years and then increased by a third between 2013 and 2016, due to increased use of urea-based fertilisers. Other emissions from agricultural soils decreased in the earlier part of the time series as numbers of some classes of animals decreased, but emissions have increased in recent years due to increased use of digestate from anaerobic digestion of non-agricultural and sewage sludges.

Emission estimates for NMVOCs are calculated using Tier 2 emission factors, PM_{10}, and TSP are calculated using simple (Tier 1) approaches, mostly assuming the same emission per animal across the time series. Trends in emissions therefore largely reflect the changes in livestock numbers, which have generally been downward for most animal types.

Emissions from 3Da2c have increased greatly from zero in 1990, to representing 6% of the UK emissions in 2022. This is because anaerobic digestion has become more prevalent and the number of digestors in the UK have increased with 660 facilities in operation in 2022[36], as a result, a greater quantity of digestate is spread on agricultural land. Further detail in the estimation of emissions from this source sector are included in Chapter 5.

2.3.8. Waste (NFR 5)

Emissions from the waste sector have a negligible effect on overall UK emissions for most pollutants. Waste is, however, a key source for Hg, PCDD/PCDF, $PM_{2.5}$, and PM_{10}. Table 2-18 shows key sources and the trends in emissions from the waste sector.

[35] Emissions from this category were zero in 1990.
[36] https://www.nnfcc.co.uk/press-release-ad-report-2022

Table 2-18 Waste: Sector share of UK emissions total in 2022 and Trends from 1990 to 2022

Pollutant	NFR Code	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
Hg	5A Biological treatment of waste – Solid waste disposal on land	9%	-48%
Hg	5C1bv Cremation	10%	-28%
PM_{10}	5C2 Open burning of waste	3%	-6%
$PM_{2.5}$	5C2 Open burning of waste	6%	-6%
PCDD/PCDF	5C2 Open burning of waste	21%	-66%
$PM_{2.5}$	5E Other waste (please specify in IIR)	3%	-39%
PCDD/PCDF	5E Other waste (please specify in IIR)	16%	-68%

Emissions from cremations (5C1bv) are a key sector for Hg (as Mercury is used in dental amalgams), and the number of cremations has increased slightly since 1990. The Hg emission factor changes from year to year, reflecting changes in dental health over the years, and abatement at crematoria.

Emissions from solid waste disposal on land (5A) are a key source for Hg. Since 1990 there has been a reduction in the mercury content of devices such as batteries and electrical equipment that are disposed of at landfill.

The burning of waste (5C2) is a key source for particulate matter and PCDD/PCDF, the main source of PM emissions in 5C2 is from the burning of waste, in particular vegetation, outdoors, and this has been estimated to increase in line with the number of households. This is one notable area where there is a lack of data available on the changing in behaviours on type and quantity of material burnt over time, and as such, the number of fires per household currently remains static over time. Further detail in the estimation of emissions from this source sector are included in Chapter 6.

2.3.9. Other (NFR 6)

The category Other (NFR 6) is not a key category in the UK, emissions from this sector only account for a small fraction of the national emissions. However, it is a key source of NH_3 see Table 2-19.

Table 2-19 Other: Sector share of UK emissions total in 2022 and Trends from 1990 to 2022

Pollutant	NFR Code	% of total emissions in 2022 for given pollutant	% change from 1990 to 2022
NH_3	6A Other (included in national total for entire territory) (please specify in IIR)	6%	+56%

NH_3 emissions from 6A Other have increased by around 56% between 1990 and 2022, reflecting an increase in emissions from domestic pets (cats, dogs and domestic chickens). From 2019 onwards, there has been a large increase in pet ownership. Further detail in the estimation of emissions from this source sector are included in Chapter 7.

3. NFR 1: Energy

3.1. NFR 1A1: Combustion in the Energy Industries

Table 3-1 Mapping of NFR Source Categories to NAEI Source Categories: Combustion in the Energy Industries

NFR Category	Pollutant coverage	NAEI Source category
1A1a Public Electricity and Heat Production	All CLRTAP pollutants	Power stations[37]
		Heat supply (sewage gas, landfill gas)[30]
		Miscellaneous industrial/commercial combustion (MSW only)[30]
1A1b Petroleum refining	All CLRTAP pollutants (except NH_3, HCB and PCBs)	Refineries - fuel combustion (including emissions from regeneration of fluidised catalytic crackers, burning off petroleum coke residues)
1A1c Manufacture of Solid Fuels and Other Energy Industries	All CLRTAP pollutants (except NH_3, HCB and PCBs)	Coke production
		Collieries - fuel combustion
		Gas production (downstream gas)[38]
		Upstream Gas Production - fuel combustion
		Upstream Oil Production - fuel combustion
		Oil terminal: fuel combustion
		Gas terminal: fuel combustion
		Nuclear fuel production
		Solid smokeless fuel production
		Town gas manufacture

Table 3-2 Summary of Emission Estimation Methods for NAEI Source Categories in NFR Category 1A1

NAEI Source Category	Method	Activity Data	Emission Factors
Power stations	UK model	UK energy statistics, ETS, operators	Major fuels: Operator reported emissions data for PRTR. Minor fuels: default factors (US EPA, EMEP/EEA, UK-specific research)
Miscellaneous industrial/commercial combustion	AD x EF	UK energy statistics	MSW: Operator reported emissions data for PRTR.
Heat supply	AD x EF	UK energy statistics	Sewage gas, LFG: default factors (US EPA, EMEP/EEA, UK-specific research)

[37] All use of MSW, landfill gas, and sewage gas to generate electricity and heat is reported in 1A1a

[38] Activity and emissions reported in the UK inventory for the downstream gas sector includes the gas use at compressors operating the UK gas distribution network. Data are not available specific to the pipeline gas compressors; only aggregate downstream gas industry data are available. Hence all emissions are reported within the 1A1c NFR category, rather than any emissions allocated to 1A3e Pipeline Compressors.

NAEI Source Category	Method	Activity Data	Emission Factors
Refineries	AD x EF	UK energy statistics, ETS	Operator reported emissions data for PRTR, Fuels Industry UK; default factors (US EPA, EMEP/EEA, UK-specific research)
Coke production	UK model	UK energy statistics, ETS, ISSB	Major fuels: Operator reported emissions data for PRTR, Tata Steel, British Steel Minor fuels: default factors (US EPA, EMEP/EEA, UK-specific research)
Collieries - fuel combustion	AD x EF	UK energy statistics	Default factors (US EPA, EMEP/EEA, UK-specific research)
Gas production (downstream gas)	AD x EF	UK energy statistics, ETS	Default factors (US EPA, EMEP/EEA, UK-specific research)
Upstream gas production	UK model	UK energy statistics, EEMS, ETS	Annual reporting by operators for EEMS and PRTR, UKOOA / OGUK / OEUK[39], other UK-specific research, US EPA, EMEP/EEA
Upstream oil production	UK model	UK energy statistics, EEMS, ETS	Annual reporting by operators for EEMS and PRTR, UKOOA / OGUK / OEUK, other UK-specific research, US EPA, EMEP/EEA
Oil terminal: fuel combustion	UK model	UK energy statistics, EEMS, ETS	Annual reporting by operators for EEMS and PRTR, UKOOA / OGUK / OEUK, other UK-specific research, US EPA, EMEP/EEA
Gas terminal: fuel combustion	UK model	UK energy statistics, EEMS, ETS	Annual reporting by operators for EEMS and PRTR, UKOOA / OGUK / OEUK, other UK-specific research, US EPA, EMEP/EEA
Nuclear fuel production	AD x EF	UK energy statistics	Default factors (US EPA, EMEP/EEA, UK-specific research)
Solid smokeless fuel production	AD x EF	UK energy statistics, ETS	Default factors (US EPA, EMEP/EEA, UK-specific research)
Town gas manufacture	AD x EF	UK energy statistics	Default factors (US EPA, EMEP/EEA, UK-specific research)

3.1.1. Classification of Activities and Sources

The NAEI utilises official UK energy statistics published annually in the Digest of UK Energy Statistics (DESNZ, 2023a), hereafter abbreviated to DUKES. The source categories and fuel types used in the NAEI therefore reflect those used in DUKES. Table 3-1 relates the detailed NAEI source categories to the equivalent NFR source categories. In most cases, it is possible to obtain a precise mapping of an NAEI source category to a NFR source category; however, there are some instances where the scope of NAEI and NFR categories are different, as discussed below. Emission estimation calculations are performed for individual NAEI source categories and then aggregated to match the NFR reporting system for the CLRTAP submission.

[39] The trade association for the offshore oil and gas sector has been formerly known as the UK Offshore Operators Association (UKOOA) and Oil and Gas UK (OGUK). It is now Offshore Energies UK (OEUK). Several data references are from the UKOOA and OGUK eras, and hence these acronyms are retained here.

Table 3-3 lists the fuels used in the inventory. In two instances, fuels listed in DUKES are combined in the NAEI: propane and butane are combined as 'liquefied petroleum gas' (LPG), whilst ethane and 'other petroleum gases', which includes 'refinery fuel gas', are combined as the NAEI fuel 'other petroleum gases' (OPG).

Table 3-3 Fuel types used in the NAEI

Fuel type	Fuel name	Comments
Crude-oil based fuels	Aviation Spirit	Includes fuel that is correctly termed jet gasoline.
	Aviation Turbine Fuel (ATF)	
	Burning Oil	Also known as kerosene.
	Fuel Oil	
	Gas Oil/ DERV	
	Liquefied Petroleum Gas (LPG)	DUKES uses the terms "propane" and "butane".
	Naphtha	
	Orimulsion®	An emulsion of bitumen in water.
	Other Petroleum Gas (OPG)	DUKES uses the terms "ethane" and "other petroleum gases"; The use of refinery fuel gas is reported in DUKES as OPG. The NAEI also reports the use of process off-gases (e.g. from petrochemical feedstocks) as OPG.
	Petrol	
	Petroleum Coke	Comprises both 'green' coke that is used as a fuel and 'catalyst' coke, which is used as a reductant.
	Refinery Miscellaneous	
	Vaporising oil	Not used as a fuel in the UK since 1978.
Coal-based fuels	Anthracite	
	Coal	
	Slurry	Coal-water slurry. Not included separately in DUKES.
	Coke	Coke oven coke, includes coke breeze.
	Solid Smokeless Fuel (SSF)	
	Coke Oven Gas	
	Blast Furnace Gas	Includes basic oxygen furnace gas.
Gas	Natural Gas	
	Sour Gas	Unrefined natural gas used by offshore installations and one power station. Not included separately in DUKES.
	Colliery Methane	
	Town Gas	Not used as a fuel in the UK since 1988.
Biomass	Wood	Covers all wood burnt by power stations and the residential sector, and waste wood used by industry. Residential sector wood is split out into wet, dry and seasoned categories.
	Straw	
	Poultry Litter	Includes meat & bone meal. DUKES uses the term "animal biomass".
	Landfill Gas	
	Sewage Gas	
	Liquid bio-fuels	Liquid bio-fuels used at power stations.
	Bioethanol	Used only in transportation and Non-Road Mobile Machinery (NRMM).
	Biodiesel	Used only in transportation and NRMM.

	Biogas Biomass	Methane generated via anaerobic digestion other than from landfill or sewage treatment plant. Solid biomass other than waste wood, used as a fuel by industry.
Wastes	Municipal Solid Waste Scrap Tyres Waste Oil/ Lubricants Waste Solvents	 Not identified separately in DUKES. Not identified separately in DUKES. Not identified separately in DUKES.

Almost all of the NFR source categories listed in Table 3-1 are key sources for one or more pollutants and so the description of the methodology will cover the whole of this NFR sector.

3.1.2. General Approach for NFR 1A1

The methodology for NFR 1A1 is based mainly on the use of emissions data reported by process operators to regulators. These data are contained within the Pollution Inventory (PI), covering England, the Welsh Emissions Inventory (WEI), the Scottish Pollutant Release Inventory (SPRI), Northern Ireland's Pollution Inventory (NIPI), and the Environmental Emissions Monitoring System (EEMS)[40] for upstream oil and gas installations situated offshore.

The PI data are managed by the Environment Agency (EA) for England and are available from https://www.data.gov.uk/dataset/cfd94301-a2f2-48a2-9915-e477ca6d8b7e/pollution-inventory

SPRI data are maintained by the Scottish Environment Protection Agency (SEPA) and are available at: https://www.sepa.org.uk/environment/environmental-data/spri/

The NIPI and WEI datasets are not available online but are supplied directly to the UK Inventory Agency by the Northern Ireland Environment Agency (NIEA) and Natural Resources Wales (NRW) respectively.

These national regulators' inventories (RIs) are the basis for the UK-wide Pollutant Release and Transfer Register (PRTR) dataset which includes emissions to atmosphere from UK installations regulated under the Environmental Permitting Regulations (EPR) (England and Wales), the Pollution Prevention and Control Regulations (Scotland) and the Pollution Prevention and Control (Industrial Emissions) Regulations (Northern Ireland); the UK PRTR is available online, searchable by region (or by installation) at: http://prtr.defra.gov.uk/area-overview

The EEMS dataset is supplied to the UK Inventory Agency by the Department for Energy Security and Net Zero (DESNZ) Offshore Petroleum Regulator for Environment and Decommissioning (OPRED), that is the regulatory authority for offshore oil and gas installations.

The operator submissions to the PI, WEI, SPRI and NIPI (the Regulator Inventories, RIs) are reported as total annual emissions of each relevant pollutant from all emission sources within the boundaries of each permitted installation; the operator submissions to the RIs do not provide any further source- or fuel/process-specific resolution to the emissions totals, but nevertheless are regarded as the best available dataset to inform UK inventory emissions for many pollutants.

During the 1990s, different parts of large, complex installations were often permitted separately so that emissions were reported for each of those (e.g. coke ovens, iron and steel production, power plant, and rolling mill furnaces at the UK steelworks were each permitted separately) but under the permitting system used since the early 2000s, there is a single permit for each installation. For example, emissions data for each integrated steelworks are now given as a single figure per pollutant, and single permits cover all plant utilities and numerous different chemical production units at each chemical works. Emissions reported for each installation are therefore not allocated by fuel or by process source.

[40] www.gov.uk/oil-and-gas-eems-database

This does impact on inventory data quality; the installation-wide emissions data reported by operators are considered to be the most accurate basis for inventory estimates overall, but the lack of transparency on emissions *per source* on each installation undermines the level of resolution that can be presented in the national inventory submission.

For offshore oil and gas installations, the EEMS dataset does provide separate emission estimates per pollutant, per installation and per emission source, including from: fuel combustion, flaring, venting, process emissions, fugitive releases and oil loading/unloading activities.

Therefore, in order to use the RI emission totals per installation to inform source-specific emission estimates in the UK inventories, it is sometimes necessary to access supplementary data in order to split the reported emissions data by fuel and/or sub-source.

For 1A1a and 1A1b, from 2005 to 2020 the Inventory Agency has access to detailed EU Emissions Trading System (EU ETS) data, and from 2021 onwards this has been replaced with the UK Emissions Trading System (UK ETS). These data sets (collectively referred to as "ETS" where both data sources are used across the time series) present the annual consumption data per fuel per installation from across the sector; the ETS data are highly complete for the power generation and oil refining sectors. These detailed activity data enables the Inventory Agency to estimate the air quality pollutant emissions per fuel from these sectors, aligning the sector total to the aggregate of operator-reported emission totals in the RIs.

For some high-emitting industries, the inventory agency consults directly with plant operators to request additional data to improve the transparency of the UK inventories. For example, the operators of all UK integrated steelworks provide data directly to the Inventory Agency to enable a more accurate estimate of emissions to be reported for sub-units on site (e.g. coke ovens, sinter plant, blast furnaces, basic oxygen furnaces); similarly, the refinery trade association provides a sector-wide split of reported emissions of air quality pollutants from process sources, combustion sources, and NMVOC estimates specific to loading/unloading and other fugitive sources.

For less emissive source sectors, the estimated split of emissions by sub-source is derived based either on periodic consultation with regulatory and industry contacts, or through expert judgement of the Inventory Agency.

Fuel use data are primarily obtained from DUKES, with some deviations where alternative data are determined to be more complete for a specific source; for example, in recent years, energy data from the ETS are used in the UK inventory as the primary energy data source for the refinery sector and the petrochemical sector, where process off-gases produced on site are used as a supplementary fuel, but logged as 'Non Energy Use' in DUKES.

The ETS data are provided by process operators and verified by accredited verifiers. The data sets cover all UK installations within certain sectors, including: refineries, major power producers, steelworks, cement and lime kilns. The energy data based on these data sets are therefore considered to be very accurate and are used for source sectors where the coverage is complete for all UK installations in that sector. There are a few instances where these alternative data sources for energy indicate a difference to the overall UK energy balance presented in DUKES; in most of these cases, because the ETS data are verified and considered to be accurate, the differences are assumed to be due to a sector mis-allocation in the energy balance. Hence where there is a deviation from the DUKES data for one sector, an equal and opposite amendment to the energy allocation of another source is made (usually for "unclassified industry" in 1A2g) in order to retain overall consistency with the demand totals in the UK energy balance for that fuel. Further information on these modifications to energy data are given in the next section.

Emissions of some pollutants are estimated using literature emission factors and activity data from DUKES or EEMS, rather than from operator-reported emissions data. This is particularly true of pollutants such as NMVOCs, benzene, 1,3-butadiene, metals and Persistent Organic Pollutants (POPs), where the level of operator reporting to regulatory mechanisms is much lower than is the case for other pollutants such as NO_X. Many operators do not have to provide annual emission estimates for these pollutants because the installation-wide emissions would fall below minimum reporting thresholds. Therefore, there are far fewer operator-reported data available for use in deriving country-specific emission factors; any such factors derived from a small dataset may not be representative of all UK installations in that sector, and therefore literature factors are used in the UK inventories for these pollutants. The sectors and pollutants where literature factors are used due to limited operator-reported emissions data are typically minor contributors to UK emission totals.

The following sections give more details of the methodology. Detailed emission factors are available at http://naei.beis.gov.uk/data/ef-all and are often updated between April and May, following the latest submission.

3.1.3. Fuel Consumption Data

Fuel consumption data used in the UK inventories are primarily taken directly from DUKES, but there are a small number of instances where alternative energy use estimates are used in preference, and hence where the NAEI energy data deviate from those presented in DUKES[41], for the reasons presented in section 1.4.3.

The most important deviations from DUKES are:

- DUKES data for the quantity of fuel oil consumed by power stations are much lower than the quantities reported by process operators under the EU ETS / UK ETS. In part, this is due to the use of recovered waste oils, which is presumed to be often reported as 'fuel oil' in the ETS data, but even when this is taken into account, the DUKES figures are still considered too low. The operators' data are used in the NAEI and split into consumption of 'waste oil' and 'fuel oil'. This split is determined by the independent estimates that are made for use of waste oils as a power station fuel (see below). Overall consistency between NAEI and DUKES for fuel oil is maintained by reducing the NAEI estimate for fuel oil consumed by the industrial sector compared with the figure in DUKES.
- Similarly, DUKES data for consumption of gas oil in power stations are also lower than data for recent years taken from EU ETS / UK ETS. As with fuel oil, a re-allocation of gas oil is made so that the NAEI is consistent with the ETS data for power stations, but also consistent with overall demand for gas oil, given in DUKES. The ETS data also shows that small quantities of burning oil are used at power stations, but DUKES does not include any data. The NAEI includes a similar re-allocation to that used for fuel oil and gas oil.
- DUKES does not include a full time series of consumption of petroleum coke as a fuel. Data are provided for:
    - the burning of catalyst coke at refineries in all years;
    - petroleum coke burnt at power stations for 2007 onwards.

[41] Detailed fuel reconciliation tables and explanations for deviations from UK energy statistics in compiling the UK emission inventories are presented in Annex 4 of the UK's National Inventory Report for submission of GHG emission estimates to the UNFCCC. The activity data that underpin GHG and AQ emission estimates are identical as the UK inventories are compiled and reported via a common database, within the National Atmospheric Emissions Inventory programme.

- NAEI activity data include estimates of petroleum coke burnt by power stations (based on data from industry sources and the EU ETS / UK ETS) which differ slightly from the data given in DUKES. Furthermore, activity data for refinery use of petroleum coke for 2005-2010, 2013, and 2015-2018 are based on EU ETS data, rather than DUKES, because the EU ETS figures exceed those given in DUKES and are regarded as more accurate. In the case of petroleum coke, it is not always possible to reconcile the NAEI estimates of total UK demand for petroleum coke with the data given in DUKES. The NAEI values for all sectors are based on detailed and generally reliable data sources such as ETS or trade bodies and in some years these data suggest higher UK demand than is given in DUKES. Because of the quality of the data and, as a conservative approach, the NAEI therefore deviates from DUKES and assumes that total use of petroleum coke (including non-energy uses) is higher than the DUKES demand figures for 1990-1991, 1999, 2001, 2005-2010, 2013, 2015-2018.
- The activity data for fuel gas use in the upstream oil and gas sector are under-reported in DUKES prior to 2001. From 2001 onwards, a new reporting system, the 'Petroleum Production Reporting System' (PPRS), has been used to compile the DUKES data on fuel gas use from upstream exploration and production. The long-term trend in DUKES indicates that fuel gas use by the oil and gas extraction industry increased by 20% between 2000 and 2001, but this step change is not a real reflection of increased activity but rather a reflection of the gap in DUKES fuel gas statistics for the upstream sector prior to PPRS. The EEMS data provides activity data and emissions from own fuel gas use at all offshore installations and onshore oil and gas terminals from 1998 onwards, and the trade association, UK Oil and Gas, has provided estimates for industry-wide activity and emissions for earlier years based on sector surveys in 1990 and 1991. These EEMS and UK Oil and Gas activity data are used in preference to the DUKES data for up to 2001, in order to present complete emission estimates in 1A1c.
- Furthermore, the DUKES data for operators' own use of fuel gas in the upstream oil and gas sector is also incomplete for later years in the time series, as the EEMS and (from 2005) ETS data also exceed DUKES data; this under-report in DUKES is primarily due to the use of process off-gases as a fuel at oil terminals. The UK inventory estimates for fuel gas use across the sector align with ETS data since 2005, and EEMS data up to 2004.
- DUKES data for refinery use of refinery fuel gas (referred to as "OPG" in DUKES) are lower than those reported within the ETS for most years of the recent time series. Analysis of the total reported emissions data from ETS (from 2005 onwards) from the activity data reported in DUKES and from the installation operators reporting to the UK Petroleum Industry Association (Fuels Industry UK) indicates that the gap in UK energy balance data is evident in most years from 2004 onwards. Therefore, in deriving estimates for the UK emission inventories, the refinery fuel gas activity is aligned with the data from the trade association (Fuels Industry UK) for 2004 and from ETS in all years where ETS data are higher than DUKES data, i.e. 2006-2011, and 2013 onwards.
- In the UK energy commodity balance tables presented in DUKES 2014 onwards, the DESNZ energy statistics team revised the energy / non-energy allocation for several petroleum-based fuels: propane, butane, naphtha, gas oil, petroleum coke. These revisions were based on re-analysis of the available data reported by fuel suppliers and the UK taxation and customs authority, His Majesty's Revenue and Customs (HMRC), but the revisions to DUKES were only applied from 2008 onwards. Therefore, in order to ensure a consistent time series of activity data and emissions in the UK

inventories, the Inventory Agency has derived (in consultation with the DESNZ energy statistics team) a revised time series for these commodities back to 1990, i.e. deviating from the published DUKES fuel activity totals for 1990-2007.

- The UK inventory shipping model, first published in 2017, generates bottom-up annual estimates of gas oil and fuel oil consumption from UK shipping based on detailed vessel movement data; these estimates are higher than the allocation of fuel use to shipping within DUKES, and are used in preference to DUKES.

3.1.4. NFR 1A1a: Power Stations

NFR Sector 1A1a is a key source in 2022 for NO_X, SO_X, $PM_{2.5}$, CO, Hg and HCB.

Electricity generation using fossil fuels is defined in the NAEI as consisting of a relatively small number of industrial sites. The main fossil fuels used are bituminous coal and natural gas. Approximately 58 PJ (net) of coal were burnt at 4 power stations during 2022 (down by around 16% from the previous year), while approximately 925 PJ (net) of gas were consumed at 41 large power stations and 4 small (<50MW_{th}) regional stations (the majority of larger gas plant are Combined-Cycle Gas Turbines, CCGTs). Gas oil or burning oil was used as the primary fuel by some power stations including a number of small new stations which provide short-term capacity for grid support. It is also used (primarily as a start-up or support fuel) for coal-fired or gas-fired power stations. Heavy fuel oil is no longer used as the primary fuel at any power station, although it too is used as a start-up and/or support fuel at coal-fired stations.

One of the gas-fired power stations has on occasions, burnt small quantities of sour gas as well as natural gas, with larger quantities being burnt in the 1990s. Several UK coal-fired power stations have trialled use of petroleum coke in the past, and at least some stations have on occasion burnt scrap tyres, bitumen emulsion, and coal slurry. None of these fuels has been used in the UK in recent years.

Biofuels are burnt as the primary fuel at a number of power generation sites to help electricity generators meet Government targets for renewable energy production including a number of former coal-burning boilers. A number of sites use wood, poultry litter or straw as the main fuel. Many coal-fired power stations also have co-fired biomass fuels to supplement the use of fossil fuels. The combination of biofuels, including solid biomass and biogas, used for electricity generation were reported to be 7,158 ktoe (gross) in 2022.

Electricity and/or heat is also generated at 75 Energy from Waste (EfW) plant in the UK (this number is expected to grow in the following years as new plant are commissioned). All UK mainland incinerators have generated electricity and/or heat since 1997; prior to that year at least some MSW was burnt in older plant without energy recovery, and emissions from those sites is reported under NFR 5C1a. It is not known if the waste incinerator on the Scilly Isles (which closed in 2014) recovered heat or generated electricity, but it was very small, and separate activity data are not available, so it is reported under 1A1 together with all other UK EfW plant, rather than separately under 5C1a.

All of the UK's EfW plant are regulated and have to report annual site emissions to the UK regulators for reporting in regulator inventories including the PRTR. Similarly, combustion plant >50MW_{th} also report annual site emissions to UK regulators. These data are used as the basis of NAEI emission estimates for the sector. For incineration and large combustion plant there are minimum requirements published in the EPR which include emission limit values (ELVs) and protocols for assessing compliance when using continuous emission monitoring systems to measure emission concentrations. These protocols include subtraction of measurement confidence intervals (a measure of uncertainty) from concentration data provided by continuous monitoring systems. Guidance on reporting annual emissions published by each of the UK regulators state explicitly that the confidence intervals must not be subtracted when generating annual emissions data (see box 2).

Box 2 *Guidance from UK Regulators on determining annual emissions from continuous emission monitoring data*

All state that: Confidence Intervals must not be subtracted from the average values generated from the raw emissions data, prior to calculation of annual mass emissions (unless part of an overriding written agreement with….[the regulator]).

England

Pollution inventory reporting: general and sector guidance here : https://www.gov.uk/government/publications/pollution-inventory-reporting-guidance-notesAlso sector specific guidance for incineration, Section 1, here : https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/923125/Pollution-inventory-reporting-incineration-activities-guidance-note.pdf

Scotland

Section 2.3 here : https://www.sepa.org.uk/media/162644/spri_release_estimation_techniques_ret.pdf

Wales

Annex 1, Section 1.b here : https://cdn.cyfoethnaturiol.cymru/media/688081/gn25-emissions-inventory-reporting.pdf?mode=pad&rnd=131947146700000000

Northern Ireland

Annex 1 Section 1.2 here : https://www.daera-ni.gov.uk/sites/default/files/publications/doe/pollution-guidance-niea-inventory-reporting-guidance-2016.pdf

In response to previous review questions, the UK Inventory Agency has sought further clarifications from UK regulatory agencies. The regulators have not identified any sites either among EfW plant or in other sectors, where permission has been given to operators to subtract confidence intervals, so we are therefore confident that the UK operator emission estimates reported to regulator inventories do not subtract confidence intervals.

Landfill gas and sewage gas are burnt to generate electricity and heat. At the end of 2022, there were over 600 sites utilising landfill gas or sewage gas to generate electricity. The UK also had around 660 sites where biogas from anaerobic digestion (AnD) of wastes from farming, food production or other industries is used to generate electricity.[42] These biogas sites were originally treated as power stations in the NAEI, but were subsequently reassigned to sector 1A2gviii. It is possible that some of the sites burning sewage gas, landfill gas could be more accurately described as auto generators, however we do not have information for the sites and so report all landfill gas and sewage gas use in the same way, in 1A1a. In the case of biogases from anaerobic digestion, we have assumed that these are far more likely to involve the provision of energy for use in industrial facilities and have therefore treated as industrial combustion.

Larger UK power stations burning fossil fuels are required to report emissions in the various regulators' inventories: The Pollution Inventory (PI), the Welsh Emissions Inventory (WEI), the Scottish Pollutant Release Inventory (SPRI), and Northern Ireland's Pollution Inventory (NIPI). The exceptions are a number of small power stations, typically providing electricity for grid support or to island communities, which burn either burning oil or diesel oil. Emissions from these non-reporting sites are relatively minor in the UK context, and emissions are estimated based on activity data from ETS or based on plant capacity information. Emission estimates for the sector are therefore largely based on the emission data reported for individual sites:

[42] https://www.nnfcc.co.uk/press-release-ad-report-2022

UK emission = Σ Reported Site Emissions

There are a few instances of sites not reporting emissions of some pollutants, generally because those emissions are below the reporting threshold, or because a site is closed down partway through a year and therefore does not submit an emissions report. In these instances, either reported activity data or plant capacity data are used to extrapolate emissions to cover any non-reporting sites; data gap-filling by extrapolation does not add substantially to emission totals, as the non-reporting sites are usually smaller, lower-emitting sites. For example, in the case of NO_X in 2021, reported emissions make up 99% of the total UK estimate for fossil fuel and biomass power stations, whilst the remaining 1% is estimated for sites where either there are no reported data, or where emissions are below reporting thresholds.

The methodology is complicated by stations burning more than one fuel; as far as possible the NAEI estimates are allocated to individual fuels. Therefore, for power stations, reported emissions are allocated across the different fuels burnt at each station. Plant-specific fuel use data are available either directly from operators, or obtained from EU ETS / UK ETS data held by UK regulators, or estimated from carbon emissions in a few cases where no other data are available. The allocation of reported emissions of a given pollutant across fuels is then achieved as follows:

1. Emissions from the use of each fuel at each power station are calculated using the reported fuel use data and a set of literature-based emission factors to give ‘default emission estimates’.
2. For each power station, the ‘default emission estimates’ for the various fuels are summed, and the percentage contribution that each fuel makes to this total is calculated.
3. The reported emission for each power station is then allocated across fuels by assuming each fuel contributes the same percentage of emissions as in the case of the ‘default emission estimates’.

The approach described above is used for most pollutants. However, in the case of emissions of POPs, reporting of emissions in the regulators’ inventories is limited (i.e. often incomplete reporting across installations) and/or highly variable. Therefore, for emission estimates of POPs the PI/SPRI/NIPI data are disregarded and emissions are calculated from literature emission factors and activity statistics.

Emissions data for NMVOCs and metals are quite scarce in the PI/WEI/SPRI/NIPI data sets, and therefore the emission factors generated using these data can show large year-on-year variations, particularly for power stations using burning oil, gas oil and poultry litter. These are relatively small plant and emissions of NMVOCs and metals are often below the reporting thresholds for the regulators’ inventories. However, these are also small-scale operations and so emissions are very small compared with UK emissions as a whole. The variation in emission factors for these sites does not therefore lead to substantial year-on-year variation in the total UK emission. The general approach described above is used for power stations burning coal, oils, natural gas and biomass as their primary fuel.

Emissions from EfW plant and MSW incinerators are also based on operator-reported data within the PI, WEI and SPRI. All reported emissions are allocated only to the combustion of the MSW, with no account being taken of any fossil fuels used to support combustion, as there are no data available on the use of fossil fuels at these sites. This methodological simplification will result in a minor inconsistency in the inventory, but its impact on UK estimates is small and it is not regarded as a priority for revision.

Emissions data are available back to 1988 in the case of NO_X and SO_X from major fossil-fuel powered stations. For NO_X, emission factors from Stewart & Walker (1997) are used for the years prior to 1989, while in the case of SO_X, factors for 1970-1987 are based on information provided by coal suppliers. The emission factors for NO_X and SO_X back to 1990 and for other pollutants back to 1997 are reviewed each year so that any changes in reported emissions, activity data, or underlying assumptions, are taken into account in recalculations. The emission factors for the remaining years in the time series (1970-1989 for NO_X and SO_X, 1970-1996 for most other pollutants) are based on a combination of the use of emissions data published by operators or supplied by regulators; use of UK-based literature emission factors; use of UK-specific fuel composition data; and use of emission factors derived from later UK emissions data.

Emissions data for EfW plant are available from the early 1990s onwards. Emission factors derived from the reported data in the early part of the time series are quite variable. Outlier emission factors are discarded as unreliable, and the estimates are associated with higher uncertainty than estimates from recent years. Gaps in the time series, and emission factors prior to the 1990s are filled either by extrapolating back emission factors from emissions data in later years, or by using literature factors.

Emissions of NO_X and SO_X from landfill gas engines and NO_X from sewage gas engines are based on emission factors derived using UK data or based on emission limit values for UK processes. Emissions of other pollutants from landfill gas and sewage gas engines are based on literature emission factors from the latest EMEP/EEA Guidebook or from AP-42 (US EPA, 2009). Several landfill gas and sewage gas sites have started to report emissions in the regulators' inventories in recent years. These data are not currently used to derive UK-specific factors, as the scope of reported installations is small and may not be representative. Furthermore, the scope of emissions reported by the sites that do report includes other emission sources (e.g. flaring) and hence source-specific estimates for the power generation source cannot be derived.

The NO_X emission factor for engines burning landfill gas and sewage gas is based on engines being typically $3MW_{th}$ and complying with the regulatory emission limit values appropriate for this size of plant. The SO_X emission factor for landfill gas engines is based on monitoring results for seven landfill gas engines (reported in Gregory, 2002).

Table 3-4 below illustrates the methodology by pollutant. To clarify the reporting scope, the metals reported within the NAEI for sector 1A1a where operator-reported data are primarily used to inform inventory estimates, the list of metals include: Hg, Cd, Zn, Pb, Cr, As, Cu, Ni, Se, V, Mn, and Be.

Table 3-4 UK Power Generation Emission Estimation Methodology by Pollutant

Fuels	Pollutant	Methodology
Coal & fuel oil (including use of Orimulsion and petroleum coke and co-firing of biomass)	NO_X	1990- latest year: O 1989: O/M 1970-1988: L
	SO_X	1990- latest year: O 1988-1989: O/M 1970-1987: F
	HCl (coal only)	1993-latest year: O 1992: O/M 1970-1991: E
	Pb	1997- latest year: O 1990-1996: O/M 1970-1989: E
	CO, NMVOCs, other metals, PM_{10}, dioxins, HF	1997- latest year: O 1993-1996: O/M 1970-1992: E
	PAH	1970- latest year: L
Sour gas	NO_X, SO_X	1992- latest year: O 1970-1991: not occurring
	CO	1997- latest year: O 1992-1996: L 1970-1991: not occurring
	NMVOCs, PM_{10}	1997- latest year: O 1992-1996: O/M 1970-1991: not occurring
	Dioxins, B[a]P	1992- latest year: L
Coal slurry	NO_X, SO_X	1994- latest year: O 1970-1993: not estimated separately, included with estimates for coal
	CO, NMVOCs, HCl, metals, PM_{10}, dioxins	1994- latest year: O 1994-1996: O/M 1970-1993: not estimated separately, included with estimates for coal
Natural gas	NO_X	1997- latest year: O 1992-1996: O/M 1970-1991: E
	SO_X	1997- latest year: O 1993-1996: O/M 1970-1992: not estimated
	CO	1997- latest year: O 1993-1996: O/M 1970-1992: E
	NMVOCs, Hg, PM_{10}	1997- latest year: O 1996: O/M 1970-1995: E
	Dioxins, PAH	1970- latest year: L
Gas oil	NO_X	1997- latest year: O 1994-1996: O/M 1970-1993: L
	SO_X	1997- latest year: O 1994-1996: O/M 1970-1993: F

Fuels	Pollutant	Methodology
	CO	1997- latest year: O 1996: O/M 1970-1995: L
	NMVOCs, metals, PM_{10}	1997- latest year: O 1970-1996: L
	Dioxins, PAH	1970- latest year: L
Poultry litter	All	1997- latest year: O 1992-1996: O/M 1970-1991: not occurring
Straw	All	2000- latest year: O 1970-1999: not occurring
Landfill/sewage gas	All	1970- latest year: L
All fuels	$PM_{2.5}$	1970- latest year: M (PM)

Key:
E - extrapolated from earliest factor based on operators' data
F - based on fuel composition data supplied by fuel suppliers
L - literature emission factor
O - based on operators' emissions data
O/M - combination of operators' emissions data and modelling using technology-specific literature emission factors
M - modelling using technology-specific literature emission factors
M (PM) - Modelled by combining PM_{10} emission estimates with $PM_{2.5}$ / PM_{10} ratios derived from emission factors for those pollutants, given in the EMEP/EEA Guidebook

3.1.5. NFR 1A1b: Refineries

NFR Sector 1A1b is a key source for SO_X.

The UK had eight oil refineries at the start of 2022, although two of these are small specialist refineries employing simple processes such as distillation to produce solvents or bitumen only. The remaining six complex refineries are much larger and produce a far wider range of products including refinery gases, petrochemical feedstock, transport fuels, gas oil, fuel oils, lubricants, and petroleum coke.

The crude oils processed, the refining techniques, and the product mix will differ from one refinery to another, and this will influence the level of emissions from the refinery, for example by dictating how much energy is required to process the crude oil.

All of these sites are required to report emissions to either the PI, WEI, or SPRI; there are no refineries in Northern Ireland. Additional data for CO, NO_X, SO_X, and PM_{10} are supplied annually by process operators via the Fuels Industry UK (formerly known as United Kingdom Petroleum Industry Association) (Fuels Industry UK, 2023). These data split the emissions[43] for the complex refineries into those from large combustion plant (burning fuel oil and refinery fuel gas) and those from processes (predominantly catalyst regeneration involving the burning of petroleum coke). Separate estimates of emissions of NMVOCs are also provided by Fuels Industry UK, from refinery process sources such as flares, tankage, spillages, process fugitives, drains/effluent, road/rail loading. Emission estimates for the sector are based on the emission data reported for individual sites:

$$\text{UK Emission} = \Sigma \text{ Reported Site Emissions}$$

The Fuels Industry UK data used in the NAEI extend back to 1999, and data for English and Welsh sites are available in the PI & WEI for the years 1998 onwards. Data for Scotland's refineries are reported in the SPRI for the years 2002 and 2004 onwards. Emissions data for NO_X and SO_X from the large

[43] The refinery category 1A1b is used for all fuel combustion related to refineries whether used to generate electricity, power or heat, and thus covers boilers, furnaces, engines, CHP etc. as well as the removal of coke deposits from catalysts in the regeneration sections of cat crackers.

combustion plant present on refinery sites is available back to 1990. Thus, emission factors are generally based on reported data back to 1990 for NO_X and SO_X, and back to 1998 for other pollutants. For earlier years, emission factors are generated by extrapolation from 1990 data for NO_X and SO_X, and 1998 data for other pollutants.

In recent years in the UK, there have been a number of changes within the refinery sector, including several closures and also several sites where ownership of the refinery and supporting plant (such as boilers and a combined heat and power (CHP) plant) have changed through mergers, acquisitions and divestments. This has made the tracking of the scope of installations in the refinery sector more challenging, and it is evident that reported data on energy use and emissions has (for some sites) become more inconsistent over time. As a result, the Inventory Agency has been working with the DESNZ energy statistics team to reconcile the UK ETS and DUKES data for the sector, to close out any differences in energy data (especially for petroleum coke and refinery fuel gases).

For the years covered by reported data, there are instances of individual sites not reporting emissions of some pollutants, generally because those emissions are below the regulators' inventories reporting thresholds or because a site had closed down partway through a year and therefore did not submit an annual emissions report to the regulator. However, DUKES has data on the capacity of each individual plant, so it is possible to extrapolate the emissions data to cover non-reporting sites as well. This extrapolation of data does not add substantially to emission totals. For example, for the 2011 and 2012 datasets, the Coryton refinery had closed in Q2 of 2012 and therefore did not return any detailed emissions data via UKPIA. The emission estimates for Coryton in the NAEI are therefore aligned with Pollution Inventory data, and source allocation of emissions is based on historic data and is somewhat more uncertain than for other refineries.

The methodology for the refinery sector is complicated by the fact that more than one fuel is burnt, as the NAEI seeks to report emissions from each fuel separately if possible. For crude oil refineries, reported emissions are either allocated to a single fuel (e.g. metal emissions are allocated to combustion of fuel oil) or else split across several fuels in the same manner used for power stations. Emissions of CO, NO_X, SO_X, and PM_{10} from catalyst regeneration involving the burning of petroleum coke are calculated directly from the data provided by Fuels Industry UK. The NAEI reporting scope for metals from 1A1b includes: Hg, Cd, Zn, Pb, Cr, As, Cu, Ni, Se, V, Mn, Be, Sn.

The approach described above is used for most pollutants, however in the case of POPs, reporting of emissions in the PI, WEI and SPRI is limited and/or highly variable, and therefore emissions are calculated from literature emission factors and activity statistics.

Activity data for the refinery sector are predominantly taken directly from DUKES (DESNZ, 2023a); however, the EU ETS / UK ETS data on energy use and emissions indicate an under-report in petroleum coke and refinery fuel gas use at UK refineries within the energy statistics, whilst there is close consistency between ETS and Fuels Industry UK emissions totals for carbon dioxide. Therefore, the ETS activity data for petroleum coke and refinery fuel gas are used in preference to DUKES, with amendments to the DUKES statistics back to 2004 inclusive in all years where ETS data are higher than DUKES (see also Section 3.1.3 above for further information).

3.1.6. NFR 1A1c: Other Energy Industries

NFR Sector 1A1c is a key source for NO_X.

The sector covers fuel combustion emissions from the production of manufactured fuels (coke, other solid smokeless fuels (SSF), town gas), coal extraction, oil and gas exploration and production, and to run compressors on the UK's natural gas distribution system (combustion emissions for gas pipelines are included in 1A1c because it is not possible to separate from other fuel uses in 1A1c).

Coke and Smokeless Solid Fuel Production

Most UK coke is produced at coke ovens associated with integrated steelworks, although independent coke manufacturers have also existed in the period covered by the inventory. In 2022, there were just two coke ovens at steelworks in the UK (Morfa and Appleby), following the closure of the Dawes Lane coke works in March 2016, two other coke ovens associated with the Teesside steelworks in 2015 and closure of the last independent coke oven in late 2014. We note that the Appleby coke ovens were shut in June 2023, however, as the current inventory report concerns the emissions of 2022, the impact from these closures will not yet be included. Solid smokeless fuels (SSF) can be manufactured in various ways but only those processes reporting in the PI and WEI are included in the inventory since these are the only processes for which we have emissions data. Currently, there are two such sites. Town gas was manufactured from coal but has not been used in the UK since 1988, after the closure of the last coal gas plant in the UK in 1987.

Table 3-5 UK Coke Ovens and SSF Manufacturing Plant in Operation, 1970-2022

Process type	Period	No. of plant
Coke ovens	2017-Latest year	2
	2015-2016	3
	2004-2014	6
	2003	7
	1993-2002	9
	1991-1992	10
	1970-1990	Insufficient data
Solid smokeless fuel manufacture	2006-Latest year	2
	2000-2005	3
	1997-1999	4
	1996	5
	1991-1995	6
	1970-1990	Insufficient data

All of these sites are required to report emissions in the PI or WEI. Emission estimates for the sector are based on the emission data reported for individual sites:

$$\text{UK Emission} = \Sigma \text{ Reported Site Emissions}$$

There are instances of sites not reporting emissions of some pollutants, generally because those emissions are below the reporting threshold. However, estimates can be made of the capacity of each individual plant, so it is possible to extrapolate the emissions data to cover non-reporting sites as well. This extrapolation of data does not add substantially to emission totals.

The methodology for this sector is complicated by the fact that more than one fuel is burnt, but the NAEI needs to record emissions from each fuel separately if possible. For coke ovens, process sources (i.e. other than fuel combustion) also lead to pollutant emissions, and the approach taken to allocate reported emissions to fuels and process sources varies from pollutant to pollutant.

The first approach is used for NO_X, where emissions are expected to occur mainly from combustion of coke oven gas (the main fuel used), with very minor contributions from the use of other fuels (blast furnace gas, colliery methane, natural gas) and from fugitive emissions from the coke oven. The approach relies upon the use of literature emission factors to estimate emissions from the minor sources. These emission estimates for the minor sources are then subtracted from the reported emissions data, with the remainder being allocated as the NO_X emissions from the coke oven gas.

Emissions of other pollutants may arise predominantly from process sources, or may arise from a combination of both fuel combustion and process sources, and the NAEI methods reflect that.

In the case of SO_X, emissions data are split between coke oven gas combustion and process sources using a ratio based on operator-reported emissions data for these sources from the mid-1990s. For CO, NMVOCs, PM_{10}, metals, B[a]P and PCDD/PCDFs, we have no detailed source- and fuel-specific emissions data on which to base a split and so all of the reported site emissions are allocated to a non-fuel specific source category covering both process and fuel combustion emission sources. These emissions are reported under NFR Sector 1B1b. The NAEI reporting scope for metals from 1A1c includes estimates from combustion of coal and gas oil using EFs that are primarily based on UK research into compositional analysis of those fuels (including Clarke & Sloss 1992; Wood 1996; Thistlethwaite 2001) or from US EPA defaults, and comprises estimates for: Hg, Cd, Zn, Pb, Cr, As, Cu, Ni, Se, V, Mn, Be, Sn.

Processes manufacturing SSF are relatively small compared with coke ovens, and the reporting of emissions is very limited in the PI and WEI as the annual emissions for most pollutants do not exceed the reporting thresholds, with only CO, NO_X and PM_{10} reported by operators on a regular basis. The reported emissions for these pollutants are allocated to a non-fuel specific source category. Emissions of other pollutants are estimated using literature emission factors, primarily taken from the EMEP/EEA Guidebook and several UK research reference sources from the early 1990s. These emissions are reported under NFR Sector 1B1b.

Gas Production (Downstream Gas)

Emissions from fuel use in the downstream gas production industry are primarily from natural gas use at compressor stations on the UK transmission and distribution network, downstream of the gas terminals where gas is injected to the UK pipeline network. This activity could be allocated to 1A3e but cannot be disaggregated from use in 1A1c without issues of data confidentiality from use of EU ETS / UK ETS statistics. For most years, the activity data for this source are taken directly from DUKES (DESNZ, 2023a); however, the ETS reporting system also provides activity data for natural gas use in compressor stations since 2005, and in some years the ETS data exceeds the natural gas allocation in DUKES. Therefore, in the NAEI we use the DUKES data unless ETS data are higher; where we use the higher ETS data, we re-allocate the difference from other sources in the inventory (1A2g, unclassified industry) in order that the overall UK gas balance in the inventory is consistent with UK energy statistics.

Default emission factors are generally applied, taken primarily from US EPA AP-42, the EMEP/EEA Guidebook and from UK industry research where it is available. The exception to this is emission factors for CO, NO_X, NMVOCs and particulate matter from the combustion of natural gas, for which Tier 2 emission factors, derived using the same approach as set out in Section 3.2.11.

Upstream Oil and Gas Exploration and Production (E&P) Sources

The NAEI includes emissions from all of the upstream oil and gas E&P sources, with emissions allocated to NFR source category 1A1c from all fuel combustion at offshore oil and gas platforms and floating production storage and offloading (FPSO) vessels, Mobile Drilling Units (MODUs), as well as from combustion sources at onshore terminals. Emissions from fuel use for the propulsion of ships servicing the oil and gas sector are reported under the Transport sector.

Offshore oil and gas facilities are regulated by DESNZ OPRED, whilst onshore facilities are regulated by the EA, NRW, and SEPA; there are no upstream oil and gas facilities in Northern Ireland.

Annual emission estimates from all offshore oil and gas facilities and onshore terminals are reported by operators to DESNZ, via the Environmental Emissions Monitoring System (EEMS) from 1998 to 2010; since 2010, offshore facilities still report to DESNZ via EEMS (DESNZ, 2023b), whilst for onshore terminals this reporting via EEMS is now voluntary, as it is regarded as duplication of the mandatory reporting of annual emissions by operators to the EA, NRW or SEPA under the EPR. For combustion of gas and gas oil, the EEMS dataset includes activity data and emission estimates for NO_X, SO_X, CO, NMVOCs and GHGs (CO_2, N_2O and CH_4).

The activity data for the emission estimates are taken from DUKES, except in instances where the data from ETS and EEMS reporting systems indicate that the UK energy statistics are under-reporting the activity (see Section 3.1.3 above).

Emission factors are derived based on the EEMS and PRTR operator reported emissions data. Emission estimates prior to 1998 are based on periodic studies by the trade association, Offshore Energies UK (formerly UK Oil and Gas, and before that the UK Offshore Operators Association), which were updated and reported to UK Government in February 2005 for emissions during the period 1990-2003 (UKOOA, 2005). Emission estimates of PM_{10} from use of gas oil and natural gas by oil and gas production facilities are derived using default factors from US EPA AP-42, while PM_{10} factors for fuel gas used at terminals are taken from the EMEP/EEA Guidebook.

Using the operator reported data as described above for EEMS, ETS and PRTR, the UK processes the data in its R/PostgreSQL based Offshore Platform and Terminal Inventory System (OPTIS) model. This Tier 2/3 model assigns emissions reported by each operator under the different reporting mechanisms to the categories combustion, flaring, venting, process sources and other fugitives, and then calculates the most appropriate emission at each source/activity level. At a site level, emissions are aligned to the reporting mechanism that reports the highest emissions to be conservative. For onshore sites, this is either EEMS or PRTR, but for offshore platforms the only reporting mechanism available is EEMS. Detailed commentary on the methods and datasets used for upstream oil and gas can be found in the Upstream Oil and Gas Improvement report (Thistlethwaite *et al*, 2022).

Other 1A1c Sources

Other emission sources reported under 1A1c include fuels used at collieries and fuels used at sites processing nuclear fuels; these are low-emitting sources in the UK context. The inventory method in all cases uses the UK energy statistics activity data and applies default emission factors from US EPA AP-42, the EMEP/EEA Guidebook or from UK industry research.

3.1.7. Source Specific QA/QC and Verification

The QA/QC procedure for this sector is covered by the general QA/QC of the NAEI in Section 1.6; however, specific additional QA/QC exists for 1A1.

The core publication for Activity Data is the annual DESNZ publication *The Digest of UK Energy Statistics* which is produced in accordance with QA/QC requirements stipulated within the UK Government's National Statistics Code of Practice, and as such is subject to regular QA audits and reviews.

Where emissions data are provided by plant operators to the UK environmental regulatory agencies (i.e. the EA, NRW, SEPA and NIEA) and reported via their respective inventories of pollutant releases (i.e. the PI, WEI, SPRI and NIPI) the data is subject to audit and review within established regulator QA systems. In England, the operator emission estimates are initially checked and verified locally by their main regulatory contact (site inspector), and then passed to a central Pollution Inventory/PRTR team where further checks are conducted prior to publication. Specific checking procedures include: benchmarking across sectors, time series consistency checks, checks on estimation methodologies and the use and applicability of emission factors used within calculations. Similar systems are being developed or in use by NRW, SEPA and NIEA, with some routine checking procedures already in place.

Further limited review of the data is undertaken by the NAEI team in order to identify any major outliers. The PI, WEI, SPRI and NIPI contain well in excess of 100,000 individual emissions data points covering thousands of sites, and at many sites, reported emissions are highly variable across the time series. Such variations may be due to factors such as changes in production rates, commissioning of new plant or closure of old plant within processes, changes in feedstocks or products, fitting of abatement, accidental releases (for example from failure of abatement systems) and many other factors that affect the operation of each facility. Furthermore, operators may change the methods used to estimate their emissions, e.g. using measurements rather than calculating emission estimates from literature emission factors. The inventory team is not in a position to be aware of the influence of all these factors, therefore it is assumed that most year-on-year variations in emissions data are a reflection of real changes in emissions, and emissions data are only rejected in a small number of cases where the reliability of the data seems to be particularly in doubt. For example, there are very rare occurrences where emissions of a pollutant in one year are more than a thousand times higher or lower than in other years for that site, and in these cases, it is generally assumed that there is a units error in the data. Conclusions from our reviews are periodically fed back to the regulators. Specific data inconsistencies are sometimes queried directly with the PI, WEI, SPRI and NIPI teams, site inspectors, operators or other technical experts within the regulatory agencies, to seek to resolve data-reporting errors and to ensure the use of appropriate data within NAEI outputs.

The OPTIS model conducts a number of QA/QC checks during the compilation of the sector estimates, including:

- Identification of new and closed terminals, platforms and MODUs;
- Gap-filling of operator reported data in EEMS where activity data is presented, but emissions are not, applying an appropriate default EF from industry guidance;
- Correcting reported data by operators on calorific values and fuel densities where the data is outside of a representative range (typically to amend order of magnitude units errors);
- Alignment to the highest reported operator data in EEMS or the RIs for onshore terminals; and
- Utilisation of reported activity data for combustion in EU ETS / UK ETS if the calculated site level emissions for CO_2 are within 2% of the reported ETS emissions.

3.1.8. Recalculations in NFR 1A1

The recalculations for 1A1 are primarily due to updates to the NMVOC emission factors within NFR 1A1c. This is as a result of migrating NMVOC calculations for a number of sectors to within the Industrial Scale Combustion model, which adopts a Tier 2 methodology. In this model, the size of combustion plant is taken into account to determine the appropriate weighted EF to use within the inventory.

Revisions to estimates arise where there are revised data in the energy statistics, or where new data impacts on gap filling approaches for plant level data.

3.1.9. Planned Improvements in NFR 1A1

Most of the emission estimates for 1A1 are generated from site-specific emissions data supplied by process operators for inclusion in regulators' inventories. The NAEI estimates are therefore only as good as the estimates supplied by the process operators. There are hundreds of UK installations within the scope of NFR Sector 1A1 that report annual emission estimates, and a high level of reporting emissions of many air pollutants (e.g. NO_X, SO_X, PM_{10}, metals, dioxins) from those sites. The data provision to regulators is governed by a QA/QC system including guidance on sampling and analysis methods and systematic checks by the regulators, prior to submitting the data to the Inventory Agency. Whilst the Inventory Agency cannot resource detailed checks for all of these data submissions every year, there are additional data consistency (across the time series, between sites, between pollutants) and completeness checks conducted. Further, for many sectors there are multiple parallel data reporting systems that enable some level of cross-checking, such as: (i) PRTR and EU ETS / UK ETS data;

(ii) PRTR data and Fuels Industry UK data for refineries, (iii) EEMS and EU ETS / UK ETS data for upstream oil and gas facilities. Therefore, the Inventory Agency considers the emission estimates for 1A1 to be associated with low uncertainty, and so this category is not regarded as a high priority for any major improvements.

Some sub-sectors within 1A1 consist mostly of smaller sites (for example power stations using gas oil or biomass as the primary fuel) which historically have not been required to report emission estimates to regulators. Therefore, for these smaller sites, the Inventory Agency applies gap-filling methods such as data extrapolation and assumptions using proxy data, in order to derive complete inventory estimates. The resulting emission estimates are therefore more uncertain and may vary from year to year due to the limited and variable input data.

Noting that the electricity supply market in the UK is changing, with greater numbers of smaller generators entering the market and an increasing shift towards use of renewable or waste-derived fuels, the data for smaller generator sites is regarded as a priority to improve the inventory estimates in future. However, the scope for inventory improvements is dependent on improvements in data availability and resolution, such as the data for renewables and waste-derived fuels within DUKES.

The Environment Agency have been in the process of re-permitting the refineries and hence there may be changes in the methods that the affected facilities will use to derive pollution inventory estimates. Discussions with the refineries and the trade body, Fuels Industry UK, are ongoing in order to understand the scope and magnitude of the potential changes.

3.2. NFR 1A2: Manufacturing Industries and Construction

Table 3-6 Mapping of NFR Source Categories to NAEI Source Categories: Stationary Combustion

NFR Category (1A2)	Pollutant coverage	NAEI Source category
1A2a Iron and Steel	All CLRTAP pollutants *(except* NH_3*, HCB)*	Blast furnaces
		Sinter production
		Iron and steel - combustion plant
1A2b Non-ferrous metals	All CLRTAP pollutants *(except* NH_3*)*	Non-ferrous metal (combustion)
		Autogenerators (coal)
1A2c Chemicals	All CLRTAP pollutants *(except* NH_3*, HCB)*	Ammonia production - combustion
		Methanol production - combustion
		Chemicals (combustion)
1A2d Pulp, Paper and Print	All CLRTAP pollutants *(except* NH_3*, HCB)*	Pulp, paper & print (combustion)
1A2e Food processing, beverages and tobacco	All CLRTAP pollutants *(except* NH_3*, HCB)*	Food & drink, tobacco (combustion)
1A2f Stationary combustion in manufacturing industries and construction: Other	All CLRTAP pollutants	Cement - non-decarbonising
		Cement production - combustion
		Lime production - non decarbonising
1A2gvii Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)	All CLRTAP pollutants *(except HCB, PCBs)*	NRMM: Construction
		NRMM: Generators
		NRMM: Mining and Quarrying
		NRMM: Waste
		MRMM: Other Industry
1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	All CLRTAP pollutants *(except HCB)*	Autogenerators
		Industrial engines (lubricants)
		Other industrial combustion

Table 3-7 Summary of Emission Estimation Methods for NAEI Source Categories in NFR Category 1A2

NAEI Source Category	Method	Activity Data	Emission Factors
Blast furnaces	UK model for integrated works	DUKES, EU ETS/UK ETS, ISSB	Operator reported emissions data for PRTR, plant-specific data from Tata Steel and British Steel. Default factors (EMEP/EEA, US EPA UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.
Iron and steel - combustion plant	UK model for integrated works; AD x EF	DUKES, EU ETS/UK ETS, ISSB	Operator reported emissions data for PRTR, plant-specific data from Tata Steel and British Steel. Default factors (EMEP/EEA, US EPA, UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.
Sinter production	UK model for integrated works	DUKES, EU ETS/UK ETS, ISSB	Operator reported emissions data for PRTR, plant-specific data from Tata Steel and British Steel. Default factors (EMEP/EEA, UK-specific research).
Non-ferrous metal (combustion)	UK model for activity allocation to unit type; AD x EF	DUKES, EU ETS/UK ETS, ISSB	Default factors (US EPA, EMEP/EEA, UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.
Ammonia production - combustion	AD x EF	DUKES, operator data: gas use for feedstock, combustion.	Operator data on annual NO_X emissions from combustion sources, Default factors (US EPA) for other pollutants.
Chemicals (combustion)	UK model for activity allocation to unit type; AD x EF	DUKES, EU ETS/UK ETS, ISSB	Default factors (US EPA, EMEP/EEA, UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.
Pulp, paper & print (combustion)	UK model for activity allocation to unit type; AD x EF	DUKES, EU ETS/UK ETS, ISSB	Default factors (US EPA, EMEP/EEA, UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.
Food & drink, tobacco (combustion)	UK model for activity allocation to unit type; AD x EF	DUKES, EU ETS/UK ETS, ISSB	Default factors (US EPA, EMEP/EEA, UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.
Autogenerators	UK model for activity allocation to unit type; AD x EF	DUKES, EU ETS/UK ETS, ISSB	Operator reported emissions data for PRTR. Default factors (US EPA, EMEP/EEA, UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.
Cement - non-decarbonising	AD x EF	Mineral Products Association clinker production data, EU ETS / UK ETS	PRTR annual reporting by operators, EFs derived via Inventory Agency model to allocate emissions across fuel combustion, non-decarbonising and process sources (i.e. between 1A2f and 2A1).

NAEI Source Category	Method	Activity Data	Emission Factors
Cement production - combustion	AD x EF	Mineral Products Association fuel use data, EU ETS / UK ETS	PRTR annual reporting by operators, default factors (US EPA, EMEP/EEA, UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.
Lime production - non decarbonising	AD x EF	EU ETS / UK ETS data, with extrapolation across time series using PRTR emissions data and production estimates from British Geological Survey.	PRTR annual reporting by operators, default factors (US EPA, EMEP/EEA, UK-specific research).
Other industrial combustion	UK model for activity allocation to unit type; AD x EF	DUKES (modified to accommodate other data sources such as MPA, EU ETS / UK ETS). EU ETS / UK ETS data (Other Petroleum Gases, OPG).	Default factors (US EPA, EMEP/EEA, HMIP, UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.
Industrial Engines	AD x EF	Lubricant use from DUKES and UK research	Fuel analysis (UK-specific research) for SO_X.
NRMM: Construction	AD x EF	Inventory Agency estimate of fuel use by different mobile units	Default factors (EMEP/EEA, US EPA, UK-specific research)
NRMM: Generators	AD x EF	Inventory Agency estimate of fuel use by different mobile units	Default factors (EMEP/EEA, US EPA, UK-specific research)
NRMM: Mining and Quarrying	AD x EF	Inventory Agency estimate of fuel use by different mobile units	Default factors (EMEP/EEA, US EPA, UK-specific research)
NRMM: Waste	AD x EF	Inventory Agency estimate of fuel use by different mobile units	Default factors (EMEP/EEA, US EPA, UK-specific research)
MRMM: Other Industry	AD x EF	Inventory Agency estimate of fuel use by different mobile units	Default factors (EMEP/EEA, US EPA, UK-specific research)

3.2.1. Classification of Activities and Sources

As with NFR sector 1A1, the source categories and fuel types used in the NAEI reflect those used in DUKES, although with some differences in detail. Fuels used in the inventory have already been listed in Table 3-3, whilst Table 3-6 relates the detailed NAEI source categories to the equivalent NFR source categories for 1A2. The NAEI source categories are the level at which emission estimates are derived, but reporting would not normally be at this detailed level, the NFR system being used instead for submission under the CLRTAP.

In most cases there is a precise mapping of an NAEI source category to a NFR source category. However, there are a few instances where the scope of NAEI and NFR categories is different because the NAEI source category is used for reporting both combustion and process-related emissions. These are ‘Cement - non-decarbonising’ and ‘Lime production - non decarbonising’, used to report emissions from cement clinker production and lime kilns respectively, and reported under 1A2f. In these cases, estimates are based on emissions data reported by operators which do not differentiate between combustion and process-related emissions (see Section 3.2.9) and so mapping of the NAEI source categories to a single NFR code is necessary.

Emissions for combustion in manufacturing industries and construction are disaggregated on an industry sector basis to categories 1A2a to 1A2g in the case of the most important fuels - coal, fuel oil, gas oil and natural gas. Data on the sectoral split of consumption for other fuels are insufficient to allow a similar disaggregation, and so all emissions from use of these fuels are allocated to 1A2g. One minor exception to this is for OPG, where fuel use is split between 1A2c and 1A2g. The chemical industry sector use of OPG is estimated from EU/UK ETS and other site-specific data, while data for 1A2g are taken from DUKES. The inventory estimates for the chemicals sector do include some additional resolution, with emissions estimated separately for natural gas combustion at ammonia and methanol production plant. This approach is necessary in order that the (installation-level) data on natural gas use for (i) combustion, and (ii) non-energy use as a feedstock, at the UK manufacturing facilities for ammonia and methanol can be accounted for accurately in the inventory, to avoid gaps and double-counts with the national energy balance for natural gas. Emission estimates for natural gas use within the source “Chemicals (combustion)” therefore cover all chemical sites other than those involved in producing ammonia and methanol.

Details of the methods used to disaggregate fuel data are given in see Section 3.2.3. Autogeneration using coal is reported in 1A2b since most of the coal burnt was, until March 2012, used at a single site which provided electricity for use at an aluminium smelter. Autogeneration using other fuels is reported in 1A2gviii.

Almost all of the NFR source categories listed in Table 3-6 are key sources for one or more pollutants and so the description of the methodology will cover the whole of this NFR sector.

3.2.2. General Approach for NFR 1A2

The following are all key categories for NFR 1A2:

- 1A2a; Stationary Combustion in Iron and Steel Industries – SO_X, CO
- 1A2f; Stationary Combustion in Mineral Products Industries – NO_X, Hg
- 1A2gvii; Industrial Off-Road Mobile Machinery – CO
- 1A2gviii; Stationary Combustion in Other Industries – SO_X, NO_X, CO, PM_{10}, $PM_{2.5}$, Pb, Hg, Cd, PCDD/Fs

Methods for 1A2 can be broadly divided into three types: those that rely solely on operator-reported emissions data for individual sites, those that rely solely on emission factors taken from inventory guidance and similar sources and UK national fuel use statistics, and lastly, those that use a combination of the two approaches.

Operator-reported emissions data can only be used in limited cases because such data are only available for larger emitters, and it is necessary for the NAEI to cover all UK emissions. Therefore, in order for operator-data to be used, it must be possible to extrapolate from the reported data to cover those plant for which we have no data, or to use some other approach to estimate emissions at those plant. In practice, this has limited the use of operator-reported data to a few sub-sectors of industry where all sites are large and report at least some data (so the need for extrapolation is very limited or not required at all):

- The cement and lime sectors are characterised by a small number of large kilns, all of which report emissions data in the PI, WEI, SPRI and NIPI, and therefore the NAEI estimates are derived from the aggregate of reported emissions, with some gap-filling assumptions applied for installations where the reported emissions fall below the reporting thresholds for regulatory inventory reporting (see 3.2.9).

- For integrated steelworks, emissions from burning of gases to heat blast furnaces are also calculated from reported data for SO_X and NO_X, with operators providing the estimates for individual plant (see 3.2.10). For other pollutant emissions there is less detailed and complete operator data, and therefore an approach using literature factors is applied.
- Emissions of CO and NO_X from OPG use in 1A2c are based on operator data reported in later years of the time series, with EFs extrapolated back for earlier years.
- NO_X from furnaces used in methanol and ammonia production are based on operator reported data for combustion emissions.
- Emissions of CO, NO_X, PM_{10}, most metals and PCDD/Fs from coal-fired autogeneration in 1A2b are based on operator-reported data for the single site that dominated consumption in the years to 2012. After 2012, this site converted to a power station and therefore an emission-factor approach has to be used for the remaining sites in the sector for 2013 onwards.

For all other sectors, there is a much more limited data set reported by operators and data are not available for the vast majority of sites. Extrapolation from reported data is difficult and so an emission factor approach is preferred. Emission factors are generally taken from the EMEP/EEA Guidebook although for SO_X, emission factors are derived from compositional analysis supplied by UK coal suppliers. In the case of NO_X, NMVOCs, CO, PM_{10}, $PM_{2.5}$, Black Carbon, Dioxins, PAHs, a hybrid method is used which allows for the use of some site-specific emissions data (for NO_X and PM_{10}) reported by operators, and the use of Tier 2 detailed emission factors where site-specific data are not available. This method is actually used for emissions from all 'industrial-scale' combustion, so including fuel reported within 1A1c, 1A4a and 1A4c as well as 1A2a-1A2g. The section 3.2 describes the approach for 1A2 therefore also explain the approach for those other NFRs.

For pollutants such as metals, halides, and other POPs, the emission factors are generally Tier 1 i.e. a single emission factor applied to all use of a given fuel across all subsectors within 1A2 (and 1A1c, 1A4a and 1A4c).

The following sections provide more details on the methodology for NFR 1A2. Section 3.2.3 describes the derivation of UK fuel consumption estimates. For the most part, these are combined with Tier 1 emission factors to produce emission estimates for pollutants other than NO_X and PM_{10}. Sections 3.2.9 and 3.2.10 describe the use of operator-reported data for cement and lime kilns, and blast furnaces respectively. Sections 3.2.11 and 3.2.12describes the NO_X and PM_{10} methodology introduced for the 2021 submission.

The 1A2g sector is sub-divided into combustion in stationary plant (1A2gviii) and combustion in off-road vehicles and mobile machinery (1A2gvii); the methodology for the latter sector is described with other transport-related sources, in section 3.3.7.

3.2.3. Fuel Consumption Data

Fuel consumption data are predominantly taken from DUKES (DESNZ, 2023a). However, there are some sources within the inventory where the NAEI energy data deviates from the detailed statistics given in DUKES, for the reasons presented in section 1.4.3. The most important deviations from DUKES in 1A2 are as follows:

1. The NAEI emission estimates for cement kilns and lime kilns are based on operator-reported emissions, but we assume that those emissions are partly due to the use of fuels at those sites. We estimate fuel used at the sites, and then remove this from the wider industrial fuel use data, so that there is no double-counting of emissions when we use emission factors to estimate emissions from that wider industrial fuel use. Fuel use data for cement kilns are

provided by the Mineral Products Association (MPA, 2023), and are also available from the EU ETS / UK ETS. The ETS data provides the basis for the Inventory Agency annual estimates of fuel used at lime kilns.

2. In some years, the NRMM model calculates the bottom-up gas oil use as being greater than that is available in DUKES. As the UK energy statistics are a top-down methodology, with a lesser degree of uncertainty, there is required to be a fuel reconciliation such that the fuel use is distributed to sectors appropriately.

   When there is not enough gas oil to allocate to bottom-up estimates, the new approach now adjusts all bottom-up off-road estimates, including agricultural off-road depending on the degree to which those bottom-up estimates agree with DUKES allocations to sectors which use those types of machinery. The logic of the new reconciliation approach can be summarised (as per Annex 4.2.1.4 in the NIR 90-21) as follows:

   - Separate out sources which should not be factored into the reconciliation (e.g. because they are well understood, like rail, or because the NAEI are deviating from DUKES for the sector as a whole, such as national navigation and port machinery), and establish the quantity of gas oil which is available for the sectors being reconciled
   - Always use the de minimis data from established (but likely incomplete) data, such as ETS on stationary fuel use
   - Always use off-road fuel use which coincides with DUKES allocations after removing the de minimis for stationary use
   - If there is not enough fuel in the DUKES balance to allocate to bottom-up off-road estimates, then scale the amount which exceed each DUKES sector. This effectively means that where the bottom-up estimates agree with DUKES, then there is no scaling, and there is more scaling when there is more disagreement
   - When there is enough fuel for all bottom-up estimates from the NAEI, split the remaining fuel by the residual of each sector which is not thought to be NRMM capped at the DUKES allocation to each sector.
   - If there is still fuel left in 'unallocated' after all fuel has been allocated in the previous step, then allocate this remainder to 'other industry'

   Note that port machinery is outside of the balance in DUKES, as this was considered as part of navigation/shipping. The reason for excluding shipping (covering national/coastal navigation, inland waterways and naval) is because the NAEI shipping improvement programme undertaken several years ago owed much higher consumption than in DUKES. This has been discussed with the DUKES team and has been accepted as a reason for deviating from DUKES.

3. Petroleum-based products used for non-energy applications can be recovered at the end of their working life and used as fuels. Waste lubricants, waste solvents, waste-products from chemicals manufacture, and waste plastics can all be used in this way. DUKES does not include the use of these products for energy, but consumption of waste lubricants and waste oils are estimated by the Inventory Agency for inclusion in the NAEI. The EU ETS / UK ETS presents data for a number of chemical and petrochemical manufacturing plant where process off-gases that are derived from petroleum feedstock materials (primarily ethane, LPG and naphtha) are burned in the plant boilers. The use of these off-gases as fuels is not reported within DUKES, whilst the original feedstock provided to the installations are reported as "non-energy use". Therefore, in the UK inventories emission estimates are based on reported ETS activity data for these installations (for 2005 onwards), with estimates for 2004 and earlier based on overall installation reported data to regulators (if available) and plant capacity data for instances where there are no operator-reported data.

4. DUKES does not include a full time series of consumption of petroleum coke as a fuel. Data are provided for petroleum coke burnt by unclassified industry from 2008. Prior to that, all petroleum coke (other than that burnt in refineries) is reported in DUKES as being used for non-energy applications. Petroleum coke is, however, known to have been used as a fuel in cement kilns and elsewhere in industry. Therefore, the Inventory Agency estimates petroleum coke use as fuel in NFR 1A2. In the case of petroleum coke, it is not always possible to reconcile the NAEI estimates of total UK demand for petroleum coke as a fuel, with the data given in DUKES, since the NAEI total exceeds the DUKES figure in some years. The NAEI figures are retained however, because they are based on more detailed data sources than DUKES and are more conservative.
5. In the UK energy commodity balance tables presented in DUKES 2014, the DESNZ energy statistics team revised the energy / non-energy allocation for several petroleum-based fuels: propane, butane, naphtha, gas oil, petroleum coke. These revisions were based on re-analysis of the available data reported by fuel suppliers and HMRC, but the revisions to DUKES were only applied from 2008 onwards. Therefore, in order to ensure a consistent time series of activity data and emissions in the UK inventories, the Inventory Agency has derived (in consultation with the DESNZ energy statistics team) a revised time series for these commodities back to 1990, i.e. deviating from the published DUKES fuel activity totals for 1990-2007.
6. Emissions for manufacturing industries and construction are disaggregated by industrial sector for separate reporting to categories 1A2a to 1A2g for coal, fuel oil, gas oil, natural gas and biomass. Full details of the methods used to generate the activity data are given below.

3.2.4. Coal

Fuel use in NFR sector 1A2f only covers the consumption in cement kilns and lime kilns, for which the Inventory Agency make estimates based on data from the Mineral Products Association (MPA) and ETS, as outlined above. For fuel use in the rest of 1A2, DUKES contains data on the use of coal by subsector for the whole of the period 1990-2021, although there are some changes to the format of data over this time series. The data for the period 1997-2000 indicates large step changes in the use of coal by some sectors, including a shortfall in coal allocated to the mineral industry between 1997 and 1999, compared with the independent estimates for fuels used for cement and lime production.

The Inventory Agency has reviewed data including the fuel use estimates provided by the cement industry; clinker production data, site closures and new site construction, site capacity, the choices of fuel available to the cement industry and installation permit documents indicating the choice of fuels in the early to mid-1990s. This evidence is consistent with a gradually changing cement industry as opposed to the step changes seen in the time series compiled from the DUKES data between 1997 and 2000. Therefore, the independently derived estimates for coal used by the cement sector are used in preference to the DUKES time series, with equal and opposite deviations made for the rest of the 1A2 sources in order to maintain the overall balance of coal use reported in the industry sector. Although the lime sector has not been reviewed in detail, there were no plant closures over that period and there is no evidence to support any major changes in that industry either. In this case independently derived estimates for the lime sector are again used. It is probable that other users within the mineral products sector will also burn coal e.g. a number of brickworks. A comparison of the DUKES data for 1996 and 2000 and the independently derived data for cement and lime production suggest that these other processes used substantial amounts of coal in those years. However, in the absence of further data, we have not attempted to generate coal consumption estimates for brickworks and other mineral processes for the years 1997-1999.

In summary, for the period 1990-1996, fuel consumption data taken directly from DUKES have been used for sectors 1A2a to 1A2e and 1A2g. DUKES data are also used from 2000 onwards. In the intervening years, the DUKES industry sector totals only have been used, together with figures for 1A2f, which are consistent with the independent cement and lime industry emissions data. Estimates for 1A2b to 1A2e, and 1A2g are then derived from the difference between the DUKES industry totals and the independent cement and lime data, with the split between the five industry sub-sectors being based on a linear interpolation between the splits in 1996 and 2000.

3.2.5. Natural Gas

As with coal, separate estimates are made for fuels used in cement and lime kilns and those estimates constitute the data for 1A2f. Fuel consumption data for 1A2a to 1A2e are taken directly from DUKES. 1A2g then makes up the rest of the industry sector and the fuel consumption total is consistent with that in DUKES. 1A2g is also used as a balance, in cases where we have deviated elsewhere from DUKES and then need to make adjustments elsewhere in order to maintain overall consistency with DUKES. For example, the natural gas use allocation in the inventory in NFR 1A1c for gas compressors in the downstream gas distribution network is estimated based on data reported by operators under UK ETS. The data from UK ETS exceeds the allocation for this source within DUKES, and therefore some natural gas is re-allocated from 1A2g to 1A1c, retaining the overall UK gas demand total, but rectifying the evident under-report (in DUKES) for 1A1c.

3.2.6. Fuel Oil

Fuel consumption data for 1A2a to 1A2e are taken directly from DUKES. 1A2g makes up the rest of the industry sector after re-allocations to 1A1a (see Section 3.1.3), and the UK demand figure for fuel oil in the NAEI is consistent with that in DUKES, other than for the shipping sector (see section 3.3.4).

3.2.7. Gas Oil

Gas oil is used in both off-road transport and machinery diesel engines, and as a fuel for stationary combustion. DUKES provides a breakdown of gas oil consumption in different industry and other sectors but does not distinguish between use of the fuel for stationary combustion and off-road machinery, a distinction which is necessary for the inventory.

The independent estimates of industrial gas oil use that are made by the Inventory Agency are disaggregated across 1A2b to 1A2e and 1A2g using detailed sector-level data from DUKES.

3.2.8. Biomass

Data for biomass are taken from DUKES. They were formerly aggregated into category 1A2gviii, however, as more resolved data has become available through the energy statistics, the NAEI is now able to reflect the allocation to each of the categories within 1A2. DUKES contains two categories for biomass, plant, and animal. Plant biomass includes straw, short rotation coppice (SRC), and other plant based biomass. Animal biomass includes poultry litter and meat and bone.

3.2.9. Methodology for Cement and Lime Kilns

The UK had 10 sites producing cement clinker during 2022. The main fuels used are coal and petroleum coke, together with a wide range of waste-derived fuels. However, use of petroleum coke is declining and use of waste-derived fuels is increasing. One of these sites produces both cement and lime, and since process emissions are not available separately for the two parts of that installation, all emissions are reported as being from cement production. Lime was produced at 11 other UK sites during 2022, however one site produces lime for use on-site in the manufacture of soda ash via the Solvay process, so emissions for that site are reported under 2B7. Four of the remaining sites produce lime for use on-site in sugar manufacturing, and one other site produces dolomitic limes. UK lime kilns use either natural gas, anthracite or coal as the main fuel.

All cement and lime kilns are required to report emissions in the PI, WEI, SPRI, or NIPI, hence emission estimates for the sector can be based on the emission data reported for the sites:

$$\text{UK Emission} = \Sigma \text{ Reported Site Emissions}$$

There are instances of sites not reporting emissions of some pollutants, either where emissions are below the reporting threshold, or because a site closed down partway through a year and therefore did not submit an emissions report. However, good data are generally available on the capacity of each individual plant, so it is possible to extrapolate the emissions data to cover non-reporting sites. This extrapolation of data does not add substantially to emission totals.

Each UK cement works typically burns a wide range of fuels, with pollutant emissions derived from each of the fuels and process emission sources also. It would be impractical to allocate emissions to each of these numerous sources; therefore, all emissions are reported using a single, non-fuel specific source category. All lime kilns burn either a single fuel such as natural gas or, in a few cases, burn a range of fuels (similar to cement kilns), so reported emissions of CO and NO_X are allocated to a single source-category for each facility, based on the main fuel burnt at each site. Note that in the case of coal this leads to quite variable emission factors, due to the fact that some of the kilns that burn coal also burn varying amounts of other fuels. As a result, the trends in emissions do not always mirror the trends in coal burnt. PM_{10} is also emitted from process sources at lime kilns, as well as from fuel combustion, so this pollutant is reported using a non-fuel specific source category.

3.2.10. Methodology for Blast Furnaces

Emissions data for the period 2000-2022 are supplied by the process operators (Tata Steel, 2023; British Steel, 2023). In the case of NO_X, emissions are allocated to the 'hot stoves' which burn blast furnace gas, coke oven gas, and natural gas to heat the blast air, and emission factors calculated using gas consumption data given in DUKES. The same emission factor is assumed to be applicable for each type of gas. For other pollutants, reported emissions are allocated to a non-fuel specific source category which is reported under NFR category 2C1.

For the period 1998-1999, emissions data are available from the PI; however, they do not distinguish between emissions from the various sources on each steelmaking site (combustion plant, blast furnaces, sinter plant etc.). Therefore, the detailed emission breakdown for 2000, supplied by the process operator, has been used to generate source-specific emissions data for 1998 and 1999, which are then allocated to fuels as normal.

Emission factors calculated from the 1998 emissions data are also used for the earlier part of the time series, despite the Pollution Inventory containing some emissions data for some pre 1998 years. The 1998 factors are used in preference because of the limited number of pollutants which are reported in earlier years, and because some of the emissions that are reported prior to 1998 are very much lower than the emissions reported in subsequent years. The Inventory Agency is not aware of any other evidence to suggest that emissions in earlier years would be vastly lower than from 1998 onwards (e.g. steel production and fuel consumption were higher in the earlier years). Therefore, the emissions data from the earlier years of the time series have been disregarded, and a conservative approach to estimating emissions (i.e. using factors derived from 1998 onwards) has been adopted.

3.2.11. Methodology for Disaggregating Fuel Use in Industrial-Scale Combustion Plant

As previously described, consumption of coal, fuel oil, gas oil and natural gas is estimated separately for 1A2a through to 1A2g, whereas for other fuels such as coke oven coke, LPG, and burning oil, all industrial fuel use is reported in 1A2g. For most pollutants, the NAEI then relies on Tier 1 or Tier 2 emission factors applied to the various sub-divisions of 1A2 to estimate emissions. Where Tier 1 factors are used (mainly for metals and halides), the methodology cannot account for differences in technologies or levels of abatement within sectors or between sectors. This is not the case for the remaining pollutants where Tier 2 factors are used and details of the methodology for these pollutants follows in this and the following section.

From the 2021 submission onwards, the Inventory Agency has used a more complex methodology to estimate emissions of NO_X and PM_{10} from industrial-scale combustion. For the 2024 submission this more complex method is extended to CO, NMVOCs, $PM_{2.5}$, Black Carbon, dioxins and PAH. This methodology is used for much of 1A2 but also within 1A1c, 1A4a and 1A4c, sectors which also involve the use of combustion plant at an ‘industrial’ scale i.e. intermediate in scale between residential combustion and very large plant used for public power generation. For convenience, the text here covers the new methodology as used in all these NFR categories. The original methodology for NO_X and PM_{10} uses a combination of Tier 2 and Tier 3 factors, although the latter apply to only a very small proportion of the fuel use. For the pollutants added to the method for this submission, we use only Tier 2 emission factors.

UK energy statistics only provide data on total use of fuel by economic sector. They do not provide any information on the proportions of fuels burnt using different technologies or give separate figures for large, medium and small combustion plant (LCP, MCP and SCP respectively). Therefore, a method for allocating national fuel consumption data to plant of different sizes and types is necessary so that higher tier methods can be used. The method does this as far as is possible with datasets that are currently available for the UK. The starting point was the development of fuel consumption estimates for larger plant using:

- Fuel use data reported by operators of LCPs, which are regulated under the Environmental Permitting Regulations (EPR);
- Fuel use reported for installations covered by the UK ETS (these will include LCPs, larger MCPs, and other large combustion plant such as offshore combustion plant, kilns, furnaces and, dryers). In the context of 1A2, the scope of UK ETS will be:
    - stationary combustion installations with a total rated thermal input exceeding 20 MW but excluding individual units with a rated thermal input under 3 MW and units which use exclusively biomass;
    - combustion associated with certain industrial processes such as production of metals and mineral products such as glass and bricks.

The EU ETS / UK ETS dataset should include all the sites that are in the LCP dataset, therefore the two were compared in order to try to identify any major outliers. The comparison was not always straightforward - for example, there can be differences in the scope of the installations in the two datasets, so there can be good reasons for differences in fuel use reported in the two datasets. But the comparison of LCP and ETS datasets was valuable in that it did allow a number of extreme outliers to be identified. In a small number of cases, a disparity between LCP and ETS data was only seen in certain years and was in those years so extreme that the difference could be assumed to be due to error. The ETS data have all been independently verified and therefore we have confidence that this dataset is highly reliable, so the ETS data were generally adopted in these cases as the more likely to be correct. In most cases, the comparison of LCP and ETS data indicated either agreement or that there were relatively small differences, perhaps linked to small differences in scope.

The ETS dataset covers a far larger number of facilities - these will be facilities where the combustion is on a scale and of a type to fall within the scope of ETS, but which will not be LCPs. So, by comparing fuel consumption given in the LCP dataset and ETS, estimates of fuel consumed in LCPs and non-LCP devices were generated. Many installations appear in ETS only, so fuel use in these installations can be allocated to non-LCP devices. The non-LCP devices will cover a wide range of sizes and types but for the purposes of the inventory were assumed to be either large or medium-sized furnaces, dryers or similar devices, or boilers, engines or gas turbines at the larger end of the range covered by the Medium Combustion Plant (MCP) Directive. Thus, the analysis of the LCP and ETS datasets allows the generation of fuel use estimates for LCPs on the one hand, and a category made up of larger MCPs with large/medium-sized furnaces/dryers on the other hand.

The installations in the LCP and ETS datasets were allocated to the twenty-four sectors listed in Table 3-8.

Table 3-8 LCP and ETS installation categories

LCP and ETS installation categories	
Gas distribution	Chipboard
Gas terminals	Glass
Oil terminals	Plaster
Offshore oil & gas	Roadstone coating
Gas separation (use of OPG)	Minor power producers
Steelworks	Autogeneration
Other steel	Other industry
Non-ferrous metals	Data centres
Chemicals	Commercial
Paper	Public
Food & drink	Railways
Brickmaking	Agriculture

Fuel consumption for LCPs, and for large MCPs/furnaces etc. was then compared with total UK fuel consumption for the related category in the NAEI. By difference, the quantity of fuel used in small MCPs/small furnaces/small combustion plant <1MW thermal input (SCP) was then calculated. These small plants will include MCPs that are <20MW_{th} as well as units that are <3MW_{th}.

The final output for these calculations is a set of assumptions on how to split activity data for each fuel and sector into three components:

1. LCPs
2. Larger MCPs and larger furnaces/kilns/dryers
3. Small MCPs, smaller furnaces/kilns/dryers, and SCPs

There were a few instances where the activity data for LCPs and large MCPs together exceeded the fuel consumption given in DUKES. In all such cases a correction was applied to both large and medium plant sufficient to bring total fuel use down to align with DUKES data. These exceedances only occurred for minor fuels and they were on a reduced scale relative to UK fuel use as a whole. The analysis covered the years from 2005 to 2021, this being the period for which data were available. Although updates should allow this to be extended in future, for the current submission, we assume the same split in 1990-2004 as in 2005, and the same split in 2022 as in 2021.

The LCP and ETS data cover a wide range of fuels and some of these fuels are used in quantities that are relatively small relative to total UK consumption. Therefore, we identified those fuels where use across all sites in the LCP/ ETS data was less than 0.5% of UK consumption of that fuel. In these cases we considered there was little merit in separating out large, medium and small plant and so for these fuels, which included kerosene and LPG, we continued to treat all fuel use as a single entity, and continued to use a Tier 1 approach.

3.2.12. Estimation Method for Industrial-Scale Combustion

The previous section describes how UK energy statistics for industrial-scale plant were disggregated into 24 sectors, each of which was further sub-divided into three groups, on the basis of the size of the installation. Emissions of each pollutant were then separately estimated for each of these sectors and groups. The approach is described in detail below for each of the three group types in turn.

3.2.13. Large Combustion Plant

In the case of NO_X and PM_{10} only, a combination of Tier 2 and Tier 3 methods is used for LCPs. Emissions data are available for many LCPs, particularly for NO_X. Many LCPs are gas-fired and there is little reporting of PM_{10} for these sites. Emission estimates for LCPs are therefore derived by using operator-reported data for those sites where it is available and using Tier 2 emission factors from the EMEP/EEA Guidebook (chapter 1A1, suitable for large combustion plant) for the rest. Emissions data are mostly those submitted to the PRTR by operators under their obligations under the EPR but some additional data were sourced in the various inventories maintained by the UK regulators. For the remaining pollutants (NMVOCs, CO, $PM_{2.5}$, Black Carbon, Dioxins, PAHs), Tier 2 factors from the EMEP/EEA Guidebook are used exclusively.

3.2.14. Large/Medium Furnaces and Large MCPs

Once again for NO_X and PM_{10} only, a combination of Tier 2 and Tier 3 methods is used for these processes, but with a greater reliance on Tier 2 methods due to the relative scarcity of operator-reported emissions compared with LCPs. For other pollutants, a Tier 2 method is used.

Tier 3 NO_X and PM_{10} emissions data were available from two main sources:

- Emissions data provided directly by UK steel manufacturers for the rolling mill furnaces operated at the steelmaking facilities at Scunthorpe, Port Talbot and Teesside.
- Emissions data from the PRTR for combustion at plant making chipboard and similar wood-based products and for glass kilns.

For all other sectors, and for emissions of other pollutants, we have insufficient operator-reported emissions data to generate robust emission estimates and so for those sectors we use factors from the EMEP/EEA Guidebook, with the selection of factors being made based on the size of plant and the likely technology. Wherever possible we have used EMEP/EEA Guidebook Tier 2 factors. One important distinction should be noted: we have generated estimates of fuel use by fuel type and economic sector. Whereas Guidebook factors relate to fuel type and combustion technology. Therefore, in order to decide which Guidebook factor should be used, a judgement about the types of combustion technology has been applied for each sector. The Guidebook recognises different types of technology: boilers (of different sizes), gas turbines and engines. So, for each sector / fuel, we applied expert judgment to decide which of those types of technology is typically used. In a small number of sectors, we have assumed a combination of technologies. But this approach is used sparingly, since we have no data to allow us to quantify the usage of the different technologies, and we can therefore only make expert judgements.

Some fuels will only be used with certain technologies - coal and fuel oil will only be used in boilers and furnaces, and coke oven coke will only be used in furnaces. But natural gas and gas oil can be used in the full range of technologies, and the choice of factor can have a big impact on emission estimates.

Many sectors are likely to use multiple types of technology, so the choice of appropriate technology is difficult. As mentioned above, we have occasionally assumed a combination of technologies (a 50/50 split of two technologies) but for most sectors we select the most ‘typical’ technology.

The EMEP/EEA Guidebook does not have emission factors for every combination of fuel and technology. In particular, there will be use of fuels in furnaces, kilns, dryers and other devices where the combustion gases are in direct contact with materials, and the Guidebook does not always have emission factors that are specific for this type of fuel use.

There are no specific emission factors for devices that use heat directly in sectors such as the chemical, paper, and food and drink sectors. Devices in these sectors will generally burn fuel such that there is no contact between the combusted fuel and the materials being heated. In these cases, we consider it reasonable to apply emission factors for boilers, on the basis that burner technology in a furnace is similar to that applied in a boiler. Clearly there will be exceptions including direct contact drying and, use of cogeneration plant with engine or gas turbines to provide heat.

The methodology currently assumes the same technology or technology split is used in each sector across the 2005-present time series.

Smaller plant

Smaller MCPs, smaller furnaces/kilns etc., and SCPs - often cover a wide range of installation types and sizes. For offshore oil and gas and autogeneration, we have assumed that certain appliance types dominate for each fuel to allow application of Tier 2 emission factors. For example, engines for offshore gas oil use and boilers/furnaces for offshore gas use, engines for autogeneration gas oil and gas use. For fuel oil generally, we have assumed that the fuel is used in boilers or furnaces and used emission factors for boilers. For coal use, we have adopted factors for small (<1 MW_{th}) boilers. For the remaining sectors and fuels, we have used the same Tier 1 factors for combustion in industry as used in previous submissions.

Choice of emission factors

The selection of Guidebook factors was reviewed as part of the process to include additional pollutants and this review led to one significant change to the factors used for industrial-scale combustion of biomass. The previously used factors were consistent with manually-fed boilers but the review concluded that the UK population of biomass boilers would be automatically-fed. Consumption of biomass by UK industry has increased markedly from relatively trivial levels ten years ago, and it seems highly likely that this large increase in demand would be due to the use of new combustion appliances which are unlikely to be manually-fed. The Guidebook factors for automatically-fed boilers are lower than those used previously so this change in factor selection results in a revision to the $PM_{2.5}$ emission estimates for biomass combustion – see recalculations section below.

3.2.15. Source specific QA/QC and Verification

The QA/QC procedure for this sector is covered by the general QA/QC of the NAEI in Section 1.6, with specific additional QA/QC for 1A2 outlined here.

Allocations of fuel use are primarily derived from DESNZ publications that are subject to established QA/QC requirements, as required for all UK Accredited Official Statistics. For specific industry sectors (iron and steel, cement, lime, autogeneration) the quality of these data is also checked by the Inventory Agency through comparison against operator-supplied activity and emissions information and energy use data obtained from the UK ETS. As discussed above, there are instances where such information has led to amendments to the fuel allocations reported by DESNZ, through fuel re-allocations between sectors whilst retaining overall consistency with total UK fuel consumption.

Some emission estimates for 1A2 rely upon emissions data reported in the PI, WEI, SPRI and NIPI. Section 3.1.7 discusses QA/QC issues regarding these data.

3.2.16. Recalculations in NFR 1A2

The main recalculations for 1A2 emissions by pollutant are as follows:

NO_X emissions within 1A2 have been reduced across the time series, as burning oil use has been disaggregated where possible into sources within NFR categories 1A4ai and 1A4ci, to better align with the allocations in DUKES. In addition, recalculations to DUKES impact the more recent years.

SO_2 is predominantly impacted in the more recent years, as a result of incorporating revisions presented in DUKES. Additionally, the treatment of sites which report emissions below the Regulatory Inventories reporting thresholds continues to be improved.

NMVOCs have been revised, as through incorporating the estimation of emissions from this pollutant within the Tier 2 Industrial Scale Combustion method, emission factors were reviewed. This had the impact of incorporating a historic factor from the US EPA for natural gas consumption with a more reliable Tier 2 factor from the EMEP/EEA Guidebook which increased emissions. This increase is offset partially through the improvements made to how combustion of biomass is handled within 1A2 (see below).

$PM_{2.5}$ was also incorporated into the Tier 2 Industrial Scale Combustion method. As part of this, the assumptions regarding the type of appliance that biomass is combusted in were revised – due to the rapid growth in biomass in the recent past, it is assumed that Tier 2 EMEP/EEA factors relating to combustion in automatic boilers are more appropriate than the previously used Tier 1 factors, which are more representative of manually-fed boilers. Emissions of $PM_{2.5}$ (and NMVOC) are reduced in 1A2gviii, as a result of removing a double count with category 2I – this is because $PM_{2.5}$ and NMVOC emissions from the combustion of waste wood (labelled as wood) are already estimated through a Tier 3 operator-reporting method from data provided by the chipboard industry. Further to this, $PM_{2.5}$ is impacted by the changes to burning oil as mentioned in the NO_X section above.

All pollutants are impacted as a result of the disaggregation of NRMM sources into a greater range of NFR categories – this decreases emissions captured within 1A2gvii, but leads to increases in categories such as 1A4aii.

Additional minor recalculations for most pollutants occur due to revisions to the activity data in DUKES and in some cases to revisions to the time series of fuel calorific values (CVs) used to convert DUKES data in mass terms to energy terms.

3.2.17. Planned Improvements in NFR 1A2

With some exceptions, the emission estimates for 1A2 are derived using literature emission factors. This ensures that the UK inventory approach is transparent and, through the use of EMEP/EEA Guidebook defaults, based on inventory good practice. The emission factor approach is augmented by site-specific emissions data reported by operators where this is practicable. The UK approach therefore takes some account of UK-specific or site-specific factors such as differences in abatement levels, fuel composition, or combustion appliance design compared with the 'typical' situation which the default factors represent. But this is limited by the availability of data and, as a result, emission estimates for 1A2 are relatively uncertain.

The Tier 2 Industrial Scale Combustion has improved the quality of emission estimates. Further refinement of the method for these pollutants would require new data to be collected, however the phased permitting of medium combustion plant will ensure that should increasingly be the case. Therefore, improvements to the methodology should be possible in future submissions using data provided to the Inventory Agency by regulators. The collection of data is still at a fairly early stage so no plans have yet been made for improving the methodology but improvements are seen as a priority. We will therefore continue to monitor the available data and will evaluate what potential there is to incorporate new data and to improve the methodology and estimates.

3.3. NFR 1A3: Transport

This section and Table 3-9 below cover NFR category 1A3 in full plus other types of mobile machinery and non-road transport included under NFR categories 1A2, 1A4 and 1A5.

Appendix 2 outlines the original sources of the PM emission factors used in the transport sector and whether they include or exclude the condensable component.

Table 3-9 Mapping of NFR Source Categories to NAEI Source Categories: Transport

NFR Category	Pollutant coverage	NAEI Source category	Source of Emission Factors
1A2gvii Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)	All CLRTAP pollutants	Industrial off-road mobile machinery	EMEP/EEA Guidebooks
1A3ai(i) International Aviation (LTO)	All CLRTAP pollutants (except NH_3 and all POPs)	Aircraft - international take-off and landing	UK literature sources
		Aircraft engines	
		Overseas Territories Aviation - Gibraltar	
1A3aii(i) Civil Aviation (Domestic, LTO)		Aircraft - domestic take-off and landing	
		Aircraft between UK and Gibraltar - TOL	
1A3bi Road transport: Passenger cars	All CLRTAP pollutants *(except PCBs)*	Petrol cars with and without catalytic converter (cold-start, urban, rural and motorway driving)	UK factors, Fuels Industry UK, or factors from COPERT 5.6 and EMEP/EEA Guidebooks
		Diesel cars (cold-start, urban, rural and motorway driving)	
		Road vehicle engines (lubricating oil)	
1A3bii Road transport: Light duty trucks		Petrol LGVs with and without catalytic converter (cold-start, urban, rural and motorway driving)	
		Diesel LGVs (cold-start, urban, rural and motorway driving)	
		LPG LGVs (urban, rural and motorway driving)	
1A3biii Road transport: Heavy duty vehicles		Buses and coaches (cold-start, urban, rural and motorway driving)	
		HGV articulated (cold-start, urban, rural and motorway driving)	
		HGV rigid (cold-start, urban, rural and motorway driving)	
		Gas-fuelled HGVs (urban, rural and motorway driving)	
1A3biv Road transport: Mopeds & motorcycles		Mopeds (<50cc 2st) - urban driving	

NFR Category	Pollutant coverage	NAEI Source category	Source of Emission Factors
		Motorcycle (>50cc 2st) - urban driving	
		Motorcycle (>50cc 4st) - urban, rural and motorway driving	
1A3bv Road transport: Gasoline evaporation	NMVOCs	Petrol cars and LGVs, mopeds and motorcycles (<50cc 2st and >50cc 4st)	
1A3bvi Road transport: Automobile tyre and brake wear	Particulate Matter, Cd, Cr, Cu, Ni and Zn	All Cars, LGVs, HGV rigid and articulated, buses and coaches, mopeds and motorcycles (urban, rural and motorway driving)	
1A3bvii Road transport: Automobile road abrasion	Particulate Matter	All Cars, LGVs, HGV rigid and articulated, buses and coaches, mopeds and motorcycles (urban, rural and motorway driving)	
1A3c Railways	All CLRTAP pollutants including PCDD/PCDFs *(except PAHs, HCB and PCBs)*	Rail - coal	UK factors, Fuels Industry UK
		Railways - freight	
		Railways - intercity	
		Railways - regional	
1A3dii National navigation (Shipping)	All CLRTAP pollutants *(except PCBs)*	Marine engines	UK factors and EMEP/EEA Guidebooks
		Shipping - coastal	Scarbrough *et al.* (2017), EMEP/EEA Guidebook, Fuels Industry UK
		Inland waterways	EMEP/EEA Guidebooks
1A3ei Pipeline transport	Included elsewhere (1A1c) - separation of the fuel used in compressors is not possible based on the information from the official energy statistics.	NA	NA
1A3eii Other (please specify in the IIR)	All CLRTAP pollutants (except NH_3, HCB and PCBs)	Aircraft - support vehicles, sea port machinery, refrigerated transport vehicles	UK Literature sources, EMEP/EEA Guidebooks
1A4bii Non-road mobile sources and machinery	All CLRTAP pollutants (except NH_3, HCB and PCBs)	Domestic house and garden mobile machinery	EMEP/EEA Guidebooks

NFR Category	Pollutant coverage	NAEI Source category	Source of Emission Factors
1A4cii Non-road mobile sources	All CLRTAP pollutants (except NH_3, HCB and PCBs)	Agricultural mobile machinery	EMEP/EEA Guidebooks
1A4ciii Non-road mobile sources	All CLRTAP pollutants *(except PCBs)*	Fishing	UK factors and EMEP/EEA Guidebooks
1A5b Other, Mobile (Including military)	All CLRTAP pollutants *(except HCB and PCBs)*	Aircraft - military	UK Literature sources, EMEP/EEA Guidebooks
		Shipping - naval	Scarbrough *et al.* (2017), EMEP/EEA Guidebook, Fuels Industry UK,, Entec (2010)

3.3.1. Classification of Activities and Sources

Fuel types used in the NAEI for transport sources are listed in Table 3-3. The detailed NAEI source categories used in the inventory for transport are presented in Table 3-9 above according to the NFR source categorisation.

Almost all of the NFR source categories listed in Table 3-9 are key sources for one or more pollutants and so the description of the methodology will cover the whole of this NFR sector.

3.3.2. NFR 1A3a: Aviation

In accordance with the agreed guidelines, the NAEI contains estimates for both domestic and international civil aviation, but only emissions related to landing and take-off (LTO) are included in the national total. Emissions from international and domestic cruise are recorded as a memo item, and so are not included in national totals. Emissions from both the LTO phase and the cruise phase are estimated. The method used to estimate emissions from military aviation can be found towards the end of this section on aviation.

The aviation estimation method in the NAEI is a complex UK-specific model that uses detailed flight records, plane-specific and engine-specific estimates for pollutant emissions throughout the different stages of LTO and cruise cycles. An overview of the method is presented below; for a more detailed description of the UK aviation method please see Watterson *et al.* 2004.

The UK aviation method estimates emissions from the number of aircraft movements broken down by aircraft type at each UK airport, and so complies with the IPCC Tier 3 specification. Emissions of a range of pollutants are estimated in addition to the reported greenhouse gases. The method reflects differences between airports and the aircraft that use them, and emissions from additional sources (such as aircraft auxiliary power units) are also included.

This method utilises data from a range of airport emission inventories compiled in the last few years by the Ricardo aviation team, including:

- The RASCO study (23 regional airports, with a 1999 case calculated from CAA movement data) carried out for the Department for Transport (DfT).
- The published inventories for Heathrow, Gatwick and Stansted airports, commissioned by the airport operators themselves. Emissions of NO_X and fuel use from the Heathrow inventory are used to verify the inventory results.

In 2006, the DfT published its report "Project for the Sustainable Development of Heathrow" (PSDH). This laid out recommendations for the improvement of emission inventories at Heathrow. The PSDH recommendations included methodological changes, which have been introduced into the NAEI. For departures, the PSDH recommended revised thrust setting at take-off and climb-out as well as revised cut-back heights, whilst for arrivals the PSDH recommended revised reverse thrust setting and durations along with revised landing-roll times. These recommendations are integrated in full within the NAEI method, for all UK flights. Other recommendations that are reflected in the NAEI method include: the effects of aircraft speed on take-off emissions; engine spool-up at take-off; the interpolation to intermediate thrust settings; hold times; approach thrusts and times; taxiing thrust and times; engine deterioration and Auxiliary Power Unit (APU) emission indices and running times.

The NAEI includes all flights to and from the overseas territories, irrespective of origin or destination. Flights between the UK and overseas territories are included as part of the domestic aviation[44]. In addition, flights to and from oilrigs are included in the inventory.

Improvements to the UK aviation method in the 2024 submission:

- Introduction of SAF (Sustainable Aviation Fuel) as a new fuel type, to reflect the addition of aviation biofuel use data in DUKES.
- Revised taxi times to align with the 2023 EMEP/EEA Guidebook.
- Revised cruise factors to align with the 2023 EMEP/EEA Guidebook.
- Revised PM methodology to align with the 2023 EMEP/EEA Guidebook and to allow separation of non-volatile particulate matter (nvPM), volatile organic matter (voPM) and volatile sulphate matter (vsPM), which was required for SAF calculations.

Separate estimates are made for emissions from the LTO cycle and the cruise phase for both domestic and international aviation. For the LTO phase, fuel consumed and emissions per LTO cycle are based on detailed airport studies and engine-specific emission factors (from the International Civil Aviation Organisation (ICAO) database). For the cruise phase, fuel use and emissions are estimated using distances (based on great circles) travelled from each airport for a set of representative aircraft.

The inventory emission trends for the sector present a noticeable reduction in domestic emissions from 2005 to 2006 despite a modest increase in aircraft movements. This is attributable to the propagation of more modern aircraft into the fleet. From 2006 to 2007 there is a further reduction in domestic emissions, which is attributable to both a modest decrease in aircraft movements and kilometres flown and the propagation of more modern aircraft into the fleet. In 2008, and again in 2009 and 2010, there are reductions in both emissions and aircraft movements, in line with the economic downturn. The impact of the economic recovery is seen in the international movements from 2011. However, domestic movements and emissions have continued to decline until growth briefly returned in 2015. Prior to the COVID-19 pandemic, domestic movements were lower in 2019 than at any time since 1990. As a result of the pandemic, domestic movements in 2020 were 60% lower than they had been in 2019.

[44] Gibraltar is the only UK Overseas Territory included under the CLRTAP. There are no UK Crown Dependencies included under the CLRTAP.

3.3.2.1. Emission Reporting Categories for Civil Aviation

Table 3-10 below shows the emissions included in the emission totals for the domestic and international civil aviation categories currently under the UNFCCC, the NECR and the CLRTAP.

Table 3-10 Components of Emissions Included in Reported Emissions from Civil Aviation

	NECR	CLRTAP	UNFCCC
Domestic aviation (landing and take-off cycle [LTO])	Included in national total	Included in national total	Included in national total
Domestic aviation (cruise)	Not included in national total	Not included in national total	Included in national total
International aviation (LTO)	Included in national total	Included in national total	Not included in national total
International aviation (cruise)	Not included in national total	Not included in national total	Not included in national total

Notes:
Emissions from the LTO cycle include emissions within a 1000 m ceiling of landing

3.3.2.2. Aircraft Movement Data (Activity Data)

The methods used to estimate emissions from aviation require the following activity data:

- Aircraft movements and distances travelled

Detailed activity data are provided by the UK Civil Aviation Authority (CAA, 2023). These data include aircraft movements broken down by: airport; aircraft type; whether the flight is international or domestic; and the next/last POC (port of call), from which sector lengths (great circle) are calculated. The data covered all Air Transport Movements (ATMs) excluding air-taxi.

Fights between the UK and overseas territories are considered international in the CAA aircraft movement data, but these have been reclassified as domestic aviation.

International flights with an intermediate stop at a domestic airport are considered international in the CAA aircraft movement data. However, these have been reclassified as having a domestic leg and an international leg.

The CAA also compiles summary statistics at reporting airports, which include air-taxi and non-ATMs.

The CAA data are supplemented with data from overseas territories, supplied by DfT (2021).

A summary of aircraft movement data is given in Table 3-11. Fights between the UK and overseas territories are included in domestic.

- Inland Deliveries of Aviation Turbine Fuel and Aviation Spirit

Total inland deliveries of aviation spirit and aviation turbine fuel to air transport are given in DUKES (DESNZ, 2023a). This is the best approximation of aviation bunker fuel consumption available and is assumed to cover international, domestic and military use.

- Consumption of Aviation Turbine Fuel and Aviation Spirit by the Military

Historically, total consumption by military aviation has been given in ONS (ONS, 1995) and MoD (MoD, 2005) and was assumed to be aviation turbine fuel. A revised, but consistent time series of military aviation fuel was provided by the Safety, Sustainable Development and Continuity Division of the Defence Fuels Group of the MoD (MoD, 2009 and 2010) covering each financial year from 2003/04 to 2009/10. These data also included estimates of aviation spirit and turbine fuel classed as “Casual

Uplift", with the latter being drawn from commercial airfields world-wide and assumed not to be included in DUKES.

In 2011 the MoD revised their methodology for calculating fuel consumption, which provided revised data for 2008/09 onwards (MoD, 2011). These data no longer separately identified aviation spirit or turbine fuel classed as "Casual Uplift", so all fuel was assumed to be aviation turbine fuel and included in DUKES. In 2013 the MoD provided revised data for 2010/11 onwards that did separately identify aviation spirit. However, these data still did not identify "Casual Uplift", so all fuel was assumed to be aviation turbine fuel and included in DUKES. In 2014 the MoD provided revised data for 2010/12 to 2013/14, which, once again, separately identified fuel classed as "Casual Uplift". In 2015, similar data were provided for 2014/15. However, data provided from 2016 no longer separately identified fuel classed as "Casual Uplift", so the 2014/15 data have been rolled forward to subsequent years.

Adjustments were made to the data to derive figures on a calendar year basis.

Table 3-11 Aircraft Movement Data

	International LTOs (000s)	Domestic LTOs (000s)	International Aircraft, Gm flown	Domestic Aircraft, Gm flown
1990	460.1	377.3	652.0	116.4
1995	530.9	365.3	849.0	118.3
2000	704.3	407.2	1190.7	145.2
2005	800.5	488.2	1447.6	178.7
2010	734.0	393.9	1395.1	146.3
2011	769.2	381.1	1465.2	141.3
2012	765.7	365.1	1444.6	137.3
2013	786.6	360.9	1471.1	134.4
2014	809.9	347.1	1524.0	130.2
2015	821.7	356.0	1565.8	135.0
2016	874.6	349.5	1675.5	133.7
2017	903.2	349.3	1751.7	135.2
2018	911.6	340.9	1803.9	130.8
2019	911.9	326.9	1818.4	126.5
2020	367.3	135.8	731.7	48.7
2021	322.5	149.0	673.4	56.9
2022	708.3	221.8	1457.5	87.7

Notes
Gm - Giga metres, or 10^9 metres
Estimated emissions from aviation are based on data provided by the CAA and, for overseas territories, the DfT.
Gm flown calculated from total flight distances for departures from UK and overseas territories airports.

3.3.2.3. Emission Factors Used

The following emission factors are used to estimate emissions from aviation. Emissions factors for SO_X and metals are derived from the contents of sulphur and metals in aviation fuels (UKPIA, 2016)[45]. These contents are reviewed, and revised as necessary, each year. Full details of the emission factors used are given in Watterson *et al*., 2004. Emission factors for SO_X from SAF (Sustainable Aviation Fuel) is negligible, this is since SAF is derived from bio-based sources which have negligible sulphur content, unlike traditional fossil-based aviation fuels which often contain sulphur impurities.

[45] Values have not been provided by UKPIA since 2016 because insufficient data were collected.

Table 3-12 Sulphur Dioxide Emission Factors for Civil and Military Aviation for 2022 (kg/t)

Fuel	SO_X (kg/t)
Aviation Turbine Fuel	0.4
Aviation Spirit	0.4
Sustainable Aviation Fuel	0

For the LTO-cycle calculations, emissions per LTO cycle are required for each of a number of representative aircraft types. Emission factors for the LTO cycle of aircraft operation are calculated from the ICAO database. The cruise emissions are taken from EMEP/EEA Guidebook data (which are Activity data for domestic and international aviation themselves developed from the same original ICAO dataset). Average factors for aviation representative of the fleet in 2022 are shown in Table 3-13.

Table 3-13 Average Emission Factors for Civil and Military Aviation for 2022 (kt/Mt)

	Fuel	NO_X	CO	NMVOC
Civil aviation				
Domestic LTO	AS	3.34	942.60	24.07
Domestic Cruise	AS	1.90	296.28	9.98
Domestic LTO	ATF, SAF	11.21	9.93	2.09
Domestic Cruise	ATF, SAF	15.89	3.48	0.64
International LTO	AS	3.30	950.99	24.64
International Cruise	AS	3.05	850.39	25.01
International LTO	ATF, SAF	13.77	8.41	1.34
International Cruise	ATF, SAF	17.18	1.39	0.18
Military aviation				
Military aviation	AS	8.50	8.20	1.00
Military aviation	ATF	8.50	8.20	1.00

Notes
AS - Aviation Spirit
ATF - Aviation Turbine Fuel
SAF - Sustainable Aviation Fuel
Use of all aviation spirit assigned to the LTO cycle

3.3.2.4. Method Used to Estimate Emissions from the LTO cycle - Civil Aviation - Domestic and International

The contribution to aircraft exhaust emissions (in kg) arising from a given mode of aircraft operation (see list below) is given by the product of the duration (seconds) of the operation, the engine fuel flow rate at the appropriate thrust setting (kg fuel per second) and the emission factor for the pollutant of interest (kg pollutant per kg fuel).

The annual emissions total for each mode (kg per year) is obtained by summing contributions over all engines for all aircraft movements in the year. The time in each mode of operation for each type of airport and aircraft has been taken from individual airport studies. The time in mode is multiplied by an emission rate (the product of fuel flow rate and emission factor) at the appropriate engine thrust setting in order to estimate emissions for each phase of the aircraft flight. The sum of the emissions from all the modes provides the total emissions for a particular aircraft journey. The modes considered are:

- Taxi-out;
- Hold;

- Take-off Roll (start of roll to wheels-off);
- Initial-climb (wheels-off to 450 m altitude);
- Climb-out (450 m to 1000 m altitude);
- Approach (from 1000 m altitude);
- Landing-roll;
- Taxi-in;
- APU use after arrival; and
- Auxiliary Power Unit (APU) use prior to departure.

Departure movements comprise the following LTO modes: taxi-out, hold, take-off roll, initial-climb, climb-out and APU use prior to departure. Arrivals comprise: approach, landing-roll, taxi-in and APU use after arrival.

3.3.2.5. Method Used to Estimate Emissions in the Cruise - Civil Aviation - Domestic and International

Cruise emissions are only calculated for aircraft departures from UK airports (emissions therefore associated with the departure airport), which gives a total fuel consumption compatible with recorded deliveries of aviation fuel to the UK. This procedure prevents double counting of emissions allocated to international aviation.

3.3.2.6. Estimating Emissions

The EMEP/EEA Guidebook provides fuel consumption and emissions of non-GHGs (NO_X, HC and CO) for a number of aircraft modes in the cruise. The data are given for a selection of generic aircraft type and for a number of standard flight distances.

The breakdown of the CAA movement by aircraft type contains a more detailed list of aircraft types than in the EMEP/EEA Guidebook. Therefore, each specific aircraft type in the CAA data are assigned to a generic type in the EMEP/EEA Guidebook.

Piecewise linear regression has been applied to these data to give emissions (and fuel consumption) as a function of distance:

$$E\_Cruise_{d,g,p} = m_{g,p} \times d + c_{g,p}$$

Where:

$E\_Cruise_{d,g,p}$ is the emissions (or fuel consumption) in cruise of pollutant p for generic aircraft type g and flight distance d (kg)

g is the generic aircraft type

p is the pollutant (or fuel consumption)

$m_{g,p}$ is the slope of regression for generic aircraft type g and pollutant p (kg/km)

$c_{g,p}$ is the intercept of regression for generic aircraft type g and pollutant p (kg)

Emissions of SO_X and metals are derived from estimates of fuels consumed in the cruise (see equation above) multiplied by the sulphur and metals contents of the aviation fuels for a given year.

3.3.2.7. Overview of Method to Estimate Emissions from Military Aviation

LTO data are not available for military aircraft movements, so a simple approach is used to estimate emissions from military aviation. A first estimate of military emissions is made using military fuel consumption data and IPCC (IPCC, 1997a) and EMEP/EEA Guidebook cruise defaults. The EMEP/EEA Guidebook factors used are appropriate for military aircraft. The military fuel data include fuel consumption by all military services in the UK. It also includes fuel shipped to overseas garrisons and casual uplift at civilian airports.

Emissions from military aircraft are reported under NFR category 1A5 Other.

3.3.2.8. Fuel Reconciliation - Aviation

The estimates of aviation fuels consumed in the commodity balance table in the DESNZ publication DUKES are the Accredited Official Statistics on fuel consumption, however, national total emissions must be calculated on the basis of fuel sales. Therefore, the estimates of emissions have been re-normalised based on the results of the comparison between the fuel consumption data in DUKES and the estimate of fuel consumed from the civil aviation emissions model, having first scaled up the emissions and fuel consumption to account for air-taxi and non-ATMs. The scaling is done separately for each airport to reflect the different fractions of air-taxi and non-ATMs at each airport and the different impacts on domestic and international emissions. Aviation fuel consumption presented in DUKES include the use of both civil and military fuel, and the military fuel use must be subtracted from the DUKES total to provide an estimate of the civil aviation consumption. This estimate of civil aviation fuel consumption is used in the fuel reconciliation. Emissions from flights originating from the overseas territories have been excluded from the fuel reconciliation process as the fuel associated with these flights is not included in DUKES. Emissions will be re-normalised each time the aircraft movement data is modified or data for another year added.

3.3.3. NFR 1A3b: Road Transport

3.3.3.1. Overview

3.3.3.1.1. Summary of Methodology

A Tier 3 methodology is used for calculating exhaust emissions from passenger cars (1A3bi), light goods vehicles (1A3bii), heavy-duty vehicles including buses and coaches (1A3biii), and motorcycles (1A3biv). A Tier 2 methodology is used for calculating evaporative emissions (1A3bv) from petrol vehicles. Non-exhaust emissions from tyre and brake wear (1A3bvi) and road abrasion (1A3bvii) are also calculated based on a Tier 2 methodology.

The following sections describe how the methodology is applied to the most detailed road transport activity data available in the UK on a national scale. Some further details are provided in a separate methodology report for the UK road transport sector covering both air pollutants and greenhouse gases (Brown *et al*., 2018).

3.3.3.1.2. Summary of Emission Factors

The emission factors are taken from the EMEP/EEA Guidebook, consistent with the speed-emission factor functions given in COPERT 5.6 (Emisia, 2022).

3.3.3.1.3. Summary of Activity Data

Traffic activity data in billion vehicle km by vehicle type and road type are provided by DfT and total fuel sales for petrol and diesel are provided in DUKES. Vehicle licensing statistics and on-road

Automatic Number Plate Recognition data provided by DfT are used to further break down the vehicle km travelled by fuel type and vehicle year (including Euro standard) of first registration.

3.3.3.2. Fuel Sold vs Fuel Used

The UK inventory for road transport emissions of key air pollutants as submitted under the current regulations for NECR and CLRTAP for tracking compliance with the UK's ERCs is currently based on fuel consumption derived from kilometres driven rather than fuel sales. Paragraph 23 of the revised Guidelines on Reporting (ECE/EB.AIR/125)[46] and references under the National Emission Ceilings Regulations (NECR) (2018)[47] allow the UK to report emissions on the basis of fuel used or kilometres driven, provided emissions are also provided which are consistent with fuel sales.

The UK has a number of reasons for deciding to report emissions on a fuel used basis. Information on total fuel sales is available on a national scale but is not broken down by vehicle type or road and area type. Emissions of air pollutants, apart from SO_X and metals, are not directly related to amounts of fuel consumed as they depend on vehicle characteristics, exhaust after treatment technology and vehicle speed or drive cycle in a manner different to the way fuel consumption responds to these factors. The availability of high-quality traffic data for different vehicle types on different roads covering the whole road network, combined with fleet composition data and other vehicle behaviour and usage trends makes the use of COPERT-type methodologies a logical choice for estimating emissions in the UK. That methodology is one based on kilometres driven.

This approach also makes it possible to develop a robust inventory, which transport and air quality policy makers can relate to Accredited Official Statistics on transport and measures to control traffic and emissions. This direct link to transport statistics and policies is lost with the adjustments that are necessary on a vehicle by vehicle basis to bring consistency with national fuel sales. The UK's projections on emissions from road transport are based on the UK's forecasts on traffic levels on an area-type basis (not on fuel sales) and the inventory projections are a benchmark against which different transport and technical measures can be assessed. This has been crucial for UK air quality policy development and is not feasible from an inventory based on fuel sales. Using a kilometres driven approach also allows the UK to produce spatially resolved inventories for road transport at 1x1 km resolution, which are widely used for national and local air quality assessments.

The UK estimates fuel consumption from kilometres driven and g/km factors and compares these each year with national fuel sales figures, as discussed in the following sections. The agreement is within 16% for both petrol and diesel consumption across the 1990-2022 time series, but the agreement tends to be better in the more recent years. A normalisation approach is used to scale the bottom-up estimates of emissions based on vehicle km travelled (fuel used) to make them consistent with fuel sales as required to make the UK's road transport inventory compliant with international reporting guidelines. The normalisation approach is described in the next section, while Section 3.3.3.8 describes how the inventory based on fuel sales is developed having first calculated it based on fuel used.

In the Annex I emissions reporting template submitted by the UK in the latest year, emission estimates by NFR code based on the fuel sold approach can be found in the main table (rows 27 to 33) while emission estimates by NFR code based on the fuel used approach can be found in rows 143 to 149. National Totals for compliance - row 152 (CLRTAP) and row 154 (NECR) are based on the fuel used approach (except for SO_X and metals as explained above).

[46] https://www.unece.org/fileadmin/DAM/env/documents/2015/AIR/EB/English.pdf
[47] The National Emission Ceilings Regulations 2018 (legislation.gov.uk)

3.3.3.3. Fuel Consumption by Road Transport

Data on petrol and diesel fuels consumed by road transport in the UK are taken from DUKES published by DESNZ (DESNZ, 2023a) and corrected for consumption by off-road vehicles and the very small amount of fuel consumed by the Crown Dependencies included in DUKES (emissions from the Crown Dependencies are calculated elsewhere).

In 2022, 10.9 Mt of petrol and 21.3 Mt of diesel fuel (DERV) was consumed in the UK. Petrol consumption has increased relative to the consumption in 2021 whereas diesel consumption has decreased. It was estimated that of this, 4.7% of petrol was consumed by inland waterways and off-road vehicles and machinery. Some 0.4% of this was used in the Crown Dependencies, leaving 10.4 Mt of petrol consumed by road vehicles in the UK in 2022. An estimated 1.4% of road diesel is estimated to be used by inland waterways and off-road vehicles and machinery (the bulk of these use gas oil), and 0.4% of this was used in the Crown Dependencies, leaving 21.1 Mt of diesel consumed by road vehicles in the UK in 2022.

According to figures in DUKES (DESNZ, 2023a), 0.061 Mt of LPG was used for transport in 2022, which is very similar to the consumption in 2021 at 0.059 Mt. The consumption of LPG is only a small percentage (0.19%) of the total amount of fuels consumed by road transport.

Since 2005, there has been a rapid growth in consumption of biofuels in the UK, although this has stabilised in recent years. Biofuels are not included in the totals presented above for petrol and diesel which according to DESNZ refer only to mineral-based fuels (fossil fuels). According to statistics in DUKES and from HMRC (HMRC, 2023a), 1.01 Mt bioethanol and 1.30 Mt biodiesel were consumed in the UK in 2022. On a volume basis, this represents an estimated 7.8% of all petrol and 4.9% of all diesel sold in the UK, respectively. This is an increase in bioethanol and biodiesel consumption compared with 2021. On an energy basis, it is estimated that consumption of bioethanol and biodiesel displaced around 0.63 Mt of mineral-based petrol (5.8% of total petrol that would have been consumed) and 1.33 Mt of mineral-based diesel (6.3% of total diesel that would have been consumed).

To distribute fuel consumption, hence emissions, between different vehicle types, a combination of data sources and approaches were used making best use of all available information.

Fuel consumption factors for petrol and diesel vehicles

The source of fuel consumption factors for all vehicle types is the fuel consumption-speed relationships given in the 2019 EMEP/EEA Guidebook. This provides a method for 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 2005-2022. 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 (SMMT, 2023). The real-world uplift uses empirically-derived equations in the Guidebook that take account of average engine capacity and vehicle mass.

Using the Guidebook factors with fleet composition data and average speeds on different road types (Section 3.3.3.4), fleet average fuel consumption factors for each main vehicle category are shown in Table 3-14 for selected years between 1990 and 2022.

Table 3-14 UK Fleet-averaged fuel consumption factors for road vehicles (in g fuel/km)

	1990	2000	2005	2010	2015	2020	2021	2022
Petrol cars	79.6	71.5	68.0	66.4	63.0	58.0	57.3	55.9
Diesel cars	60.3	59.1	59.7	60.7	58.4	57.7	57.8	57.6
LGVs	101.6	82.7	75.9	74.5	73.5	72.8	72.7	72.2
HGVs	234.0	217.8	229.8	230.2	230.1	235.0	234.9	235.0
Mopeds and motorcycles	58.4	57.6	49.8	46.8	45.4	40.2	40.0	39.4
Buses and coaches	316.7	288.1	282.4	275.2	266.5	259.5	257.6	256.8

Fuel reconciliation and normalisation

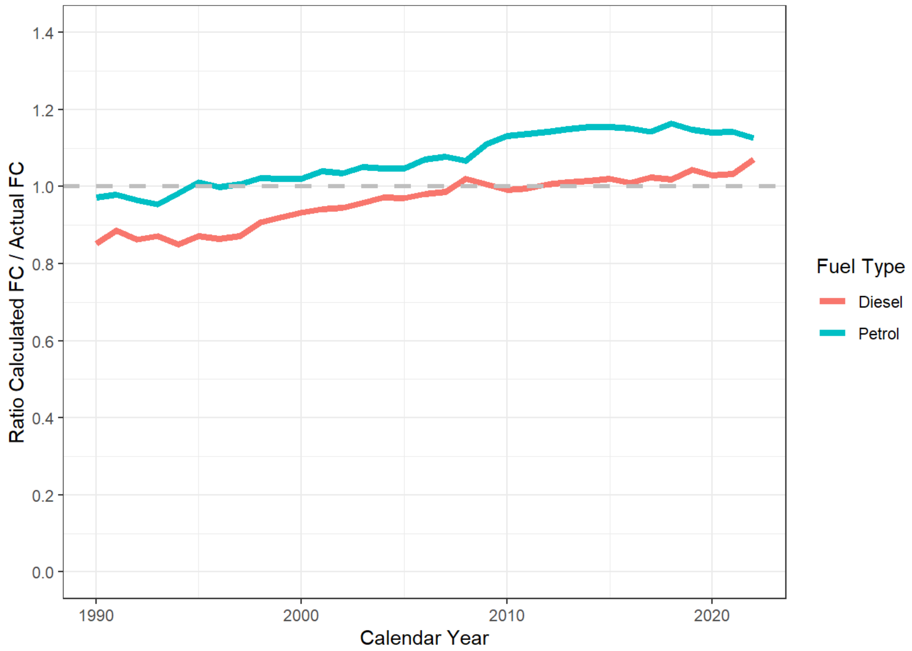
A model is used to calculate total petrol and diesel consumption by combining these factors with relevant traffic data. The "bottom-up" calculated estimates of petrol and diesel consumption are then compared with DESNZ figures for total fuel consumption in the UK published in DUKES, adjusted for the small amount of consumption by inland waterways, off-road machinery and consumption in the Crown Dependencies and taking account of biofuel consumption.

Figure 3-1 shows the ratio of model calculated fuel consumption to the figures in DUKES based on total fuel sales of petrol and diesel in the UK, allowing for off-road consumption. For a valid comparison with DUKES, the amount of petrol and diesel displaced by biofuel consumption has been used to correct the calculated consumption of petrol and diesel. In the earlier part of the time series, there was a greater deviation from the DUKES figures with maximum deviation at 16% (for DERV, in 1994). When the ratio tends to be towards 1, it indicates a better agreement with fuel sales data. The bottom-up method for petrol consumption in 2022 was 112.6% and for diesel was 107.0% of the value from DUKES.

To report emissions by vehicle types on a fuel sold basis, a normalisation process is applied based on the ratio of fuel sales according to DUKES and the fuel consumption estimates for each vehicle type derived from the bottom-up calculations. This is described in Section 3.3.3.8.

The normalisation process introduces uncertainties into the fuel sales estimates for individual vehicle classes even though the totals for road transport are known with high accuracy. This uncertainty carries through to the emission estimates according to fuel sales. Petrol fuel consumption calculated for each vehicle type was scaled up by the same proportions to make the total consumption align with DUKES. The same procedure was used to scale up diesel consumption by each vehicle type. Most of the petrol in the UK is consumed by passenger cars, so one would expect that DUKES provides a relatively accurate description of the trends in fuel consumption by petrol cars. This suggests the gap in the early part of the inventory time series between DUKES and bottom-up estimates is due to inaccuracies in the estimation of fuel consumption by passenger cars during the 1990s. On the other hand, diesel is consumed in more equal shares by different vehicle types (light and heavy-duty vehicles), so DUKES is not such a good indicator on trends in consumption on a vehicle type basis.

Figure 3-1 Ratio of calculated consumption of petrol and diesel fuel based on traffic movement and fuel consumption factors summed for different vehicle types to the DUKES figures for these fuels based on fuel sales in the UK.



Emissions from LPG consumption

Few vehicles in the UK run on LPG. Vehicle licensing data in GB (and in the UK) suggest that 0.09% of all light duty vehicles run on LPG in 2022. Figures from DUKES suggest that the consumption of LPG is around 0.19% of the total amount of petrol, diesel and natural gas consumed by road transport in 2022.

Emissions from natural gas consumption

Very few vehicles in the UK run on natural gas (NG). Vehicle licensing data in the UK suggest that less than 0.21% of all road vehicles run on NG in 2022. Figures from DUKES suggest that the consumption of NG is around 0.22% of the total fuel consumed by road transport in 2022.

Fuel-based emission factors

Emissions of some pollutants such as SO_X and metals, vary in direct proportion to the amount of fuel consumed and are less influenced by after-treatment technologies that affect other pollutants, other than as much as these technologies affect fuel efficiency. For these pollutants, emissions are derived directly from fuel-based emission factors.

SO_X

Emission factors for SO_X are based on the sulphur content of the fuel. Values of the fuel-based emission factors for SO_X vary annually as the sulphur-content of fuels change and are shown in Table 3-15 for 2022 fuels based on data from Fuels Industry UK (Fuels Industry UK, 2023).

Table 3-15 Fuel-Based SO_X 2022 Emission Factor for Road Transport (kg/tonne fuel)

Fuel	SO_X[a]
Petrol	0.009
Diesel	0.015

[a] 2022 emission factor calculated from Fuels Industry UK, 2023 - figures on the weighted average sulphur-content of fuels delivered in the UK in 2022.

Metals

Emission factors for metals are based on the EMEP/EEA Guidebook for road transport. Regarding the emissions of all other heavy metals, as well as trace lead content of unleaded petrol, the fuel metal content factors provided in t/Mt are assumed to include emissions from fuel consumption and engine-wear. The factors presented in Table 3-16 are taken from the EMEP/EEA Guidebook.

Table 3-16 Fuel metal content emission factors used in the NAEI for road transport

Metal	Fuel	Emission Factor (t/Mt)
Cr	DERV	0.0085
Cr	Petrol	0.0063
As	DERV	0.0001
As	Petrol	0.0003
Cd	DERV	5.00E-05
Cd	Petrol	0.0002
Cu	DERV	0.0057
Cu	Petrol	0.0045
Hg	DERV	0.0053
Hg	Petrol	0.0087
Ni	DERV	0.0002
Ni	Petrol	0.0023
Pb	DERV	0.0005
Se	DERV	0.0001
Se	Petrol	0.0002
Zn	DERV	0.018
Zn	Petrol	0.033

Lubricant oil includes several heavy metals which are assumed to be emitted to the atmosphere when oil is burnt (especially in the case of 2-stroke engines). Emissions factors of heavy metals from lubricant oil consumption are provided in t/Mt in Table 3-17 and are taken from the EMEP/EEA Guidebook.

Table 3-17 Lubricant consumption dependant emission factors used in the NAEI for road transport

Metal	Fuel	Emission Factor (t/Mt)
Cr	DERV	19.2
Cr	Petrol	19.2
Cd	DERV	4.56
Cd	Petrol	4.56
Cu	DERV	778
Cu	Petrol	778
Ni	DERV	31.89
Ni	Petrol	31.89
Pb	DERV	0.0332
Se	DERV	4.54
Se	Petrol	4.54
Zn	DERV	450.2
Zn	Petrol	450.2

The Guidebook does not provide factors for the metals V, Mn, Be and Sn, so for these metals UK specific factors are used and presented in Table 3-18.

Table 3-18 Heavy metals emissions factors used in the NAEI for road transport

Metal	Fuel	Emission Factor (t/Mt)
V	DERV	12.74
Mn	DERV	0.040
Be	DERV	0.144
Sn	DERV	0.304

To retain a consistent time series in lead emissions from petrol consumption, UK-specific emission factors continued to be used based on the lead content of leaded petrol (used up until 2000) and unleaded petrol. These figures were provided by the UK petroleum industry. The factors for leaded petrol up until 2000 are year-dependent. Following the Guidebook, the lead emission factors are used in conjunction with a scaling factor of 0.75 to account for the fact that only 75% of the lead in the fuel is emitted to air. Emissions of SO_X and metals are broken down by vehicle type based on estimated fuel consumption factors and traffic data in a similar manner to the traffic-based emissions described below for other pollutants.

3.3.3.4. Traffic-Based (Fuel Used) Emissions

Emissions of the pollutants NMVOCs, NO_X, CO, PM, NH_3 and other air pollutants are calculated on a fuel used basis from measured emission factors expressed in g/km and road traffic statistics from DfT. The emission factors are based on experimental measurements of emissions from in-service vehicles of different types driven under test cycles with different average speeds. The road traffic data used are vehicle kilometre estimates for the different vehicle types and different road classifications on the UK road network. These data must be further broken down by composition of each vehicle fleet in terms of the fraction of diesel- and petrol-fuelled vehicles on the road and in terms of the fraction of vehicles on the road made to the different emission regulations that applied when the vehicle was first registered. These are related to the age profile of the vehicle fleet in each year.

Emissions from motor vehicles fall into several different categories, which are each calculated in a different manner. These are hot exhaust emissions, cold-start emissions, evaporative emissions of NMVOCs, and tyre wear, brake wear and road abrasion emissions of PM_{10} and $PM_{2.5}$.

Hot exhaust emissions

Hot exhaust emissions are emissions from the vehicle exhaust when the engine has warmed up to its normal operating temperature. Emissions depend on the type of vehicle, the type of fuel, the driving style or traffic situation of the vehicle on a journey and the emission regulations which applied when the vehicle was first registered as this defines the type of technology the vehicle is equipped with that affects emissions.

For a particular vehicle, the driving style or traffic situation over a journey is the key factor that determines the amount of pollutant emitted over a given distance. Key parameters affecting emissions are the acceleration, deceleration, steady speed, and idling characteristics of the journey, as well as other factors affecting load on the engine such as road gradient and vehicle weight. However, work has shown that for modelling vehicle emissions for an inventory covering a road network on a national scale, it is sufficient to calculate emissions from emission factors in g/km related to the average speed of the vehicle in the drive cycle (Zachariadis and Samaras, 1997). A similar conclusion was reached in the review of emission modelling methodology carried out by Transport Research Laboratory (TRL[48]) on behalf of DfT (Barlow and Boulter, 2009). Emission factors for average speeds on the road network are then combined with the national road traffic data.

[48] TRL Report PPR355 at https://www.gov.uk/government/publications/road-vehicle-emission-factors-2009

Vehicle and fuel type

Emissions are calculated for vehicles of the following types:

- Petrol cars;
- Diesel cars;
- Petrol Light Goods Vehicles (Gross Vehicle Weight (GVW) ≤ 3.5 tonnes);
- Diesel Light Goods Vehicles (Gross Vehicle Weight (GVW) ≤ 3.5 tonnes);
- Rigid-axle Heavy Goods Vehicles (GVW ≥ 3.5 tonnes);
- Articulated Heavy Goods Vehicles (GVW ≥ 3.5 tonnes);
- Buses and coaches;
- Motorcycles.

Total emission rates are calculated by multiplying emission factors in g/km with annual vehicle kilometre figures for each of these vehicle types on different types of roads.

Vehicle kilometres by road type

Hot exhaust emission factors are dependent on average vehicle speed and therefore the type of road the vehicle is travelling on. Average emission factors are combined with the number of vehicle kilometres travelled by each type of vehicle on rural roads and higher speed motorways/dual carriageways and many different types of urban roads with different average speeds. The emission results are combined to yield emissions on each of these main road types:

- Urban;
- Rural single carriageway; and
- Motorway/dual carriageway.

DfT estimates annual vehicle kilometres (vkm) for the road network in Great Britain by vehicle type on roads classified as trunk, principal, and minor roads in built-up areas (urban), non-built-up areas (rural) and motorways (DfT, 2023a). DfT provides a consistent time series of vehicle km data by vehicle and road types going back to 1993 for the 2022 inventory, considering any revisions to historic data. The vkm data are derived by DfT from analysis of national traffic census data involving automatic and manual traffic counts. Additional information discussed later are used to provide the breakdown in vkm for cars by fuel type.

Vehicle kilometre data for Northern Ireland by vehicle type and road class were provided by the Department for Regional Development, Northern Ireland, Road Services (DRDNI, 2016). This gave a time series of vehicle km data from 2008 to 2014. To create a time series of vehicle km data for 1990 to 2007, the vehicle km data from DRDNI (DRDNI, 2013) was used. The data were scaled up or down based on the ratio of the data for 2008 between DRDNI (2016) and DRDNI (2013) for the given vehicle type and road type considered. Data for 2015-2022 were not available for the current inventory compilation and thus they were extrapolated from 2014 vehicle km data for Northern Ireland based on the traffic growth rates between 2014 and 2022 in Great Britain. Motorcycle vehicle km data were not available for Northern Ireland so they were derived based on the ratio of motorcycles registered in Northern Ireland relative to Great Britain each year. The ratios were then applied to the motorcycle vehicle km activity data for Great Britain. Information about the petrol/diesel split for cars and LGVs in the traffic flow are based on licensing data for Northern Ireland as provided by DfT (DfT, 2023b).

The Northern Ireland data has been combined with the DfT data for Great Britain to produce a time series of total UK vehicle kilometres by vehicle and road type from 1970 to 2022. Table 3-19 shows the UK vehicle kilometres data for selected years.

Table 3-19 UK vehicle km by road vehicles (in billion vkm)

		1990	2000	2005	2010	2015	2020	2021	2022
Petrol cars	urban	142.2	134.8	118.1	98	89.4	70.2	78.4	84.4
	rural	140.9	134.1	127.6	110.5	95.6	76.4	85.7	94.5
	m-way	49.3	53	48.9	41.9	34.5	26.7	32.8	38.8
Diesel cars	urban	5.8	26.1	40.3	52.8	64.9	52	55.3	56.7
	rural	6.1	28.3	47.8	66.6	90.2	71.9	78.3	81.3
	m-way	2.8	14.7	25.2	33.4	45.7	29.3	31	34.5
Petrol LGVs	urban	11.2	4.5	2.1	1.2	1	0.7	0.8	0.8
	rural	11.6	5.4	2.6	1.7	1.3	1.2	1.3	1.4
	m-way	4	2.1	1.1	0.6	0.6	0.5	0.6	0.6
Diesel LGVs	urban	5.7	15.1	20.2	21.9	25	24.1	25.8	26.3
	rural	5.9	18.3	25.1	29.4	34.7	36.2	40.7	43.3
	m-way	2	7.2	10	11.2	14.4	15.5	18.1	19.7
Electric cars	urban	0	0	0	0	0.2	2.4	4.4	7.8
	rural	0	0	0	0	0.3	2.2	4.6	8.7
	m-way	0	0	0	0	0.1	0.9	1.8	3.7
Electric LGVs	urban	0	0	0	0	0	0.1	0.3	0.3
	rural	0	0	0	0	0	0.2	0.4	0.5
	m-way	0	0	0	0	0	0.1	0.2	0.2
LPG LGVs	urban	0	0.1	0.5	0.4	0.3	0.2	0.2	0.2
	rural	0	0.1	0.8	0.7	0.5	0.4	0.4	0.4
	m-way	0	0.1	0.3	0.3	0.2	0.2	0.2	0.2
Rigid HGVs	urban	4.5	3.9	4	3.2	3	2.4	2.5	2.5
	rural	7.1	7.2	7.5	6.7	6.4	5.5	5.9	5.9
	m-way	3.7	4.2	4.2	4.1	3.9	3.6	3.9	3.9
Artic HGVs	urban	1.1	1.1	1.1	0.8	0.9	0.9	1	1
	rural	4.4	5.2	5.4	5.1	5.3	5.6	6.1	6.2
	m-way	4.7	7.4	7.9	7.5	8.4	8.9	9.5	9.4
Buses	urban	2.4	3	3.1	3	2.7	1.6	1.8	2.1
	Rural	1.7	1.7	1.5	1.6	1.4	0.9	1	1.1
	m-way	0.6	0.5	0.5	0.5	0.4	0.1	0.1	0.2
M/cycle	Urban	3.3	2.3	2.9	2.5	2.2	1.9	2.3	2.6

		1990	2000	2005	2010	2015	2020	2021	2022
	Rural	2	2	2.2	1.8	1.9	1.5	1.6	1.8
	m-way	0.3	0.4	0.4	0.4	0.4	0.2	0.2	0.3
Total		423.3	482.7	511.2	507.9	535.9	444.5	497.4	541.3

Vehicle speeds by road type

Vehicle speed data are used to calculate emission factors from the emission factor-speed relationships available for different pollutants. Average speeds of traffic were assigned to road classes categorised by speed limit and type of road (urban, rural and motorway). The speed limits assigned to major roads are derived from a speed limit data set provided by Basemaps for Great Britain (Basemap, 2022). Average speeds for each road class are calculated from GPS vehicle tracking data for England (Teletrac Navman, 2021) supplied by DfT. Traffic speeds are calculated separately for central, inner, and outer London and areas outside of London. The observed average speeds for England are applied across the UK.

Table 3-20 Average Traffic Speeds in Great Britain

Road Type		speed limit (mph)	Cars and motorcycles (kph)	LGV (kph)	HGV (kph)	Buses and coaches (kph)
Central London	Urban Major Trunk	20	14	13	12	13
		30	14	13	12	13
	Urban Major Principal	20	14	13	12	13
		30	14	13	12	13
	Urban Minor	30	14	13	12	13
Inner London	Rural Major Trunk	20	25	25	23	18
		30	28	27	29	27
	Urban Major Trunk	20	18	18	16	17
		30	20	19	17	19
		40	40	37	36	38
		50	49	46	51	44
	Rural Major Principal	20	25	25	23	18
		30	28	27	29	27
	Urban Major Principal	20	18	18	16	17
		30	20	19	17	19
		40	40	37	36	38
		50	49	46	51	44
	Urban Minor	30	20	19	17	19
Outer London	Rural Major Trunk	30	35	34	30	28
		40	42	41	38	37
		50	55	52	48	46
		60	52	50	46	51
		70	78	71	65	82
	Rural Major Principal	30	35	34	30	28
		40	42	41	38	37
		50	55	52	48	46

Road Type		speed limit (mph)	Cars and motorcycles (kph)	LGV (kph)	HGV (kph)	Buses and coaches (kph)
		60	52	50	46	51
		70	78	71	65	82
	Urban Major Trunk	20	20	20	18	19
		30	25	25	23	23
		40	35	34	32	33
		50	54	51	49	46
		60	60	56	53	54
		70	79	74	73	70
	Urban Major Principal	20	20	20	18	19
		30	25	25	23	23
		40	35	34	32	33
		50	54	51	49	46
		60	60	56	53	54
		70	79	74	73	70
	Rural Motorway	50	78	75	73	76
		70	91	85	75	85
	Urban Motorway	40	64	59	56	61
		50	54	51	48	47
		60	71	64	64	70
		70	77	67	62	68
	Rural Minor	60	52	50	46	51
	Urban Minor	30	25	25	23	23
UK (Outside London)	Rural Major Trunk	20	25	25	23	18
		30	38	38	35	35
		40	48	47	44	46
		50	58	57	53	55
		60	64	62	57	60
		70	82	77	67	78
	Rural Major Principal	20	25	25	23	18
		30	38	38	35	35
		40	48	47	44	46
		50	58	57	53	55
		60	64	62	57	60
		70	82	77	67	78
	Urban Major Trunk	20	17	17	17	15
		30	29	28	27	26
		40	38	37	35	35
		50	53	51	49	50
		60	47	46	43	45
		70	69	66	60	60
	Urban Major Principal	20	17	17	17	15
		30	29	28	27	26
		40	38	37	35	35

Road Type		speed limit (mph)	Cars and motorcycles (kph)	LGV (kph)	HGV (kph)	Buses and coaches (kph)
		50	53	51	49	50
		60	47	46	43	45
		70	69	66	60	60
	Rural Motorway	30	45	43	40	48
		40	45	43	40	48
		50	75	71	64	81
		60	73	71	62	70
		70	92	87	75	85
	Urban Motorway	30	43	42	44	54
		40	43	42	44	54
		50	48	47	44	46
		60	59	57	54	53
		70	80	75	68	77
	Rural Minor	60	64	62	57	60
	Urban Minor	30	29	28	27	26

Vehicle fleet composition: by age, size, technology, and fuel type

Vehicle kilometre data based on traffic surveys do not distinguish between the type of fuels the vehicles are being run on (petrol and diesel), nor on their age. Automatic Number Plate Recognition (ANPR) data provided by DfT (DfT, 2022k) are used to define the petrol and diesel mix in the car fleet on different road types (urban and rural major/minor roads, and motorways). The ANPR data has been collected annually (since 2007) at over 256 sites in the UK on different road types and regions. Measurements are made at each site on one weekday (8am-2pm and 3pm-9pm) and one half weekend day (either 8am-2pm or 3pm-9pm) each year in June and are currently available for years 2007 to 2011, 2013, 2015, 2017, 2019, and 2021. Since 2011, measurements are made biennially. There are approximately 1.4-1.7 million observations recorded from all the sites each year, and they cover various vehicle and road characteristics such as fuel type, age of vehicle, engine sizes, vehicle weight and road types.

Devolved Administration (DA)-country specific vehicle licensing data from DVLA (DfT, 2023j) are used to define the variation in some aspects of the vehicle fleet composition between DA-country.

As the ANPR data are only available between 2007 and 2011 and for 2013, 2015, 2017, 2019, and 2021, it was necessary to estimate the petrol/diesel mix of the GB car for the years 2014, 2016, 2018, 2020 and 2022 and before the ANPR became available, otherwise a step-change would be introduced in the emission time series. This was done by extrapolating the 2007 ANPR data back to 1990 based on the rate of change in the proportion of diesel vehicles as indicated by the DfT Vehicle Licensing Statistics. The ANPR data confirmed that there is a greater use of diesel cars on motorways, as was previously assumed in the inventory, but that higher usage of diesel cars also extended to urban roads as well, although not to the extent as seen on motorways. For Northern Ireland, there were six years of ANPR data (2010, 2011, 2013, 2015, 2017, 2019, and 2021) with reasonable number of observations being recorded. However, they did not show a consistent trend or major difference in the proportion of diesel cars observed on different road types, and that the proportion was like that implied by the licensing data. As a result, it is assumed that there is no preferential use of diesel cars in Northern Ireland and the petrol/diesel mix in car km should follow the proportion as indicated by the licensing statistics provided by DRDNI. This leads to the vehicle km data for petrol and diesel cars on different road types in the UK shown in Table 3-19.

The age of a vehicle determines the type of emission regulation that applied when it was first registered. These have entailed the successive introduction of tighter emission control technologies, for example three-way catalysts and diesel particulate filters, better fuel injection and engine management systems and real driving emissions tests.

Table 3-21 shows the regulations that have come into force up to 2022 for each vehicle type. The date into service is taken to be roughly the mid-point of the Directive's implementation dates for Type-Approval and New Registrations.

Table 3-21 Vehicle types and regulation classes

Vehicle Type	Fuel	Regulation	Approx. date into service in UK
Cars	Petrol	Pre-Euro 1	
		91/441/EEC (Euro 1)	1/7/1992
		94/12/EC (Euro 2)	1/1/1997
		98/69/EC (Euro 3)	1/1/2001
		98/69/EC (Euro 4)	1/1/2006
		EC 715/2007 (Euro 5)	1/7/2010
		Euro 6 a/b/c[49]	¼/2015
		Euro 6 d-temp[50]	1/1/2019
		Euro 6d[51]	1/1/2021
	Diesel	Pre-Euro 1	
		91/441/EEC (Euro 1)	1/1/1993
		94/12/EC (Euro 2)	1/1/1997
		98/69/EC (Euro 3)	1/1/2001
		98/69/EC (Euro 4)	1/1/2006
		EC 715/2007 (Euro 5)	1/7/2010
		Euro 6 a/b/c	¼/2015
		Euro 6 d-temp	1/1/2019
		Euro 6d	1/1/2021
LGVs	Petrol	Pre-Euro 1	
		93/59/EEC (Euro 1)	1/7/1994
		96/69/EEC (Euro 2)	1/7/1997
		98/69/EC (Euro 3)	1/1/2001 (<1.3 t) 1/1/2002 (>1.3 t)
		98/69/EC (Euro 4)	1/1/2006
		EC 715/2007 (Euro 5)	1/7/2011
		Euro 6 a/b/c	¼/2017
		Euro 6 d-temp	1/1/2018
		Euro 6d	1/1/2021
	Diesel	Pre-Euro 1	
		93/59/EEC (Euro 1)	1/7/1994
		96/69/EEC (Euro 2)	1/7/1997
		98/69/EC (Euro 3)	1/1/2001 (<1.3 t) 1/1/2002 (>1.3 t)
		98/69/EC (Euro 4)	1/1/2006
		EC 715/2007 (Euro 5)	1/7/2011
		Euro 6 a/b/c	¼/2017

[49] The implementation date refers to date of introduction of the first stage of Euro 6 a/b/c emission factors according to COPERT 5.6 and the EMEP/EEA 2022 Guidebook – update October 2021 and broadly coincides with the Euro 6 legislation referred to as Euro 6c.

[50] The implementation date refers to date of introduction of the second stage of Euro 6 emission factors according to COPERT 5.6 and the EMEP/EEA 2022 Guidebook- update October 2021 and broadly coincides with the Euro 6 legislation referred to as Euro 6d-temp.

[51] The implementation date refers to date of introduction of the third stage of Euro 6 emission factors according to COPERT 5.6 and the EMEP/EEA 2022 Guidebook- update October 2021 and broadly coincides with the Euro 6 legislation referred to as Euro 6d.

Vehicle Type	Fuel	Regulation	Approx. date into service in UK
		Euro 6 d-temp Euro 6d	1/1/2018 1/1/2021
HGVs and buses	Diesel (All types)	Pre-1988 88/77/EEC (Pre-Euro I) 91/542/EEC (Euro I) 91/542/EEC (Euro II) 99/96/EC (Euro III) 99/96/EC (Euro IV) 99/96/EC (Euro V) EC 595/2009 (Euro VI)	 1/10/1988 1/10/1993 1/10/1996 1/10/2001 1/10/2006 1/10/2008 1/7/2013
Motorcycles	Petrol	Pre-2000: < 50cc, >50cc (2st, 4st) 97/24/EC: all sizes (Euro 1) 2002/51/EC (Euro 2) 2002/51/EC (Euro 3) Regulation (EU) No 168/2013 (Euro 4) Regulation (EU) 2019/129 (Euro 5)	 1/1/2000 1/7/2004 1/1/2007 1/7/2016 30/6/2020

The current inventory is using comprehensive vehicle licensing statistics (DfT, 2023l) and annual mileage data from MOT records (DfT, 2023m), covering years between 2007 and 2022 (licensing data back to 1994, MOT data also available for 2022). These have been supplemented with additional DfT data from the Continuing Survey of Road Goods Transport (CSRGT) and National Travel Survey to develop revised vehicle survival rates and mileage with age profiles that vary by year and have been used to update the NAEI's fleet turnover model. The fleet turnover model uses vehicle licensing statistics, MOT data, vkm data, alongside ANPR data to determine the proportion of vehicle kilometres travelled by fuel type per vehicles of different Euro emission standards from 1970 to 2022.

For some pollutants, the emission factors cover three engine size ranges for cars: <1400cc, 1400-2000cc and >2000cc. The vehicle licensing statistics have shown that there has been a growing trend in the sales of bigger and smaller engine-sized cars in recent years, in particular for diesel cars at the expense of medium-sized cars. The inventory uses the proportion of cars by engine size varying each year from 2000 onwards based on the vehicle licensing data (DfT, 2023b). In addition, the relative mileage done by different size of vehicles was factored into the ratios, to take account of the fact that larger cars do more annual mileage than smaller cars (DfT, 2008). The emissions impact of alternative vehicle technologies (e.g. hybrid and electric cars) has been taken into account based on emission factors provided in the EMEP/EEA Guidebook (EMEP, 2022). Uptake rates of these alternative vehicles technologies are based on information provided by DfT (2023d).

For other vehicle categories, additional investigation had to be made in terms of the vehicle sizes in the fleet as the emission factors cover eight different size classes of rigid HGVs, six different weight classes of articulated HGVs, five different weight classes of buses and coaches and six different engine types (2-stroke and 4-stroke) and size classes of mopeds and motorcycles. Information on the size fractions of these different vehicle types was obtained from vehicle licensing statistics (DfT, 2023b), or else provided by direct communication with officials in DfT and used to break down the vehicle km data. Some data were not available, and assumptions were necessary in the case of buses, coaches and motorcycles.

DfT Road Freight Statistics (DfT, 2023c) provided a time series of vehicle km (2000-2022) travelled by different HGV weight classes based on the Continuing Survey of Road Goods Transport (CSRGT). The data show that there has been a gradual reduction in traffic activity for the rigid HGVs below 25 tonnes across the time series, while there has been an increase in traffic activity for rigid HGVs over 25 tonnes. For artic HGVs, the dominant group continues to be those over 33 tonnes, and traffic activity from the below 33 tonnes category have been decreasing over time. This information has been used to allocate

HGV vehicle km between different weight classes, although further assumptions have to be made as the inventory uses a more detailed breakdown of weight classes than those defined in the Road Freight Statistics.

Only limited information on the sizes of buses and coaches by weight exists; based on analysis of local bus operator information, it was assumed that 72% of all bus and coach km on urban and rural roads are done by buses, the remaining 28% by coaches, while on motorways all the bus and coach km are done by coaches.

Assumptions on the split in vehicle km for buses outside London by vehicle weight class are based on licensing information and correlations between vehicle weight class and number of seats and whether it is single- or double-decker. It is assumed that 31% of buses are <15 t and the remaining are 15-18 t. For London buses, the split is defined by the fleet composition provided by Transport for London (TfL, 2023).

For motorcycles, the whole time series of vkm for 2-stroke and 4 stroke motorcycles by different engine sizes are based on a detailed review of motorcycle sales, population, and lifetime by engine size. It was also assumed that mopeds (<50cc) operate only in urban areas, while only larger >750cc, 4-stroke motorcycles are used on motorways. Otherwise, the number of vehicle kilometres driven on each road type was disaggregated by motorcycle type according to the proportions estimated to be in the fleet. Research on the motorcycle fleet indicated that 2-stroke motorcycles are confined to the <150cc class.

Assumptions made about the proportion of failing catalysts in the petrol car fleet

A sensitive parameter in the emission calculations for petrol cars is the assumption made about the proportion of the fleet with catalyst systems that have failed, for example due to mechanical damage or failure of the lambda sensor. Following discussions with DfT, it is assumed that the failure rate is 5% per annum for all Euro standards and that up to 2008, only 20% of failed catalysts were rectified properly, but those that were rectified were done so within a year of failing. The revisions are based on evidence on fitting of replacement catalysts (DfT, 2009). According to DfT, there is evidence that a high proportion of replacement catalysts before 2009 were not Type Approved and did not restore the emission performance of the vehicle to its original level (DfT, 2009). This is being addressed through the Regulations Controlling Sale and Installation of Replacement Catalytic Converters and Particle Filters for Light Vehicles for Euro 3 (or above) LDVs after June 2009. Therefore, a change in the successful repair rate is taken into account for petrol LDVs adhering to Euro 3 standards from 20% prior to mid-2009 to 100% after 2009.

Voluntary measures and retrofits to reduce emissions

The inventory also takes account of the early introduction of certain emission standards and additional voluntary measures such as incentives for HDVs to upgrade engines and retrofit with particle traps to reduce emissions from road vehicles in the UK fleet. This was based on advice from officials in DfT.

Emissions from HGVs, buses, LGVs and black cabs (taxis) in London

The inventory considers fleet composition information specific to each year provided by Transport for London for central, inner, and outer parts of London. The features of the vehicle fleets in London are different to the rest of the UK because they also account for the phased introduction of specific schemes to reduce emissions and improve air quality in London (TfL, 2023). This includes the very specific features of the fleet of buses operated by TfL and the introduction of the scheme to reduce emissions from taxis in London which requires new taxis to be Zero Emission Capable (ZEC) from January 2018. Emission factors for conventional (non-ZEC) London black cabs were assumed to be the same as diesel LGVs and information from TfL was used to disaggregate the car vkm data between passenger cars and black cab taxis. This was important to take into account the high share of diesel-powered light duty vehicles in areas of inner and central London where black cabs make up a high proportion of the traffic flow and the consequences this has on NO_X and PM emissions.

The introduction of the Low Emission Zone (LEZ) in 2008 required HGVs and buses to be compliant with Euro III standards in respect of PM emissions. This was extended in 2012 to require the minimum of Euro 3 PM standards for larger vans and minibuses. The Ultra-Low Emission Zone (ULEZ) was introduced in Central London in 2019 and requires diesel cars, vans, and minibuses to meet Euro 6 standards for NO_X and PM; HGVs, buses and coaches to meet the LEZ tightening (Euro VI standards) for NO_X and PM; and petrol cars a minimum of Euro 4 standards. Finally, the expanded area of the ULEZ up to, but not including the North and South Circular Roads, was introduced in 2021, is also taken into account.

Fuel quality

In January 2000, European Council Directive 98/70/EC came into effect relating to the quality of petrol and diesel fuels. This introduced tighter standards on several fuel properties affecting emissions. The principal changes in UK market fuels were the sulphur content and density of diesel and the sulphur and benzene content of petrol. The volatility of summer blends of petrol was also reduced, affecting evaporative losses. During 2000-2004, virtually all the diesel sold in the UK was of ultra-low sulphur grade (<50 ppmS), even though this low-level sulphur content was not required by the Directive until 2005. Similarly, ultra-low sulphur petrol (ULSP) became on-line in filling stations in 2000, with around one-third of sales being of ULSP quality during 2000, the remainder being of the quality specified by the Directive. In 2001-2004, virtually all unleaded petrol sold was of ULSP grade. These factors and their effect on emissions were considered in the inventory. It is assumed that prior to 2000, only buses had made a notable switch to ULSD, as this fuel was not widely available in UK filling stations.

The introduction of road fuels with sulphur content less than 10ppm from January 2009 is considered according to Directive 2009/30/EC.

Lubricant consumption

The emissions from lubricant consumption by 2-stroke engines are included in 1A3biv (motorcycles). The emissions of lubricant consumption by all 4-stroke engines are allocated to 2G category rather than 1A3b, according to the Guidebook (EMEP, 2022). The measured emission factors for heavy metal species and lead from unleaded petrol, which form the basis of the exhaust emission factors in COPERT and the Guidebook (EMEP, 2022) are provided for fuel consumption and engine-wear, and separately for lubricant consumption.

Hot Emission Factors

The emission factors for different pollutants are now taken from COPERT 5.6 and the EMEP/EEA Guidebook (EMEP, 2022).

Regulated pollutants NO_X**, CO, NMVOCs,** $PM_{10/2.5}$

COPERT and the EMEP/EEA Guidebook provide emission factors as equations relating emission factor in g/km to average speed. Factors for NMVOC emissions are derived by subtracting COPERT factors for CH_4 from the factors given for total hydrocarbons (THC) because THC include CH_4 emissions. These baseline emission factors correspond to a fleet of average mileage in the range of 30,000 to 60,000 kilometres. For petrol cars and LGVs, COPERT provides additional correction factors (for NO_X, CO and THC) to take account of degradation in emissions with accumulated mileage. The detailed methodology of emission degradation is provided in the EMEP/EEA Guidebook. The degradation factors and methodology have been updated as the inventory adopted COPERT 5.6. New degradation functions were given for Euro 5 and 6 petrol Light Duty Vehicles and Euro 1 to 6 diesel Light Duty Vehicles.

Scaling factors are also provided to consider the effects of fuel quality since some of the measurements for older vehicles would have been made during times when available fuels were of inferior quality than they are now, particularly in terms of sulphur content. These fuel scaling factors are also applied to the COPERT 5.6 NO_X, PM, CO, and THC emission factors.

COPERT 5.6 provides separate emission functions for Euro V heavy duty vehicles (HGVs and buses) equipped with Selective Catalytic Reduction (SCR) and Exhaust Gas Recirculation (EGR) systems for NO_X control. According to European Automobile Manufacturers' association (ACEA), around 75% of Euro V HDVs sold in 2008 and 2009 are equipped with SCR systems, and this is recommended to be used if the country has no other information available (it is not expected that the UK situation will vary from this European average).

The speed-emission factor equations were used to calculate emission factor values for each vehicle type and Euro emission standard at each of the average speeds of the road and area types shown in Table 3-20. The calculated values were averaged to produce single emission factors for the three main road classes described earlier (urban, rural single carriageway and motorway/dual carriageway), weighted by the estimated vehicle kilometres on each of the detailed road types taken from DfT.

Various other assumptions and adjustments were applied to the emission factors, as follows.

The emission factors used for NMVOCs, NO_X, CO and PM are already adjusted to take account of improvements in fuel quality for conventional petrol and diesel, mainly due to reductions in the fuel sulphur content of refinery fuels. An additional correction was also made to take account of the presence of biofuels blended into conventional fossil fuel. Uptake rates of biofuels were based on the figures from HMRC (HMRC, 2023a) and it was assumed that all fuels were consumed as weak (typically 5%) blends with fossil fuel. The effect of biofuel (bioethanol and biodiesel) on exhaust emissions of particulate matter are represented by a set of scaling factors given in a report produced by Ricardo for Defra following a review of the literature in 2017. Scaling factors of 0.925 and 0.948 are used for older petrol and diesel vehicles respectively (mainly pre-Euro 5 light duty and pre-Euro IV heavy duty) running on 5% blends. No scaling factors are applied for motorcycles, Euro 5 or 6 light duty vehicles, and Euro IV, V or VI heavy duty vehicles. The effect of biofuel (bioethanol and biodiesel) on exhaust emissions of other pollutants are represented by a set of scaling factors (Murrells and Li, 2008). A combined scaling factor was applied to the emission factors according to both the emission effects of the biofuel and its uptake rates each year. The effects on these pollutants are generally rather small for these weak blends.

Account was taken of some heavy-duty vehicles in the fleet being retrofitted with pollution abatement devices, perhaps to control particulate matter emissions (PM), or that otherwise lead to reductions in NO_X, CO, and NMVOC emissions beyond that required by Directives. Emissions from some Euro II buses and HGVs were scaled down according to the proportion fitted with oxidation catalysts or diesel particulate filters (DPFs) and the effectiveness of these measures in reducing emissions from the vehicles.

Table 3-22 shows implied emission factors (in g/km or equivalent units) for each main vehicle category and pollutant for the UK fleet from 1990-2022. These are weighted according to the mix of Euro classes and technologies in the fleet each year as well as the proportion of kilometres travelled at different speeds and therefore with different emission factors. Implied emission factors over the whole time series are also shown in Figure 3-2 to Figure 3-7 (including NH_3 and benzo(a)pyrene discussed below).

Table 3-22 UK fleet averaged hot exhaust emission factors for road transport

Pollutant	Source	Units	1990	2000	2005	2010	2015	2020	2021	2022
CO	Petrol cars	g/km	8	3.8	2.1	1	0.7	0.4	0.4	0.4

Pollutant	Source	Units	1990	2000	2005	2010	2015	2020	2021	2022
	DERV cars		0.6	0.3	0.1	0.1	0.1	0.0	0.0	0.0
	LGVs		9.1	2.6	0.9	0.5	0.2	0.1	0.1	0.1
	HGVs		2.1	1.7	1.6	1.3	0.9	0.3	0.3	0.2
	Buses and coaches		3.6	2.1	1.7	1.5	1.3	0.7	0.7	0.6
	Mopeds and motorcycles		19.5	18.1	12.1	6.9	4.5	2.1	2.0	1.6
NO_X	Petrol cars	g/km	2.2	1.1	0.6	0.3	0.1	0.1	0.1	0.1
	DERV cars		0.6	0.7	0.7	0.6	0.6	0.5	0.5	0.5
	LGVs		2.4	1.4	1.1	0.9	1.0	0.8	0.7	0.6
	HGVs		9.1	7.5	6.9	5.2	2.7	0.9	0.7	0.6
	Buses and coaches		12.2	10.0	8.6	7.1	5.0	2.4	2.2	2.0
	Mopeds and motorcycles		0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1
NMVOC	Petrol cars	mg/km	1203.8	525	244	85.3	37.5	21.5	20.1	18.6
	DERV cars		111.1	53.6	36.2	21.1	11.3	5.9	5.5	4.8
	LGVs		945.8	310.3	145.1	79.5	37.4	14.0	11.6	9.6
	HGVs		670.4	418.8	290.5	149.2	65.1	33.0	31.0	29.4
	Buses and coaches		1271.8	672.7	396.6	217.3	125.9	59.5	54.2	49.7
	Mopeds and motorcycles		2620.9	2081.3	1358.1	801.1	532.3	260	240.9	202.5
PM_{10}	Petrol cars	mg/km	5.7	2.4	1.8	1.3	0.8	0.5	0.5	0.5
	DERV cars		183.2	62.7	34.5	22.8	10.7	5.2	4.8	4.1
	LGVs		99.8	79.2	55.1	36	16.6	5.9	5.0	4.2
	HGVs		360	221.7	161.5	88.9	37.9	12.0	9.9	8.4
	Buses and coaches		561.4	283.5	161.9	103.4	65.8	27.3	24.0	21.5
	Mopeds and motorcycles		40.6	31.2	21.6	13.4	10.0	5.0	4.7	4.1
NH_3	Petrol cars	mg/km	1.7	59.7	53.6	40	22.6	13.3	12.8	12.2
	DERV cars		0.9	0.9	0.9	0.9	1.8	3.5	3.6	3.8
	LGVs		1.4	5.9	4.5	3.1	2.5	4.5	4.8	5
	HGVs		2.9	2.9	2.9	4.5	8	8.8	8.9	8.9
	Buses and coaches		2.9	2.9	2.9	4.4	7.0	8.3	8.5	8.6
	Mopeds and motorcycles		1.9	1.9	1.9	1.9	2.0	2.0	2.0	2.0
B[a]p	Petrol cars	µg/km	0.5	0.3	0.2	0.2	0.1	0.1	0.1	0.1
	DERV cars		2.9	0.8	0.4	0.2	0.2	0.1	0.1	0.1
	LGVs		1.8	1.2	0.6	0.4	0.3	0.2	0.2	0.2
	HGVs		1.5	0.8	0.5	0.3	0.2	0.1	0.1	0.1
	Buses and coaches		2.6	1.4	0.8	0.5	0.4	0.2	0.2	0.2
	Mopeds and motorcycles		2.8	2.8	2.9	2.9	2.9	2.9	2.9	2.9

Figure 3-2 UK fleet averaged CO hot exhaust emission factors for road transport

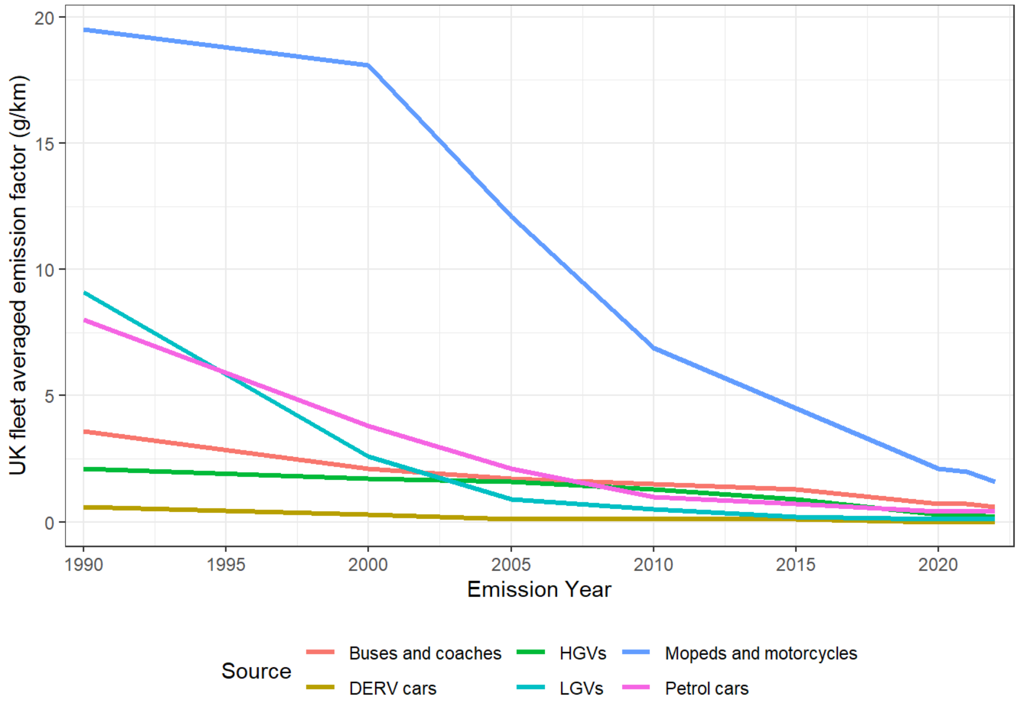


Figure 3-3 UK fleet averaged NO_X hot exhaust emission factors for road transport

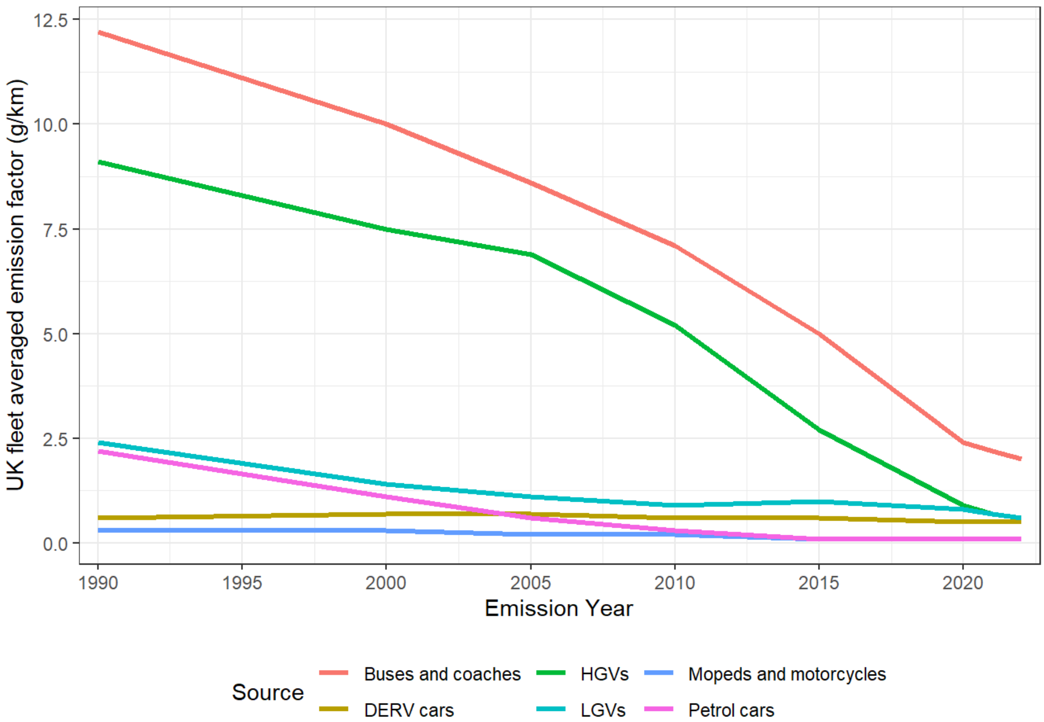


Figure 3-4 UK fleet averaged NMVOC hot exhaust emission factors for road transport

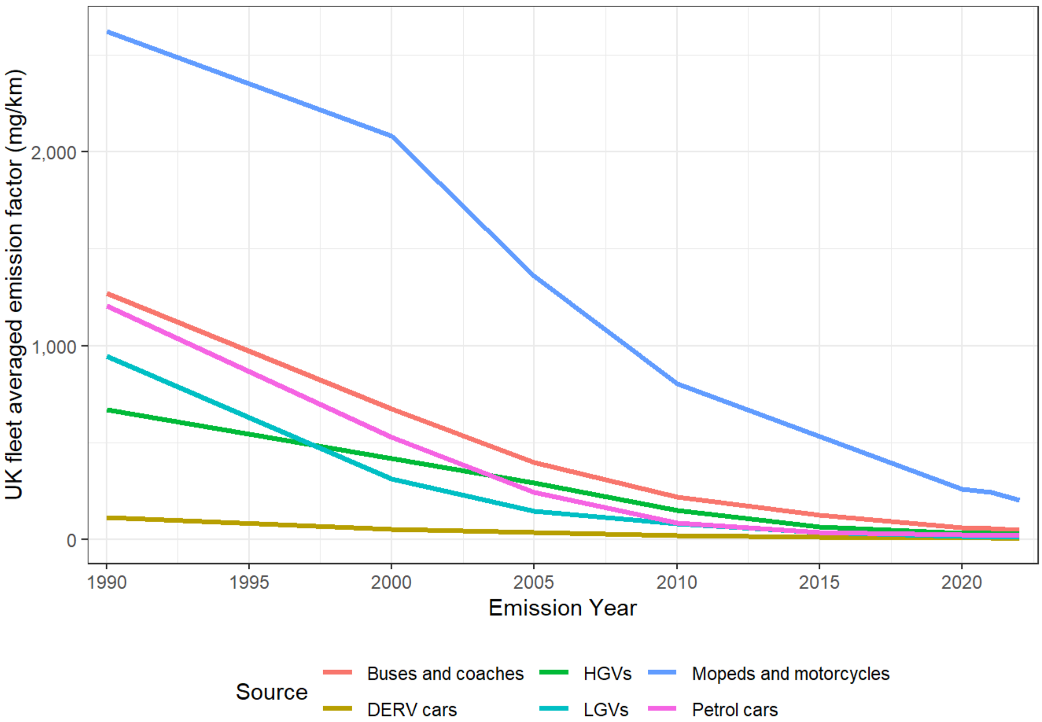


Figure 3-5 UK fleet averaged PM_{10} hot exhaust emission factors for road transport

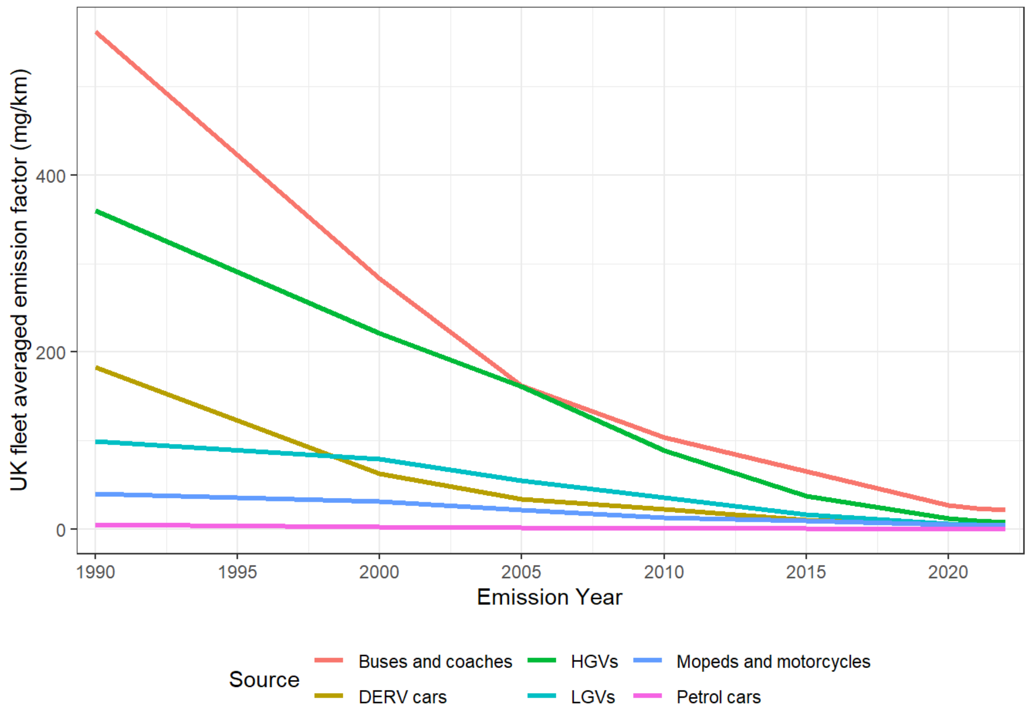


Figure 3-6 UK fleet averaged NH_3 hot exhaust emission factors for road transport

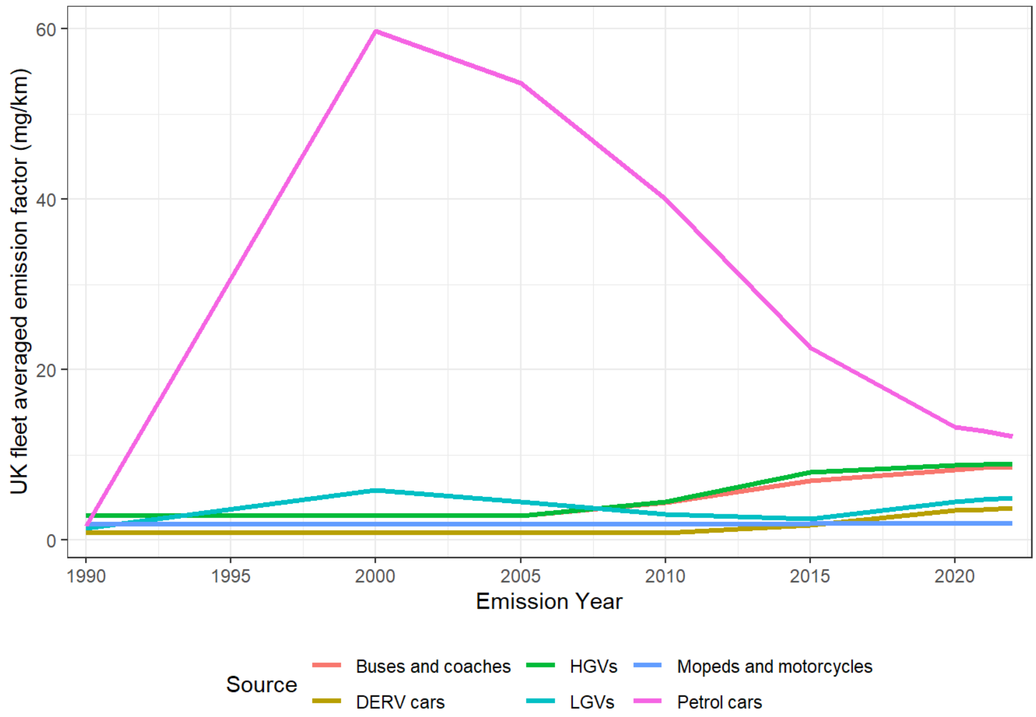
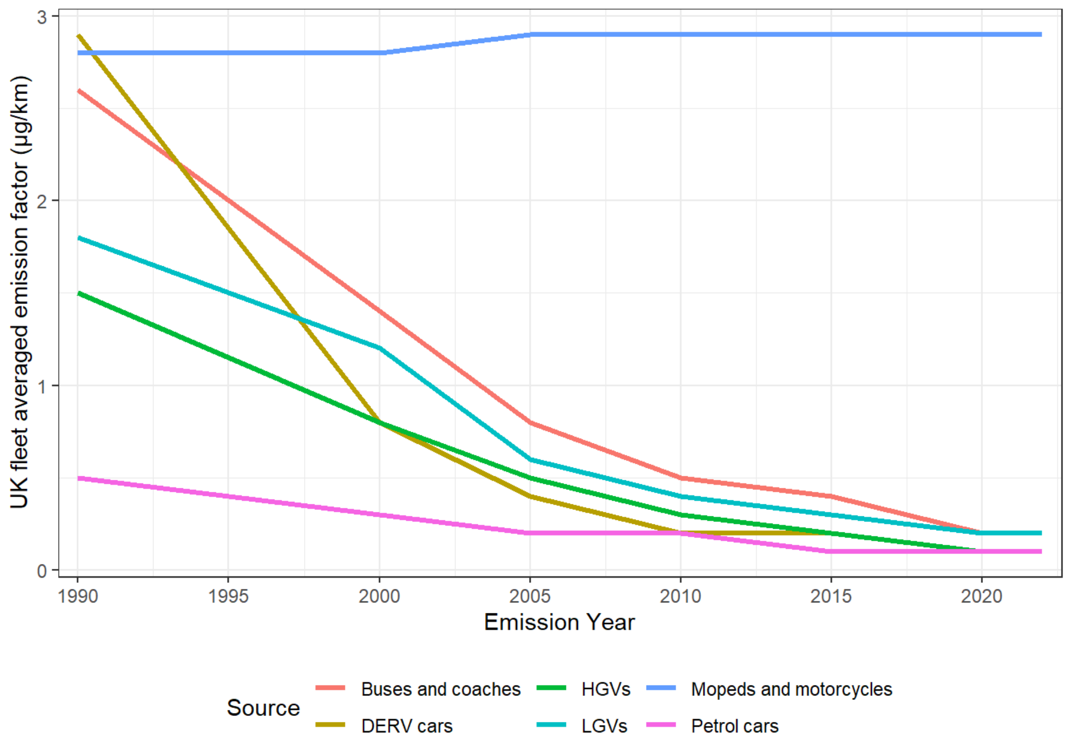


Figure 3-7 UK fleet averaged Benzo(a)pyrene (B[a]p) hot exhaust emission factors for road transport



Non-regulated pollutants: NH_3**, PAHs, PCDD/PCDFs, PCBs, HCB**

Ammonia emissions from combustion sources are usually small, but notable levels can be emitted from road vehicles equipped with catalyst devices to control NO_X emissions. Nitrogen oxides (N_2O), and ammonia emissions are an unintended by-product of the NO_X reduction process on the catalyst and were more pronounced for early generation petrol cars with catalysts (Euro 1 and 2). Factors for later petrol vehicle Euro standards and for diesel vehicles are much lower.

The emission factors for NH_3 for all vehicle types are based on the recommendation of the EMEP/EEA Guidebook and the COPERT 5.6 source.

For NH_3 emissions from petrol cars and LGVs, emission factors are provided for different Euro standards and driving conditions (urban, rural, highway) with adjustment factors that take into account the vehicle's accumulated mileage and the fuel sulphur content. The factors for diesel vehicles and motorcycles make no distinction between different Euro standards and road types and bulk emission factors are provided.

Table 3-22 and Figure 3-6 show the implied emission factors for NH_3 for each main vehicle category in the UK fleet from 1990-2022.

Polyaromatic hydrocarbons (PAHs) are emitted from exhausts as a result of incomplete combustion. The NAEI focuses on 16 PAH compounds that have been designated by the US EPA as compounds of interest using a suggested procedure for reporting test measurement results (US EPA, 1988). Road transport emission factors for these 16 compounds were developed through a combination of expert judgement and factors from various compilations. A thorough review of the DfT/TRL emission factors[52] was initially undertaken. Single emission factors were given for a number of PAHs, including the 16 US EPA species, for all driving conditions. Where possible, information from the database of emission measurements was used, however in the absence of such data, COPERT 4 emission factors were used in the DfT/TRL review. The factors were provided in g/km, and independent of speed (Boulter *et al*., 2009). The review indicated that data from additional sources should be reviewed, and as a result the NAEI emission factors have been derived from the following data sources or combination of sources:

- DfT/TRL emission factors (Boulter *et al.*, 2009) ;
- 2009 EMEP/EEA Guidebook, updated June 2010 (EMEP, 2009); and
- Expert judgement.

The expert judgement focused on how PAH emission factors change with Euro standard and technologies using trends shown by other pollutants as proxy. Consideration was largely based on whether the PAH species were volatile or in a condensed phase and either trends in NMVOCs or PM emissions, respectively, were taken as proxy. The aim was to develop an internally consistent set of factors for each PAH species across the vehicle types and Euro classes.

Emission factors have been specified by vehicle type and Euro standard for all 16 PAHs. As an example, Table 3-22 and Figure 3-7 show the implied emission factors for benzo[a]pyrene for each main vehicle category for the UK fleet from 1990-2022.

Emission factors for PCDD/PCDFs are based on the EMEP/EEA Guidebook. However, the factors for petrol vehicles before 2000 were scaled up to take into account the much higher emissions from vehicles using leaded petrol. This assumption has been made in previous versions of the NAEI and is consistent with information in the European dioxin inventory[53]. The inventory also includes emission factors for PCBs, consistent with those in the EMEP/EEA Guidebook. In the 2015 submission, HCB emissions were estimated based on recommendations provided in the 'Update of the Air Emissions Inventory Guidebook – Road Transport 2014 Update' report (i.e. to assume HCB=PCDD/PCDFs due to lack of data); however, this recommendation was not included in the 2019 EMEP/EEA Guidebook and thus HCB emissions are no longer estimated.

[52] https://www.gov.uk/government/publications/road-vehicle-emission-factors-2009,
[53] http://ec.europa.eu/environment/archives/dioxin/pdf/stage1/road_transport.pdf

Pollutant speciation

Several pollutants covered by the inventory are actually groups of discrete chemical species and emissions are reported as the sum of its components. Of key interest to road transport is the speciation in emissions of the groups of compounds represented as NO_X, NMVOCs and PM.

Nitrogen oxides are emitted in the form of nitric oxide (NO) and nitrogen dioxide (NO_2). The fraction emitted directly as NO_2 (f-NO_2) is of particular interest for air quality modelling and the NAEI is required to provide estimates of the fraction emitted as NO_2 for different vehicle categories. Values of f-NO_2 have been developed from recent real-world roadside vehicle emissions remote sensing measurements of NO_2/NO_X ratios compiled by Ricardo and the University of York[54]. Factors were developed for different vehicle types and Euro standards, with the exception of buses. The f-NO_2 factors for buses were taken from the EMEP/EEA Emissions Inventory Guidebook (EMEP, 2022) and previous roadside remote sensing studies by Carslaw et al, 2016. Analysis of the Ricardo and University of York roadside vehicle remote sensing data suggests that f-NO_2 factors for Euro 3, 4 and 5 diesel cars and LGVs are lower than in the EMEP/EEA Emissions Inventory Guidebook. The f-NO_2 factors for Euro IV and V HGVs derived from roadside remote sensing are lower than in the EMEP/EEA Guidebook, while for Euro VI the remote sensing factors suggest higher factors than the EMEP/EEA Guidebook. Based on these and the turnover in the fleet, the fleet-averaged values of f-NO_2 for each main vehicle class have been calculated and whilst not reported here, factors for the UK fleet are available on the UK's inventory website[55]. These factors are updated annually with fleet-averaged factors representative of the vehicle fleet in the latest inventory year.

Particulate matter is emitted from vehicles in various mass ranges. PM emissions from vehicle exhausts fall almost entirely in the PM_{10} mass range. Emissions of $PM_{2.5}$ and smaller mass ranges can be estimated from the fraction of $PM_{2.5}$ in the PM_{10} range. Mass fractions of PM_{10} for different PM sizes are given elsewhere in this report for different sources. Using information from the EMEP/EEA Guidebook, the fraction of PM_{10} emitted as $PM_{2.5}$ is assumed to be 1.0 for all vehicle exhaust emissions.

NMVOCs are emitted in many different chemical forms. Because of their different chemical reactivity in the atmosphere, the formation of ozone and secondary organic aerosols depends on the mix of NMVOCs emitted and the chemical speciation of emissions differs for different sources. The speciation of NMVOCs emitted from vehicle exhausts is taken from EMEP/EEA Guidebook.

3.3.3.5. Cold-Start Emissions

Cold-start emissions are the excess emissions that occur when a vehicle is started with its engine below its normal operating temperature. The excess emissions occur from petrol and diesel vehicles because of the lower efficiency of the engine and the additional fuel used when it is cold, but more significantly for petrol cars, because the three-way catalyst does not function properly and reduce emissions from the tailpipe until it has reached its normal operating temperature. Cold start emissions can also be significant for diesel vehicles equipped with catalyst-based tailpipe abatement systems such as SCR.

Cold start emissions are calculated using the method provided in the EMEP/EEA Emissions Inventory Guidebook (2019), consistent with COPERT 5.6. This is a trip-based methodology which uses the proportion of distance travelled on each trip with the engine cold and a ratio of cold/hot emission factor. Both are dependent on ambient temperature. Different cold/hot emission factor ratios are used for different vehicle types, Euro standards, technologies, and pollutants.

[54] Grange et al. (2019), "Strong Temperature Dependence for light-Duty Diesel Vehicle NO_X emissions", Environ, Sci.Technol., 53, 6587-6596

[55] http://naei.defra.gov.uk/data/ef-transport

Cold-start emissions are calculated from the formula:

$$E_{cold} = \beta \,.\, E_{hot} \,.\, (e^{cold}/e^{hot} - 1)$$

where

E_{hot} = hot exhaust emissions from the vehicle type

β = fraction of kilometres driven with cold engines

e^{cold}/e^{hot} = ratio of cold to hot emissions for the particular pollutant and vehicle type

The parameters β and e^{cold}/e^{hot} are both dependent on ambient temperature and β is also dependent on driving behaviour in particular the average trip length, as this determines the time available for the engine and catalyst to warm up. The equations relating e^{cold}/e^{hot} to ambient temperature for each pollutant and vehicle type were taken from the Guidebook. These were used with new temperature data from the Met Office that provides temperature values for each Devolved Administration and separately for London (using the "England SE/Central S" for London). This allows the model to account for regional variability in ambient temperature[56].

The factor β is related to ambient temperature and average trip length by the following equation taken from the Guidebook:

$$\beta = 0.6474 - 0.02545 \,.\, l_{trip} - (0.00974 - 0.000385 \,.\, l_{trip}) \,.\, t_a$$

where

l_{trip} = average trip length

t_a = average temperature

The method is sensitive to the choice of average trip length in the calculation. A review of average trip lengths was made, including those from the National Travel Survey, which highlighted the variability in average trip lengths available (DfT, 2007). A key issue seems to be what the definition of a trip is according to motorist surveys. The mid-point seems to be a value of 10 km given for the UK in the latest EMEP/EEA Guidebook, so this figure was adopted for Light-Duty Vehicles.

Cold start emissions from HGVs and buses have historically assumed to be negligible and were not considered in previous versions of the Guidebook and COPERT. However, Euro V and VI HGVs and buses are fitted with more complex engine control technologies and SCR and oxidation catalysts that do not function effectively below a minimum operating temperature. Recent evidence from vehicle measurements has allowed cold start emissions from Euro V and VI HGVs and buses to be quantified. COPERT 5.6 sees the introduction of cold start emissions of CO, NO_X, and VOC from Euro V and VI diesel heavy duty vehicles.

Trip Lengths

Vehicle trip length is an input parameter for the cold start emissions methodology in the Guidebook. The longer the vehicle trip length, the lower the cold start emissions are as a fraction of hot exhaust emissions. To accommodate the new method in COPERT 5.6, new data was required to use for HDV trip lengths, which is described immediately below for each of HGVs, buses, and coaches.

HGVs

For HGVs, data from DfT publication RFS0108 was used[57]. This gives the average length of haul separately for rigids and artics over the most recent 12 months (January - December 2022 in this

[56] https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-and-regional-series

[57] https://www.gov.uk/government/statistical-data-sets/rfs01-goods-lifted-and-distance-hauled

case). These values were 60 km and 137 km for rigids and artics, respectively, which are much longer than the average trip length for passenger cars. This is unsurprising as HGVs, particularly artics, tend to do more long-distance haulage.

Buses

For buses, similar length of "haul" information was not available from DfT. The average trip length was calculated as:

$$\text{Average trip length} = \text{Total bus vkm} \,/\, (\text{Total no. buses} \, * \, 365 \text{ days})$$

on the assumption that a bus makes only one trip per day starting with a cold engine, i.e., any other stops that a bus makes are not with the engine turned off long enough for it to cool down. Note that this is different to the higher emissions that might result from the cooling down of aftertreatment SCR systems when idling as this is already reflected in the speed-emission curves provided for buses in COPERT. DfT publication BUS06[58] was used for the stock of vehicles and DfT publication BUS02[59] was used for the vehicle kilometres travelled. The average trip length was calculated separately for London and the four Devolved Authorities. The average trip length from 2004-2021 ranged from 144 km for London, to 203 km for Scotland.

Coaches

For coaches, similar length of "haul" information was not available from DfT. The average trip length was calculated as described in Equation 3-1.

Equation 3-1 Calculation for the average trip length of coaches

$$Average\ Trip\ Length\ (vkm) = \frac{Annual\ Coach\ Distance\ (vkm)}{Total\ no.Coaches \times 365}$$

DfT publication BUS06 was used for the stock of vehicles and the coach vehicle kilometre data from the 2023 NAEI submission was used for the vehicle kilometres travelled. The average trip length from 2004-2021 was calculated as 429 km. This is significantly higher than the other vehicle types, though it is reasonable as coaches tend to do a lot of long-distance travel on motorways.

The Guidebook method provides pollutant-specific reduction factors for β to take account of the effects of Euro 2 to Euro 6 technologies in reducing cold-start emissions relative to Euro 1.

This methodology was used to estimate annual UK cold-start emissions of NO_X, PM, CO and NMVOCs from petrol and diesel cars and LGVs. Emissions were calculated separately for each Euro standard of petrol cars.

The vast majority of cold start emissions were assigned to urban driving. Any small excess that could not be assigned to urban was assigned to rural driving, as per the EMEP/EEA Guidebook (2022).

Cold-start emissions of NH_3 were estimated using a method provided by the EMEP/EEA Guidebook. The method is simpler in the sense that it uses a mg/km emission factor to be used in combination with the distances travelled with the vehicle not fully warmed up., i.e., under "cold urban" conditions. For petrol cars and LGVs, a correction is made to the cold-start factor that considers the vehicle's accumulated mileage and the fuel sulphur content, in the same way as for the hot exhaust emission. The cold-start factors in mg/km for NH_3 emissions from light duty vehicles are shown in Table 3-23,

[58] https://www.gov.uk/government/statistical-data-sets/bus-statistics-data-tables#vehicles-operated-by-local-bus-operators-bus06
[59] https://www.gov.uk/government/statistical-data-sets/bus-statistics-data-tables#local-bus-vehicle-distance-travelled-bus02

calculated for zero cumulative mileage and <30ppm S fuel. There are no NH_3 cold-start factors for HGVs and buses available in COPERT 5.6.

Table 3-23 Average Cold-start Emission Factors for NH_3 (in mg/km)

mg/km	Petrol cars and LGVs
Pre-Euro 1	2.0
Euro 1	40.7
Euro 2	46.7
Euro 3	5.7
Euro 4	5.5
Euro 5	15.6
Euro 6 a/b/c	14.3
Euro 6d-temp	13.5
Euro 6d	12.8

3.3.3.6. NFR 1A3bv: Evaporative Emissions

Evaporative emissions of petrol fuel vapour from the tank and fuel delivery system in vehicles fall under NFR category 1A3bv and constitute a substantial fraction of total NMVOC emissions from road transport. The methodology for estimating evaporative emissions uses the Tier 2 method approach given in the EMEP/EEA Guidebook.

Further details of the method used for each of the three different mechanisms by which gasoline fuel evaporates from vehicles are given in section 6.3 of the standalone road transport methodology report (Brown *et al.*, 2018).

An implied emission factor based on the population, composition of the fleet and trips made in 2022 is shown for petrol cars and motorcycles in Table 3-24. The units are in g per vehicle per day.

Table 3-24 Fleet-average emission factor for evaporative emissions of NMVOCs in 2022

Vehicle type	g/vehicle/day
Petrol cars	1.71
Motorcycles	2.72

3.3.3.7. NFR 1A3bvi/1A3bvii: Non-Exhaust Emissions of Particulate Matter

Particulate matter is emitted from the mechanical wear of material used in vehicle tyres, brake linings and road surface.

Methods for calculating emissions from tyre and brake wear are provided in the EMEP/EEA Guidebook derived from a review of measurements by the UNECE Task Force on Emissions Inventories[60]. Emission factors are provided in g/km for different vehicle types with speed correction factors which imply higher emission factors at lower speeds. For heavy duty vehicles, a load correction factor is provided, and tyre wear emissions depend on the number of axles. Further details are given in the AQEG report on PM (AQEG, 2005). Table 3-25 shows the PM_{10} emission factors (in mg/km) for tyre and brake wear for each main vehicle and road type based on the average speed data used in the inventory. COPERT 5.6 accounts for the effect of vehicle technology (internal combustion engine, hybrid, electric) in the non-exhaust emission factor and this is now accounted for in the UK road transport inventory. For example, hybrid and electric vehicles tend to have relatively higher tyre wear and road abrasion

[60] http://vergina.eng.auth.gr/mech0/lat/PM10/

emission factors due to their higher weight, but they also have lower brake wear emission factors as they use regenerative braking. The emission factors are still independent of Euro Standard, however. Emissions are calculated by combining emission factors with vehicle km data and are reported under NFR code 1A3bvi.

Table 3-25 Emission factors for PM_{10} from tyre and brake wear

mg PM_{10} /km		Tyre	Brake
Cars	Urban	9.0	19.1
	Rural	7.3	11.0
	Motorway	5.9	3.8
LGVs	Urban	14.1	27.5
	Rural	11.7	16.8
	Motorway	9.7	7.8
Rigid HGVs	Urban	21.2	54.5
	Rural	19.2	37.7
	Motorway	16.5	24.8
Artic HGVs	Urban	48.1	54.5
	Rural	41.2	35.2
	Motorway	37	24.5
Buses	Urban	35.2	54.5
	Rural	30.2	36.5
	Motorway	24.8	17.1
Motorcycles	Urban	3.8	6.1
	Rural	3.2	3.7
	Motorway	2.5	1.2

PM emissions from road abrasion are estimated based upon the emission factors and methodology provided by the EMEP/EEA Guidebook. The emission factors are given in g/km for each main vehicle type and are constant for all years, with no road type dependence. The factors for PM_{10} (in mg/km) are shown in Table 3-26. The factors are combined with vehicle-km data to calculate the national emissions of PM from this source. Emissions from road abrasion are reported under 1A3bvii.

Table 3-26 Emission factors for PM_{10} from road abrasion

mg PM_{10}/km	Road abrasion
Cars – conventional	7.5
Cars- hybrids	7.95
Cars – plug-in hybrids	8.05
Cars – battery electric	8.45
LGVs – conventional	7.5
LGVs- hybrids	38.0
LGVs – plug-in hybrids	38.0
LGVs - battery electric	38.0
Rigid HGVs	38.0
Artic HGVs	38.0
Buses	38.0
Motorcycles	3.0

Emissions of $PM_{2.5}$ and smaller mass ranges are estimated from the fraction of $PM_{2.5}$ in the PM_{10} range. Mass fractions of PM_{10} for different PM sizes are given elsewhere in this report for different sources. Using information from the EMEP/EEA Guidebook, the fraction of PM_{10} emitted as $PM_{2.5}$ for tyre wear, brake wear and road abrasion is shown in Table 3-27.

Table 3-27 Fraction of PM_{10} emitted as $PM_{2.5}$ for non-exhaust traffic emission sources

Source	$PM_{2.5}/PM_{10}$
Tyre wear	0.7
Brake wear	0.4
Road abrasion	0.54

The particulate matter emitted from tyre and brake wear comprise various metal and PAHs components. Based on the species profiles provided in the EMEP/EEA Guidebook, metal and PAHs emissions from tyre and brake wear are included in the inventory and calculated from the mass content of each component in the PM.

3.3.3.8. Inventory Based on Fuel Sold

In response to the recommendation from the 2017 NECD review, the UK has since then provided road transport emission estimates based on the fuel sold approach as part of the annual submission under the CLRTAP and NECR. The approach used is described as follows:

A. Implied emission factors (g of pollutant / kg of fuel consumed) were derived for each vehicle and fuel type from emission estimates of each pollutant[61] and fuel consumption calculated from vehicle-kilometre data (i.e., the so-called bottom-up or fuel used approach).

B. Bottom-up petrol fuel consumption calculated for each vehicle type was scaled up by the same proportions to make the total consumption align with DUKES, as described in Section 3.3.3.3. The same procedure was used to scale up diesel consumption by each vehicle type.

C. The normalised fuel consumption calculated in step b) was then combined with the implied emission factors calculated in step a) to produce emission estimates for each vehicle type based on the fuel sold approach.

Table 3-28 and Table 3-29 summarise the results for NO_X, NMVOCs, $PM_{2.5}$ and NH_3 based on fuel sold versus fuel used approaches. It should be noted that emissions of NO_X, NMVOCs, $PM_{2.5}$ and NH_3 based on the fuel used approach are to be used for tracking compliance with the UK's ERCs. The differences between emissions calculated by the fuel sold and fuel used approaches fluctuate year on year due to a variety of reasons such as modelling uncertainty of the bottom-up estimates of fuel consumption based on traffic activity. However, this year the differences between the two approaches are mainly due to the adoption of COPERT 5.6 factors, especially the effect of additional bottom-up fuel consumption estimates in the fuel used approach as COPERT 5.6 now provides cold start fuel consumption factors for Light Duty Vehicles.

Table 3-28 Road transport emissions (in kt) based on fuel sold vs fuel used approaches

	Approach	2005	2010	2015	2020	2021	2022
NO_X	Fuel used	605.7	426.6	345	197.3	199.8	194.9
	Fuel sold	608.2	420.1	333.8	189.9	191.8	181.2
NMVOCs	Fuel used	213.7	98.3	54.3	29.1	30.5	30.2
	Fuel sold	205.5	88.6	47.9	25.8	27	27
NH_3	Fuel used	17.2	11	6.2	3.9	4.3	4.6
	Fuel sold	16.4	9.8	5.4	3.5	3.9	4.1
	Fuel used	23.2	18.5	13.2	8.1	8.7	8.9

[61] With the exception to SO_X and metals emission estimates as they were calculated based on the sulphur or metal content of fuels.

$PM_{2.5}$	Fuel sold	23.5	18.2	12.6	7.6	8.1	8

Table 3-29 Differences in national totals (NT) between fuel used and fuel sold approaches

		2005	2010	2015	2020	2021	2022
NO_X	Differences in kt	-2.5	6.5	11.1	7.4	8.0	13.7
	% change	-0.10%	0.50%	1.10%	1.10%	1.20%	2.10%
NMVOCs	Differences in kt	8.1	9.7	6.4	3.3	3.5	3.3
	% change	0.70%	1.00%	0.80%	0.40%	0.40%	0.40%
NH_3	Differences in kt	0.8	1.3	0.8	0.4	0.4	0.5
	% change	0.30%	0.50%	0.30%	0.10%	0.20%	0.20%
$PM_{2.5}$	Differences in kt	-0.4	0.3	0.6	0.5	0.6	0.9
	% change	-0.30%	0.30%	0.80%	0.80%	0.90%	1.30%

3.3.4. NFR 1A3c: Railways

A Tier 2 methodology is used for calculating emissions from intercity, regional and freight diesel trains, a less technology specific method is used for coal-fired heritage trains.

Apart from the relevant activity data updates for 2022, all main aspects of the inventory remain consistent with the 2023 submission. In the 2021 submission, emissions estimates were improved on the basis of work undertaken for the UK's Rail Safety and Standards Board (RSSB; 2020a and 2020b) to develop new emission factors for NO_X and PM_{10}. These changes better reflected the actual operation of diesel engines and accounted for the non-linear relationships between engine power output and emissions of air quality pollutants.

Other passenger train emission factors in g/vehicle or train km are taken from the DfT Rail Emissions Model (REM) for different train and locomotive classes based on factors provided by WS Atkins Rail. Other freight emission factors were obtained from the London Research Centre (LRC). From January 2012, the EU Fuel Quality Directive (2009/30/EC) required gas oil consumed in the railway sector to contain a maximum sulphur content of 10ppm. Figures on the average sulphur content of gas oil were obtained from Fuels Industry UK and since 2015 this requirement has been exceeded.

Gas oil consumption data was obtained from the Office of Rail and Road for passenger and freight trains for 2005-2009 and 2011-2021. This was combined with trends in train kilometres to estimate consumption for 2022 as well as other historic years.

3.3.4.1. Details of Methodology

The UK inventory reports emissions from both stationary and mobile sources.

3.3.4.2. Railways (Stationary)

The inventory source "*railways (stationary)*" comprises emissions from the combustion of burning oil, fuel oil and natural gas by the railway sector. The natural gas emission derives from generation plant used for the London Underground. These stationary emissions are reported in NFR 1A4ai and are based on fuel consumption data from DESNZ (DESNZ, 2023a).

3.3.4.3. Railways (Mobile)

Most of the electricity used by the railways for electric traction is supplied from the public distribution system, so the emissions arising from its generation are reported under 1A1a Public Electricity. In this sector, emissions are reported from gas oil used to power trains and from coal used to power steam trains; the latter of which only contributes a small element.

Coal consumption data are obtained from DUKES. Estimates are made across the time series from 1990-present and are believed to be due to consumption by heritage trains. For the air pollutants, United States Environmental Protection Agency (US EPA) emission factors for hand-stoked coal-fired boilers are used to estimate emissions from coal-fired steam trains.

The UK inventory reports emissions from trains that run on gas oil in three categories: freight, intercity and regional. These are reported under NFR code 1A3c Railways. Emission estimates are based on:

- Vehicle kilometres travelled and emission factors in grams per vehicle kilometre for passenger trains.
- Train kilometres travelled and emission factors in grams per train kilometre for freight trains.

For Great Britain, vehicle kilometre data for intercity and regional trains are obtained from REM for 2009 to 2011, 2014 and 2018 and then estimated for other years from train kilometre data from the Office of Rail and Road (ORR) National Rail Trends Yearbook (NRTY) and data portal. Adjustments to the diesel vehicle kilometres for 2019, 2020, 2021 and 2022 were made to account for the introduction of new bi-mode passenger trains. Actual train kilometre data for diesel freight train movements in 2019 is available and this has been scaled forward to 2022 and back to 2005 using information on the trend in net tonne km of freight moved, which has been obtained from the ORR NRTY and data portal. Train kilometre data for freight trains is also available for 2004 and, similarly, this data is scaled back to the start of the time series using information on the trend in net tonne km of freight moved.

Gas oil consumption by passenger and freight trains is obtained from the 2011 NRTY for the period 2005-2009 and from ORR's data portal for the years 2011-2021 No data are available for the years 1970-2004 and 2010, and data for 2022 had not yet been released at time of compilation, therefore fuel consumption for these years was estimated based on the trend in train kilometres.

Diesel passenger train kilometres steadily increased from 220 million km in 2000 to almost 256 million km in 2019. In 2020, train kilometres decreased to 186 million km, primarily as a result of reduced services due to restrictions in place during the COVID-19 pandemic. In 2021 , total diesel passenger train kilometres increased slightly to 208 million km, but were still significantly lower than those seen in years prior to 2020 due to the continuing effects of the pandemic. In 2022, activity levels are estimated to have remained similar to the previous year due in part to industrial action across the UK and also due to a switch to more electric passenger trains on the network. This trend is generally reflected in the passenger train fuel consumption data. The amount of freight moved has declined since 2013 as a result of a substantial reduction in the amount of coal hauled and then due to the COVID-19 pandemic. The amount of freight moved in 2020 was around 68% of the amount estimated for 2013 but increased to around 75% of the 2013 value in 2021 and remained similar in 2022.

For Northern Ireland, train kilometre data and fuel consumption data are provided by Translink, the operator of rail services in the region, and is calculated via the operator timetable.

CO_2, SO_X, and NH_3 emissions are calculated using fuel-based emission factors and the total fuel consumed. Emissions of CO, NMVOCs, NO_X and PM are based on the vehicle/train kilometre estimates and emission factors for different train classes. The distribution of the train fleet by train class is determined based on:

- For passenger trains:
  - Proportions of total vehicle kilometres data for different train classes for 2009, 2010, 2011, 2014 and 2018 are derived from REM. The fleet for other years is based on the year of introduction of new trains and locomotives.
- For freight trains:
  - The breakdown by locomotive class weighted by train kilometres travelled was obtained from REM for 2009. The fleet for other years is estimated based on the year of introduction of new locomotives.

The emission factors shown in Table 3-30 are aggregated implied factors for trains running on gas oil in 2022, so that all factors are reported on the common basis of fuel consumption. These factors differ from previous inventory versions, due to changes year-on-year in the composition of the rail fleet and in the estimated fuel consumption. As outlined in Appendix 2 (Tables on Condensables), the original source of many of the PM emission factors is unknown and therefore no information is currently available on whether they include the condensable fraction or not.

Table 3-30 Railway Emission Factors for 2022 (kt/Mt fuel)

	NO_X	CO	NMVOC	SO_X	PM_{10}
Freight	27.79	4.11	0.71	0.012	0.66
Intercity	25.53	4.24	1.04	0.01	0.79
Regional	18.33	9.22	1.11	0.01	0.55

An emission factor of 0.01 kt/Mt fuel for NH_3 was taken from Tables 3.2-3.4 of the 1.A.3.c Railways chapter of the EMEP/EEA Guidebook.

3.3.5. NFR 1A3d, 1A4ciii, 1A5b: Navigation

The UK inventory provides emission estimates for domestic coastal shipping and inland waterways (1A3dii), fishing (1A4ciii), international marine bunkers (1A3di) and naval shipping (1A5b). International marine bunker emissions are reported as a Memo item and are not included in the UK national totals.

The shipping emissions model applied uses terrestrial Automatic Identification System (AIS) vessel movement data for 2014 supplied by the UK Maritime and Coastguard Agency. The methodology meets and exceeds the requirements of a Tier 3 methodology set out in the latest EMEP/EEA Guidebook and the requirements for reporting national greenhouse gas emissions to the UNFCCC under the 2006 IPCC Guidelines. The methodology carries out an emission calculation specific to each vessel and for each point of the vessel's voyage around the UK coast that is tracked with AIS receivers on the UK shore.

The receivers capture a number of smaller vessels and voyages such as movements to and from off-shore oil and gas rigs. A detailed set of port statistics for different vessel categories are used as proxies for estimating activities in years back to 1990 and forward to 2022 from the 2014 base year. Emission factors are based on detailed values for different main and auxiliary engine types, fuels and vessel movement types, consistent with those used in the International Maritime Organization (IMO) global emissions inventory and accounting for current regulations on fuel sulphur content in different sea territories around the UK.

This AIS-based shipping model is used to estimate emissions for the following sources:

- National Navigation (source category 1A3dii), the main category of domestic voyages for coastal shipping.
- Fishing vessels (source category 1A4ciii), within and outside of UK waters.
- Movements to/from/between the Crown Dependencies (within source category 1A3dii and 1A4ciii). Included in reporting to the UNFCCC but not included in other official reporting.

Full details on the method used for this model are given in Scarbrough *et al*. (2017). A brief overview of the method is given below.

3.3.5.1. Overview of Methodology

The NAEI shipping model methodology (Scarbrough *et al.* (2017)) estimates fuel consumption and emissions in detail for a base year (in this case, 2014), and less detailed shipping activity statistics are used as the main driver to estimate emissions and fuel consumption for previous years and up to the latest inventory year. Future shipping fuel consumption and emissions are estimated using assumed projected activity growth rates and considerations of emission factors for future vessels and fuels accounting for current and forthcoming legislation.

Emissions are calculated by multiplying an emission factor expressed in grams per kWh by estimated engine demand in kWh. In this sense, the model methodology meets the requirements of Tier 3 in EMEP/EEA Guidebook. The bottom-up methodology calculates fuel consumption and emissions for each vessel. The methodology goes beyond the Tier 3 approach set out in the Guidebook by calculating fuel consumption and emissions for each part of a voyage using high resolution Automatic Identification System (AIS) vessel tracking data, rather than carrying out the calculation for each port-to-port voyage as a whole. The use of AIS data to support an emission inventory follows the same practice as the work by the IMO in its 3rd GHG study (IMO, 2015). Many of the assumptions used in the modelling have been drawn from the IMO's work (IMO, 2015).

The emissions are calculated separately for each vessel and for each AIS data point, accounting for the time duration until the next AIS data point at 5-minute intervals, assuming that the vessel continues to combust fuel and emit pollution at the same rate until the subsequent AIS message. The fuel consumption and emission factors are tailored to the specific vessel that is identified in the AIS dataset. The factors account for:

- The fuel type assumed to be used by the vessel, the known engine type and engine speed (rpm).
- The rated power of the engines for each vessel, which are either known from a third-party database, or estimated based on other known or reported vessel characteristics (e.g. vessel length)
- The actual power demands on the main engines for each AIS message, expressed as a function of reported and designed vessel speed, and reported and designed vessel draught.
- The location and type of the vessel, i.e. whether the vessel is in a sulphur emission control area (SECA), whether the vessel is at berth, and whether the vessel is a passenger vessel.

The calculation of fuel consumption and emissions of vessels accounts for the actual speed of the vessel at any given point. The emission calculation also uses the reported draught of the vessel to estimate the engine load factor. This enhances the Tier 3 approach by making use of the data reported under AIS. Thus, the approach allows for variation in speed and load at points during the voyage.

Auxiliary engine power demand is varied by vessel category, size and by mode, and estimates from auxiliary boilers, used on board larger vessels for heating and hot water production, are also made.

Vessel type and size classification are aligned with the IMO classification, which gives 47 categories after splitting by size and type. Separate assumptions are made for the fuel and emission calculations by category.

Emissions associated with movements among and to/from the three crown dependencies can be distinguished within the model.

An important step in the process is identifying whether a vessel movement is a UK domestic movement, and reported under 1A3dii, or part of an international voyage calling in the UK reported as a Memo item under 1A3di. Vessel movements are separated into domestic, international and passing the UK (transit). The domestic estimate is used for UK reporting of national emission totals in inventory submissions to the UNFCCC, CLRTAP and NECR.

Further Tier 3 approaches are used to estimate emissions from inland waterways, and other emissions away from UK waters for which the UK is responsible, including vessel movements between the UK and overseas territories. Emissions from military shipping are estimated from information provided by the MoD.

A summary of the source of activity data and emission factors for each navigation source covered in the inventory is given in Table 3-31.

Table 3-31 Sources of activity data and emission factors for navigation

Source		NFR	Activity data			Emission factors
			Source	Base year	Time series	
Domestic	Domestic coastal	1A3dii	Scarbrough *et al*. (2017) based on detailed AIS vessel movement data	2014	DfT port movement data to scale from 2014 to other years	Scarbrough *et al*. (2017), EMEP/EEA Guidebook, Fuels Industry UK (2023)
Domestic	Fishing in UK sea territories	1A4ciii	Scarbrough *et al*. (2017) based on detailed AIS vessel movement data	2014	MMO fish landing statistics to scale from 2014 to other years	Scarbrough *et al*. (2017), EMEP/EEA Guidebook, Fuels Industry UK (2023)
Domestic	Fishing in non-UK sea territories					
Domestic	Naval	1A5b	MoD data on fuel consumption by naval vessels			Assumed same as international shipping vessels using gas oil, Entec (2010)
Domestic	Shipping between UK and OTs	1A3dii	DfT Maritime Statistics and OT port authorities: number of sailings between UK and OT	2000-2022	Trends for years before 2000 based on trends in fuel consumption derived by Entec for international shipping and trends in DfT data on number of cruise passengers	Assumed same as international shipping vessels using fuel oil

Source		NFR	Activity data			Emission factors
			Source	Base year	Time series	
Domestic	Inland waterways	1A3dii	Based on estimates of vessel population and usage estimates using data from various sources	2008	Statistics on expenditure on recreation (ONS, 2022a), tourism (Visit England), port freight traffic (DfT), inland waterways goods lifted (DfT) used to scale from 2008	EMEP/EEA Guidebook, Fuels Industry UK (2023)
International	International	1A3di	Fuel consumption from marine bunkers from DUKES (DESNZ, 2023a)			Implied emission factor for international shipping from Scarbrough *et al*. (2017)

Details in the approach for each of these parts of the inventory for navigation are given in the following sections, including the methodologies for inland waterways, naval shipping, and shipping movements between the UK and Overseas Territories.

3.3.5.2. Domestic Navigation

3.3.5.2.1. NFR 1A3dii: Coastal Shipping

The shipping emissions model applied uses 2014 terrestrial Automatic Identification System (AIS) vessel movement data supplied by the UK Maritime and Coastguard Agency. The methodology carries out an emission calculation specific to each vessel and for each point of the vessel's voyage that is tracked with AIS receivers on the UK shore.

Details of the new methodology are given in the report by Scarbrough *et al*. (2017) and only a summary is given here.

a) Activity data for 2014

The model methodology estimates the Heavy Fuel Oil (HFO) and Marine Diesel Oil (MDO) fuel consumption for each AIS position message down-sampled to a 5-minute temporal resolution. The calculation takes into account, where available, the individual vessel characteristics of main engine power, engine speed and load, and makes bottom-up assumptions for auxiliary engines. The fuel and emissions are estimated for each AIS message to cover the time period until the next AIS message, which is often 5 minutes, but in cases where the vessel travels at or outside the range of the terrestrial AIS receivers, may be longer or much longer. Many assumptions for the modelling have been drawn from the International Maritime Organization's (IMO) Third Greenhouse Gas Study (IMO, 2015).

The emissions are calculated separately for each vessel and for each AIS data point assuming that the vessel continues to combust fuel and emit pollution at the same rate until the subsequent AIS message. The fuel consumption and emission factors are tailored to the specific vessel that is identified in the AIS dataset. The factors account for:

- The fuel type assumed to be used by the vessel, the known engine type and engine speed (rpm).

- The rated power of the engines, which are either known from a third-party vessel characteristics database, or estimated based on other known or reported vessel characteristics (e.g. vessel length)
- The actual power demands on the main engines for each AIS message, expressed as a function of reported and designed vessel speed, and reported and designed vessel draught.
- The location and type of the vessel, i.e. whether the vessel is in a SECA, whether the vessel is at berth, and whether the vessel is a passenger vessel.

In those cases where part of a voyage is not captured within the range of the terrestrial AIS dataset (defined as a gap in AIS coverage of 24 hours), allocation assumptions have been based on vessel type. Specifically, if cargo or passenger vessel journeys had a gap between AIS messages of greater than 24 hours, these vessels were assumed to have been on UK international voyages if they had started or finished at a UK port. For the remaining vessel types, which includes offshore industry vessels, fishing fleets and service vessels, voyages were assumed to be UK domestic if the AIS dataset showed the vessel had started and finished at a UK port, regardless of the length of time of any gaps in AIS coverage.

The detailed Tier 3 approach used in Scarbrough *et al*. (2017) is able to distinguish fuel consumption and emissions between domestic movements from one UK port to another and UK international movements between a UK port and a port overseas. This enables the correct activities and emissions to be allocated to the NFR category 1A3dii Domestic Water-borne Navigation.

The Scarbrough *et al*. (2017) inventory excluded emissions and fuel consumption from military vessel movements which are not captured in the AIS movements database. Naval shipping emissions are reported separately using fuel consumption data supplied by the Ministry of Defence (MoD). The Scarbrough *et al*. (2017) study did not cover small tugs and service craft used in estuaries, private leisure craft and vessels used in UK rivers, lakes and canals as these were not captured in the AIS data. These were captured in the estimates for inland waterways described below.

Commercial fishing vessels were captured by AIS data, including those that eventually leave the UK to fish in overseas waters, before returning later so emissions could be calculated in the same way as for other domestic navigation and reported separately under 1A4ciii.

b) Time series trends in activity data

The approach to estimate emissions for historical years before 2014 and years after 2014 uses DfT port statistics for each vessel category as proxies for activity levels. This is detailed further in section 3 of Scarbrough *et al*. (2017).

Overall, there are 15 separate vessel categories considered. The statistical time series cover all years back from 2014 to 1990 and forward to the most recent year of statistics (currently 2022). In many cases, multiple statistical series need to be used if no complete series is available to cover the entire period to 1990. The specific statistical series used for each new vessel category is indicated in Table 3-32, against the index previously used. The main DfT statistics used is PORT0201 domestic UK major port freight traffic by cargo type and direction, annually: 2000 - 2022 (DfT, 2023e).

Table 3-32 Summary of new activity indices

Vessel category	Activity index used	Separate Domestic index
Bulk carrier	2000-2022: Table PORT0201 - 'All dry bulk traffic' [Note 1]	Yes
Chemical tanker	2000-2022: Table PORT0201 - 'Other liquid bulk products' [Note 1]	Yes
Container	2000-2022: Table PORT0201 - 'All container traffic' [Note 1]	Yes
General cargo	2000-2022: Table PORT0201 - 'All other general cargo traffic' [Note 1]	Yes
Liquefied gas tanker	2000-2022: Table PORT0201 - 'liquefied gas' [Note 1]	Yes
Oil tanker	2000-2022: Table PORT0201 - 'total of Crude Oil and Oil Products' [Note 1]	Yes
Ferry-pax only	2003-2022: UK domestic sea passenger movements by type of route - Table SPAS0201. Pre-2003 trend uses the approach described in Entec (2010).	Yes
Cruise	Same approach as used for the Ferry-pax only vessel category	Yes
Refrigerated bulk	2000-2022: Table PORT0201 - 'Other dry bulk' [Note 1]	Yes
Ro-Ro	2000-2022: Table PORT0201 - 'Roll-on/roll-off traffic' [Note 1]	Yes
Service - tug	2000-2022: Table PORT0201 - 'total domestic traffic' [Note 1]	Yes
Miscellaneous - fishing	2010-2022: MMO UK Sea Fisheries Annual Statistics - Chapter 3 Landings. Pre-2010 trend uses the approach described in Entec (2010).	No
Offshore	Gross UK Oil and NGL Production in kt (DUKES table 3.1.1 Crude oil and petroleum products: production, imports and exports; Indigenous production of crude oil)	No
Service – other	2000-2022: Table PORT0201 - 'total domestic traffic' [Note 1]	Yes
Miscellaneous - other	2000-2022: Table PORT0201 - 'total domestic traffic' [Note 1]	Yes

Note 1 - pre-2000 trend uses the approach described in Entec (2010).

The model assumes that there is a switch from HFO to MDO as a result of the tightening in 2015 of the SECA fuel sulphur limit from 0.5% to 0.1%. This assumption is made on the basis of evidence that low sulphur heavy fuel oil was available to comply with the SECA fuel sulphur limits of 1.5% to 2010 and 1% from 2010 (IMO, 2010).

The requirement that vessels at berth from 2010 use fuel which complies with a sulphur limit of 0.1% implies the need for MDO. Therefore, in the back casted inventory prior to 2010, any vessels that would have used HFO, save for the at berth requirement of 0.1% S fuel, are assumed to use HFO.

c) Emission factors

Pollutants covered in Scarbrough *et al*. (2017)

The source of the raw emission factors used for NO_X, SO_X, PM, CO, and NMVOCs is given in section 2.2.8 of Scarbrough *et al*. (2017). These emission factors are derived from the IMO (IMO, 2015). Table 3-35 of this document gives the implied emission factors developed from the Scarbrough *et al*. (2017)

model. Details of how emission factors for these pollutants vary from the base year of 2014 is given in section 3.1.2 of Scarbrough *et al*. (2017).

Vessels using HFO in a SECA are assumed to switch to using MDO from 2015 onwards, with an SO_X emission factor reduction of 90% (from 1% S HFO to 0.1% MDO) accordingly.

NO_X emission factors are assumed to reduce over time due to continued turnover in the fleet leading to larger proportions of vessels with more recent engines which meet later (more stringent) NO_X emission tiers. Reductions from fleet turnover are expected to continue at the same approximate rate until 2021. The IMO indicates NO_X emission factor reductions of around 0.5% per year for HFO and distillate (IMO,2015). IVL (IVL, 2016) indicates slightly higher reduction rates of 0.7% to 0.8% over time. The figure of 0.7% annual reduction is selected from 2014 to 2021:

$$EF\ index_{NOx,2014\ to\ 2021} = 0.993^{(y-2014)}$$

From the fleet turnover model, the fleet average NO_X emission factor is assumed to reduce by 4% per year from 2021:

$$EF\ index_{NOx,2021+} = 0.993^{(2020-2014)} \times 0.96^{(y-2021)}$$

Changes affecting PM emission factors since 2014 are given in section 3.2.2.4 of Scarbrough *et al*. (2017). PM factors generally decrease with reductions in fuel sulphur content so are higher in the earlier part of the time series relative to 2014.

Other pollutants

Emissions factors for the following pollutants are taken from Tables 3-1 and 3-2 of the 2016 EMEP/EEA Guidebook chapter on 1A3d; Zn, Pb, Hg, Se, Cd, Ni, Cr, HCB, Cu, As, PCBs, PCDD/PCDF. There are no factors for NH_3 emissions from shipping in the EMEP/EEA Guidebook. It was deemed reasonable to assume the emission factors would be the equivalent to those of a diesel railway train. The emission factor used is the Tier 2 NH_3 emission factor from Tables 3.2-3.4 of the 1.A.3.c Railways chapter of the EMEP/EEA Guidebook. This emission factor, in mass-based units, is 10 g/tonne fuel. These emission factors are assumed to remain constant over time.

d) Efficiency index

Over time it is expected that shipping transport efficiency increases over time in response to financial and regulatory drivers. For all vessels it is assumed that the efficiency of sea transport improves by 1% per year from 2014 to 2035 to account for lower fuel consumption per unit (tonne or container or passenger) transported and more fuel-efficient new vessels compared to old vessels

i.e. $Efficiency\ index_y = 0.99^{(y-2014)}$

Further details on how this value was derived are given in section 3.2.3. of Scarbrough *et al*. (2017). The current inventory therefore implies a small improvement in the fuel efficiency of the fleet from the 2014 base to 2022.

e) Summary of fuel consumption trends and implied emission factors

A summary of fuel consumption trends for coastal shipping and implied emission factors for 2022 are provided in Section 3.3.5.4.

3.3.5.2.2. NFR 1A5b: Military Shipping

Emissions from military shipping are reported separately under NFR code 1A5b. Emissions are calculated using a time series of naval fuel consumption data (naval diesel and marine gas oil) provided directly by the Sustainable Development team of the MoD (MoD, 2023). Data are provided on a financial year basis, so adjustments were made to derive figures on a calendar year basis.

The time series in fuel consumption from military shipping is included with that for coastal shipping in Section 3.3.5.4.

Implied emission factors derived for international shipping vessels running on marine distillate oil from Scarbrough *et al*. (2017) were assumed to apply for military shipping vessels. The exception to this is for NO_X emission factors where higher emission factors from the Entec study (Entec, 2010) for marine distillate oil (marine gas oil and MDO) were considered more appropriate.

3.3.5.2.3. NFR 1A3dii: Emissions from Vessel Movements Between the UK and Overseas Territories

Emissions are estimated for vessel movements between the UK and Overseas Territories. These were not included in Scarbrough *et al*. (2017) but need to be included in the UK national totals.

a) Activity data

There are no published data on the number and types of voyages between the UK and overseas territories (OTs). However, officials at the UK Department for Transport were able to interrogate their ports database which forms the basis of the less detailed information published in DfT's Maritime Statistics. This included information on freight shipping movements and passenger vessel movements. Additional information on passenger vessel movements were gathered from individual OT port authorities.

For freight shipping, the DfT were able to provide the number of trips made between a UK port and an OT port by each unique vessel recorded. The information provided the type of vessel and the departure and arrival port. Figures were provided for all years between 2000 and 2022.

The information on the type of vessel was used to define:

- The average cruise speed of the vessel
- The average main engine power (in kW), and
- The specific fuel consumption factor (g/kWh)

This information was taken from the latest EMEP/EEA Guidebook. Distances for each voyage were taken from http://ports.com/sea-route and https://sea-distances.org/. These two websites have tools to calculate route distance by specifying the departure and arrival ports.

Using the distance, average speed, engine power and fuel consumption factor it was possible to calculate the amount of fuel consumed for every voyage made.

DfT were unable to provide the detailed port data for years before 2000. The individual OT port authorities also did not have this information. The trends in fuel consumption calculated by Entec for all UK international shipping from 1990 to 2000 (based on less detailed UK port statistics) were used to define the trend in fuel consumption between the UK and OTs over these years.

For passenger vessels, the information held by OT port authorities indicated the only movements were by cruise ships (i.e. not ferries). Detailed movement data were held by the port authority of Gibraltar listing all voyages departing to or arriving from the UK back from 2003 to 2012. The DfT also held information on the number of UK port arrivals by cruise ships from the OTs, but only between 1999 and 2004. This is unpublished information and was provided via direct communication with DfT officials.

The data held by DfT showed the majority of sailings were from Gibraltar and the data were consistent with the information provided by the Gibraltar port authority. However, the DfT data also showed a total 3 arrivals from the Falkland Islands between 1999 and 2004.

This information was combined to show the total number of cruise ship movements between the UK and OTs from 1999 to 2017. To estimate the fuel consumption for passenger vessels for 2018, the mean fuel consumption of the previous five years (2013 - 2017) by OT was used. As no updated data were available, the fuel consumption for passenger vessels in 2019 was assumed to be the same as that for 2018. For 2020 to 2022, the estimated fuel consumption values were based on the trend of “UK All Cruise Passengers" from the SPAS0101 DfT data set, relative to the index value of 1 in 2019.

The same source of information as described above was used to define the distances travelled, cruise speed, engine power and fuel consumption factor to calculate total fuel consumption by cruise ships between the UK and each OT. The information for passenger ships was taken from the EMEP/EEA Guidebook.

No cruise ship information was available before 1999 from either DfT or the individual OT port authorities. Trends in the total number of passengers on cruises beginning or ending at UK ports between 1990 and 1999 published in DfT’s Maritime Statistics (from Table 3.1(a) UK international short sea passenger movements, by port and port area: 1950 - 2009) were used to define the trend in fuel consumption by cruise ships between the UK and OTs over these years.

The total fuel consumed by vessels moving between the UK and each OT was calculated as the sum of all fuel consumed by freight and passenger vessels. This was calculated separately for movements from the UK to each OT and from each OT to the UK.

The time series in fuel consumption from the UK to OTs is shown in Section 3.3.5.4.

b) Emission factors

All fuel used for voyages between the UK and OTs is assumed to be fuel oil. The emission factors used are average factors implied by Scarbrough *et al*. (2017) for all vessels involved in international voyages from or to a UK port from/to a non-UK destination.

Implied emission factors for 2022 derived for vessels using fuel oil for international voyages including to/from the OTs are shown in Section 3.3.5.4.

3.3.5.2.4. NFR 1A3dii: Emissions from Inland Waterways

The category 1A3dii Waterborne Navigation must include emissions from fuel used for small passenger vessels, ferries, recreational watercraft, other inland watercraft, and other gasoline-fuelled watercraft. These small vessels were not included in Scarbrough *et al*. (2017). The Guidelines recommend national energy statistics be used to calculate emissions, but if these are unavailable then emissions should be estimated from surveys of fuel suppliers, vessel movement data or equipment (engine) counts and passenger and cargo tonnage counts. The UK has no national fuel consumption statistics on the amount of fuel used by inland waterways in DUKES, but they are included in the overall marine fuel statistics. A Tier 3 bottom-up approach based on estimates of population and usage of different types of inland waterway vessels is used to estimate their emissions. In the UK, all emissions from inland waterways are included in domestic totals.

The methodology applied to derive emissions from the inland waterways sector uses an approach consistent with the latest EMEP/EEA Guidebook. The inland waterways class is divided into four categories and sub-categories:

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

Details of the approach used are given in the report by Walker *et al.*, 2011.

a) Activity data for 2008

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/occasionally going to sea. For this, data were collected from stakeholders, including the British Waterways, DfT, Environment Agency, Maritime and Coastguard Agency (MCGA), and Waterways Ireland.

The methodology used to estimate the total amount of each fuel consumed by the inland waterways sector follows that described in the EMEP/EEA Guidebook where emissions from individual vessel types are calculated using the following equation:

$$E = \sum_i N \times HRS \times HP \times LF \times EFi$$

where:

E = mass of emissions of pollutant i or fuel consumed during inventory period,

N = source population (units),

HRS = annual hours of use,

HP = average rated horsepower,

LF = typical load factor,

EFi = average emissions of pollutant i or fuel consumed per unit of use (e.g. g/kWh).

The method requires:

- a categorisation of the types of vessels and the fuel that they use (petrol, DERV or gas oil);
- numbers for each type of vessel, together with the number of hours that each type of vessel is used;
- data on the average rated engine power for each type of vessel, and the fraction of this (the load factor) that is used on average to propel the boat;
- g/kWh fuel consumption factors and fuel-based emission factors.

A key assumption made is that privately-owned vessels with diesel engines used for recreational purposes use DERV while only commercial and service craft and canal boats use gas oil (Walker *et al.*, 2011). Some smaller vessels also run on petrol engines.

Walker at al.,2011 and Murrells *et al.*,2011 had previously drawn attention to the potential overlap between the larger vessels using the inland waterways and the smaller vessels in the shipping sectors (namely tugboats and chartered and commercial fishing vessels), and the judgement and assumptions made to try to avoid such an overlap. This potential overlap was reconsidered in light of the methodology for domestic shipping since certain types of vessels operating at sea close to shore that were previously included in the inland waterways sector of the inventory were now captured in the AIS data. Hence their emissions are included under coastal shipping described above and by Scarbrough *et al*. (2017). These vessels were considered to be passenger vessels with >12 passengers and 3 or more engines operating in estuaries, tugs, cranes, and chartered and commercial fishing vessels. To avoid a double count, the activities for these vessels are no longer included in the inland waterways database.

b) Time series trends in activity data

As it was only possible to estimate population and activities for one year (2008), proxy statistics were used to estimate activities for different groups of vessels for other years in the time series 1990-2022:

- Private leisure craft - ONS Social Trends 41: Expenditure, Table 1, Volume of household expenditure on “Recreation and culture”[62]. No data were available for this dataset after 2009, therefore a second dataset was used to estimate the activity from 2010: OECD. Stat data (Final consumption expenditure of household, UK, P31CP090: Recreation and culture)[63];
- Commercial passenger/tourist craft - Visit Britain, Visitor Attraction Trends in England 2022, Full Report ("Total England Attractions")[64]
- Freight - DfT - Waterborne transport in the UK: goods lifted and moved by traffic type, Table PORT0701[65].

One of these three proxy data sets was assigned to each of the detailed vessel types covered in the inventory and used to define the trends in their fuel consumption from the 2008 base year estimate.

Table 3-33 shows the trend in fuel consumption by inland waterways from 1990-2022 developed for the inventory in selected years. More detail regarding the vessels and their fuel type can be found in the report by Walker *et al.,* 2011.

Table 3-33 Fuel consumption for inland waterways derived from inventory method

Year	Fuel Consumption (kt)					
	Gas Oil		Diesel		Petrol	
	Motorboats / workboats	Inland goods carrying vessels	Sailing boats with auxiliary engines	Motorboats / workboats	Motorboats / workboats	Personal watercraft
1990	30.1	3.8	0.6	27.6	22.0	11.2
2000	30.4	2.7	1.1	53.5	34.8	21.6
2005	33.3	2.2	1.6	72.9	45.2	29.5
2010	39.2	2.2	2.0	92.5	56.5	37.4

[62] http://www.ons.gov.uk/ons/rel/social-trends-rd/social-trends/social-trends-41/index.html
[63] http://stats.oecd.org/Index.aspx?DataSetCode=SNA_TABLE5
[64] https://www.visitbritain.org/annual-survey-visits-visitor-attractions-latest-results
[65] https://www.gov.uk/government/statistical-data-sets/port-and-domestic-waterborne-freight-statistics-port

Year	Fuel Consumption (kt)					
	Gas Oil		Diesel		Petrol	
	Motorboats / workboats	Inland goods carrying vessels	Sailing boats with auxiliary engines	Motorboats / workboats	Motorboats / workboats	Personal watercraft
2015	44.2	2.3	2.3	105.9	64.5	42.9
2016	45.1	2.2	2.3	107.9	65.7	43.6
2017	45.7	2.3	2.5	116.3	70.0	47.1
2018	46.6	2.0	2.6	119.1	71.6	48.2
2019	47.8	2.4	2.7	125.5	75.1	50.8
2020	16.8	2.3	2.3	108.5	58.0	43.9
2021	21.8	2.0	2.7	124.3	67.2	50.3
2022	31.0	2.0	2.9	137.1	76.0	55.5

c) Emission factors

The fuel-based emission factors used for all inland waterway vessels were taken from the EMEP/EEA Guidebook and implied factors for 2022 are presented later. The factors for SO_X from vessels using gas oil took into account the introduction of the much tighter limits on the sulphur content of gas oil for use by inland waterway vessels, the limit reduced to 10ppm from January 2011.

3.3.5.3. NFR 1A3di: International Navigation

Emissions from international marine bunkers are calculated but reported as a Memo item and not included in the UK totals.

a) Activity data

Fuel consumption for international shipping is taken directly from DUKES figures for international marine fuel bunkers, as discussions with DESNZ indicate that there is higher confidence in the DUKES estimates of the international 'marine bunkers' fuel sales data than the portion allocated to national navigation. As such, the marine bunkers fuel statistics in DUKES are used without further adjustment as the activity data for emissions from the international navigation Memo item under 1A3di.

The consequence of having emissions for national navigation and inland waterways (1A3dii), fishing (1A4ciii) and naval (1A5b) based on a bottom-up method derived from vessel activity and of having emissions for international navigation (1A3di) based on DUKES data for international bunkers is that the total marine fuel consumption exceeds that given in DUKES for national navigation plus marine bunkers. In some years, the fuel consumption for national navigation and inland waterways (1A3dii), fishing (1A4ciii) and naval (1A5b) alone exceeds the total given in DUKES for national navigation plus marine bunkers.

Aside from uncertainties in the modelling approach (discussed in Scarbrough *et al.* (2017)), one possible reason for the difference between total DUKES fuel consumption figures for national navigation and figures calculated from the bottom-up approach is that a substantial proportion of domestic voyages in the UK are taken by vessels that fuelled overseas. This amount of "fuel tankering" is not known. However, given the high uncertainty in the DUKES figure on fuel used for national navigation and for consistency with the EMEP/EEA and IPCC Emissions Inventory Guidelines definition of domestic shipping, the UK prefers to use the higher bottom-up estimates for the domestic sources to be included in the national totals, particularly as they provide a more robust estimate on shipping emissions for estimating air pollution impacts of shipping in the UK, being based directly on vessel activities.

The activity data for the International navigation Memo item 1A3di in this inventory is based solely on figures in DUKES for international fuel bunkers. It reflects emissions from UK international marine fuel sales whereas the emissions for national navigation and inland waterways (1A3dii) and fishing (1A4ciii) reflect the amount of fuel used for domestic navigation purposes.

b) Emission factors

Emissions for international shipping (1A3di) were calculated by multiplying the fuel consumption calculated above with an implied emission factor for international vessel movements. The emission factors used are average factors implied by Scarbrough *et al*. (2017) for all vessels involved in international voyages from or to a UK port from/to a non-UK destination.

Implied emission factors for international navigation in 2022 are shown in Section 3.3.5.4.

3.3.5.4. Summary of all Activity Data Trends and Emission Factors for Navigation

3.3.5.4.1. Trends in Fuel Consumption

This section summarises the time series in gas oil and fuel oil consumption for domestic coastal and military shipping, fishing, inland waterways, international shipping and voyages from the UK to the OTs in selected years. Fuel consumed in the OTs and for voyages from the OTs to the UK is not included in Table 3-34.

Table 3-34 Fuel consumption for UK marine derived from inventory method

	Gas oil				Fuel oil			
Mt fuel	Domestic coastal and military	Fishing	Inland water-ways	Inter-national bunkers	Domestic coastal and military	Fishing	Voyages from UK to OTs	Inter-national bunkers
1990	1.89	0.23	0.03	1.14	0.82	0.82	0.008	1.39
2000	1.96	0.18	0.03	1.14	0.80	0.80	0.011	0.93
2005	1.64	0.19	0.04	0.89	0.78	0.78	0.009	1.16
2010	1.41	0.17	0.04	0.96	0.57	0.57	0.011	1.83
2015	1.41	0.16	0.05	1.67	0.18	0.18	0.009	0.83
2016	1.38	0.17	0.05	1.77	0.17	0.17	0.010	0.88
2017	1.35	0.17	0.05	1.67	0.17	0.17	0.011	0.77
2018	1.37	0.16	0.05	1.63	0.16	0.16	0.009	0.81
2019	1.37	0.15	0.05	1.59	0.16	0.16	0.009	0.68
2020	1.18	0.14	0.02	1.33	0.15	0.15	0.006	0.54
2021	1.22	0.14	0.02	1.33	0.16	0.16	0.006	0.59
2022	1.19	0.13	0.03	1.29	0.15	0.15	0.011	0.66

The method for estimating fuel consumption by domestic, fishing and international shipping prior to 1990 is based on the relative share of these movement types in 1990 itself which was assumed to remain constant in all previous years. The 1990 share was applied to the total fuel consumption figures given in DUKES for each year back to 1970 (after deducting consumption by military vessels).

3.3.5.4.2. Emission Factors

Table 3-35 shows the implied emission factors for each main pollutant, for both domestic and international vessel movements and fishing in 2022. The units are in g/kg fuel and are implied by the figures in Scarbrough *et al*. (2017) and the fuel sulphur content.

Table 3-35 2022 Inventory Implied Emission Factors for Shipping

Fuel	Source	NO_X	SO_X	NMVOC	PM_{10}	CO	NH_3
		g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
Gas Oil	Domestic (excl. fishing)	49.5	3.6	1.6	0.9	3.2	0.010
	Fishing	61.2	4.3	2.3	1.0	3.1	0.010
	International	58.9	4.0	1.6	0.9	3.3	0.010
Fuel Oil	Domestic	64.4	10.0	2.5	1.2	2.9	0.010
	Fishing	80.2	10.0	3.1	1.4	2.7	0.010
	International	73.1	10.0	2.9	1.3	2.9	0.010

Table 3-36 provides emission factors for each main pollutant, assumed for all vessel types operating on the UK's inland waterways in 2022.

Table 3-36 2022 Inventory Emission Factors for Inland Waterway Vessels

Fuel	NO_X	SO_X	NMVOC	PM_{10}	CO	NH_3
	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
DERV	42.5	0.015	4.7	4.1	10.9	0.007
Gas Oil	42.5	0.012	4.7	4.1	10.9	0.007
Petrol	9.00	0.009	50	0.04	300	0.005

3.3.6. NFR 1A4: Other Emissions Associated with Transport Sectors

Emissions associated with other transport sources are mapped to 1A4, Combustion in Residential/Commercial/Public sectors covered in Section 3.4. This includes stationary combustion emissions from the railway sector in 1A4a, including generating plant dedicated to railways. For most sources, the estimation procedure follows that of the base combustion module using DESNZ reported fuel use data. The 1A4a Commercial and Institutional sector also contains emissions from stationary combustion at military installations, which should be reported under 1A5b Other, Mobile (including military).

Emissions from 1A4b Residential and 1A4c Agriculture/Forestry/Fishing are disaggregated into those arising from stationary combustion and those from off-road vehicles and other machinery. The estimation of emissions from off-road sources is discussed in Section 3.3.7. Emissions from fishing vessels are included in 1A4ciii and were described in the section on Navigation, Section 3.3.4.

3.3.7. Non-Road Mobile Machinery (NRMM)

Emissions from a variety of off-road mobile machinery sources are included in 1A2gvii, 1A4bii, 1A4cii and 1A3eii. These are for industrial and construction mobile machinery, domestic house and garden machinery, agricultural machinery and airport support machinery, respectively. Military aircraft and naval shipping are covered under 1A5b and have been previously described.

Between 2019 and 2022, Defra commissioned Ricardo to conduct improvement projects to gather updated activity data used for estimating emissions from NRMM through engagement with industry stakeholders. The scope of these improvement projects covered NFR sectors 1A2gvii, 1A4cii and

1A3eii, but not 1A4bii. Following review, agreed implementation of the data into an updated version of the off-road machinery model has been conducted, containing revised activity and population data. As such, there are two models, the house and garden model, and the other off-road machinery model.

3.3.7.1. NFR 1A4bii: House and Garden Machinery

A Tier 3 methodology is used for calculating emissions from individual types of house and garden machinery. Machinery or engine-specific fuel consumption, and emission factors (g/kWh) for house and garden machinery are taken from the 2009 EMEP/EEA Guidebook. Emission factors for more modern machinery are based on engine or machinery-specific emission limits established in the EU Non-Road Mobile Machinery Directives. Detailed activity data for house and garden machinery were derived from bottom-up estimates from population and hours of use of equipment in 2004. Proxy statistics are used as activity drivers to estimate fuel consumption in other years.

Summary of activity data (1A4bii)

For domestic house and garden, bottom-up estimates from population and hours of use of equipment for the year 2004. Various proxy statistics are used to estimate fuel consumption for all other years. House and garden machinery refers to the kinds of machinery available for domestic use, regardless of whether they are then used privately or professionally, so covers all use of these types of machinery rather than only covering domestic use.

Details of Methodology (1A4bii)

Emissions for house and garden machinery are calculated from a bottom-up approach using machinery or engine-specific emission factors in g/kWh based on the power of the engine, and estimates of the UK population and annual hours of use of each type of machinery.

The emission estimates for house and garden are calculated using the methodology given in the 2009 EMEP/EEA Guidebook. Emissions are calculated using the following equation for each machinery class:

$$E_j = N_j \,.\, H_j \,.\, P_j \,.\, L_j \,.\, W_j .(1 + Y_j \,.\, a_j /2).\, e_j$$

where

E_j	=	Emission of pollutant from class j	(kg/y)
N_j	=	Population of class j.	
H_j	=	Annual usage of class j	(hours/year)
P_j	=	Average power rating of class j	(kW)
L_j	=	Load factor of class j	(-)
Y_j	=	Lifetime of class j	(years)
W_j	=	Engine design factor of class j	(-)
a_j	=	Age factor of class j	(y^{-1})
e_j	=	Emission factor of class j	(kg/kWh)

For petrol-engined sources, evaporative NMVOC emissions are also estimated as:

$$E_{vj} = N_j \,.\, H_j \,.\, e_{vj}$$

where

E_{vj}	=	Evaporative emission from class j	kg
evj	=	Evaporative emission factor for class j	kg/h

The population, usage and lifetime of different types of house and garden machineries were based on a study carried out by Ricardo on behalf of the Department for Transport (Netcen, 2004). This study researched the current UK population, annual usage rates, lifetime and average engine power for a range of different types of diesel-powered non-road mobile machinery. Additional information including data for earlier years were based on research, Off Highway Research Ltd, 2000 and market research polls amongst equipment suppliers and trade associations by Precision Research International on behalf of the former DoE (Department of the Environment) (PRI, 1995, 1998). Usage rates from data published by Samaras and Zierock (1993, 1994) were also used.

The population and usage surveys and assessments in the previous approach were only able to provide estimates on activity of off-road machinery for years up to 2004. These are one-off studies requiring intensive resources and are not updated on an annual basis.

As in previous years, various activity drivers were used to estimate activity rates from 2005. For domestic house and garden machinery, historic and projected trends in number of households are used (CLG, 2016 and ONS, 2023e).

3.3.7.2. NFR 1A2gvii, 1A4cii, 1A4eii Non-Road Mobile Machinery for Industry, Agriculture and Airport Support

Data and information for the other off-road machinery model were provided by industry trade associations and stakeholder groups including the Off Highway Engine and Equipment Group (OHEEG), the Agricultural Engineers Association (AEA), Department for Transport (DfT) and the Construction and Agriculture Equipment Security and Registration (CESAR) database, and though these data were not designed for use in inventories, they provided valuable information.

Machinery or engine-specific fuel consumption and emission factors (g/kWh) in this model are based on stakeholder consultation and the EMEP/EEA Guidebook. The AEA were able to provide fuel consumption rates for different agricultural machinery types in litres per hour based on telemetry data. The exceptions were agricultural telehandlers which were adjusted to align with fuel consumption rate implied by Guidebook factors.

Using activity data collated from OHEEG, AEA, DfT licensing statistics supplemented by various assumptions from expert judgement from discussions with AEA where data are missing, the model was constructed and used to calculate trends in fuel consumption and emissions, initially from agricultural machinery and then extended to other off-road machinery (excluding house and garden).

Inventories for these machinery were grouped into portable generators, construction machinery, forklifts, machinery used in mining and quarrying, waste services, airport support and seaport support machinery and Transport Refrigeration Units (TRUs). Nearly all types of machinery use gas oil, but for some machinery types, a further breakdown in consumption and emissions is provided for machines running on petrol and LPG, where relevant.

Summary of activity data (1A2gvii, 1A4cii and 1A3eii)

Bottom-up estimates from population and hours of use of equipment were taken in 2018. Various proxy statistics are used to estimate fuel consumption for other years, these include:

- In the case of portable generators, cement mixers, cranes and various lifting equipment used in construction and industry, data from Eurostat PRODCOM[66] statistics on sales/production of these equipment were used. ONS[67] construction statistics and DUKES for other types of construction and industry machinery continue to be used.
- Confidential data provided by the British Industrial Truck Association (BITA) have been adopted for trends in sales of forklifts.
- For airport machinery, statistics on number of terminal passengers at UK airports[68] continue to be used.
- DfT port freight statistics[69] have been used as proxies for trends in activities for machinery used in sea ports.
- Trends in TRU activities were based on DfT statistics[70] on licensed "insulated vans" vehicle category.
- For agricultural off-road machinery, the trends in gas oil allocated to agriculture in DUKES (DESNZ, 2023a) are used.

Details of Methodology (1A2gvii, 1A4cii and 1A3eii)

In the model, emissions from off-road machinery (1A2gvii, 1A4cii and 1A3eii) are calculated using the Tier 3 method in the EMEP/EEA Guidebook. The equation to calculate the emissions is given below:

$$E = N\ x\ HRS\ x\ P\ x\ LF\ x\ (1 + DFA)\ x\ LFA\ x\ EF_{Base}$$

where:

E = mass of emissions of pollutant during inventory period (g),

N = number of engines (units),

HRS = annual hours of use,

P = engine size (kW),

LF = load factor,

DFA = deterioration factor adjustment,

LFA = load factor adjustment,

EFBase = Base emission factor (g/kWh).

The emission factors are taken from the EMEP/EEA Guidebook, as provided for different legislative stages and engine power ratings. The exception to this was for the smallest and largest machinery in the power bands <19 kW or greater than 560 kW for the other machinery types. For these machines, OHEEG noted that although off-road in these power classes were unregulated in Europe prior to Stage

[66]https://www.ons.gov.uk/businessindustryandtrade/manufacturingandproductionindustry/bulletins/ukmanufacturerssalesbyproductprodcom/2021results
[67] https://www.ons.gov.uk/businessindustryandtrade/constructionindustry/datasets/outputintheconstructionindustry
[68] https://www.caa.co.uk/Documents/Download/9116/47a460b2-0592-4ef7-b24b-aa5e27ccfce4/5634
[69] https://www.gov.uk/government/collections/maritime-and-shipping-statistics
[70] Personal communication with DfT

V, nevertheless it was common for machines in these size classes to be fitted with engines suitable for the US market, with the exception of >560 kW gensets. Thus, a notable proportion will have lower emissions than might be assumed for ‘unregulated’ engines as provided in the Guidebook. As a result, emission factors were changed to reflect US Tier 2 or Tier 4 regulations prior to Stage V. Tier 2 machines were phased into the market from 2006 for machinery for >560kW. Tier 4 is phased in from 2008 for those machines <19kW.

Emissions of SO_X were derived from the calculation of fuel consumption and sulphur content of gas oil fuel used in the UK, as provided by Fuels Industry UK each year for the NAEI.

The machinery were grouped and mapped across nine sector types (excluding house and garden which remains in the house and garden model), based on stakeholder feedback. Each machinery type was placed into eight power bands from P < 8 to P > 560, where P is power in kW. Table 3-37 summarises the machinery types and sectors in this other off-road machinery model.

Table 3-37 Machinery types and sectors in the other off-road model

Machinery Type	Sector (NFR)								
	Construction 1A2gvii	Waste 1A2gvii	Mining/Quarrying 1A2gvii	Airport 1A3eii	Port 1A3eii	Other Industry 1A2gvii	Refrigeration 1A3eii	Agriculture 1A4cii	Forklifts 1A4aii
Trencher/mini excavator	√								
Excavator	√								
Forklifts									√
Telehandlers	√	√	√		√				
Rough terrain forklifts	√		√						
Dumpers/tenders	√		√			√			
Rollers	√								
Cement & mortar mixers	√								
Cranes	√				√				
Rubber tyred gantry cranes					√				
Pumps	√								
Air compressors	√								
Gas compressors						√			
Bore/drill rigs	√		√						
Plate compactors	√								
Landfill compactors		√							
Loaders	√	√	√						
Bulldozers	√	√	√						
Asphalt /concrete pavers	√								
Generators	√					√			
Scrapers	√								

Machinery Type	Sector (NFR)								
	Construction 1A2gvii	Waste 1A2gvii	Mining/Quarrying 1A2gvii	Airport 1A3eii	Port 1A3eii	Other Industry 1A2gvii	Refrigeration 1A3eii	Agriculture 1A4cii	Forklifts 1A4aii
Graders	√								
Crushing/processing equipment	√		√						
Aerial Lifts	√		√			√			
Sweepers/scrubbers	√	√							
Welding equipment	√		√			√			
Concrete/industrial saws	√								
Pressure washers	√					√			
Tampers/rammers	√								
Aircraft support equipment				√					
Terminal tractors				√					
Reachstackers					√				
Shuttle carrier/Straddle carrier					√				
Terminal tractors - port					√				
Industrial tractors, burden and personnel carriers						√			
Other material handling equipment						√			
Bitumen Applicator						√			
Aggregate Applicator						√			
TRUs							√		
Other general industrial equipment						√			
Paving equipment	√								
Surfacing equipment	√								

Machinery Type	Sector (NFR)								
	Construction 1A2gvii	Waste 1A2gvii	Mining/Quarrying 1A2gvii	Airport 1A3eii	Port 1A3eii	Other Industry 1A2gvii	Refrigeration 1A3eii	Agriculture 1A4cii	Forklifts 1A4aii
Concrete pumps	√								
Agricultural machine								√	
Agricultural tractor								√	
Agricultural telescopic handler								√	
Combine harvester								√	
Forage harvester								√	
Root crop harvester								√	
Sprayer								√	
Windrower								√	

3.3.7.3. Gas Oil Reconciliation

In some years, the NRMM model calculates the bottom-up gas oil use as being greater than that is available in DUKES. As the UK energy statistics are a top-down methodology, with a greater degree of certainty, there is required to be a fuel reconciliation such that the fuel use is distributed to sectors appropriately.

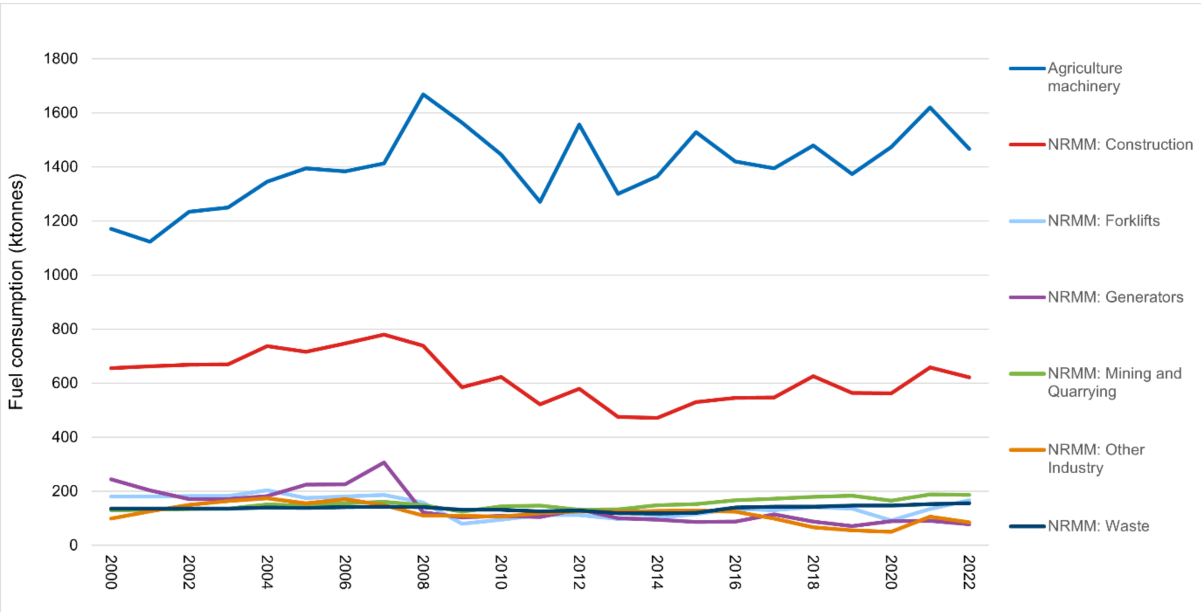
When there is not enough gas oil to allocate to bottom-up estimates, the approach is to adjust all bottom-up off-road estimates, including agricultural off-road depending on the degree to which those bottom-up estimates agree with DUKES allocations to sectors which use those types of machinery. The logic of the reconciliation approach is summarised in Annex 4.2.1.4 of the UK's National Inventory Report 1990-2022, which is due to be published in April 2024[71].

Because of this reconciliation process, changes in fuel consumption and emissions for industrial machinery occur when revisions to the allocation of gas oil consumption to other sources are made.

In the model, it is assumed all diesel used off-road is gas oil, and that there is no DERV, based on feedback from stakeholders. Likewise, input from stakeholders indicated that there is notable use of LPG in the industrial off-road sector, particularly from forklifts. Thus, DERV is only used in the house and garden sector.

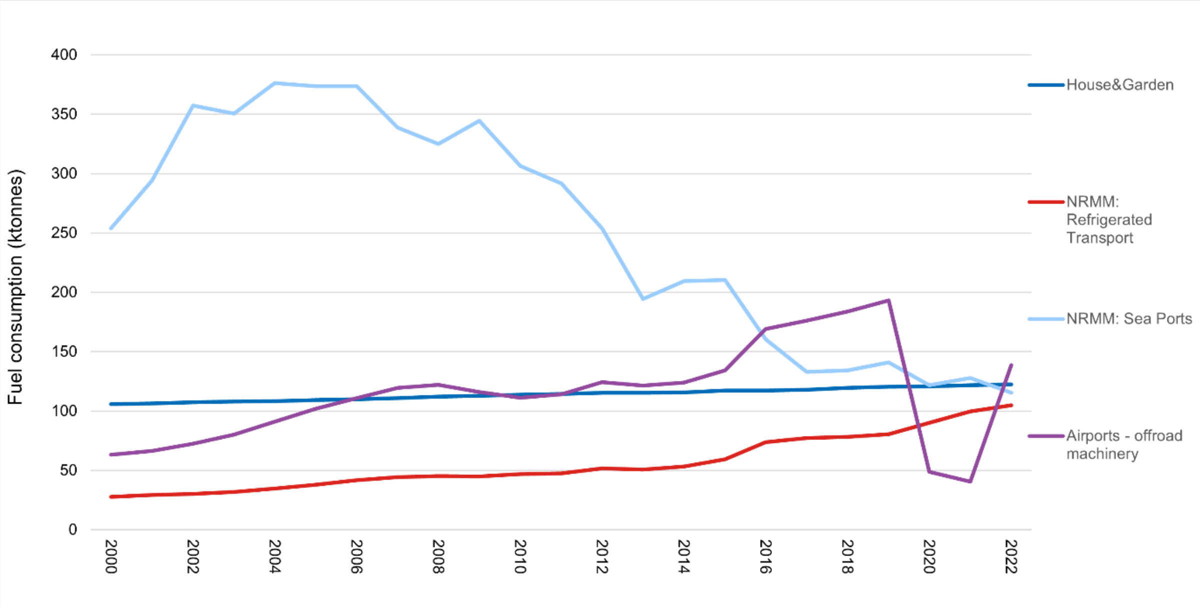
Figure 3-8 and Figure 3-9 show the trend in total fuel consumption for the four main off-road categories since 2000. These include the combined consumption of gas oil, road diesel and petrol by each sector. The trend in consumption for the industry and construction machinery sector reflects the fuel reconciliation process used as well as the effect of activity drivers used which themselves are a reflection of economic conditions, for example fuel consumption in many sectors drops in 2020, reflecting the impact of restrictions in place during the COVID-19 pandemic.

Figure 3-8 Fuel consumption by off-road machinery (1A2gvii, 1A4aii and 1A4cii) in kt fuel from 2000



[71] https://naei.beis.gov.uk/reports/

Figure 3-9 Fuel consumption by off-road machinery (1A4bii and 1A3eii) in kt fuel from 2000



The fuel reconciliation process described above essentially overrides any changes in estimates of fuel consumption calculated from the bottom-up procedure arising from the recent improvement of activity data for some selected machinery types. However, this improvement still affects the emissions of air pollutants by leading to changes in implied emission factors for these machinery types, e.g., through revisions to the lifetime assumptions and emission limit values.

Aggregated emission factors for the four main off-road machinery categories by fuel type in 2022 are shown in Table 3-38. The factors for SO_X in 2022 reflect the sulphur content of fuels used, according to figures provided by Fuels Industry UK (2023).

Table 3-38 Aggregated Emission Factors for Off-Road Source Categories in 2022 (t/kt fuel)

Source	Fuel	CO	NO_X	PM_{10}	SO_X[1]	NMVOC
Domestic House & Garden	DERV	4.3	48.0	1.7	0.015	2.6
Domestic House & Garden	Petrol	668	3.0	0.03	0.009	11.8
Agricultural Power Units	Gas oil	8.1	6.4	0.3	0.012	0.9
Industrial Off-road	Gas oil	10.4	8.2	0.5	0.012	1.3
Industrial Off-road	Petrol	1032	5.1	0.26	0.009	32.6
Industrial Off-road	LPG	4.8	32.2	0.23	0.038	6.7
Aircraft Support	Gas oil	8.6	8.7	0.39	0.012	1.0

[1] Based on sulphur content of fuels in 2022 from Fuels Industry UK, 2023.

3.3.8. Recalculations in Transport Sources

Aviation (1A3a)

There were minor revisions (<1%) due to time series revision to taxi times to align with 2023 EMEP/EEA guidebook and revised cruise factors for several aircraft models from 2006. In 2021 there were recalculations due to revised activity data from Heathrow and DUKES.

Road transport (1A3b)

Time series emissions revisions are mainly a result of the adoption of the COPERT 5.6 emission factors and methodology. The previous inventory was based on COPERT 5.4. The effect this has varies for different pollutants and across the timeseries. For Particulate Matter, for example, emission are higher than in the previous inventory due to the significantly higher brake wear emission factors for internal combustion engine Light Duty Vehicles. For NO_X, emissions have generally increased across the timeseries. In the early timeseries, this was initially driven by changes due to degradation methodology and factors. In the later timeseries, increases due to cold start become more important .

Rail (1A3c)

The use of all available historic freight moved data from the Office of Road and Rail has resulted in recalculations of freight emissions for some years in the period 1982-2003.

Navigation (1A3dii), fishing (1A4ciii) and naval shipping (1A5b)

Within navigation, NO_X emission factors in 2021 for all vessels (except naval vessels) were reduced because the annual NO_X reduction rate changed from 0.7% from 2014 to 2020 to 4% per year from 2021 based on the fleet turnover model. There were also minor changes in 2021 in the DfT port and sea passenger statistics used as time series proxies resulted in minor revisions (<0.001%) in the average emission factors for this sector.

Within inland waterways, revised ONS data has led to a downward revision in the activity for private leisure craft from 2010. This is a downward revision with the largest decrease in 2020. Revised DfT data for goods lifted by domestic waterborne traffic in 2018, 2019 and 2021 also led to an upward revision in freight vessels activity with the largest increase in 2021.

Off-road machinery (1A2gvii, 1A4bii, 1A4cii, 1A3eii)

The main recalculation in the off-road sector was the increase in gas oil consumption from Agriculture between 2018 and 2021, due to updates in DESNZ (2023a). Activity is down in 2017, especially for the Agriculture and Industry sectors, and down for Industry slightly in most years across the time-series. This is due to consequences of the complex fuel reconciliation for gas oil. There were no significant recalculations for 1A4bii (house and garden machinery), where activity changed by <0.2% in 2020 and 2021.

Emissions from transport refrigeration units and machineries used in ports were previously reported under 1A2gvii but are now reported under 1A3eii.

3.3.9. Planned Improvements in Transport Sources

Most of the improvements in the transport sectors will depend on the availability of new or revised forms of activity data and emission factors and not all of these can be anticipated at this stage. For the road transport sector, the evidence on which to base changes in emission factors is a fast developing and changing area. In particular, there has been updated evidence of vehicle emissions from remote sensing campaigns. We are assessing this updated evidence and will undertake work improve the accuracy of road transport emissions estimates in future submissions. A watching brief is kept on developments in emission factors and activity data for all modes of transport, especially those that may arise from stakeholder initiatives and which can be reasonably incorporated in the inventory.

For the off-road sector, major improvements were made two years ago, where a new model was developed for 1A2gvii, 1A4cii and 1A3eii. We will look to incorporate the calculations of emissions from 1A4bii house and garden machineries into the new model (so to ensure consistent methodology will be used) when resources are available to do so.

For shipping, a major data update is expected for the 2025 submission based on more recent base year AIS vessel movement data and updated DfT port statistics.

3.4. NFR 1A4: Stationary Combustion in the Residential / Commercial / Public Sectors

Table 3-39 Mapping of NFR Source Categories to NAEI Source Categories: Residential / Commercial / Public Sectors[72]

NFR Category (other 1A4)	Pollutant coverage	NAEI Source category
1A4ai Commercial/ institutional: Stationary	All CLRTAP pollutants	Miscellaneous industrial & commercial combustion
		Public sector combustion
		Railways - stationary combustion
1A4aii Commercial/institutional: Mobile	All CLRTAP pollutants *(except HCB and PCBs)*	NRMM: Forklifts
1A4bi Residential: Stationary plant	All CLRTAP pollutants	Domestic combustion (split by technology type)
1A4bii Residential: Household and gardening (mobile)	All CLRTAP pollutants *(except HCB and PCBs)*	House and garden machinery
1A4ci Agriculture/Forestry/Fishing: Stationary	All CLRTAP pollutants *(except* NH_3 *and HCB)*	Agriculture - stationary combustion
1A4cii Agriculture/Forestry/Fishing: Off-road vehicles and other machinery	All CLRTAP pollutants *(except HCB and PCBs)*	Agricultural engines
		NRMM: Agriculture
1A4ciii Agriculture/Forestry/Fishing: National fishing	All CLRTAP pollutants	Fishing vessels

Table 3-40 Summary of Emission Estimation Methods for NAEI Source Categories in NFR Category 1A4

NAEI Source Category	Method	Activity Data	Emission Factors
Miscellaneous industrial & commercial combustion	UK model for activity allocation to unit type; AD x EF	DUKES, UK ETS, Operator reported data	Some operator-reported emission data for LCP. Default factors (US EPA, EMEP/EEA, UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.
Public sector combustion	UK model for activity allocation to unit type; AD x EF	DUKES, UK ETS, Operator reported data	Some operator-reported emission data for LCP. Default factors (US EPA, EMEP/EEA, UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.

[72] Please note that emissions covered under NFR 1A4aii are not included in this table. These emissions are covered under 1A2gvii.

NAEI Source Category	Method	Activity Data	Emission Factors
Railways - stationary combustion	UK model for activity allocation to unit type; AD x EF	DUKES, UK ETS, Operator reported data	Default factors (US EPA, EMEP/EEA, UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.
NRMM: Forklifts	See Section 3.3.7 on off-road machinery	Inventory Agency estimate of fuel use by different mobile units. Updated study on population and usage of machinery in 2018. Trends in activities for other years based on trends from BITA[73]. See Section 3.3.7	Factors from EMEP/EEA Guidebook combined with estimates of effect of more recent NRMM emission regulations on more modern equipment. See Section 3.3.7. Fuel analysis (Fuels Industry UK) for SO_X.
Domestic combustion	UK model for activity allocation to unit type; AD x EF	DUKES	Country Specific factors derived through measurements (for wood only). Default factors (US EPA, EMEP/EEA, UK-specific research). Fuel analysis (Fuels Industry UK, others) for SO_X.
House and garden machinery	See Section 3.3.7 on off-road machinery	Study on population and usage of machinery in 2004. Trends in activities for other years based on trends in household numbers. See Section 3.3.7	Factors from EMEP/EEA Guidebook combined with estimates of effect of more recent NRMM emission regulations on more modern equipment. See Section 3.3.7. Fuel analysis (Fuels Industry UK) for SO_X.
Agriculture - stationary combustion	UK model for activity allocation to unit type; AD x EF	DUKES, UK ETS, Operator reported data	Default factors (US EPA, EMEP/EEA, UK-specific research). Fuel analysis (Fuels Industry UK) for SO_X.
Agricultural engines	See Section 3.3.7 on off-road machinery	Inventory Agency estimate of fuel use by different mobile units	See Section 3.3.7. Default factors (EMEP/EEA). Fuel analysis (Fuels Industry UK) for SO_X.

[73] The British Industrial Truck Association (BITA) now known as the UK Material Handling Association (UKMHA). Data received via personal communication.

NAEI Source Category	Method	Activity Data	Emission Factors
NRMM: Agriculture	See Section 3.3.7 on off-road machinery	Inventory Agency estimate of fuel use by different mobile units. Updated study on population and usage of machinery in 2021. Trends in activities for other years based on DUKES trends in gas oil consumption by agriculture. See Section 3.3.7	Factors from EMEP/EEA Guidebook combined with estimates of effect of more recent NRMM emission regulations on more modern equipment. See Section 3.3.7. Fuel analysis (Fuels Industry UK) for SO_X.
Fishing vessels	See Section 3.3.4 on navigation	Inventory Agency estimate of fuel use across different shipping types, based on 2017 NAEI Shipping emissions methodology and use of trends in MMO fish landing statistics to estimate trends in fuel use in other years. See Section 3.3.4	See Section 3.3.4. Default factors mainly from UK-specific research (2017 BEIS review of the NAEI shipping emissions methodology), EMEP/EEA Guidebook and fuel analysis (Fuels Industry UK) for SO_X.

3.4.1. Classification of Activities and Sources

The NAEI utilises energy statistics published annually in the Digest of UK Energy Statistics, DUKES (DESNZ, 2023a). The source categories and fuel types used in the NAEI therefore reflect those used in DUKES.

Table 3-3 lists the fuels used in the inventory. In two instances, fuels listed in DUKES are combined in the NAEI: propane and butane are combined as ‘liquefied petroleum gas’ (LPG), whilst ethane and ‘other petroleum gases’ are combined as the NAEI fuel ‘other petroleum gases’ (OPG).

Table 3-39 relates the detailed NAEI source categories to the equivalent NFR (Nomenclature for Reporting) source categories for stationary combustion. Most NAEI sources can be mapped directly to an NFR source category, but there are some instances where the scope of NAEI and NFR categories are notably different, and these are highlighted in the methodology descriptions below. The NAEI source categories are presented at the level at which the UK emission estimates are derived, which is more detailed than that required for reporting; the NFR system is the reporting format used for submission of the UK inventories under the CLRTAP.

Almost all the NFR source categories listed in Table 3-39 are key sources for one or more pollutants and so the description of the methodology will cover the whole of this NFR sector. However, the emission inventory methodology for the mobile sources listed in Table 3-39 is described elsewhere (Sections 3.3.4 and 3.3.7).

3.4.2. General Approach for NFR 1A4

NFR Sector 1A4bi is a key category for SO_X, NO_X, NMVOCs, CO, TSP, PM_{10}, $PM_{2.5}$, Hg, Cd, PCDD/PCDFs and PAH. In addition, sector 1A4ai is a key source for NO_X and $PM_{2.5}$, and 1A4bii is a key source for CO.

The NAEI stationary source categories reported under 1A4 consist mainly of large numbers of very small plant with only a few large plant in the commercial and public sectors. Therefore, a bottom-up inventory approach utilising reported emissions is not possible for all plant. A combined bottom-up and top-down methodology is adopted for NO_X and PM_{10} but for other pollutants, emission factors are used exclusively. Plant-specific data for NO_X / PM_{10} emissions and activity data are used where available, but these cover just a few sites and so literature emission factors are used for the major part of 1A4. The approach is described in Section 3.2 (NFR 1A2).

3.4.3. Fuel Consumption Data

The current submission includes source-specific fuel consumption data for larger plant which are drawn from:

- Fuel use data for 2005-2017 reported by operators of Large Combustion Plant (LCP), which were at that time regulated under legislation implementing the Large Combustion Plant Directive (LCPD) and then Chapter III of the Industrial Emissions Directive (IED);
- Fuel use reported for installations covered by the EU Emissions Trading System (ETS) and, subsequently, the UK ETS (these will include LCP, larger Medium Combustion Plant (MCP) and other large combustion plant such as offshore combustion plant, kilns, furnaces and dryers). In the context of 1A4, the scope of both EU ETS and UK ETS will be limited to stationary combustion installations with a total rated thermal input exceeding 20 MW but excluding individual units with a rated thermal input under 3 MW and units which use exclusively biomass.

The final output for these calculations is a set of assumptions on how to split activity data for each fuel into three components (see Section 3.2 for more details):

1. LCPs
2. Larger MCP and larger furnaces/kilns/dryers (all $>20MW_{th}$ with individual units of $>3MW_{th}$)
3. Small MCP, smaller furnaces/kilns/dryers, and SCP (Small Combustion Plant)

In the 2024 submission, investigation of burning oil data in national energy statistics has allowed allocation of burning oil activity allocated to 1A2gviii in previous submissions to be split between 1A2gviii, 1A4ai and 1A4ci.

The most important deviations from UK energy statistics in 1A4 are as follows:

- DUKES does not include any energy uses of petroleum coke within any source categories in this NFR sector, and only includes very recent data for some sectors covered by 1A1 and 1A2. Instead, the remaining consumption of petroleum coke in DUKES is allocated to 'non-energy use' in the commodity balance tables for petroleum products. However, based on regular consultation with UK industry fuel suppliers, such as CPL Industries and the Solid Fuel Association, the Inventory Agency is able to make estimates of the annual consumption of petroleum coke as a fuel in other UK sectors, including for the domestic sector (1A4bi).
- Gas oil is used in large quantities as a fuel for off-road vehicles and mobile machinery. These devices are not treated as a separate category in DUKES and the fuel they use is included in the DUKES data for agriculture, industry, public administration, railways, and the commercial sector. The Inventory Agency generates independent estimates of gas oil use for off-road vehicles and mobile machinery, derived from estimates of the numbers of each type of

vehicle/machinery in use, and the fuel consumption characteristics. See Section 3.3.7 for method description. Overall consistency with UK consumption of gas oil, as given in DUKES, is maintained by reducing NAEI estimates for gas oil consumed by the sectors listed above. Off-road vehicles and mobile machinery reported in 1A4 includes agricultural tractors and other machinery, and garden equipment such as lawn-mowers.

- Estimates of gas oil and fuel oil use in the fishing industry, which underpin emission estimates in NFR sector 1A4ciii, are based on the 2017 review of UK shipping emissions methodology (Scarbrough *et al*., 2017), which applies a bottom-up method based on vessel movements using AIS transponder signals to the UK Maritime and Coastguard Agency. More details on the methodology are provided in Section 3.3.5.1.

In the 2014 version of DUKES, petroleum coke was listed as an input to smokeless fuel manufacture for the first time. Data extended back to 2009 and, for those years, the data in DUKES relating to production of solid smokeless fuels is therefore assumed to include that component of the smokeless fuel derived from the petroleum coke. Therefore, in the NAEI:

- For 1970-2008, the Inventory Agency uses the estimates of petroleum coke for the domestic sector as provided by industry;
- For 2009-present, the Inventory Agency uses the industry data, but reduced by the amount of petroleum coke reported in DUKES as used in solid smokeless fuel (SSF) manufacture, to avoid double-counting of the petroleum coke component of SSF.

3.4.4. NFR 1A4ai, 1A4ci: Commercial, Public Sector and Agricultural Combustion

3.4.4.1. Method for SO_X

Emission factors for SO_X are generated by combining UK-specific data on the sulphur content of coals and oils, provided by fuel suppliers and assuming EMEP/EEA Guidebook EFs for coals for which we have no data; this is more relevant for the more recent years of the inventory. Previous data was obtained from UK producers, but this is no longer accurate as the UK has substantially reduced its coal production.

3.4.4.2. Large Combustion Plant and Medium-Sized Plant

Site-specific emission estimates have been developed for the small number of LCP sites that fall within the scope of 1A4. These estimates were based on reported emissions of NO_X, and PM_{10} only, and emissions of other pollutants are not estimated in this way. Most combustion plant within 1A4 are small or medium-sized and emissions for these have to be estimated using an appropriate emission factor. Wherever possible for the larger (>20 MW_{th} total input and individually >3MW_{th}) medium plant within the scope of UK ETS, we have used EMEP/EEA Guidebook 2019 Tier 2 factors. A more complete methodology is described in Section 3.2.11.

There are limited data on appliance populations, which mean that the selection of appropriate Tier 2 factors has to be made based on simple assumptions. This means that we assume that equipment used in each sector is limited to a single type of device: for example, we assume that devices using gas oil within the commercial sector are engines. In reality, there will be a variety of technologies in use, though one broad type of technology probably will dominate.

Work to support development and implementation of the Medium Combustion Plant Directive may result in the collection of datasets that allow a more detailed inventory in future.

3.4.4.3. Smaller Plant

Smaller plant are those that are too small to be covered by UK ETS, so installations with a total rated thermal input of less than 20 MW, as well as all units with a rated thermal input of less than 3 MW and all units of whatever size which use exclusively biomass. So this scope will include many smaller MCP, smaller furnaces/kilns etc., and SCPs (as well as larger plant fuelled with biomass). This category therefore covers a wide range of installation types and sizes. For fuel oil generally, we have assumed that the fuel is used in boilers or furnaces and apply emission factors for boilers. For coal use, we have adopted factors for small (<1 MW_{th}) boilers. For the remaining sectors and non-biomass fuels, we have used the same Tier 1 factors for combustion in industry as used in previous submissions.

As with EMEP/EEA Guidebook emission factors for medium-sized plant, there is a limited choice of factors available for smaller plant. Given the large number of installations and the fact that many are unregulated, it would be challenging to develop UK-specific factors and Guidebook emission factors are likely to always be the most appropriate option for such plant.

However, for biomass combustion, a review of emission factors has been undertaken for the 2024 submission allowing replacement of conservative Tier 1 emission factors with more appropriate Tier 2 emission factors. Growth in use of biomass for heat in recent years has been driven by various decarbonising policies which means that the UK stock of such boilers is relatively new, and this implies automatic operation and relatively low emissions compared to manual boilers. Relevant measures controls include:

- The non-domestic Renewable Heat Incentive (RHI) scheme (from late 2011 until closure to new applications in March 2021) drove installation of many boilers and included a 30g/GJ threshold for PM (TSP) emissions.
- For boilers up to 500 kW output the maximum allowed TSP concentration for type-approval under EN303-5:2012[74] was about 72 g/GJ but automatic Class 5 biogenic boilers achieve 20 g/GJ (and Ecodesign requirements[75] in place since January 2020 are about 30 g/GJ and 20g/GJ for manual and automatic boilers respectively).
- Burning of waste wood has been a regulated activity for many years and emission limits (applicable since 2013) for EPR small waste incineration plant are lower than 40 g/GJ (the IED-derived emission limit for treated waste wood and the BAT requirements for larger waste plant are lower).

Although use of older technologies including manually-stoked boilers cannot be ruled out, it is considered that wood-burning in the industrial and commercial sectors has been predominantly from use of automatic boilers.

3.4.5. NFR 1A4bi: Residential Combustion

3.4.5.1. Overview of Approach

Emissions from residential combustion are estimated using a 'top down' methodology which is applied based on national energy statistics (DUKES) and emission factors. See Section 3.4.3 for details of deviations from UK energy statistics.

Emission factors applied in the NAEI are from UK research, literature and the EMEP/EEA Guidebook 2019 Tier 1 and Tier 2 factors. Suitable factors are not always available for some minor fuels, and so

[74] BS EN 303-5:2012 Heating Boilers, Part 5 : Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500kW – Terminology, requirements, testing and marking (since replaced by the 2021 version but classes of dust emission unchanged)
[75] COMMISSION REGULATION (EU) 2015/1189 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R1189

emission factors for a similar fuel are used instead, e.g. a factor reported in the literature for coke might be used for other manufactured smokeless fuels.

The domestic combustion model is an integrated inventory system with separate modules for solid, liquid and gaseous fuels. This enables the Inventory Agency to:

i) incorporate findings of the 2018-19 Defra burning survey into the NAEI.

ii) implement a flexible system that can easily accept data from the ongoing domestic combustion research projects, including the Emission Factors for Domestic Solid Fuels project.

iii) ensure that assumptions regarding appliance mix are consistent across all relevant activities.

Solid fuels include wood, coal, anthracite, petroleum coke, manufactured solid fuels (including coke in the historic inventory), peat and charcoal. The solid fuel module is the most complex component of the new model as this is a combination of different types of appliance, each of which may have multiple technologies and associated emission factors, and also are capable of burning a range of fuels. In comparison, the Liquid and Gaseous emission modules have much more limited variation in fuel type and technologies.

Since the 2023 submission, the NAEI uses a Tier 2 model for most fuels and pollutants as described in the following sections. SO_X emission estimates for solid mineral fuels and liquid fuels use country specific emission factors.

3.4.6. Residential Solid Fuel - Wood

3.4.6.1. Activity Data for Wood

A survey of solid fuel use in the residential sector was undertaken in 2018/19 and published by Defra[76] in 2020 which led to a large reduction in the estimates for use of wood in the residential sector in the UK[77] in the DUKES 2021 publication. The adoption of the Defra research has led to a new time series of activity data in DUKES, revising the residential wood use activity from 2003 onwards. The Inventory Agency has also (in consultation with the DESNZ energy statistics team) derived a new time series for residential wood use back to 1998, to address an inconsistency in wood calorific values across the early years in the time series.

These recalculations to the wood activity data had a notable impact on the level and trend of emission estimates from the UK residential sector in the 2022 submission compared to earlier inventories. The most notable impact is that the recalculated DUKES activity data present a large decrease in wood use in later years of the time series, and this leads to much lower reported emissions (notably of particulate matter) from the sector.

Note that the Department of Energy and Climate Change, DECC (now DESNZ) conducted research during 2014-15 into the use of wood for residential heating[78]. This Residential Wood Combustion (RWC) survey led to a very substantial increase in the estimated use of wood in the residential sector within the DUKES 2015 publication, compared to previous UK energy statistics. The new research

[76] Burning in UK Homes and Gardens, Dec 2020 report by Kantar for Defra available here : http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=20159

[77] The DUKES analysis of residential wood use is provided here https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/976039/Domestic_wood_consumption_new_baseline.pdf

[78] Summary results of domestic wood survey here : https://www.gov.uk/government/publications/summary-results-of-the-domestic-wood-use-survey

incorporated in DUKES 2021 removed this increase. The Defra survey adopted a different approach to the RWC survey in particular around the time period that householders were asked about their use of heating appliances. The Defra survey asked respondents whether they had burned any fuel in the previous week rather than over a season. Users' recollection of activity over a longer period was felt to be a key uncertainty in the RWC survey, in particular around accurate recollection of when an appliance was not in use.

The previous RWC research enabled some improved assumptions regarding allocation of activity between different appliance types over time. Most of the wood burned in 2014 was in non-automatic appliances including about half in open appliances. Although the RWC and recent Defra surveys are a 'snapshot' and primarily intended to provide information on total fuel consumption, they also included information on appliance type and age. The Defra survey indicates a lower percentage of fuel burned in open fires than the RWC research and this information has been incorporated into the 2023 submission.

The appliance population across the time series is modelled assuming that the proportion of wood fuel used in open appliances from 1970-1990 compared to closed appliances was 3:1. Between 1990 and 2014 the ratio was interpolated between 3:1 (1990) and about 1:1 (2014 from the RWC study) and about 1:2 (2020 from Defra Domestic Burning Study). This allows allocation of activity to the different technologies.

Further outputs from Defra research on domestic burning have been implemented to allow wood use in the residential sector to be allocated between dry, seasoned and wet wood. In the 2024 submission, further refinements have been undertaken :

(i) To align inventory assumptions for years since the Defra burning survey with those applied in the activity data presented in DUKES.

(ii) To adjust wood use to reflect implementation of the Air Quality Domestic Solid Fuel Standards (England) Regulations 2018 which sets a maximum moisture content for sales of wood below $2m^3$.

The activity data is rebased from the survey year using heating degree data and information on installations of appliances – if wood activity in recent years is higher than attributable to temperature changes, additional wood activity is attributed to new technology. The inventory models the ban on wet wood in England based on the regulatory impact assessment assumptions on effectiveness.

Activity data for this source category remain highly uncertain; the accurate assessment of wood use in the residential sector is extremely difficult due to the lack of comprehensive fuel sales data, this is due, in part, to a substantial component of wood fuel sourced outside conventional fuel markets. A further domestic burning survey was completed in 2023 and is expected to be reported in 2024.

3.4.6.2. Emission Factors for Wood

The EMEP/EEA Guidebook includes default emission factors for open fireplace, different grades of stove and boilers. The RWC and Defra survey information on appliance type and age is used to allocate EMEP/EEA Guidebook emission factors for different technologies (fireplace or stove) and, appliance age is used to allocate stoves type.

Combustion on open fires is less controlled, and therefore typically emits higher levels of many pollutants; consequently, the assumptions made on appliance technologies have a large impact on the emission estimates.

Country-specific emission factors, based on measurement work commissioned by Defra[79] on four appliance types (open fireplace and wood log stoves) and three moisture levels in wood are used in the model. A ‘real-world’ test protocol matching the typical stove/fireplace burning period in UK was used. The following pollutants are now estimated using country-specific emission factors:

- Dioxins/furans
- PAH
- SO_X
- NO_X
- CO
- NMVOCs

The emission factors are summarised in

Table **3-41**. The SO_X emission factors are average values for the three fuel moisture levels.

Ammonia emissions are calculated at a derived Tier 2 level. Following review of the NAEI during the 2017 submission cycle, the ammonia emission factors in the latest EMEP/EEA Guidebook were assessed and determined to be based on wildland fires and consequently were highly uncertain. Since the 2023 submission, the emission factors have been derived from the original reference and the country-specific CO emission factors.

Other emissions from wood combustion are calculated using EMEP/EEA Guidebook Tier 2 emission factors.

Particulate matter emissions for residential wood combustion in the NAEI are based on emission factors for total particulate matter (filterable and condensable). It is hoped to implement country-specific emission factors for TPM, PM_{10}, $PM_{2.5}$ and PM_1 for wood in the 2025 submission.

Table 3-41 Summary of country specific emission factors

Technology[+]	Pollutant	Units (net heat input)	Emission factors		
			Dry wood	Seasoned wood	Wet wood
Open fireplace	SO_X	g/GJ	3.7	3.7	3.7
	NO_X	g/GJ	43.7	44.7	39.1
	CO	g/GJ	1025	1711	2892
	NMVOC	g/GJ	121	274	680
	Dioxins/furans	ngTEQ/GJ	5.6	4.4	7.9
	Benzo(a)pyrene	mg/GJ	4.3	4.3	48.2
	Benzo(b)fluoranthene	mg/GJ	3.2	5.3	20.6
	Benzo(k)fluoranthene	mg/GJ	2.0	3.4	17.2
	Indeno(123-cd)Pyrene	mg/GJ	2.7	5.1	24.7
Old stove	SO_X	g/GJ	4.0	4.0	4.0
Pre-2000	NO_X	g/GJ	49.4	45.7	58.6
	CO	g/GJ	1449	1638	3318
	NMVOC	g/GJ	241	108	394
	Dioxins/furans	ngTEQ/GJ	55.0	47.0	7.6
	Benzo(a)pyrene	mg/GJ	24.7	6.8	14.4

[79] Emission Factors for Domestic Solid Fuel study – Work Package 1 report (https://naei.beis.gov.uk/reports/reports?report_id=1133)

	Benzo(b)fluoranthene	mg/GJ	20.9	5.9	9.7
	Benzo(k)fluoranthene	mg/GJ	12.8	3.4	6.0
	Indeno(123-cd)Pyrene	mg/GJ	21.6	5.1	8.3
Middle stove	SO_X	g/GJ	5.7	5.7	5.7
2001-2021	NO_X	g/GJ	38.2	64.8	55.0
	CO	g/GJ	1368	2382	3272
	NMVOC	g/GJ	84	535	722
	Dioxins/furans	ngTEQ/GJ	175.7	23.8	6.2
	Benzo(a)pyrene	mg/GJ	35.8	37.7	49.5
	Benzo(b)fluoranthene	mg/GJ	32.3	24.0	25.0
	Benzo(k)fluoranthene	mg/GJ	19.3	17.1	17.1
	Indeno(123-cd)Pyrene	mg/GJ	35.4	20.7	26.4
New stove	SO_X	g/GJ	4.9	4.9	4.9
2017-present	NO_X	g/GJ	31.2	49.2	62.7
	CO	g/GJ	2643	1147	3095
	NMVOC	g/GJ	198	136	333
	Dioxins/furans	ngTEQ/GJ	20.7	25.0	23.4
	Benzo(a)pyrene	mg/GJ	89.2	13.1	17.5
	Benzo(b)fluoranthene	mg/GJ	69.7	9.7	12.2
	Benzo(k)fluoranthene	mg/GJ	43.7	6.0	7.4
	Indeno(123-cd)Pyrene	mg/GJ	87.4	9.8	9.7

+Stove technologies are as follows are :
Open fire – UK standard open grate fireplace.
Old stove – notionally pre-2000 stove with primary and secondary air controls.
Middle stove –Notionally 2001-2021 pre-Ecodesign EN13240 stove with primary and secondary air controls.
New stove – Notionally post 2017 Ecodesign-compliant appliance with primary, secondary and tertiary (airwash) air controls.

3.4.7. Residential Solid Fuels - Other

3.4.7.1. Activity Data for Other Solid Fuels

Emissions from residential combustion of coal and coal-based solid fuels are estimated from national energy statistics for coal, anthracite, manufactured solid fuels, coke and petroleum coke. In the 2023 submission, allocation of fuel use to different technologies has been aligned with the outputs of the Domestic Burning Survey and (in earlier years) historic research on types of residential appliances. Previous submissions have allocated fuel use based on other research which included a high proportion of boiler technology – this assumption has now been revised based on the Domestic Burning Survey. The model also assumes that anthracite fuel is not burned in open fireplaces as experiences in the Emission Factors for Domestic Solid Fuel project (and subsequent discussion with fuel suppliers) indicated that maintaining combustion of anthracite in an open fireplace was not possible without the use of other fuels.

Activity data for peat and charcoal are not reported in national energy statistics. Charcoal activity data are from data submitted to The Food and Agriculture Organization (FAO) agency of the United Nations. For peat, fuel use estimates are provided by the UK Centre for Ecology and Hydrology.

Activity data are allocated to indoor use for wood and peat, charcoal is assumed to be outdoor use. Outdoor waste wood burning is estimated as a waste activity and is not included in 1A4. For mineral fuels an allocation between indoor and outdoor use is made based on data from the Defra Burning Survey.

3.4.7.2. Emission Factors for Other Solid Fuels

In the 2023 submission, almost all emission factors are from the EMEP/EEA Guidebook Tier 2 emission factors that take into account the various types of appliances used in the UK. Country-specific emission factors are applied as detailed below

- PM emission factors relating to Particulate Matter for petroleum coke, coke and solid smokeless fuel (SSF) are one-fifth of that quoted in the EMEP/EEA Guidebook table based on UK country-specific research on emission limits for Authorised fuels approved for use in Smoke Control Areas under the Clean Air Act 1993.
- SO_X emission factors for mineral fuels – the UK Inventory Agency uses country-specific data on the sulphur content of coal and other mineral fuels and, in most cases, SO_X emissions are driven by the sulphur content of the fuel rather than technology, especially on the domestic scale where no abatement measures are applied for SO_X. There may be some sulphur retained in ash and the proportion can vary for different combustion technologies, but these are generally minor differences. Where we have received data on the quantity and sulphur content of coal from suppliers for the domestic market, we make use of the data. For the remaining proportion of coal use, the EMEP/EEA Guidebook is used. For domestic coal use, the EMEP/EEA Guidebook SO_X emission factors are used for approximately 70% of residential solid mineral used.
- Metals and petroleum coke – Due to the manufacturing methods of petroleum coke, small amount of the catalysts used may be included in the final product, and hence the concentrations of the metals emissions are higher than would be the case in other mineral fuels, these factors are obtained from Passant N and Loader, A (2008).
- NMVOC Mineral fuels – Following research into the current NAEI data source (Brain et al, 1994), the model uses the EMEP/EEA Guidebook emission factors for NMVOCs for coal and applies a ratio between coal and other solid mineral fuels from Brain et al to other solid mineral fuels.

It is anticipated that the Emission Factors for Domestic Solid Fuels project will produce EFs for mineral fuels in time for adoption in the 2025 submission.

3.4.8. Gaseous Fuels

3.4.8.1. Activity Data for Gaseous Fuels

Emissions from residential combustion of natural gas and LPG (which is gaseous when burned) are taken from national energy statistics. Following a review of activity data in the 2024 submission, allocation of fuel use to different technologies has been assigned to boilers and cookers based on the Energy Consumption UK (ECUK) dataset[80].

[80] Information here https://www.gov.uk/government/statistics/energy-consumption-in-the-uk-2022

3.4.8.2. Emission Factors for Gaseous Fuels

Emissions from residential combustion of gaseous fuels are estimated from EMEP/EEA Guidebook Tier 2 emission factors for all pollutants except for NO_X.

The NAEI applies a modelled approach for NO_X emissions to reflect changes in appliance technologies. The method for boilers assumes the following emission factors for new boilers in the following four periods:

- 1970-1989 70 g NO_X/GJ net
- 1990-2004 24 g NO_X/GJ net
- >2004 19.4 g NO_X/GJ net
- >2017 15.6 g NO_X/GJ net

The four emission factors chosen are, respectively:

1. The 2009 EMEP/EEA Guidebook default Tier 2 factor (Table 3-20) for domestic natural gas combustion - note that the 2019 EMEP/EEA Guidebook default Tier 2 factor is lower (42 g/GJ[81]) but is believed to represent more modern boilers;
2. A factor taken from the Ecodesign Directive preparatory studies on central heating boilers (Lot 1) and water heaters (Lot 2) and derived from the GEMIS database for natural gas boilers;
3. The Class 5 standard for new natural gas-fired boilers introduced in EN 483;
4. The Ecodesign emission limit of 56 mg/kWh fuel input on a gross basis, introduced in Commission Regulation 814/2013.

An age profile is applied for gas boilers. The age profile is based on a survey of 44,000 homes as part of the RE:NEW home energy retrofit scheme in London in 2012, which indicated that about 50% of boilers are up to five years old whilst 11% are over 15 years old.

3.4.9. Liquid Fuels

3.4.9.1. Activity Data for Liquid Fuels

Emissions from residential combustion of gas oil, burning oil and fuel oil are taken from national energy statistics. Fuel oil is not a typical fuel in residential use but there is a very small quantity of fuel oil allocated to residential use in the national energy statistics in the period 1970-2003. In the 2023 submission, allocation of fuel use to different technologies has been assigned to boilers and other appliances (assumed to be room heaters) based on the Energy Consumption UK (ECUK) dataset[80]. Most fuel (>99%) is allocated to boilers.

A population model is used to allocate fuel to older appliances and more recent, Ecodesign-compliant, boilers. In the absence of national or other data, the same age profile is used for liquid fuel as applied for gas-fired boilers. Due to the small allocation of liquid fuels to room heater use (<1%), no allocation is made between existing and new room heaters.

[81] 2019 EMEP/EEA guidebook chapter *1.A.4 Small combustion 2019*, table 3.16

3.4.9.2. Emission Factors for Liquid Fuels

Tier 2 emission factors for pollutants (except SO_X and, for boilers, NO_X) are taken from the EMEP/EEA Guidebook 2019, SO_X emission factors are based on UK-specific data on fuel composition. The NAEI applies a modelled approach for NO_X emissions to reflect changes in boiler technologies. The method for boilers assumes the following emission factors for boilers as follows:

- 1990-2018 69 g NO_X/GJ net
- >2018 35 g NO_X/GJ net

The emission factors chosen are, respectively:

1. The 2019 EMEP/EEA Guidebook default Tier 2 factor for residential plants burning gas oil in boilers (<50 kWth) and other equipment;
2. The Ecodesign emission limit introduced in Commission Regulation 814/2013.

3.4.10. Source Specific QA/QC and Verification

The QA/QC procedure for this sector is largely covered by the general QA/QC of the NAEI in Section 1.6. In addition, during the development of the new integrated model there was validation against previous inventory estimation models.

3.4.11. Recalculations in NFR Sector 1A4

Recalculations of historic emissions have occurred due to revisions in activity data reported since the previous submission.

Revisions to reported emissions in 1A4ai and 1A4ci also arise from improvement to allocation of emission factors to biomass combustion. Investigation of burning oil data in national energy statistics has allowed allocation of burning oil activity allocated to 1A2gviii in previous submissions to be split between 1A2gviii, 1A4ai and 1A4ci.

In the 2024 submission, elements of the domestic fuel models have been revised and recalculations relate to changes to :

i) Align inventory methodology to approach used in national energy data to estimate residential wood use in years since the domestic burning survey.
ii) Estimate changes in wet wood use in England following the implementation of the Air Quality Domestic Solid Fuel Standards (England) Regulations 2018.
iii) Adjustment of methodology for domestic gas use – to reflect better understanding of apportioning of gaseous fuels to appliance types.
iv) Allocation of petroleum coke to solid fuel manufacture (impacts nickel emissions).

Table 3-42 presents a summary of the more significant revisions in sector 1A4 for pollutants, together with the main reason(s) for change of emissions in 2021.

Table 3-42 Recalculations and Reasons for Change for NFR 1A4 Sectors

NFR, Pollutant	Revision to 2021 emissions	Reason for Change
1A4ai		
NO_X	+15.5 kt	Recalculations (across time series) due to inclusion of emissions from Burning Oil in 1A4ai
SO_X	+0.1 kt	

NFR, Pollutant	Revision to 2021 emissions	Reason for Change
$PM_{2.5}$	+0.8 kt	(from 1A2gviii) – but overall impact limited as activity and emissions were included elsewhere previously, this mainly impacts NO_X. Also changes in EFs due to migration of EFs for combustion in Public/Institutional to Industrial Scale Combustion model allowing disaggregation of small/medium/large combustion and more representative emission factors, particularly impacting NMVOCs, $PM_{2.5}$ and Black Carbon.
PM_{10}	+0.9 kt	
NMVOC	+3.5 kt	
NH_3	<0.1kt	
BC	+0.4 kt	
1A4bi		
NO_X	-8.0 kt	Revision across time series of assumptions on technology mix for gas-fired appliances.
SO_X	+0.5kt	Revisions to solid mineral fuels and oil activity data.
$PM_{2.5}$	-3.1 kt	Largely due to revisions in allocations of activity in most recent years between the various categories of residential wood combustion. Alignment of the assumptions in the Residential Combustion model with those in recent annual activity data (to rebase domestic burning survey to recent years).
PM_{10}	-3.2 kt	
NMVOC	-1.0 kt	
NH_3	<-0.1kt	
PAHs (Benzo[a]pyrene, Benzo[b]fluoranthene, Benzo[k]fluoranthene, Indeno[123-cd]pyrene)	+0.1 to +0.2 kt	
Metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Se, Zn)	+17.8 kt (Ni)	Revision of activity data to recognise inclusion of petroleum coke that is contained within solid smokeless fuels.
1A4ci		
NO_X	+3.4 kt	Recalculations (across time series) due to inclusion of emissions from Burning Oil in 1A4ci (from 1A2gviii) – but overall impact limited as activity and emissions were included elsewhere previously, primarily affecting NO_X. Also changes in EFs due to migration of EFs for combustion in 1A4ci to Industrial Scale Combustion model allowing disaggregation of small/medium/large combustion and more representative emission factors.
SO_X	+0.1 kt	
$PM_{2.5}$	+0.2 kt	
PM_{10}	+0.2 kt	
NMVOC	+0.1 kt	
NH_3	NE	

For recalculations in 1A4bii, 1A4cii, 1A4ciii please refer to Section 3.3.8.

3.4.12. Planned Improvements in NFR Sector 1A4

A revised version of EMEP/EEA Emission Inventory Guidebook was published in 2023 and changes in emission factors are expected to be incorporated in the next submission. Notably the Guidebook revisions for biomass combustion include amendments to ammonia emission factors.

The inventory methods aim to reflect the change in emission factors over time as lower-emitting technologies have penetrated the UK stock of residential combustion units. However, even where we split into different technologies, the methods are still quite simplistic and suffer both from a lack of data on the market share of different technologies in the UK, and also a limited set of emission factors for different technologies. The Emission Factors for Domestic Solid Fuel project is expected to provide country-specific emission factors for several solid mineral fuels and PM emission factors for wood for the 2025 submission. Ongoing work to extend the number of appliances tested may allow some further refinement of emission factors.

Legislation has been introduced which controls sale of residential combustion of coal and wet wood in England[82]. A repeat of the Domestic Burning Survey (of solid fuel use) is underway with data collection completed in 2023. It is anticipated that outputs from the current survey will provide better activity data by technology and feed into compilation of the inventory in the 2025 submission. We intend to revisit the previous survey along with the result of the current survey to assess where information can be used to improve estimates of domestic outdoor burning.

Gas combustion is the dominant source of NO_X emissions within 1A4, so further data on the use and performance of different technologies in both the residential and non-residential markets would be valuable. Although no new data were identified in time for the current submission, updated technology and age profiles or emission factors for gas (and oil) combustion could be implemented relatively easily should it be identified.

Further improvement to the Industrial Scale combustion model to improve activity and emission factor allocation to different sizes of combustion plant.

[82] The Air Quality (Domestic Solid Fuels Standards) (England) Regulations 2020, available here: https://www.legislation.gov.uk/uksi/2020/1095/pdfs/uksi_20201095_en.pdf

3.5. NFR 1B1 and 1B2: Fugitive Emissions from Fuels

Table 3-43 Mapping of NFR Source Categories to NAEI Source Categories: Fugitive Emissions from Fuels.

NFR Category	Pollutant coverage	Source
1B1a Fugitive emission from solid fuels: Coal mining and handling	NMVOCs, Particulate Matter, PM_{10}, $PM_{2.5}$	Deep-mined coal
		Open-cast coal
1B1b Solid fuel transformation	All CLRTAP pollutants *(except Se, HCB)*	Charcoal production
		Coke production
		Iron and steel flaring
		Solid smokeless fuel production
1B2ai Oil (Exploration, production, transport)	NO_X, NMVOCs, SO_X, CO, benzene	Upstream Oil Production - Offshore Oil Loading
		Upstream Oil Production - Offshore Well Testing
		Upstream Oil Production - Oil terminal storage
		Upstream Oil Production - Onshore Oil Loading
		Onshore oil well exploration (conventional)
		Oil transport fugitives: pipelines (onshore)
		Oil transport fugitives: road tankers
		Onshore oil production (conventional)
		Upstream Oil Production: direct process emissions
		Oil Terminal: Other Fugitives
		Upstream Oil Production - fugitive emissions
		Oil Terminal: Direct Process
		Petroleum processes
1B2aiv Oil (Refining / Storage)	NMVOCs, NH_3, 1,3 butadiene, benzene	Refineries - drainage
		Refineries - general
		Refineries - process
		Refineries - tankage
1B2av Distribution of oil products	NMVOCs, 1,3 butadiene, benzene	Petrol stations - petrol delivery
		Petrol stations - spillages
		Petrol stations - storage tanks
		Petrol stations - vehicle refuelling
		Petrol terminals - storage
		Petrol terminals - tanker loading
		Refineries - road/rail loading
		Sea going vessel loading
1B2b Natural gas (exploration, production, processing, transmission, storage, distribution and other)	NO_X, NMVOCs, SO_X, CO, benzene	Upstream Gas Production - Gas terminal storage
		Upstream Gas Production - Offshore Well Testing
		Well exploration (unconventional gas)
		Onshore natural gas production (conventional)
		Onshore natural gas gathering
		Upstream Gas Production: direct process emissions
		Gas Terminal: Other Fugitives
		Gas Terminal: Direct Process
		Upstream Gas Production - fugitive emissions
		Gasification processes
		Gas transmission network leakage
		Gas distribution network leakage
		Gas leakage at point of use
		Upstream gas production - flaring

NFR Category	Pollutant coverage	Source
1B2c Venting and flaring (oil, gas, combined oil and gas)	NO_X, NMVOCs, SO_X, Black carbon, CO, benzene, Particulate Matter, PM_{10} and $PM_{2.5}$	Upstream gas production - venting
		Upstream oil production - flaring
		Upstream oil production - venting
		Oil Terminal: Gas Flaring
		Gas Terminal: Gas Flaring
		Oil Terminal: Venting
		Gas Terminal: Venting
		Onshore oil production: gas flaring
		Refineries - flares
1B2d Other fugitive emissions from energy production	NA (not applicable)	

Table 3-44 Summary of Emission Estimation Methods for NAEI Source Categories in NFR Category 1B

NAEI Source Category	Method	Activity Data	Emission Factors
Deep-mined coal	AD x EF	UK energy statistics	EMEP/EEA Guidebook
Open-cast coal	AD x EF	UK energy statistics	EMEP/EEA Guidebook
Charcoal production	AD x EF	FAOSTAT	Default factors (US EPA AP-42, EMEP/EEA Guidebook, IPCC 2006, IPCC 1996)
Coke production	UK I&S model, AD x EF	UK energy statistics, ISSB, EU ETS, UK ETS, Tata Steel, British Steel	Operator data reported for PRTR, Tata Steel, British Steel, default factors (US EPA, EIPPCB, EMEP/EEA Guidebook, UK research)
Iron and steel flaring	UK I&S model, AD x EF	UK energy statistics, UK ETS, EU ETS, Tata Steel, British Steel	Operator data reported for PRTR; Default factors (EMEP/EEA Guidebook, UK research)
Solid smokeless fuel production	UK model for SSF production, AD x EF	UK energy statistics	Operator data reported for PRTR, default factors (EMEP/EEA Guidebook, EIPPCB, UK research)
Upstream Oil Production - flaring	UK model, Operator data	EU ETS (2008-2020), UK ETS (2021-present), EEMS (1998-present), UKOOA (1990-1997)	Operator data reported under EEMS, with emissions reported since 1998. Earlier data based on estimates from UKOOA.
Upstream Gas Production - flaring			
Oil Terminal: Gas Flaring	UK model, Operator data	EU ETS (2008-2020), UK ETS (2021-present) EEMS (1998-2010), UKOOA (1990-1997)	Operator emissions data reported under EEMS from 1998 to 2010. Earlier data based on estimates from UKOOA. Estimates since 2010 based on ETS AD and emissions modelled using industry default EFs, with site totals aligned with RI operator emission totals per pollutant.
Gas Terminal: Gas Flaring			

NAEI Source Category	Method	Activity Data	Emission Factors
Onshore oil production: gas flaring	AD x UK EF	Field-level flaring data from NSTA PPRS (2001-present) and the DTI Brown Book data (to 2000)	Assumed EF from offshore oil flaring as representative, based on operator reporting to EEMS.
Upstream Oil Production - Offshore Well Testing	UK model. ∑ operator data (and/or from industry surveys)	EEMS (1998-present); UKOOA data for 1995-1997 using well drilling statistics as a proxy to extrapolate AD across 1990-1994	Operator reported emissions data from EEMS (1998-present); earlier data based on UKOOA data from industry surveys, 1995-1997 and extrapolation of EFs back across 1990-1994.
Upstream Gas Production - Offshore Well Testing			
Upstream Oil Production: direct process emissions	UK model. ∑ operator data (and/or from industry surveys)	EEMS (1998-present); UKOOA data for 1995-1997 using oil and gas production statistics as a proxy to extrapolate AD across 1990-1994	Operator reported emissions data from EEMS (1998-present); earlier data based on UKOOA data from industry surveys, 1995-1997 and extrapolation of EFs back across 1990-1994.
Upstream Oil Production - fugitive emissions			
Upstream Gas Production: direct process emissions			
Upstream Gas Production - fugitive emissions			
Upstream Gas Production - venting			
Upstream Oil Production - venting			
Upstream Oil Production - Oil terminal storage	UK model. ∑ operator data (and/or from industry surveys)	EEMS (1998-2010); UKOOA data for 1995-1997 using oil and gas production statistics as a proxy to extrapolate AD across 1990-1994; AD for onshore terminal emissions per source are modelled based on historic terminal operator reporting, i.e. to consider the source-specific share of total emissions per pollutant across all sources reported via RIs.	Operator reported emissions data from EEMS (1998-2010); earlier data based on UKOOA data from industry surveys, 1995-1997 and extrapolation of EFs back across 1990-1994. EFs for terminal emission sources since 2010 are modelled, as per the AD, with the sum of all onshore terminal emission sources aligned with the operator reported emission totals across terminal installations via RIs
Oil Terminal: Other Fugitives			
Oil Terminal: Direct Process			
Upstream Gas Production - Gas terminal storage			
Gas Terminal: Other Fugitives			
Gas Terminal: Direct Process			
Oil Terminal: Venting			
Gas Terminal: Venting			
Upstream Oil Production - Offshore Oil Loading	AD x EF	Field-level oil loading data from NSTA PPRS (2004-present) and the DTI Brown Book data (to 2003).	2019 IPCC Refinement, sector 1B2aiii default EFs for loading without the use of VRUs
Oil transport fugitives:	AD x EF	Onshore oil production from NSTA PPRS data (2004 onwards)	2019 IPCC Refinement, sector 1B2aiii default EFs for oil

NAEI Source Category	Method	Activity Data	Emission Factors
pipelines (onshore)		and from the DTI Brown Book for 1990-2003. Sites serviced by pipelines are aggregated, and the remainder (from the total) are the AD for the road tankers source.	transported (i) by pipelines, and (ii) by tanker, truck and rail cars.
Oil transport fugitives: road tankers			
Well exploration (unconventional gas)	Emission = ∑regulator data on NMVOC emissions.	Unconventional gas production (DESNZ); *currently zero in all years.*	No EFs, but the method has reviewed data from regulators at the sites where unconventional gas wells have been drilled; none have gone into production, so the emissions of NMVOCs are just the sum of regulator estimates across all UK well sites per year.
Onshore natural gas production (conventional)	AD x EF	Onshore gas production data from DESNZ energy statistics, table F2 (1999-present); earlier years from DTI Brown Book publications	NMVOC EFs taken from 2019 IPCC Refinement, sector 1B2bii (higher-emitting activities) default EFs for onshore gas production and gas gathering.
Onshore natural gas gathering			
Onshore oil well exploration (conventional)	AD x EF	Number of oil and gas wells drilled onshore, including for exploration, appraisal and development. 2000 onwards data from the NSTA Well Operations Notification System (WONS); earlier data from DTI Brown Book publications.	NMVOC EFs taken from 2019 IPCC Refinement, sector 1B2ai default EFs for onshore oil wells drilled. There are no separate UK data for oil wells vs gas wells drilled, but the vast majority of onshore UK production is of oil, hence the EF selected.
Abandoned oil wells (onshore)	AD x EF	Cumulative # of wells abandoned onshore or offshore, from NSTA WONS data, and from the DTI Brown Book publications for earlier years.	NMVOC EFs taken from 2019 IPCC Refinement, sector 1B2avi default EFs for onshore or offshore wells abandoned (plugged and unplugged). *The EFs for NMVOCs are zero, hence currently zero emission estimates, but method established to allow for future EF development, as HCs will be emitted from abandoned wells.*
Abandoned oil wells (offshore)			
Onshore oil production (conventional)	UK Tier2/3 method. ∑operator emissions, then AD x EF for smaller sites	Onshore oil production from NSTA PPRS data (2004 onwards) and from the DTI Brown Book for 1990-2003.	Hybrid method: NMVOC estimates from reporting (by higher emitting well sites) to RIs are used directly. For smaller well sites, the AD (oil production) is used with an EF derived from other UK operator reporting, i.e. a country specific EF.
Gasification processes	AD x EF	UK energy statistics	Operator reported emissions for PRTR
Petroleum processes	Operator reported emissions	UK energy statistics	Operator reported emissions for PRTR; UK operators
Refineries - Drainage, General, Process, Tankage	Operator reported emissions	Fuels Industry UK	Operator reported emissions for PRTR, Fuels Industry UK data for all refinery sources.

NAEI Source Category	Method	Activity Data	Emission Factors
Petrol stations and terminals (all sources)	AD x EF	UK energy statistics	UK periodic research, annual data on fuel vapour pressures (Fuels Industry UK), UK mean temperature data (Met Office), and abatement controls (IoP annual surveys).
Refineries - road/rail loading	Trade association estimates	UK energy statistics	Fuels Industry UK estimates based on petroleum consumption. Pre-1994 data scaled on energy statistics data for UK petrol use.
Sea-going vessel loading	AD x EF	UK energy statistics	UK periodic research (IoP) and annual data on fuel vapour pressures (Fuels Industry UK) and temperature data (Met Office).
Gas transmission network leakage	UK gas leakage model	Cadent Gas, National Grid, Northern Gas Networks, Phoenix Gas, Firmus Energy, SGN, Wales and West Utilities	Annual gas compositional analysis by the UK gas network operators.
Gas distribution network leakage			
Gas leakage at point of use	UK model	UK energy statistics. Leakage % of total by end user sector based on assumptions on unit leakage, operational cycles of gas-fired heaters, boilers, cookers.	Annual gas compositional analysis by the UK gas network operators.
Refineries - flares	Trade association estimates	Fuels Industry UK	Operator reported emissions for PRTR, Fuels Industry UK data for all refinery sources.

3.5.1. Classification of Activities and Sources

The UK emission inventory estimates are derived from a range of methods, but in the 1B sector the key activity data are:

- fuel use production and consumption data from the Digest of UK Energy Statistics (DUKES), including data on coal extraction, production of coke and other manufactured solid fuels, gas flaring and venting volumes at UK oil and gas production sites (DESNZ, 2023a);
- refinery activity and source emission estimates reported by refinery operators via the trade association (Fuels Industry UK, 2023);
- upstream oil and gas flaring activity data from a combination of UK ETS, EU ETS and EEMS operator reported data;
- other upstream oil and gas activity data from the EEMS reporting system managed by offshore regulatory team at DESNZ OPRED (DESNZ, 2023b);
- UK oil and gas production statistics, well drilling statistics and well abandonment statistics, predominantly from statistical data sources managed by the North Sea Transition Authority (NSTA) such as the WONS, PPRS, and from DESNZ energy statistics; and
- natural gas leakage data provided annually by the natural gas supply network operators in the UK (National Grid, Cadent Gas, Northern Gas Networks, SGN, Phoenix Gas, Firmus Energy, Wales and West Utilities; all 2023).

The most notable emission estimates in the 1B sector are calculated using operator-reported data from refineries and oil and gas exploration/production; these data are reported by operators to EEMS for offshore installations and MODUs, and to RIs for onshore installations. Other emission estimates are derived from a combination of:

- periodic UK research and UK industry models (such as the British Gas model developed and used by all UK gas transporters to estimate losses from the natural gas supply network);
- literature factors (where available, literature EFs are taken from the latest available EMEP/EEA Guidebook, and in some instances from the 2019 refinement to the IPCC 2006 Guidelines, IPCC 2006 Guidelines, IPCC 1996 Guidelines, US EPA AP-42, EEMS atmospherics operator guidance and from publications from the EIPPCB);
- annual sampling and analysis, e.g. to determine natural gas composition, upstream fuel gas composition; and
- calculations that utilise fuel qualities and UK temperature data, e.g. to determine fugitive/tank breathing/evaporative losses from petroleum fuel supply infrastructure.

3.5.2. NFR 1B1: Fugitive Emissions from Solid Fuels

3.5.2.1. NFR 1B1a: Coal Mining and Handling

There are no key source categories in 1B1a of the UK inventory. Coal seams contain a proportion of highly volatile material which is released during the extraction, and the handling and storage of coal. This material is known as firedamp when emitted in coalmines and is primarily comprised of methane, although other compounds are present in minor quantities. During coal extraction, a number of processes are connected with firedamp emission release:

- developing access to the coal deposit and preparation for extraction;
- coal extraction and transport to the surface;
- coal processing, disposal, transport, and crushing before final use;
- deposit de-gassing before, during, and after its excavation; and
- disposal of spoils from the coal extraction system.

The extraction of deep-mine coal has almost ceased in the UK from 2016 onwards with the closure of all remaining large-scale deep coal mines. Consequently, fugitive emissions from the whole mining sector only accounts for <0.1% of total UK NMVOC emissions in 2022, compared to 1.0% of the UK NMVOC inventory in 2015.

The inventory draws emission factors from the latest EMEP/EEA Guidebook for both open-cast and deep-mined coal extraction. The uncertainty in emission factors for NMVOCs is very high. The EMEP/EEA Guidebook factors are calculated using methane emission factors and the species profile of the firedamp, which both carry high levels of uncertainty when considered in isolation.

Activity data are derived from UK energy statistics (DESNZ, 2023a), providing data on the tonnage of saleable coal produced from both deep-mine and open-cast sites. At open-cast sites, coal is upgraded to saleable form with some coal rejected in the form of coarse discards containing high mineral-content matter and also in the form of unrecoverable fines. Typically, around 20% of the weight of the raw coal feed is lost through these preparation processes, according to the 2006 IPCC guidelines (IPCC, 2006). Raw coal production is therefore estimated by increasing the amount of saleable coal by 20%, to account for the fraction lost through washing.

3.5.2.2. NFR 1B1b: Solid Fuel Transformation

The following are key source categories for pollutants in 2022:

- 1B1b (4.6% of the UK SO_X inventory total)

For many pollutants the main source of emissions across the time series from 1B1b is coke production, the activity for which decreased by 14.7% between 2021 and 2022. Coke production was responsible for 0.4% of UK lead emissions and 0.6 % of UK benzo[a]pyrene emissions in 2022. The manufacture of other, patented solid fuels is a minor source in the context of the UK inventory.

Solid fuel transformations include the manufacture of coke oven coke, charcoal and other solid smokeless fuel (SSF); the sector also includes emissions from losses/flaring of coke oven gas at coke ovens and steelworks. Emissions can occur both from the combustion of fuels used to provide heat required for the transformations, but also from fugitive releases from the transformation process itself. Total emissions at UK coke ovens and certain SSF manufacturing sites are reported annually to the EPR regulated pollution inventories of the regulatory agencies, but it is not possible to reliably split these emissions data into a combustion component and a fugitive component. Therefore, emissions are usually reported either under 1A1c or 1B1b and contain both types of emissions. For most pollutants, reporting is under 1B1b.

Coke production and iron and steel flaring emissions of all key pollutants are reported by operators within the pollution inventories. For integrated steelworks, the breakdown of emissions from different sub-sources on the facility are provided to the Inventory Agency by plant operators. The data for coke oven emissions are used directly within the NAEI. For many other pollutants where emissions from these sources are generally of lower significance, the inventory estimates draw upon emission factors from literature sources such as the latest EMEP/EEA Guidebook, BREF notes, US EPA AP-42 and industry-specific studies.

Operator-reporting of annual emissions to the PRTR is less comprehensive for other solid smokeless fuel production, therefore emissions in the NAEI are generally estimated using literature factors and, in some cases (e.g. SO_X) using a mass balance approach.

From 2015 onwards, all UK coke oven coke is produced at coke ovens associated with integrated steelworks, although for most of the period covered by the inventory there were independent coke ovens as well. Other solid smokeless fuels (SSF) can be manufactured in various ways but only those processes employing thermal techniques are included in the inventory since only these give rise to substantial emissions. Currently, there are two sites manufacturing SSF using such processes.

All of these sites are required to report annual emission estimates to the UK environmental regulatory agencies for the PRTR. Emission estimates for the sector can be based on the emission data reported for individual sites:

$$\text{UK Emission} = \Sigma \text{ Reported Site Emissions}$$

There are instances of sites not reporting emissions of some pollutants where the annual estimate is below the reporting threshold under the terms of their regulatory permit and/or the PRTR reporting threshold. In these instances, the Inventory Agency derives estimates of the annual emissions based on surrogate information (typically the plant operating capacity) and extrapolating implied emission factors from other reporting plant in the sector, i.e. assuming that emissions per unit production from non-reporting plant are similar to those for other sites. This method to extrapolate data is typically only needed to cover smaller operating sites, and therefore does not add substantially to the UK emission inventory totals.

3.5.3. NFR 1B2: Fugitive emissions from Oil and Gas Industries

The following are all key source categories for NMVOCs (only) in 2022:

- 1B2ai (3.2% of the UK NMVOC inventory total). These emissions are from fugitive releases of gases during oil loading and unloading at onshore and offshore facilities, as well as other upstream oil production process and fugitive releases, including from oil well testing;
- 1B2av (2.9% of the UK NMVOC inventory total). These emissions are from downstream oil distribution systems such as spillages, storage losses, and loading/unloading losses at petrol stations and intermediate petrol storage terminals. The most important sources are vehicle refuelling and loading/unloading of refined petroleum products into sea-going tankers for transfer or export;
- 1B2b (2.7% of the UK NMVOC inventory total). These emissions comprise all fugitive releases from upstream gas processing as well as from the downstream gas transmission and distribution networks and losses at the point of use (prior to ignition);

The following are not key source categories in 2022, but do make a notable contribution

- 1B2c (1.9% of the UK NMVOC inventory total). These are primarily from venting and flaring sources in upstream oil and gas exploration and production facilities, with a small contribution from refinery flaring activities;
- 1B2aiv (1.7% of the UK NMVOC inventory total). These are fugitive releases at refineries from components such as valves and flanges on process units, emissions from wastewater treatment systems and emissions from crude oil and product storage tanks.

Other notable emissions from the fugitive sector are those from refinery processes and fugitive releases in oil distribution for non-CLRTAP pollutants such as benzene and 1,3-butadiene.

Most of the emissions from the extraction, transport and refining of crude oil, natural gas and related fuels are fugitive in nature. Rather than being released via a stack or vent, emissions occur in an uncontained manner, often as numerous individual small emissions. Typical examples are leakage of gases and volatile liquids from valves and flanges in oil and gas production facilities and refineries, and displacement of vapour-laden air during the transfer of volatile liquids between storage containers such as road tankers and stationary tanks. The magnitude of the emission from individual sources will depend upon many factors including the characteristics of the gas or liquid fuel, process technology in use, air temperature and other meteorological factors, the level of plant maintenance, and the use of abatement systems.

For these reasons it is generally impractical to estimate emissions using simple emission factors applied to a readily available national activity statistic. Instead, methodologies have been developed by industries which allow emission estimates to be derived using detailed process data and it is this type of approach which is used in the inventory for many sources. In most cases, the methodologies are used by process operators to generate emission estimates which are then supplied for use in the inventory. In other cases, where the methodologies are simpler, estimates are derived directly by the Inventory Agency.

The data sources and inventory methods applied to estimate emissions for each NFR sector are described below.

3.5.3.1. NFR 1B2ai: Fugitive Emissions from Oil - Exploration, Production, Transport

Emission estimates for the transport of oil, the largest source of NMVOC emissions within this sector, are derived from operator reporting of production to the NSTA's Petroleum Production Reporting

System (PPRS) from 2004 and DTI Brown Book data in the years before. Due to the importance of this source to the UK NMVOC total, research has been undertaken to identify a similarly accurate emission factor, with particular focus on the loading of oil from offshore platforms and storage units onto shuttle tankers. However, due to a lack of reliable information about practises and ship-specific technologies in UK waters, the IPCC 2019 Refinement emission factor that does not consider VOC abatement equipment has been used to produce a conservative estimate of emissions.

Emission estimates for the majority of sources are made using operator-reported emissions where these are available (1998 onwards), and trade association (OKOOA) periodic research for earlier years. Since 1998, oil and gas production site operators have submitted annual returns via EEMS managed by OPRED, which includes emission estimates of NMVOCs, CO_2, CH_4, CO, NO_X, SO_X and fluorinated gases, reported by emission source and (where appropriate) fuel type. Under 1B2ai, EEMS reporting is used to estimate emissions from:

- oil and gas treatment processes (such as acid gas treatment);
- fugitive releases (including tank storage emissions); and
- emissions from well testing.

All offshore upstream oil and gas production sites (i.e. offshore platforms, FPSOs and MODUs) operate under license to OPRED and report atmospheric emission estimates on a voluntary basis via the EEMS mechanism; the UK inventory estimates per source are generally the sum of the EEMS submissions across all offshore installations. Emissions are also gap-filled for sites which have not reported to EEMS in cases where activity data is available via the ETS, appropriate emission factors from EEMS are used in combination.

Onshore terminals report annual installation-wide pollutant emissions to the RIs; these sites have also reported to EEMS in the past, however not regularly since 2010. In the years where there is an overlap, the total site emissions have been aligned to the maximum of EEMS and RIs through the UK's OPTIS model; in recent years where the source resolution of reporting in EEMS is not available, the OPTIS model estimates the source-specific allocations based on historic reporting per terminal, with the sum of all sources per pollutant aligned to the RI total.

Each year the Inventory Agency conducts quality checking on the EEMS dataset, notably to check time series consistency and address any gaps or inconsistencies through consultation with the regulators at DESNZ and the site operators where necessary.

For the years prior to the EEMS data reporting system, i.e. 1990-1997, the inventory estimates are based on a submission by the oil and gas trade association, then UKOOA, to UK Government in February 2005; the data from UKOOA for 1995 to 1997 are source-specific, aggregated across installations with separate estimates presented for onshore terminals, and for all offshore installations. The UKOOA 2005 dataset for 1990-1994 is much more highly aggregated, with pollutant totals presented for onshore and offshore with very limited source resolution. The table of methods above indicates the proxy data used per source to estimate the source emissions during 1990-1994, including: well drilling statistics (for exploration emission estimates) and oil and gas production statistics.

In addition to these offshore production and terminal sites, there are some additional onshore well-sites involved in oil extraction from onshore fields in England that report their emissions annually under EPR to the Environment Agency. The emission estimates from these sites are added to those from sites regulated under EEMS and reported within 1B2ai.

For more detailed information regarding methods used to estimate emissions from upstream oil and gas sources in 1B2, please refer to the BEIS Oil and Gas improvement report (Thistlethwaite et al, 2022).

3.5.3.2. NFR 1B2aiv: Fugitive Emissions from Refining and Storage

In the UK, all refinery emissions from combustion and fugitive sources are reported under 1A1b, apart from NMVOCs and NH_3 emissions from oil handling and process fugitive sources. Emissions of NMVOCs and speciated NMVOCs such as benzene and 1,3-butadiene arise from drainage, process and tankage sources on refinery sites, and these emissions are reported within NFR 1B2aiv. Emissions of NMVOCs occur at refineries due to venting of process plant for reasons of safety, from flaring of waste products, leakages from process plant components such as flanges and valves, evaporation of organic contaminants in refinery wastewater, regeneration of catalysts by burning off carbon fouling, and storage of crude oil, intermediates, and products at refineries.

The NMVOC emissions from all refineries are estimated annually and reported to the Inventory Agency via Fuels Industry UK (Fuels Industry UK, 2023), the trade association for the refinery sector. The estimates from Fuels Industry UK are compiled by the refinery operators using agreed industry standard methods. The NAEI estimates are the sum of the data reported from each of the refineries operating each year (six sites remained in operation at the end of 2022). Annual estimates have been provided by Fuels Industry UK since 1993, with 1993 data assumed also to be applicable to all earlier years in the case of emissions from tankage and drainage systems. For process releases on the other hand, the 1993 emission has been extrapolated to earlier years in the time series in line with changes in production. In a few cases, where data for a particular site are not available for a particular year, data from the EPR reporting mechanisms to UK regulators have been used instead.

3.5.3.3. NFR 1B2av: Fugitive Emissions from Distribution of Oil Products

Petrol distribution begins at refineries where petrol may be loaded into rail or road vehicles. Petrol is then distributed either directly to petrol stations or via intermediate petrol terminals where it is stored prior to loading into road tankers for distribution to petrol stations. At petrol stations it is stored and then dispensed into the fuel tanks of road vehicles. Emissions of NMVOCs occur from each storage stage and from each transfer stage.

Petrol distribution emissions are calculated using petrol sales data taken from DUKES and emission factors calculated using the UK Institute of Petroleum's protocol on estimation of emissions from petrol distribution. This protocol requires certain other data such as average temperatures, Reid Vapour Pressure (RVP) of petrol and details of the level of abatement in place.

Central England Temperature (CET) data, obtained from the Met Office, is used for the temperature data, while Fuels Industry UK supply RVP estimates for summer and winter blend petrol, and estimates of the level of emission control are based on statistics given in the Institute of Petroleum's annual petrol retail survey.

3.5.3.4. NFR 1B2b: Fugitive Emissions from Natural Gas Transmission and Distribution

Emission estimates from the natural gas distribution network in the UK are provided by the gas network operators: National Grid, Cadent gas, SGN, Northern Gas Networks, Wales and West, and from Northern Ireland gas suppliers: Phoenix Gas and Firmus Energy. Natural gas compositional analysis is provided by the gas network operators and emissions of NMVOCs (as well as methane and carbon dioxide) from leaks are included within the UK emissions inventories. The estimates are derived from industry models that calculate the leakages from:

- Losses from high pressure (transmission) networks (National Grid, 2023);
- Losses from low pressure (distribution) networks (Cadent Gas, SGN, Northern Gas Networks, Wales & West, Phoenix Gas, Firmus Energy; all 2023); and

- Other losses, from above-ground installations and other sources (Cadent Gas, SGN, Northern Gas Networks, Wales & West; all 2023).

Additional estimates of emissions from natural gas leakage at the point of use within heating, boiler and cooking appliances in the residential and commercial sectors are made using a combination of:

- Annual gas use in domestic and commercial sectors for heating, cooking (DESNZ, 2023a)
- Numbers of appliances in the UK in these sectors (Inventory Agency estimate, 2023)
- Estimates of natural gas leakage prior to ignition and typical operational cycle times for different appliances, to determine an overall % of gas that is not burned (and assumed released to atmosphere) (Inventory Agency estimate, 2023, based on UK energy efficiency research for recent Government programmes)
- Natural gas compositional analysis from each of the gas network operators in Great Britain.

The emissions of NMVOCs from these sources are then calculated thus:

Emission (t) = UK mean NMVOC concentration in gas (t/kt) x total gas leakage (kt)

The estimates for 1B2b also include emissions reported in the PI by operators at onshore installations extracting gas from onshore fields in England.

3.5.3.5. NFR 1B2c: Venting and Flaring of Natural Gas and Oil

Emissions from gas flaring and venting at offshore and onshore oil and gas production sites and at refineries are all included within 1B2c. The inventory estimation methodology is the same as for the sources outlined above in 1B2a. For upstream oil and gas flaring, Activity Data are obtained from either UK ETS / EU ETS or EEMS, depending on the comparability of CO_2 emission outputs from OPTIS with those reported in UK ETS. If calculated CO_2 emissions are not within 2% of those reported in the ETS, then AD is obtained from EEMS. Emissions data are reported by plant operators in EEMS for both flaring and venting. There are no AD reported for venting within EEMS; operators simply report the emissions of each individual gas within the annual venting estimate. Therefore, the inventory method is simply an aggregation of the mass of each pollutant reported as vented across all upstream installations in EEMS.

In some instances, operators may report AD of flaring in EEMS but may omit to report the emissions of individual pollutants; in these cases the Inventory Agency applies a default EF to fill that reporting gap in order to report a complete UK inventory.

All upstream oil and gas production sites report annual emission estimates for these sources via the EEMS system to DESNZ OPRED (DESNZ, 2023b), whilst refinery flaring estimates are generated by operators and reported annually to the Inventory Agency via the refinery trade association (Fuels Industry UK, 2023). The NMVOC emission estimates in the UK inventories are simply the sum of the reported emissions data for the years where operator reporting is complete (1998 onwards), with industry-wide estimates from periodic studies for earlier years (UKOOA: 2005).

For more detailed information regarding methods used in 1B2c, please refer to the UK's National Inventory Report (Brown et al., 2024)[83].

3.5.4. Source Specific QA/QC and Verification

This source category is covered by the general QA/QC of the NAEI in Section 1.6. However, specific, additional QA/QC exists for 1B and is described below.

[83] The UK's National Inventory Report is due to be published on 15th April 2024, at https://naei.beis.gov.uk/reports/.

1B1a

Activity data for coal production in deep-mined and open-cast mines in the UK are quality-checked through comparison of data reported within DUKES and data reported directly by the UK Coal Authority, which provides regional and UK totals of coal production, for the years where both datasets are available. The information provided directly by colliery operators regarding their methane recovery systems are also checked against the data published by DESNZ on coal mine methane projects in the UK (which encompasses both operating and closed/abandoned mines with coal mine methane recovery systems).

1B2ai, 1B2c

DESNZ OPRED, as the regulator for offshore oil and gas activities, provides emission estimation guidance for all operators to assist in the completion of EEMS and UK ETS returns, including the provision of appropriate default emission factors for specific activities, where installation-specific factors are not available.

Emission estimates for 1990-1997 (i.e. pre-EEMS) are estimated based on industry studies (UKOOA 1995, 1998), which were revised and updated in 2005 (UKOOA, 2005), and appropriate proxies such as oil and gas production data. The emission estimates for 1998 onwards are based on the EEMS dataset.

EEMS data quality has improved over recent years through the development of online reporting systems, which have in-built quality checking functions. In addition, the Inventory Agency's development of the OPTIS (Offshore Platform and Terminal Inventory System) has added further quality checking routines, e.g. to compare EEMS emissions and activity data against UK ETS / EU ETS emissions and activity data, and to compare the implied emission factors for specific emission sources between sites (within year) and across the reporting time series for a given installation.

Despite these improvements, however, the completeness and accuracy of emissions reported via the EEMS reporting system is still subject to uncertainty. Reporting gaps for some sites are evident and, in some cases, operators report identical values from one year to the next. These data quality issues are typically associated with periodic emission sources where gathering activity data and emissions estimates are problematic (e.g. for health and safety reasons, such as measuring process fugitives), or where the ownership of a site has changed mid-year. The Inventory Agency continues to work with the regulatory agency, OPRED, to improve the completeness and accuracy of emission estimates from these sources.

The EEMS data are reviewed in detail each year by the Inventory Agency, to assess data consistency and completeness across the time series; this analysis seeks to reconcile data on energy and emissions reported to OPRED, DESNZ and the UK environmental regulatory agencies, comparing and aligning data from DUKES, EEMS and UK ETS/EU ETS.

1B2aiv, 1B2av

The emission estimates from refineries and from petrol distribution use consistent methods across the time series based on industry standard methods and UK-specific emission factors and models. Uncertainties arise primarily from the use of emission factors for different process designs and delivery systems, especially in the refinery storage, transfer and petrol distribution systems. Quality checking and verification involves time series consistency checks and periodic benchmarking against international emission factors for these sources.

1B2b

The emission estimates from leakage from the gas transmission and distribution network are based on UK industry models and annual activity data. Uncertainties stem predominantly from the assumptions within the industry model that derives mass leakage estimates based on input data such as network pipe replacement (plastic replacing old metal pipelines) and activities/incidents at above-ground installations; for these sources the NMVOC content of the gas released is known to a high degree of accuracy, but the mass emitted is based on industry calculations.

The estimates of emission from leakage at the point of use are based on the same gas compositional analysis as outlined above, combined with a series of assumptions regarding leakage from residential and commercial appliances. The same assumptions and factors are applied across the time series. There is a high degree of uncertainty associated with the activity data for this source, but in the context of the NAEI it is a minor source of uncertainty.

Quality checking and verification involves time series consistency checks and periodic benchmarking against international emission factors for these sources. In addition, checks between datasets from the different UK network operators provides UK-wide consistency checking.

3.5.5. Recalculations in NFR Sectors 1B1 and 1B2

For most pollutants there are no notable recalculations in NFR 1B in recent years, including for 2021.

3.5.6. Planned Improvements in Fugitive Emissions (NFR 1B1 and 1B2)

The UK does not currently report complete emissions from the transport of dusty materials and has included this as a high priority on the improvements list.

Following the use of the NSTA's PPRS dataset and NMVOC EFs from the IPCC 2019 Refinement to estimate emissions from oil loading, the UK will continue to seek out information on specific circumstances of oil loading vessels and the abatement used.

Each of the six refineries are going (or have gone) through a re-permitting process to ensure consistency with the mineral oil refinery BREF note, including their estimation methods to determine fugitive emissions, which are a notable source of NMVOCs in the UK. Several sites are now reporting under PRTR using a Tier 2 leak/no leak methodology, supported by LDAR programmes, rather than using a throughput-based methodology. This has led to a notable step change (down) in operator reported NMVOC emissions within PRTR for recent years. We are in dialogue with the UK trade association in order to ensure that the UK can, in future, report time series consistent and accurate emissions for refinery fugitive emissions; the current latest year estimates are considered to be conservative.

4. NFR 2: Industrial Processes and Product Use

4.1. Classification of Emission Sources and Activities

Table 4-1 relates the detailed NAEI source categories to the equivalent NFR source categories in the Industrial Process and Product Use (IPPU) sector. Note that there are some reporting conventions in the NAEI that may differ from the approaches used in other inventories, including:

- all emissions from cement and lime kilns are reported in 1A2f, rather than 2A1 and 2A2; 2A1 in the NAEI is limited to emissions from the manufacture (by grinding) of slag cement only;
- all emissions from the processing of bitumen are reported in 2D3b, including emissions of NMVOCs, particulate matter and PAH.

Table 4-1 Mapping of NFR Source Categories to NAEI Source Categories: IPPU

NFR Category	CLRTAP pollutant coverage	NAEI Source Category	Source of EFs
2A1 Cement Production	TSP, PM_{10}, $PM_{2.5}$, BC	Slag cement production (See 1A2f for cement kilns)	Literature factors (EMEP/EEA Guidebook; US EPA AP-42)
2A2 Lime Production	See 1A2f	See 1A2f	See 1A2f
2A3 Glass Production	NMVOCs, metals (Hg, Cd, Zn, Pb, Cr, As, Cu, Ni, Se, V), NH_3, TSP, PM_{10}, $PM_{2.5}$, PCDD/PCDF, BC	Glass production: - container - continuous filament glass fibre - domestic - flat - frits - lead glass - special - wool - ballotini	Operator reporting to Regulators for PRTR; UK-specific factors / research, HMIP, EMEP/EEA Guidebook.
2A5a Quarrying & mining of minerals other than coal	TSP, PM_{10}, $PM_{2.5}$	Dewatering lead concentrates Quarrying	EMEP/EEA Guidebook and other literature factors
2A5b Construction and demolition	TSP, PM_{10}, $PM_{2.5}$	Construction of apartments Construction of houses Non-residential construction Road construction	EMEP/EEA Guidebook
2A6 Other mineral products	CO, NMVOCs, SO_x, TSP, PM_{10}, $PM_{2.5}$, PCDD/PCDF, BC	Cement & concrete batching	Operator-reported emissions; UK-specific factors/research, HMIP, EMEP/EEA Guidebook, US EPA AP-42.
		Fletton Bricks	
		Ceramics: - glazed - unglazed	
		Refractories: - chromite based - non chromite based	
		Non-Fletton Bricks	
2B1 Ammonia production	See 1A2c	See 1A2c	See 1A2c
2B2 Nitric Acid Production	NO_x	Nitric acid production	Operator-reported activity and emissions

NFR Category	CLRTAP pollutant coverage	NAEI Source Category	Source of EFs
2B3 Adipic Acid Production	NO_X	Adipic acid production	Operator-reported activity and emissions
2B6 Titanium dioxide production	CO, TSP, PM_{10}, $PM_{2.5}$, BC	Titanium dioxide production	Operator-reported emissions. Literature factors, EMEP/EEA Guidebook
2B7 Soda ash production	CO, NH_3, TSP, PM_{10}, $PM_{2.5}$, BC	Soda ash Production	Operator-reported emissions. Literature factors, EMEP/EEA Guidebook, US EPA AP-42
2B10a Other chemical industry	All except B[b]F, I(123-cd)P, PCBs	Chemical industry: - carbon tetrachloride - halogenated chemicals - pesticide production - picloram production - sodium pentachlorophenoxide - tetrachloroethylene - trichloroethylene	Literature factors (US EPA AP-42, HMIP, other UK references)
		Chemical industry: - alkyl lead - ammonia based fertilizer - ammonia use - cadmium pigments/stabilizers - carbon black - chloralkali process - chromium chemicals - general chemicals - magnesia - nitric acid use - phosphate based fertilizers - pigment manufacture - reforming - sulphuric acid use	Operator reporting to Regulators for PRTR. Literature factors (EMEP/EEA Guidebook, UK research, US EPA AP-42)
		Coal tar distillation	
		Coal tar & bitumen processes	
		Solvent and oil recovery	
		Sulphuric acid production	
2B10b Storage, handling, transport of chemical products	NMVOCs	Ship purging	Emission estimate from UK research
2C1 Iron and steel production	All except NH_3	Electric arc furnaces	Operator reporting to Regulators for PRTR, plus additional operator reporting and literature sources (EMEP/EEA Guidebook, IPCC, other)
		Integrated steelworks: - Basic oxygen furnaces - Blast furnaces - Flaring - sinter production - other processes - stockpiles	
		Cold rolling of steel	Literature factors (EMEP/EEA)
		Hot rolling of steel	
2C3 Aluminium production		Alumina production	Operator reporting to Regulators for PRTR, plus additional operator reporting
		Primary aluminium: - anode baking	

NFR Category	CLRTAP pollutant coverage	NAEI Source Category	Source of EFs
	All except NMVOCs, NH_3, Se, PCBs	- general - pre-baked anode process - vertical stud Soderberg process	and literature sources (HMIP, EMEP/EEA Guidebook, UK references)
		Secondary aluminium production	
2C4 Magnesium production	PCDD/PCDF	Magnesium alloying	Literature factors (HMIP)
2C5 Lead production	CO, SO_X, TSP, PM_{10}, $PM_{2.5}$, metals (except Cr & Ni), PCBs & PCDD/PCDF	Lead battery manufacture	Operator reporting to Regulators for PRTR and literature sources (EMEP/EEA Guidebook, UK references)
		Secondary lead production	
2C6 Zinc production	CO, NO_X, TSP, PM_{10}, $PM_{2.5}$, BC, metals (except Se), PCBs, PCDD/PCDF	Primary lead/zinc production	Operator reporting to Regulators for PRTR and literature sources (EMEP/EEA Guidebook, UNEP, HMIP, UK references)
		Zinc alloy and semis production	
		Zinc oxide production	
		Non-ferrous metal processes	
2C7a Copper production	TSP, PM_{10}, $PM_{2.5}$, CO, metals (except Cr & Se), PCBs & PCDD/PCDF, BC	Copper alloy/semis production	Operator reporting to Regulators for PRTR and literature sources (EMEP/EEA Guidebook)
		Secondary copper production	
2C7b Nickel production	Ni, PCDD/PCDF	Nickel production	Operator reporting to Regulators for PRTR and literature sources (HMIP)
2C7c Other metal production	CO, NH_3, TSP, PM_{10}, $PM_{2.5}$, metals & PCDD/PCDF	Foundries	Operator reporting to Regulators for PRTR. Literature sources (EMEP/EEA, HMIP, other references)
		Other non-ferrous metal processes	
		Tin production	
2D3a Domestic solvent use	NMVOCs, NH_3	Agriculture - agrochemicals use	UK industry data (BAMA, CPA, ESIG)
		Aerosols: - cosmetics and toiletries - household products - other products excluding adhesives and paints	
		Non-aerosol products: - automotive products - cosmetics and toiletries - domestic adhesives - household products - paint thinner	UK-specific and US emission factors (UK industry including BASA; US EPA)
		Professional cleaning products	UK CPI
		Automotive screen wash	Dutch Inventory team
		Hand sanitiser	Average of MSDS
2D3b Road paving with asphalt	NMVOCs, TSP, PM_{10}, $PM_{2.5}$, PAHs, PCDD/PCDF, BC	Bitumen use	UK industry data and country-specific factors. Literature factors (EMEP/EEA
		Road dressings	
		Asphalt manufacture	

NFR Category	CLRTAP pollutant coverage	NAEI Source Category	Source of EFs
			Guidebook, HMIP, other references)
2D3d Coating applications	NMVOCs, TSP, PM_{10}, $PM_{2.5}$	Decorative paint - retail	UK industry data and literature factors (EMEP/EEA Guidebook, UK research)
		Decorative paint - trade	
		Industrial coatings: - agricultural and construction - aircraft - commercial vehicles - high performance - marine - metal and plastic - vehicle refinishing - wood	
		Industrial coatings: - automotive - coil - drum - metal packaging	Operator-reported data and literature factors (EMEP/EEA Guidebook, UK research)
		Paper coating	Operator-reported data
		Textile coating	
		Leather coating	
		Film coating	
2D3e Degreasing	NMVOCs	Leather degreasing	UK industry data
		Surface cleaning using: - 111-trichloroethane - dichloromethane - tetrachloroethene - trichloroethene - hydrocarbons - oxygenated solvents	UK industry data and emission factors based on EMEP/EEA Guidebook
2D3f Dry cleaning	NMVOCs	Dry cleaning	UK industry data
2D3g Chemical products	NMVOCs, TSP, PM_{10}, $PM_{2.5}$	Coating manufacture: - adhesives - printing inks - other coatings	UK-specific & literature factors (EMEP/EEA Guidebook, US EPA AP-42)
		Tyre manufacture	UK industry data
		Other rubber products	
		Foam blowing	
		Pressure sensitive tapes	
2D3h Printing	NMVOCs	Printing: - heatset web offset - metal decorating - newspapers - other flexography - other inks - other offset - overprint varnishes - print chemicals - screen printing	UK industry data and country-specific factors (BCF)
		Printing: - flexible packaging - publication gravure	Operator-reported data
	NMVOCs	Seed oil extraction	Operator-reported data

NFR Category	CLRTAP pollutant coverage	NAEI Source Category	Source of EFs
2D3i Other solvent use		Industrial adhesives - other	EMEP/EEA Guidebook, UK industry data (BASA, ESIG) and country-specific factors, Giddings *et al.*, 1991)
		Aircraft and Runway de-icer	
		Other solvent use	
		Wood impregnation - LOSP, light organic solvent preservatives	
		Wood impregnation - creosote	
2G Other product use	All except PCBs, HCB	Cigarette smoking	EMEP/EEA Guidebook
		Fireworks	
2H1 Pulp and Paper Industry	BC, CO, NO_X, PM_{10}, $PM_{2,5}$, SO_X, TSP, NMVOCs	Paper production	EMEP/EEA 2023 Guidebook
2H2 Food and Drink	NMVOCs and NH_3	Animal rendering	EMEP/EEA Guidebook
		Bread baking	
		Brewing - fermentation	Literature factors, mainly from UK industry research
		Brewing - wort boiling	
		Cider manufacture	
		Malting	
		Other food - animal feed manufacture - cakes, biscuits, and cereals - coffee roasting - margarine and other solid fats - meat, fish, and poultry	EMEP/EEA Guidebook
		Other food - sugar production	Operator reported emissions
		Spirit manufacture: - casking - distillation - fermentation - other maturation - Scotch whisky maturation	Literature factors, mainly from UK industry research, some EMEP/EEA factors for NMVOCs
		Sugar beet processing	
		Spirit manufacture - spent grain drying	Literature factor (US EPA AP-42)
		Wine manufacture	EMEP/EEA Guidebook
2H3 Other	TSP, PM_{10}, $PM_{2.5}$	Other industry - part B processes	Literature factors (UK research, EMEP/EEA)
2I Wood processing	NMVOCs, TSP, PM_{10}, $PM_{2.5}$, metals (except Se), PAHs and PCDD/PCDFs	Creosote use	Literature factors (EMEP/EEA, HMIP)
		Wood impregnation - general	
		Wood products manufacture	Operator reporting to Regulators for PRTR & literature factors (EMEP/EEA, US EPA AP-42, and UK references)
2K Consumption of POPs and heavy metals	PCDD/ PCDFs, PCBs	Capacitors	Literature factors (Dyke *et al.*, 1997)
		Fragmentisers	
		Transformers	

Note that NFR 2B5 (carbide production) is not occurring and 2C2 (Ferro-alloys) is a very limited activity in the UK, and emissions are not reported. Any use of fossil fuels in ferro-alloy production is included in 1A2. NFR 2L (other bulk products production, storage, handling and transport) is likely to be limited outside the industries listed in Table 4-1 above and there is no methodology in the EMEP/EEA Guidebook.

NFR 2 covers a large number of different emission sources, many of which are low-emitting sources in the NAEI context. Due to resource limitations, detailed methodological descriptions are provided for high-emitting source categories only, to reflect their importance in the UK inventory.

The following NFR source categories were key sources for major pollutants in the UK in 2022:

- 2A5a: Quarrying and mining non-coal (TSP, PM_{10}, $PM_{2.5}$)
- 2A5b: Construction and demolition (TSP, PM_{10}, $PM_{2.5}$)
- 2C1: Iron and steel production (CO, TSP, PM_{10}, $PM_{2.5}$, Pb, Hg, Cd, PCDD/PCDFs)
- 2C7c: Other metal production (Hg)
- 2D3a: Domestic solvent use (NMVOC)
- 2D3d: Coating applications (NMVOC)
- 2D3g: Chemical Products (NMVOC)
- 2D3i: Other solvent use (NMVOC)
- 2G: Other product use ($PM_{2.5}$, Pb, Cd)
- 2H2: Food and drink (NMVOC)

The following other IPPU NFR source categories are also quite substantial contributors to UK inventory totals for the specified pollutants in 2022; these are source categories that are outside the definition of a ‘key source category’ but include key source categories in earlier years and/or previous submissions:

- 2A6 Other mineral products (SO_X, PM_{10}, $PM_{2.5}$)
- 2B10a Other chemical industry (Hg)
- 2C3 Aluminium production (HCB)
- 2C6 Zinc production (Cd, Hg)
- 2C7a Copper production (Cd)
- 2D3e: Degreasing (NMVOC)
- 2D3h Printing (NMVOC)
- 2H1 Pulp and paper industry (SO_X, PM_{10}, $PM_{2.5}$)
- 2H3 Other industrial processes (PM_{10}, $PM_{2.5}$)
- 2I Wood processing (Pb)

The description of the inventory methodologies in this chapter focuses primarily on the key sources and other substantial source categories in the lists above.

4.2. Activity Data

Key data suppliers for UK industrial production and other activity data (e.g. annual product sales data) that underpin IPPU inventory estimates include the Iron and Steel Statistics Bureau (ISSB), the British Geological Survey (BGS), and trade associations such as the Mineral Products Association (MPA), British Glass, British Coatings Federation (BCF), European Solvent Industry Group (ESIG), British Adhesives and Sealants Association (BASA), and the Scotch Whisky Association (SWA).

There are also numerous trade associations and industry contacts that provide data periodically on product use or annual sales data, most notably for sources of NMVOCs from solvent use, including the British Aerosol Manufacturers Association (BAMA).

Activity data for many UK industrial sources are available from accredited official statistics published by the ONS. The main source of detailed information on industrial production is the PRODuction COMmunautaire (PRODCOM) dataset, and ONS also publish production indices at a fairly aggregated level e.g. for the chemical sector as a whole. The detailed PRODCOM data are frequently incomplete due to the need to suppress data that are commercially sensitive, although aggregated data may still be available. Furthermore, for some industries, the PRODCOM data might be presented on the basis of sales value, or the number of items produced, rather than on the mass of product. Finally, PRODCOM often disaggregates production into categories that do not align well with inventory methods and reporting requirements. The usefulness of the PRODCOM dataset for inventory compilation and reporting is therefore limited for many sectors (ONS, 2023a).

The Inventory Agency therefore makes best use of the published data and supplements this information through direct consultation with regulators, industry contacts and trade associations, to generate activity estimates for many high-emitting industrial sectors such as:

- chemical manufacture;
- some mineral industry processes such as glass production;
- secondary non-ferrous metal processes;
- foundry production;
- solvent use;
- food and drink production; and
- pulp and paper processes.

Some of the emission estimates for sources within NFR2 are based on emissions data which are available directly for all sites in a sector (for example from the PI/SPRI/WEI/NIPI) and so activity data have no direct impact on the UK emission estimates. Where activity data exist, they can be used to generate an 'implied' emission factor (IEF) to compare against, for example, default factors given in the EMEP/EEA Guidebook, to check comparability and accuracy of UK data. Where activity data do not exist (or cannot be derived/estimated from industry information), then the NAEI estimates are derived from the sum of reported emissions with no derivation of an IEF to aid comparability checks. A further limitation is that where the reported emissions data only cover some years (which is often the case), emissions for other years cannot be estimated on the basis of trends in activity data. In those instances, the Inventory Agency applies gap-filling assumptions to derive a time series consistent inventory dataset, for example using industrial production or economic indices, or taking consideration of the time series of plant capacity data (where available) and in some instances merely interpolating or extrapolating reported emissions data to adjacent years.

Emission estimates for NFR sector 2D3 are predominantly based on solvent consumption data supplied by industry or regulators as activity data, rather than production data, since this is a more reliable indicator of NMVOC emissions, particularly in sectors with numerous different product types. National activity data are not used to any notable extent, as few data are available that can reliably be used for the purposes of estimating emissions from solvent use. For example, there are no UK Government statistics on the consumption of paints, inks, adhesives, other coatings, cleaning solvents, aerosols, or other consumer products. Information obtained directly from industrial contacts is therefore the best available data to derive NAEI estimates. However, complete information from industrial contacts is not always available on an annual basis and therefore to derive a complete and consistent time series of data the Inventory Agency applies assumptions or extrapolation techniques, using the best available proxy data for each source. Emission estimates for non-aerosol consumer products rely upon purchased market data.

In many industrial sectors, the number of sites in the UK has declined considerably since 1990, with some sources no longer occurring in the UK. Table 4-2 illustrates this declining trend, with numbers of installations for key industrial sectors. For several sectors there are Government or industry statistics on production trends that report the decline in industrial sectors, whereas for other sectors it is assumed that the decline in plant numbers and capacity has led to a decline in UK production and emissions but there are no Government statistics to confirm the trends.

Table 4-2 Number of installations in the UK for some key industrial process sectors.

Year	Nitric acid	Adipic acid	Integrated Steel	Electric arc furnaces	Primary aluminium	Glass-Works[a]	Fletton brick works
1990	8	1	4	21	4	37[b]	8
1995	6	1	4	21	4	37[b]	5
2000	6	1	4	17	4	36	3
2005	4	1	3	12	3	34	3
2010	2	0	2	7	2	25	2
2011	2	0	2	7	2	25	1
2012	2	0	3	6	1	25	1
2013	2	0	3	6	1	25	1
2014	2	0	3	6	1	24	1
2015	2	0	3	6	1	24	1
2016	2	0	2	6	1	24	1
2017	2	0	2	6	1	24	1
2018	2	0	2	6	1	24	1
2019	2	0	2	6	1	24	1
2020	2	0	2	6	1	24	1
2021	2	0	2	6	1	24	1
2022	2	0	2	6	1	24	1

[a] excludes very small glassworks producing lead crystal glass, frits, domestic glass etc.
[b] approximate figures only

4.3. NFR 2A5a: Mining and Quarrying

The UK currently has few active underground mines and most minerals in the UK are extracted from quarries. Production is dominated by aggregate minerals, clays, and industrial minerals; the production of metalliferous ores has been a very minor activity in the UK for many years. Emissions are predominantly from extraction of the minerals and primary processing stages such as crushing. Emissions are generally fugitive in nature and difficult to quantify. Emission estimates for particulate matter are based on the use of the EMEP/EEA Guidebook Tier 2 emission factor, assuming a medium to high level of emissions. Quarries in the UK are regulated, and many process stages are typically required to install dust suppression systems, so the alternative Tier 2 factor for low to medium emission levels might be appropriate for the UK. However, in the absence of any detailed comparison of the practices of the UK quarrying industry with those assumed for the two Guidebook factors, we have adopted the conservative approach of using the higher factor. Activity data are gathered from statistics published by the BGS and consist of production data for each product type: igneous rock, sandstone, limestone, clays, metalliferous ores of various kinds, etc. Data are not available for all mineral types for the latest year, and in some cases for other years also, and in these instances the Inventory Agency has extrapolated mineral production data from the latest year of data that are available. In most cases, the lack of data is because statistics are not published in time for the compilation of the NAEI, and therefore there is a one year time lag for the activity data. For certain mineral types, only a combined value is provided and therefore the split has been held constant from the latest year for which a breakdown is provided .

4.4. NFR 2A5b: Construction

Emissions of particulate matter from construction are estimated using the default method given in the EMEP/EEA Guidebook. This consists of separate emission factors for four types of construction: houses, apartments, non-residential buildings, and roads. Activity data are required for each type in the form of the annual area of new construction. These activity data do not exist for the UK, so the Inventory Agency estimates the activity data based on other statistics such as the number and type of dwellings built, the value of construction work, and the annually reported length of the road network.

For houses and apartments, the number of new permanent dwellings are available from government house building statistics (see Table 1a within data available from the Office for National Statistics at https://www.ons.gov.uk/peoplepopulationandcommunity/housing/datasets/ukhousebuildingpermanentdwellingsstartedandcompleted). This dataset covers both houses and apartments, and the percentage of new dwellings that are houses, rather than flats, is available from government house building statistics (Table 254, from the Department for Levelling Up, Housing and Communities - see https://www.gov.uk/government/statistical-data-sets/live-tables-on-house-building). These data are combined to produce estimates of the number of new houses and new apartments. The Guidebook method also requires an estimate of the number of houses by the type of house (e.g. detached single family, detached two family (i.e. semi-detached), terraced). Data on the numbers of houses registered by house type (NHBC, 2023) are used to generate a split which is applied to the estimates of houses constructed, to obtain estimates of the number of houses built annually by house type.

For non-residential construction, the EMEP/EEA Guidebook method is based on the total number of non-residential buildings constructed or total constructed utility floor area from national or industry statistics. Through a desk review and consultation with an Economic Researcher at the Office for National Statistics, the Inventory Agency has determined that there are no such statistics for the UK. In such cases, the Guidebook method indicates that estimates of the affected area can be based on financial data for commercial non-residential construction. Data on the value of construction output (ONS, 2023a) provides statistics in £million, which is converted to Euros using the annual average currency exchange rate for 2016 (ONS, 2018), this year being assumed to be the most consistent with this particular Guidebook approach, although this is not stated in the Guidebook. The affected area is then estimated by multiplying the value of work in Euros by the scaling factor from the Guidebook of 0.001 m^2 per Euro, to obtain an estimate for the affected area for the construction of non-residential housing. Note that the UK statistics used will include the value of all non-residential construction, so will include road construction within the figures for infrastructure construction. As there are no statistics available to breakdown the infrastructure work by project type, there will be some degree of double-counting in the estimates due to the inclusion of road construction project data.

For road construction, the Guidebook method indicates that "*the affected area for road construction may be estimated from the total length of new road constructed, which is available from national statistical sources*". Through a desk review and consultation with the Road Conditions and Road Length Statistics team at the Department for Transport, the Inventory Agency determined that there are no such statistics available for the UK. However, the Department for Transport produces statistics on "*Road lengths by road type in Great Britain*" (DfT, 2023g) i.e., total length of roads, including both new and existing roads, and through comparison of the data across the time series, the Inventory Agency calculates the annual net change in road length by road type. These net changes may result from a range of factors, including the inclusion of new roads, step changes in methodology used to generate the statistics, as well as, presumably, the removal of some old roads. As such, the statistics do not separately identify the area of road that has been constructed, but they are the best option currently available for generating UK activity data for road construction. For each road type, an annual increase in the road length is assumed to reflect the length of new road constructed. Reported reductions in road length by road type are disregarded, assumed to be due to method change or removal of roads.

For all sources in this sector, both the emission factors and the activity data are associated with high uncertainty, particularly for non-residential and road construction.

4.5. NFR 2A6: Fletton Bricks

Fletton bricks are manufactured using deposits of the Lower Oxford Clay found in South-East England. This clay has an exceptionally high content of carbonaceous material which acts as an additional fuel when the bricks are fired, but also produces a characteristic appearance in the finished bricks. The Lower Oxford clay also contains sulphurous material, which results in substantial SO_X emissions during firing.

Until 1984, all Fletton brickworks used coal as the principal fuel in the brick kilns but from then on there was a gradual change towards the use of natural gas. The use of coal as a fuel ended completely in 2008 and the only site remaining in operation today uses natural gas. The fossil fuels burnt in the kilns contribute to emissions, although natural gas will make either a minimal contribution or no contribution at all to emissions of pollutants such as SO_X, halides and metals.

Emissions data for particulate matter and SO_X from each Fletton works have been reported in the PI since 1993 and are the basis of the NAEI estimates. These reported emissions will cover all sources at the brickworks including both fuel combustion and process sources. Fuel-related emissions will already be reported in 1A2gviii, and we do not want to duplicate them in 2A6. To avoid this, we split the reported emission into a fuel-related and a process-related part, and only report the latter in 2A6. First, the NAEI estimates the fuel usage at each brickworks (based on UK ETS data and PI data for CO_2 from fuel combustion) and then calculates what emissions will already have been included in 1A2gviii for that quantity of fuel. Those fuel-related emissions are then subtracted from the total emission figures reported in the PI in order to generate estimates of the process emissions from the brickmaking, which are then reported in 2A6. The calculations ignore any contribution that natural gas combustion makes to SO_X emissions i.e. we assume that all of the SO_X reported by sites burning natural gas originate in the sulphurous material in the clay. Natural gas may contain traces of sulphur but the contribution to SO_X emissions will be small and so this is ignored. This means that there will be a small double-count of SO_X in the NAEI for the sites that burn gas, with some SO_X included both in the estimates reported in 1A2gviii for natural gas combustion and then also in 2A6 for Fletton brickmaking.

The calculations for the 1993-2008 period, when both coal and natural gas were being used, indicate that process sources contributed about 85% of particulate matter emissions from Fletton brickmaking. Since 2008, gas has been the only fuel used and emissions have been almost entirely (99.9%) from the process. In the case of SO_X, process sources contributed about 95% of the emission in the 1993-2008 period. Because we ignore the contribution of natural gas to SO_X emissions, this means that process sources are assumed to contribute 100% of site emissions since 2009.

Estimates of the tonnage of Fletton bricks produced each year are based on annual brick production data (DESNZ, 2023d), which includes the total numbers of bricks produced (including Fletton and other brick types). Fletton bricks have had a declining share of the UK brick market for many years and are no longer used in the construction of new buildings. The number of production sites has declined from 8 in 1990 to just one by the end of 2017. Information on the market share is limited: we have industry estimates of 25% in 1990 and 20% for 1995, and by 2011, following the announcement that the last but one Fletton brickworks was being closed, local media reports all stated that Fletton bricks now accounted for less than 10% of the UK market. In order to estimate the annual Fletton and non-Fletton brick production, using the UK statistics on all brick production, the Inventory Agency assumes Fletton bricks to have a 25% share in 1990, falling to 20% in 1995, then falling to 10% by 2010. ETS data for the Fletton works indicates that production has fallen further since 2010 and therefore the UK ETS data (DESNZ, 2023c) are used to estimate the trend for Fletton bricks since 2010, with the non-Fletton production estimated by difference from the reported total bricks data.

There are no available emissions data prior to 1993 and therefore the emission factors derived for 1993 are applied to activity data for earlier years as well.

4.6. NFR 2B: Chemical Processes

There are no data for UK chemicals production in the public domain, and so it is not possible to use methods involving emission factors to estimate emissions in the UK. Instead, the NAEI method for the chemical industry is based on the use of site-specific emissions data provided by each operator to the regulators for Pollutant Release and Transfer Register (PRTR). These site-specific emissions data are available from the regulator inventories: Pollution Inventory (PI), Scottish Pollutant Release Inventory (SPRI), Welsh Emissions Inventory (WEI) and Northern Ireland Pollution Inventory (NIPI). The UK has had more than a thousand chemical processes operating at some point over the period 1990-2022 and all these sites have been regulated and required to provide emissions data to the regulator, in many cases based on continuous or periodic emissions monitoring. However, the data supplied to regulators is the total site emission of each pollutant and therefore includes both process emissions and fuel combustion emissions (from sources such as the site boilers). Combustion-related emissions are included in the NAEI in 1A2c using national energy statistics and Tier 1 Guidebook factors. Therefore, by using the reported site-specific emissions data directly in NFR2, the UK inventory methodology is conservative and may overestimate emissions by double-counting emissions from combustion that are also reported in 1A2c. The Inventory Agency seeks to minimise this risk of double counting through analysis and expert knowledge of emission sources on larger chemical sites, to exclude reported emissions that are likely to be solely from combustion. For example, emissions of metals would generally be assumed to be from combustion at sites which only use and make organic chemicals, particularly if that site is known to burn coal or heavy fuel oil in site boilers.

The data provided to the regulators covers most of the pollutants that the UK is required to report under the CLRTAP, however it is usually difficult or impossible to assign the emissions at each site to production of a specific chemical. Specific emission estimates can be derived for a very small number of individual chemicals, either in cases where data specific to individual processes are available directly from the site operators (such as nitric acid and sulphuric acid manufacture), or where the Inventory Agency is confident that the emissions reported for particular sites are all due to the manufacture of a particular chemical. However, the UK chemical industry manufactures hundreds or thousands of different chemicals, the vast bulk of which are not explicitly mentioned in the Guidebook and many sites manufacture a range of products. It is not possible, therefore, to distinguish between the emissions from different sources (combustion, individual chemical process sources etc.) at most sites, and hence the operator-reported, installation-wide emissions are aggregated and reported in 2B10a.

Currently, of the specific chemicals recognised in the NFR categories, separate emission estimates are reported for the following chemicals, based on the reported emissions:

- 2B1 Ammonia NO_X
  (but reported in 1A2c as combustion is the dominant source)
- 2B2 Nitric acid NO_X;
- 2B3 Adipic acid NO_X;
  (no production after 2005)
- 2B6 Titanium dioxide CO, TSP, PM_{10}, $PM_{2.5}$, BC;

- 2B7 Soda ash CO, NH_3, TSP, PM_{10}, $PM_{2.5}$, BC.

All other chemical industry process emissions of all pollutants are aggregated and reported in 2B10a.

Since emission estimates for chemical industry processes are based on reported emissions data, the quality of the national emission estimates depends upon the quality of the operator-reported data. These are subject to the appropriate regulator's QA/QC procedures and are regarded to be good quality for most pollutants. For NMVOC emissions data, however, the reported data are not all used directly, as further calculations and extrapolations are required by the Inventory Agency to address known issues that affect data accuracy, completeness and time series consistency. Particularly during the early years of operator reporting to regulator inventories (e.g. PI, SPRI), emissions of organic compounds were reported in such a way that double counting of emissions was possible in many cases, with emissions of 'total' NMVOCs reported as well as individual NMVOC species. Furthermore, the species reported often changed from year to year and the emissions reported for many sites also varied greatly from one year to the next. It is not certain whether these inter-annual variations are due to gaps in reporting or whether they reflect real changes in production and emissions. The NAEI estimates for NMVOCs from chemical industry processes therefore rely upon a substantial degree of interpretation of the regulators' data with 'gaps' being filled (by using reported data for the same process in other years) when this seems appropriate, and other reported data being ignored to minimise the risk of double counts. As a result, the national emission estimates for NMVOCs from chemical processes are associated with higher uncertainty than most other UK estimates based on regulators' data.

Emission estimates for HCB, PAH and PCDD/PCDFs from NFR 2B10a are mostly based on literature sources rather than reported data. Emissions of these pollutants at many chemical sites are below the threshold for operator reporting to Regulators for PRTR, and therefore there is a low level of reporting, hence the use of literature data in these instances. Emissions of HCB are estimated for the manufacture of carbon tetrachloride, sodium pentachlorophenoxide, tetrachloroethylene and trichloroethylene using factors from Duiser *et al.*, 1989. Production of carbon tetrachloride and sodium pentachlorophenoxide in the UK terminated in 1993 and 1996, respectively and the UK's sole manufacturer of tetrachloroethylene and trichloroethylene ceased production in early 2009, hence emissions of HCB from NFR 2B10a are assumed to be zero for 2009 onwards. Emission estimates for PCDD/PCDF from manufacture of halogenated chemicals are taken from HMIP (1995) and emissions of PAH from bitumen-based products are based on CONCAWE (1992). Emission estimates for Cd and Zn from phosphate fertilizer manufacture are also based on literature sources (van der Most *et al.*, 1992; Pacyna, 1988), again because of a lack of reported emissions. Emissions of PAH from processes handling coal tars are, however, based on emissions data reported to regulators.

4.7. NFR 2C1: Iron and Steel Processes

UK iron and steel production leads to emissions; from integrated steelworks, electric arc steelworks, downstream processes such as continuous casting and rolling of steel, and iron and steel foundries.

Integrated steelworks convert iron ores into steel using the three processes of sintering, pig iron production in blast furnaces and conversion of pig iron to steel in basic oxygen furnaces. These works also have coke ovens to produce the coke needed in the process, but emissions from this part of the works are reported elsewhere in the NAEI.

Sintering involves the agglomeration of the raw materials used to produce pig iron. This is done by mixing these materials with fine coke (coke breeze) and placing it on a travelling grate where it is ignited. The heat generated fuses the raw materials together into a porous material called sinter.

Blast furnaces are used to reduce the iron oxides in iron ore to iron. The furnaces are continuously charged with a mixture of sinter, fluxing agents such as limestone, and reducing agents such as coke and coal. Hot air is blown into the lower part of the furnace and reacts with the coke, producing carbon monoxide, which reduces the iron ore to iron.

Gas leaving the top of the blast furnace has a high heat value because of the residual CO content and is used as a fuel in the steelworks. Molten iron and liquid slag are withdrawn from the base of the furnace. Subsequent cooling of the slag with water can cause emissions of SO_X.

Gases emitted from the top of the blast furnace are collected and emissions should only occur when this gas is subsequently used as fuel. These emissions are allocated to the process using the fuel. However, some blast furnace gas is not collected and is instead lost and emissions from these gas losses are reported under NFR category 2C1.

Pig iron has a high carbon content derived from the coke used in the blast furnace. A substantial proportion of this must be removed in order to make steel and this is done in the basic oxygen furnace. Molten pig iron is charged to the furnace and oxygen is blown through the metal to oxidise carbon and other contaminants. As a result, carbon monoxide and carbon dioxide are emitted from the furnace and are collected for use as a fuel. As with blast furnace gases, not all gases are collected, and some gas may be flared. Emissions from this flared gas are reported with other blast furnace gas losses (e.g. through the bleeder valves) under NFR category 2C1.

Electric arc furnaces produce steel from ferrous scrap, using electricity to provide the high temperatures necessary to melt the scrap. Emissions of NO_X occur due to oxidation of nitrogen in air at the high temperatures within the furnace. Emissions of NMVOCs and CO occur due to the presence of organic contaminants in the scrap, which are evaporated and partially oxidised.

Emission estimates for all of these steelmaking processes are generally based on a bottom-up approach using:

1. data covering the period 2000 to 2022 from the operators of UK integrated works, one large electric arc steelworks and a further electric arc furnace steelworks that ceased production in 2005; and
2. emissions reported in the PI, WEI & SPRI (there are no sites in Northern Ireland) for other electric arc steelworks and data covering 1998 to 1999 in the case of integrated steelworks.

There are a few gaps in the first data set referenced above but since all operational integrated steelworks are located in England and Wales, data in the PI & WEI has been used to fill those gaps. While the PI & WEI emissions should be comparable with the sum of the emissions data requested from the operator, the PI/WEI data are less detailed, consisting of just a site-total for each works, rather than the separate figures for sintering, blast furnaces, oxygen furnaces etc., that the operators would normally provide. Where source-specific estimates are not available from operators, the Inventory Agency reconciles total installation emissions against PI/WEI data and generates source-specific estimates for the different process stages in an integrated works based on the reported split of emissions in other years.

Literature emission factors, including defaults from the EMEP/EEA Guidebook, are used for some minor emission sources where operators do not report emissions, while emissions for the earlier part of the time series for processes at integrated and electric arc steelworks are estimated by extrapolating emission factors from later years.

4.8. NFR 2C3: Aluminium Processes

The UK had one small primary aluminium producing site at the end of 2022 following the closure of a large smelter in Wales and another in England in late 2009 and early 2012 respectively. The UK also has many secondary aluminium processes, including the recovery of aluminium from scrap metal, and the production of aluminium foil and alloys.

All primary aluminium sites operating in the UK in the recent past have used the pre-baked anode process, with anodes baked at the two sites which closed in 2009 and 2012. Anodes are no longer baked in the UK, since the remaining pre-baked process imports anodes. One small smelter employed the vertical stud Soderberg process but closed in 2000. All primary sites and the large secondary processes report emissions in the PI, SPRI, WEI or NIPI and these data are used in the NAEI. It is possible that some small secondary aluminium processes may operate in the UK and be regulated by local authorities in England, Wales or Northern Ireland, and therefore do not report emissions in the PI, WEI or NIPI. There are no data available to the Inventory Agency to enable emissions to be estimated from any such sites, but their omission should not add substantially to the uncertainty in NAEI estimates for the sector. Aluminium processes used to be a key source of PAHs but since the largest sites have now closed, emissions are close to zero and much lower than previously, and therefore no longer a key source.

HCB emissions deriving from the use of hexachloroethane (HCE) in secondary aluminium production are estimated using an emission factor of 5g/tonne of aluminium produced (taken from van der Most *et al.*, 1992, and also recommended in the EMEP/EEA Guidebook). The use of HCE by the aluminium industry ended in 1998, so emissions thereafter are assumed to be zero.

4.9. NFR 2C6: Zinc Processes

The only primary lead/zinc producer in the UK closed in 2003, and since then the production of zinc has been very low in the UK. The large smelter site was a substantial contributor to UK emissions of some metals before its closure in 2003. Some relatively small-scale zinc processes remain in operation, manufacturing zinc oxide or zinc alloys from zinc metal, but emissions from these processes are low.

Emission estimates are based on a bottom-up approach using emissions reported in the PI & WEI only since no substantial processes operate in Scotland or Northern Ireland.

4.10. NFR 2C7a: Copper Processes

The UK has no primary copper production and the only secondary copper production process closed in 1999. This site was a substantial contributor to UK emissions of some metals before its closure. Various small copper processes producing copper wire, alloys etc. from copper metal are still in operation but emissions from these sites are low.

Emission estimates are based on a bottom-up approach using emissions reported in the PI only since no substantial processes operate in Scotland, Wales, or Northern Ireland.

4.11. NFR 2C7c: Other Non-Ferrous Metal Processes

The UK has an unknown but probably large number of mainly small foundries, most of which would be regulated by local authorities. Therefore, unlike the non-ferrous metal processes covered by 2C5, 2C6, 2C7a, and 2C7b, most of these processes do not report emissions in the available regulator inventories, so there is very little data on which to base a bottom-up emission estimate. Emissions are instead generated using UK foundry activity data and UK-specific emission factors. A small number of other non-ferrous metal processes are regulated by national regulators (e.g. solder manufacturers and production of precious metals) and do report in the PI, and emissions from these sites are also included in the estimates for 2C7c.

4.12. NFR 2D3: Uses of Solvents

Solvents are used by a wide range of industrial sectors as well as being used by the general public. Many applications for industrial solvent use require that the solvent is evaporated at some stage, for example solvent in the numerous types of paints, inks, adhesives and other industrial coatings must evaporate in order for the coating to cure. The solvent contained in many consumer products such as fragrances, polishes and aerosols will also be released to atmosphere when the product is used.

Emissions of NMVOCs from the use of solvents can often be assumed to be 100% of the solvent used, although there are some industrial applications where it will be less than 100%, such as when the solvent is recovered or destroyed using devices such as thermal oxidizers. For non-industrial uses of solvents, the default assumption is that all solvent are emitted. However, in the case of non-aerosol consumer products, the proportion of solvent emitted is assumed to depend on whether the product is used where water is present (so, for example soaps and detergents). In cases where this is so, we assume a much lower rate of emission: typically 5%, i.e. 95% of the emissions are to water and hence not considered in the NAEI. For smaller industrial processes, such as vehicle refinishing processes, the use of arrestment devices such as thermal oxidisers would be prohibitively expensive and abatement strategies therefore concentrate on minimising solvent consumption. Solvent recovery or solvent destruction are therefore considered unlikely to be used to any significant extent by these smaller industrial processes.

In comparison, larger industrial solvent users such as many flexible packaging print works, car manufacturing plant and specialist coating processes such as the manufacture of hot stamping foils often use thermal oxidisers or other devices to capture and destroy solvent emissions. In these cases, NMVOC emissions will still occur, partly due to incomplete destruction of solvent by the arrestment device, but also because some fugitive emissions will occur. The level of fugitive emissions will vary from process to process and will depend upon the extent to which the process is enclosed. For these sectors, it is still possible to estimate emissions based on solvent consumed, but allowance must be made for solvent destroyed or recovered. This can only be done accurately if the extent of abatement can be reliably estimated for each site. In most cases this means that detailed information at individual plant level must be gathered.

Other uses of solvents do not rely upon the solvent being evaporated at some stage and, in contrast, losses of solvent in this way are prevented as far as possible – for example in paint and ink manufacture, where solvents are used in the manufacture of saleable products. Emission estimates for these sectors can be made using emission factors (i.e. assuming some percentage loss of solvent). Further processes such as publication gravure printing, seed oil extraction, and dry cleaning can include recovery and re-use of as much of the solvent as possible, although new solvent must be introduced to balance any fugitive losses. Emission estimates for these sectors are made using solvent consumption data. Finally, there are some applications where solvent is used in products but is not entirely released to atmosphere when those products are used. Solvent used in wood treatments and certain grades of bitumen can be retained in treated timber and in road dressings respectively. In these cases, emission estimates are based on solvent consumption data but include an allowance for solvent not released.

Most industrial solvent-using processes in England, Wales and Northern Ireland are regulated by local authorities rather than by the national regulatory agencies. Any operator-reported emissions data for these processes are managed across hundreds of separate local authorities, with records typically in hard copy and not easily accessible to the Inventory Agency other than from the sub-set of installations that also report under PRTR. The Inventory Agency does not have the resources to access, collect, analyse, and use the data reported to Local Authorities on an annual basis; periodically information has been gathered to assess the scope and completeness of these data, but data are scarce across the time series. Annual data for some Scottish sites are available from SEPA but these processes will contribute only a very small proportion of UK emissions. Regulation of processes, first under UK regulations, and then under the Solvent Emissions Directive (SED) and Industrial Emissions Directive (IED), and most recently EPR 2016 (England and Wales) and The Pollution Prevention and Control (PPC) Regulations for Scotland and Northern Ireland have led to reductions in the NMVOC emissions from many solvent-using processes and it is a key challenge for the inventory to represent that. Since most data from industry are only available on an infrequent basis, it is very difficult to ensure that the inventory reflects all reductions that have occurred due to the regulation of processes. In addition, much of the data are from solvent/product suppliers rather than solvent/product users, and they may have an imperfect understanding of the level of abatement of emissions, and therefore over- or under-estimate reductions that occur due to end-of-pipe abatement. Table 4-3 shows how estimates have been derived for each NAEI source category.

Table 4-3 Methods for Estimating Emissions from 2D3 Solvent and Other Product Use.

NFR	NAEI Source Category	General method
2D3a	Aerosols: - cosmetics & toiletries - household products - other excl. adhesives & paints	Estimates for UK consumption of aerosols (in millions of units) and solvent / propellant consumption in these aerosols supplied by industry for 1991, 1996-2002, and 2012-present. Emissions in each of those years are assumed to equal solvent / propellant consumption in that year. Estimates of UK aerosol consumption for other years are either interpolated, or adjusted using population as a proxy. Data are available for UK fillings of aerosols, but these are considered not to be a reliable indicator of UK consumption because of very substantial import/export markets for aerosols. The 'other excl. adhesives and paints' category has been introduced in the latest version of the NAEI. Previously, this category, which was based on data from BAMA, covered all aerosols other than those covered by the other two categories. However, this meant that the category included paints and adhesives supplied in aerosol form. These products were also included in the emissions data from BASA and BCF which were used to estimate emissions in 2D3i and 2D3d respectively, so there was duplication in the NAEI. None of the three datasets contained sufficient detail that the double-count could be removed. For this cycle, we have received new data from BAMA on aerosols used for adhesives and paints in 2021. We have used these data, plus statistics from BASA and BCF, to generate a full timeseries of emission estimates for paint/adhesives in aerosol form. We can therefore now remove the double count. This has been done by removing the double-count from 2D3a due to increased uncertainty in the categories and proportions where aerosols are used within the detailed source breakdown, i.e. emissions from aerosols used for adhesives and paints are still included in the estimates for paints (in 2D3d) and adhesives (2D3i). Emissions from all aerosols in 1990 and 1992-1995 are estimated by deriving implied emission factors from the industry data for 1991, 1996, and 2002 and assuming that the 1991 figure is applicable to 1990 and that an average of the figures for 1991 and 1996-2002 is applicable for the remaining years. The different treatment for 1990 reflects the fact that aerosol formulations were undergoing rapid change in that period, due to efforts to end the use of CFC propellants. Emission factors for years between 2003-2011 and 2018 onwards are calculated via interpolating industry reported data, or extrapolating the latest available year.

NFR	NAEI Source Category	General method
2D3a	Non aerosol products: - car care - cosmetics & toiletries - household	The starting point for the inventory estimates is a study (Atlantic Consulting, 1995) which involved consultation with industry, and which produced UK activity and emission estimates for numerous sub-categories of consumer product for 1988 and 1994. Estimates of recent (2004-present) consumption of many categories of personal care and household products were purchased from a market research company (Euromonitor) and used to recalculate the activity data for the 'cosmetics & toiletries' and 'household product' categories in the NAEI. Activity data for the period 1995-2003 were generated by assuming a linear trend between the 1994 figure and that for 2004. The market research company does not collect data on car-care products. The activity data for 1994 from the Atlantic Consulting report therefore are extrapolated using vehicle numbers. Emission factors suggested by Atlantic Consulting are used for all years, except for household products where consultation with the UK Cleaning Products Industry (UKCPI) Association has resulted in that body recommending changes to factors for most of the important household product types (such as dish & laundry detergents, surface cleaners, polishes and toilet blocks) and we have adopted these suggestions.
2D3a	Professional cleaning products	Professional cleaning products, or more appropriately – the use of cleaning products purchased through routes other than supermarkets, e.g. wholesalers, or online purchases are not captured through the data gathered for the consumer products sector. The data provided by Atlantic Consulting for the early time series is also assumed to not include these products. Data has been obtained from the UKCPI regarding the size of the food service and janitorial cleaning products market in the UK. Statistics on the market size of the domestic cleaning product sector are also gathered and used in combination with NAEI estimates on the kt of product to determine the quantity of professional cleaning products. An aggregated EF for domestic cleaning products is used to calculate emissions for the professional cleaning sector for 2021 (the year of data provided by UKCPI). Activity data is extrapolated for the whole time series through use of employment statistics.

NFR	NAEI Source Category	General method
2D3a	Vehicle Screen wash	The method used in the NAEI is based on the Dutch method, as laid out by RIVM (2021). This builds on the original Finnish method by introducing: - Differing EFs for consumer and goods/service vehicles (in g/km). - A method to scale the EF to take into account higher screen wash use in colder temperatures. Activity data used for each year is vehicle kilometre data as calculated for the road transport inventory reported under 1A3b. Emission factors are calculated by multiplying the EF for each vehicle type by a correction factor to account for frost days. The correction factor utilises data on frost days (days where the temperature is less than 0 °C) obtained from the Met Office, this is available for each year at a UK level. Subsequently, the correction factor is calculated as laid out by the Netherlands: $$correction_{climate} = \frac{Frost\ Days_{UK} + Non\ Frost\ Days_{UK} \times 0.23}{Frost\ Days_{FI} + Non\ Frost\ Days_{FI} \times 0.23}$$ Where the factor of 0.23 relates to an assumption held by the US EPA that the use of screen wash at temperatures above local temperatures of 0 °C is 23% of the use at local temperatures below 0 °C. To adapt the Dutch EFs for use in the UK appropriately, it is then necessary to scale the EFs by calculating the percentage difference of the UK's correction factor for each year, to that of the Netherlands (0.43).

NFR	NAEI Source Category	General method
2D3a	Hand Sanitiser	Activity data is obtained from each of the Devolved Administrations for the use of hand sanitiser in each constituent country's health service in 2020. One of the data sets provides activity in terms of litres and units allows the calculation of a volume/unit rate, and activity data for 2019, allowing for an estimation of hand sanitiser use pre-COVID to be made. NHS staff numbers are obtained to calculate an estimation of hand sanitiser usage per staff member. It is assumed that the rate of hand sanitiser use in the NHS is comparable to that of other care-giving staff within the adult social care sector. For 2021, limited data could be obtained for hand sanitiser use in each UK constituent country. Where possible, the trend in hand sanitiser usage was applied, however where this was not possible, the trend in the most reliable of the four data sets was used. To estimate the activity of hand sanitiser use in all other areas (i.e. non-healthcare use of hand sanitiser), the total non-sanitiser ethanol use was estimated using the UK's NMVOC speciation model. This ethanol use is then subtracted from ESIG's estimate of ethanol use together with the healthcare use of sanitiser. The emission factor used represents a hand sanitiser of 80% ethanol and assumes that all of this NMVOC is emitted to air. For 2022, data from ESIG no longer indicates any excess ethanol use beyond that expected in NHS sanitiser and non-sanitiser applications and so we have assumed that usage of hand sanitiser outside of the NHS in the UK has fallen to negligible levels.
2D3a	Non-aerosol products: domestic adhesives	Emission estimates are derived from detailed industry data for 2005, 2007-2010, and 2012-present. Estimates for 2006 and 2011 are made by interpolation, while the time series for 1990-2004 is generated from estimates of emissions from all adhesives use (see 2D3i below) by assuming that domestic adhesive use contributes the same proportion of emissions (22%) as in 2005.
2D3a	Non-aerosol products: paint thinner	A per capita emission factor from US EPA, 1996 is used across the time series.
2D3a	Agrochemicals use	Estimates of total solvent consumption in agrochemical formulations are available from industry sources for 1990, 1995, 2000, 2008, 2013 and 2015-present. Industry data on UK sales of agrochemicals are available for 1990-2001 and 2008-2011, and Government statistics on use are available for 2008 onwards, however these suggest substantially lower usage than the industry data. As a result, we use the industry data for 2008-2011 and then extrapolate from the 2011 value using the trend in the Government statistics. Activity estimates are generated for 2002-2007 by interpolation between the 2001 and 2008 values from industry. The activity estimates can be used with the industry emission estimates to derive implied emission factors for 1990, 1995, 2000, 2008, 2013, 2015-present and interpolation/extrapolation is used to generate emission factors for the remaining years.

NFR	NAEI Source Category	General method
2D3b	Asphalt manufacture	Activity data are for production of coated roadstone and are obtained from the British Geological Survey (2023). Data are not available for years beyond 2014 and so the 2014 value has been used for those years as well. Emission factors are taken from the EMEP/EEA Guidebook (Tier 2 emission factor for batch mix plant).
2D3b	Road dressings	Estimates of emissions from kerosene use in 'cut-back' bitumens are available for 1988, 2008, 2013 and 2015-present. In the absence of other data, we have generated implied emission factors for these four years using UK consumption of bitumen (from DESNZ, 2023a), and then used these factors to estimate kerosene emissions in all other years. Emissions from bitumen use in road dressings are estimated using data from DUKES (DESNZ, 2023a) and emission factors from the EMEP/EEA Guidebook.
2D3d 2D3h	Decorative paint: - retail - trade Industrial coatings: - agricultural & construction - aircraft - commercial vehicles - high performance - marine - metal & plastic - vehicle refinishing - wood Printing: - heatset web offset - metal decorating - newspapers - other flexography - other offset - screen printing - other inks - overprint varnishes - print chemicals	Sales data (covering trade association members) are supplied on an annual basis by UK industry sources, together with periodic estimates of total UK consumption (so including estimates of sales by non-members) and estimates of sectoral emissions. The ratios between member sales and UK consumption are then used to generate UK consumption estimates for years where we only have the trade association sales data only. Similarly, the periodic estimates of emissions can be converted into emission factors which are then used to estimate emissions for those years where we have no industry emission estimates but only have sales data. There have been changes to the categories used in the industry data sets over time, and so some assumptions are needed to generate a full time series of activity data and emission factors for each of the sources listed. However, the availability of data is far greater for paints, inks and industrial coatings, than for most other sources within 2D3. The periodic information on emissions takes into account the gradual changes in coating formulations over time in response to UK regulation, the EPR/PPC and Paints Directive (The Volatile Organic Compounds in Paints, Varnishes and Vehicle Refinishing Products Regulations 2012). For example, the replacement of high-solvent content coatings with high solids or waterborne coatings. They also incorporate assumptions regarding the level of NMVOC emission abatement for sectors where that is appropriate (such as heatset web offset). For most sectors, however, emissions of NMVOCs are assumed to be the same as the solvent content of the coatings supplied.

NFR	NAEI Source Category	General method
2D3d 2D3h	Industrial coatings: - automotive - coil - drum - metal packaging Printing: - flexible packaging - publication gravure	As with the previous group, annual sales by trade association members, and periodic estimates of UK consumption are available. Since all of the processes in these sectors are thought to be regulated under EPR/PPC, the data from the trade association are complemented by site-specific emissions data collected either from local-authority regulators (for the period 1990-2001) or from UK-PRTR and earlier UK estimates for UK-PRTR processes (2002 onwards). These data are used in preference to the sectoral emission estimates from trade associations, on the basis that site-specific are likely to be more reliable, particularly in taking account of abatement.
2D3d	Film coating Leather coating Paper coating Textile coating	No activity data are available for these processes, and no trade associations have been identified who can provide sectoral estimates. Therefore, and since all processes in these sectors are thought to be regulated under EPR/PPC, site-specific emissions data have been collected from local-authority regulators (1990-2001) and from UK-PRTR and earlier UK estimates for UK-PRTR processes (2002 onwards). There are numerous gaps in the records for each site and these are filled by means of interpolation/extrapolation from existing data. As far as possible, we identify where sites have ceased operation, and take that into account in the estimates. Due to the general approach, however, it is likely that we may over-estimate emissions at some sites which have in fact closed or changed their process to reduce emissions. Conversely, it has not been possible to carry out any thorough search for new sites since the early 2000s and therefore it is quite possible that some new coating processes have begun operation and are not covered by the estimates.
2D3e	Surface cleaning: - 111-trichloroethane (TCE) - dichloromethane (DCM) - tetrachloroethylene (PER) - trichloroethylene (TRI)	Various estimates of UK chlorinated solvent consumption are available for 1990-1996, 1999, 2008, 2009, 2013 and 2015, and these are used as the basis of a time series of activity data for each solvent, with consumption after 2015 assumed to be at the same level as in 2015. It should be noted that the data cover all uses of these solvents (other than dry cleaning) and not just surface cleaning. However, we cannot split out different uses and, in any case, we believe that degreasing and surface cleaning will be the dominant use. Emission factors are based on industry estimates for the early 1990s: 90% of solvent emitted in 1990, falling to 80% by 1995 due to improved process management, and then more substantial reductions in emission factors over the period 1996-2010 due to the requirements of UK legislation and the IED. By 2010, emission rates are assumed to be 5% for TRI and DCM, and 12% for PER. Use of TCE is assumed to have ended in 1998, following the introduction of a ban under the Montreal Protocol. The factors for 2010 onwards are taken from the latest EMEP/EEA Guidebook, and are based on the following assumptions: All use of TRI from 2010 onwards being in enclosed machines (confirmed by industry sources)

NFR	NAEI Source Category	General method
		90% of PER in enclosed systems, 10% in semi-open systems (an industry source states that “the use of closed systems is being strongly recommended” and “is becoming industry standard.”) In the absence of other data, the situation for DCM is assumed to be as for TRI
2D3e	Surface cleaning: - hydrocarbons - oxygenates	Estimates of UK consumption of non-chlorinated solvents for surface cleaning are available for 1991, 1993, 1996 & 1999 from industry. Estimates for other years are made by extrapolation from these data, using indices of manufacturing output from sectors such as production of electronics, machinery and vehicles (ONS, 2023a). Emissions are estimated by assuming all solvent was emitted until 1995 but that since then, emission rates have decreased to 75% as a result of regulation of cleaning activities under UK legislation and the SED/IED. The factor chosen is that for use of semi-open systems & good housekeeping, in the EMEP/EEA Guidebook.
2D3e	Leather degreasing	A single estimate of emissions is available for 1990 from UK research (Sykes, 1992), and this is extrapolated to other years using an index of output for the leather sector (ONS, 2023a). Due to the relatively minor emissions, this source is not a priority for further research.
2D3f	Dry cleaning	Various data are available on the size of the UK dry cleaning sector, including estimates of the numbers and types of plant, and estimates of solvent consumption. We have used these data to construct a simple model of the sector, which incorporates assumptions concerning growth in dry cleaning (assumed to grow in line with population), and change from older ‘open’ dry cleaning machines (installed in the 1970s), to ‘closed’ machines (installed in the 1980s and 1990s) and, most recently, machines compliant with the SED/IED (installed since 2000).
2D3g	Coating manufacture - adhesives - inks - other coatings	Activity data are the estimates of solvent present in coatings - see 2D3d above. This solvent is present in the coatings as supplied to users, but additional solvent would have been used during the manufacture of the coating but emitted during that process. For 1990, this is assumed to have been 2.5% of the total solvent used i.e. the remaining 97.5% of solvent was left in the coatings sold to users. Coating manufacturing processes have been regulated under UK legislation and the SED/IED from the early 1990s onwards and so a lower factor (Guidebook Tier 2 factor of 11 g/kg) is used for 2001 onwards (when upgrading of processes to comply with UK legislation should have been complete).
2D3g	Pressure sensitive tapes Tyre manufacture	No activity data are available for these processes, but since both sectors consist of only a few sites, all of which are thought to be regulated under EPR, site-specific emissions data have been collected from local-authority regulators (1990-2001) and from UK-PRTR and earlier UK estimates for UK-PRTR processes (2002 onwards). As with other sectors where emissions data are used, there are gaps in the data which are filled by means of interpolation/extrapolation from existing data, taking account also of site closures.

NFR	NAEI Source Category	General method
2D3g	Foam blowing Other rubber goods	In both cases, we have no activity data and only sector emission estimates for a few years from industry sources: 2008, 2013 and 2015-present for foam blowing (ESIG), and 1993 (Straughan, 1994) and 2000 (Dost, 2001) for other rubber goods. Emission estimates for other years are generated by extrapolation from the data using indices of manufacturing output for the rubber and plastics sectors (ONS, 2023a)
2D3i	Seed oil extraction	Since there are only a few sites, all of which are thought to be regulated under EPR and PPC for Scotland and Northern Ireland, site-specific emissions data have been collected from local-authority regulators (1990-2001) and from the PI (2006 onwards). Gaps are filled by means of interpolation/extrapolation from existing data, taking account also of site closures.
2D3i	Industrial adhesives	Emission estimates have been made for 1996-1998, 2005, 2007-2010, 2012 onwards, based on detailed consumption data provided by the adhesives industry (broken down by technology and/or solvent type). Estimates of total solvent supplied to the sector are available for 1991, 1993 and 1996. We combine these elements into a time series, interpolating between the data to fill in the gaps. The estimates are also split into industrial use and domestic use, with the latter being reported separately in 2D3a.
2D3i	Wood Impregnation: - creosote - light organic solvent-based	Activity data are extremely limited with industry estimates for 1990 and then just a figure for creosote in 2000, and a suggestion from industry sources that use of light organic solvent preservatives had decreased by 80% from 1990 to 2002. We have assumed that usage after 2002 is in line with the index of manufacturing output for the wood sector (ONS, 2022a). The use of creosote by the general public ceased after 2003, which reduced consumption by 40% compared with levels in 2000. NMVOC emissions are estimated by assuming that these are 90% of the mass of light organic solvent preservatives, and 10% of the mass of creosote, figures suggested by UK research (Giddings *et al.*, 1991).
2D3i	Aircraft and Runway De-icer	Activity data has been obtained from one UK airport regarding de-icer use on aircraft and runways separately. To extend this to the rest of the UK for: Aircraft - Activity is scaled by using aircraft movement data obtained from the CAA for each airport. Activity is also scaled for each year by calculating the ratio of the number of frost days in the UK in 2020, obtained from the Met Office, compared to that of the year in question. Runways - Activity is scaled according to total runway length. Airports are also assigned regions in accordance with data that the Met Office reports, and a frost day scaling factor is calculated to adjust activity from the single airport for which we have data. The emission factor is obtained from the EMEP/EEA Guidebook.
2D3i	Other solvent use	This source category covers binders and release agents, metal working/rolling oils, lubricants, oil-field chemicals, fuel use (such as lighter fuel), fuel additives and water-treatment chemicals. Emission estimates are available from industry sources for 2008, 2013 and 2015-present and estimates for other years are made by extrapolation using surrogate data such as indices of manufacturing output (ONS, 2022a) or UK Government statistics regarding drilling of oil/gas wells in the North Sea.

Some solvent using processes have the potential to emit dust, for example when coatings are applied by spraying. UK-specific emission factors for industrial coating processes have been developed by combining assumptions such as:

- Proportion of coatings in each sector that are applied by spraying (100% for some sectors such as vehicle respraying, but lower in others such as can coating). Spraying is not used for some types of coatings such as those for metal coil.
- Average solids contents of the coatings sprayed. The approach takes account of the small changes in average solids content for some coating types over the time series.
- Average transfer efficiency of the spraying process, allowing the total loss of coating to be calculated. By combining with the solids content, an estimate of the total particulate matter resulting from overspray can be calculated. Transfer efficiencies have improved over the reported time period and this is taken account of in the method.
- Average efficiency for abatement of dust emissions from spraying operations. Most industrial spray coating processes are well-controlled, and removal of dust emissions is standard procedure. Emissions would have been less well controlled in 1990 and the factors take this into account: it is assumed that 90% of overspray was collected until 1995 (i.e. before regulation of sites) but that collection then increased to 98% by 2005, by which time most regulated operations would have been required to meet emission limit values.
- The Inventory Agency assume that particulate matter is 85% PM_{10} and 30% $PM_{2.5}$ based on the US EPA generalised particle size distribution for mechanically generated non-metallic material.

The estimates for solvent-using sectors are all heavily dependent upon data from trade associations, process operators and regulators. Government statistics are not available for most of the activities that result in emissions of solvents - there are no detailed Government data on consumption of paints, inks, adhesives, aerosols, or other consumer products, for example. Without suitable activity data, the emission factors provided in the latest EMEP/EEA Guidebook cannot generally be used, and so the NAEI methods mostly rely upon estimates of solvent consumption and/or solvent emissions in each sector. That information has been provided by UK industry and regulators, but on an ad-hoc basis and there is relatively little information that is updated routinely.

Collecting data is extremely resource-intensive both for the Inventory Agency and for industry and regulators and so only a limited amount of new data can be collected in any year. In recent years, the Inventory Agency and the UK Government has worked with trade bodies representing manufacturers of paints, inks, adhesives, sealants, consumer products (both aerosol and non-aerosol types), as well as solvent suppliers. The discussions with these trade bodies have resulted in new data being made available for use in the NAEI and a corresponding improvement in the quality of emission estimates over recent years for sub-categories within 2D3a; 2D3d; 2D3e, 2D3g, 2D3h and 2D3i. Recently, substantial improvements to 2D3a have been made: these have resulted from incorporation of new estimates of consumer product consumption, and the elimination of double-counted emissions from certain aerosols. Estimates for 2D3d and 2D3h were also improved due to the collection of additional site-specific data submitted for inclusion in UK-PRTR.

There are some less significant categories within 2D3 that are subject to relatively high uncertainty. Estimates for these sectors rely on relatively old or very limited data, for example estimates for car-care products (excluding screen wash), agrochemicals, blowing agents and wood preservatives. Emission estimates for car-care products (both aerosol and non-aerosol types) are the highest priority for improvement within sector 2D3, but they are also difficult to address due to a lack of any obvious source of activity data or any trade body representing the sector. In addition to researching those sectors that have not already been reviewed in recent years, it will also be necessary to maintain a dialogue with those sectors that have been investigated: data collected has often been supplied on an ad-hoc basis and further effort will be needed to ensure that periodic updates can be obtained so that the inventory estimates are based on the latest available evidence.

4.13. NFR 2G: Other Product Use

Emissions from cigarettes smoking and fireworks are reported under 2G. Emission factors for both sources are taken from the latest EMEP/EEA Guidebook.

Statistics from HM Revenue & Customs (HMRC, 2023c) provide annual activity data on the quantity of both readymade cigarettes and loose tobacco. To convert all activity to the same units the Inventory Agency makes an assumption about the average weight of tobacco in machine-rolled cigarettes to convert numbers of cigarettes into a mass of tobacco. For this we use the default 1g tobacco/cigarette figure suggested by the latest EMEP/EEA Guidebook.

Activity data for fireworks are obtained from UK statistics PRODCOM (ONS, 2023a) and from the HMRC UK Trade Info website (HMRC, 2023d) which report the quantity of fireworks imported and sold in the UK each year. Almost all fireworks sold in the UK are believed to be imported since the UK has no known producers of mass-market fireworks. Some high-end products were manufactured for use at large, professional fireworks displays however the last UK manufacturer of significance (Kimbolton Fireworks) ceased trading in 2019. The Inventory Agency historically assumed that Kimbolton and any other much smaller UK manufacturers supplied an additional 5% of fireworks to those supplied by importers. Following the closure of Kimbolton, recent information suggests that there was practically no UK manufacture from 2020 and we have therefore added only 1% (even this level may be too high if Kimbolton was the only UK manufacturer). A further method assumption is that all fireworks imported each year are used in that year, although it is possible that some stocks may get carried over.

4.14. NFR 2H1: Pulp and Paper Industry

Paper manufacturing requires wood pulp, which is made by separating wood into individual fibres. It is the production of the pulp, rather than the manufacture of the paper that can lead to process emissions of air pollutants. Wood pulping can be done either by chemical or mechanical means. By far the most common process worldwide is the Kraft process which uses sodium hydroxide and sodium sulphide to liberate the fibres. The use of chemicals (and the stages needed to recover and recycle the chemicals) leads to emissions of air pollutants. However the UK only currently uses mechanical pulping - where the fibres are separated using mechanical energy only and where there is no need for any chemicals (or any emissions from use of chemicals). Up until February 2006, there was also one site that used the neutral sulphite semi-chemical process (NSSC). The NSSC process involves partial digestion of wood using chemical means followed by mechanical separation, so there are more emissions than with mechanical pulping but less than with Kraft pulping. Note that the UK paper industry also imports large quantities of pulp (including Kraft pulp) but there are no emissions in the UK from use of this imported pulp.

Activity data for years 2012 onwards are taken from statistical reports written by the Confederation of European Paper Industries (CEPI, 2022). Data on 'Total Pulp Production' within Europe are combined with the UK's proportion of that pulp production to calculate the activity data. The statistics only lists share of the UK market for the largest producers and the UK does not always appear among these largest producers. So, for those years where the UK is not specifically mentioned, then it is assumed that the UK's share of pulp production is equal to the minimum of those countries that are mentioned. This should be a conservative assumption - the UK share in that year may actually be much lower than that of any of the identified countries.

For years between 2009-2011, activity data are calculated using Forest Research's statistics on pulp and paper production (Forest Research, 2019) and applying a scaling factor derived from CEPI for the ratio of pulp produced to that of paper products. The time series is extended back historically using Index of Production data for pulp and paper from ONS (ONS, 2022a). The single NSSC site had a known annual capacity of 0.08 Megatonnes, and this is subtracted from the estimated total quantity of pulp production in 1990-2005 to yield a split between mechanical and NSSC pulp in those years. For 2006, since the NSSC works closed towards the start of the year, we assume a proportionately lower production at the site. For 2007 onwards, the closure of the NSSC process meant that all UK pulp production is by mechanical means.

The emission factors have been taken from the 2023 EMEP/EEA Guidebook. In the previous version of the NAEI, factors were taken from the 2019 edition of the Guidebook and the only option then for NFR 2H1 was a set of emission factors that implied use of the Kraft process. The 2023 edition now also provides Tier 2 factors for mechanical pulping and NSSC and so these are now used instead. Since these two processes have much lower emissions than Kraft pulping, the change in factors leads to lower emission estimates for this sector.

4.15. NFR 2H2: Food and Drink Processes

Emissions occur from a variety of processes including bakeries, malting, animal feed manufacture and production of fats and oils, but the most substantial emissions are those from manufacture of Scotch Whisky and other spirits.

Activity data are sourced from a range of Government statistics such as the HMRC Alcohol Bulletin (HMRC, 2023b) and Defra Family Food Survey, together with industry-specific information from organisations such as the Scottish Whisky Association, Maltsters Association of GB and the Federation of Bakers. However, the NAEI has not been able to obtain full data from the Scotch Whisky Association for several years, thus there has been a need to extrapolate activity data for these key sources.

Emission factors for spirits manufacturing, and brewing are UK-specific and derived based on information supplied by industry. The NMVOC emitting processes on these sites are either mainly or entirely outside the scope of the EPR, and there is little or no NMVOC emissions data for these sites, and the industry data are therefore considered more reliable. No industry data for sugar production is obtained; but all of the UK plant which recover sugar from sugar beet report emissions in the PI. This includes very limited data for NMVOC emissions, and this is used as the basis of the NAEI estimate.

Most UK bread is manufactured using a process that is different to those used in much of Europe and so we have previously investigated whether the Guidebook factor for “typical European” bread is applicable. Most UK bread is produced using the Chorleywood Bread Process (CBP) which involves fast proving of doughs through use of mechanical means. CBP is not thought to be used to any extent in mainland Europe. Though this method speeds up the production of bread, an expert from Campden BRI (the UK food research organisation that invented the CBP) considered that the conversion of carbohydrates (with by-production of ethanol) would be similar regardless of whether CBP was used, or other fast-proving methods like spiral mixers (sometimes used in the UK by supermarket bakeries) or slow-fermentation methods (used only by artisan bakers in the UK). The EMEP/EEA Guidebook does contain a factor (2g/kg) for the ‘shortened bread process’, but the Campden BRI expert considered this emission factor to be too low, and instead considered that the default factor for “White bread, typical European” (4.5g/kg) to be most consistent with Campden BRI’s own measurements of the CBP process. Therefore, this Guidebook factor is used for the UK across the time series.

Emission factors for other substantial sources are all taken from the latest EMEP/EEA Guidebook.

Emission factors for substantial sources related to spirits manufacture are expected to be quite reliable, despite being generally based on industry approximations (e.g. the factors used for whisky casking, distillation, and maturation). This is due to close monitoring of production and losses that is carried out both because of the value of the product, and the need for Government to monitor production for the purposes of calculating duty to be paid.

Factors for other processes, particularly those related to processes other than manufacture of alcoholic beverages or bread, are much more uncertain and are regarded as among the most uncertain sources within the NMVOC inventory.

Emissions from animal rendering use emission factors from the latest EMEP/EEA Guidebook, and estimates of activity data based on meat consumption figures from Defra's family food data set (Defra, 2022). We have used data on the percentage of cattle, pigs, poultry and fish that are consumed by humans, based on Hamilton and Meeker (2006), and Zagklis et al. (2020), to derive estimates of the ratio of consumed meat/fish to non-consumed material and then assumed that all of this non-consumed material needs to be rendered.

4.16. NFR 2I: Wood Processes

The manufacture of fibreboard, chipboard and oriented strand board is a key category for lead emissions. There were six known sites manufacturing such products in 2022, with two others having closed in 2009 and 2012 respectively. Three of these sites are in Scotland, and these 3 sites have reported emissions data for metals to their respective UK regulators, and some emissions data for the remaining 3 sites are present in the UK-PRTR. These data indicate that the sites emit substantial quantities of metals, particularly lead, and for the Scottish sites at least, this is known to be due to the burning of waste wood as fuel. NMVOC emissions are also reported for most of the sites. Metal and NMVOC emission estimates for the sector have been derived from the emissions data reported by the eight sites in operation from 2004 onwards. The data are not complete: while there is an almost complete record of emissions of As, Cd, Cr, Cu, Hg, Ni and Pb for the three Scottish sites over the period 2004-present, data for the remaining sites is more fragmentary. For example, the largest plant is believed to be the single site in Wales, for which near-complete sets of emissions data are available for 2009, 2012-2014 and 2017-2018 but with much less or no data for other years. The Inventory Agency use the emissions data available to generate emission factors which are then used to fill in the gaps in reporting, using estimates of the capacity of each site as activity data. There is a similar situation for NMVOCs where we have a high level of reporting for some sites but less (or even no data at all) for other sites.

Together with the emissions of metals reported in 2I, estimates are also made of particulate matter, PM_{10}, $PM_{2.5}$, Black Carbon and POPs such as PCDD/Fs and benzo[a]pyrene. The reporting of emissions of these pollutants by operators is very scarce across the time series and therefore the method uses activity data based on ONS UK Manufacturers' Sales by Product (PRODCOM) statistics (ONS, 2023a), and emission factors from literature sources including the EMEP/EEA Guidebook (for PAHs); HMIP 1995 (for dioxins); US EPA (PM); Erlich *et al*. 2007 (for black carbon).

4.17. NFR 2K: Consumption of POPs

Emissions of PCBs from di-electric liquids from electric equipment (transformers and capacitors) and fragmentisers are reported under category 2K.

PCBs have been used historically as heat transfer fluids within di-electric equipment. However, PCBs have not been made in the UK since 1977 and were banned (within the EU) from new equipment since 1985. The major releases to the environment are thought to be from fragmentising operations, along with leaks from electric equipment, even following the ban of the use of PCB in closed applications such as electrical equipment since 1986. This was then followed by the removal of di-electric equipment assumed to contain more than 5kg of PCB from service by 2000 (Whiting, et al., 2012; Conolly, et al,. 2009).

The methodology to estimate the leakage of PCBs from equipment or direct PCBs emissions occurring, for example, from fluid leaks from di-electric equipment during service or from filling or disposal operations, was based on estimates of existing stock, against predicted leak rates and the phase out and removal of PCB containing equipment. The methodology has been refined in the 2022 and 2023 submissions to assume a larger initial quantity of PCBs are used for transformers and capacitors, and a longer equipment lifespan and removal rate than previously adopted.

4.18. Source specific QA/QC and verification

For most industrial process sources, the QA/QC procedure is covered under the general QA/QC of the NAEI in Section 1.6. Additional procedures are given below for the indicated categories.

Some emission estimates for 2A, 2B, 2C, 2D and 2I rely upon emissions data reported in the PI, SPRI, WEI, and NIPI. Section 3.1.7 discusses QA/QC issues regarding these data. The estimates for 2I also use some data from the UK-PRTR for Part A2 processes in England and Wales and we have less information on the likely quality of these data, which will likely vary substantially between sites. We assume that the majority of sites will estimate emissions using site-specific measurements and/or factors and that the typical uncertainty is relatively low. However, there are a small minority of data that are obvious outliers, and possibly suspect, however because there is limited site-specific information, it is rarely possible to conclude that these data should be excluded. The preference is always to use operator-reported data, unless there are very strong reasons not to. These site-specific emissions data should take account of site-specific factors to some extent and so are more preferable than the use of literature-factors.

QC of activity data for specific industries is also carried out between trade association data and other reference sources, such as a comparison between data from major iron and steel producers and the ISSB. Any discrepancies are investigated and resolved via stakeholder consultation. However, for many sources we have only one set of data and often for part of the time series only, so cross-checking of data sources is rarely possible.

4.19. Recalculations in Industrial Processes and Product Use (NFR 2)

The most noteworthy recalculations in NFR 2 since the previous submission are:

- 2D3a is revised upwards by +12 kt NMVOC sin 2021 as a result of incorporating emissions from the use of consumer products in the professional cleaning sector.
- This is offset by a change of -14 kt NMVOCs also in 2D3a for 2021 which is as a result of:
    - Incorporating up-to-date data on the aerosol sector based on statistics from BAMA.
    - Removing a long-standing double count between emissions from aerosols captured in the aerosols, paints and adhesives sectors.
- Updating the paper production methodology to a Tier 2 method, using newly available emission factors for mechanical pulping and NSSC processes leads to the following recalculations in 2021 for 2H1 for the NECR pollutants:
    - NO_X: -1 kt
    - NMVOC: -1 kt
    - $PM_{2.5}$: -1 kt
    - SO_2: -2 kt
- Updated data from the British Coatings Federation led to NMVOC emissions being revised by +1 kt in 2021 for 2D3d.
- Updated data from agricultural statistics and family food statistics led to NMVOC emissions being revised by -2 kt in 2021 for 2H2.

4.20. Planned Improvements in Industrial Processes and Product Use (NFR 2)

The industrial process and product use sector includes a diverse range of sources. For many of these sources there is relatively little data on which to base inventory estimates. There are no suitable UK activity data for many of the processes and product types. Most of the inventory estimates for NFR 2 therefore rely heavily on either site-specific emissions data from regulators, or activity data and/or emissions data from industrial trade bodies. The large number of individual sites and distinct source categories mean that maintaining or improving the estimates for NFR 2 can be resource-intensive. As a result, there are relatively few major improvements that can be planned. Instead, the Inventory Agency tends to look for opportunities to engage with stakeholders and to update the inventory where possible.

Many of the emission estimates for industrial processes are based on emissions data reported by process operators in the PI/SPRI/WEI/NIPI, and so the inventory can be updated each year with a further years' worth of data, and the quality of emission estimates is generally considered high. However, the completeness of the reported data varies from sector to sector and from pollutant to pollutant. Some industrial sectors, such as non-ferrous metals, are typically made up of relatively small emitters and reporting is not complete. Reporting to the PI/SPRI/WEI/NIPI is only required in cases where emissions from a permitted process exceed a pollutant-specific threshold, and so many smaller processes only report that their emissions do not exceed the threshold. Another issue is that there are some processes for which the operators provide no information on emissions (i.e. no emission estimate or confirmation that emissions are below reporting thresholds) and yet the type of process is such that there must be emissions. As a result, it is not possible to simply aggregate the emissions data provided by the regulators to obtain the UK total. Instead the Inventory Agency must interpret the data and perhaps add emission estimates to fill apparent gaps or to deal with those many sites that report emissions below reporting thresholds. The processing of the data carried out in a MySQL database system, which ensures the completeness and consistency of the estimates derived, as far as that is possible within the limitations of the raw data. Each year refinements are made to the assumptions which are likely to result in very minor changes to UK totals.

Many of the emission estimates for particulate matter are highly uncertain for two reasons, the first being that the emissions in many cases are essentially fugitive in nature and hard to quantify. Secondly, many processes that emit dust are regulated by local authorities (Part A2 and Part B), and there is no central database of emissions data for the Part B processes (i.e. nothing comparable to the PI, WEI, SPRI or NIPI). Emissions therefore must be estimated using top-down approaches such as use of literature emission factors. Since the sites are regulated, it is reasonable to assume that some strategies will be in place to minimise dust emissions but again, the lack of any centrally-held records, and the fact that these sites will be regulated by hundreds of different authorities make it difficult to be certain what level of control of emissions will be in place or even what technologies and processes occur at each site. In addition, national activity data are not always readily available for all of the process types. Improvement of this area of the inventory is a priority and the first steps are being carried out to produce an improved methodology.

The NMVOC inventory is similar to that for particulate matter in that there are many different industrial process sources of significance, including many types of process that are not Part A1 processes and therefore do not provide data to the PI, WEI, SPRI or NIPI. Many industrial solvent-using processes are Part A2 or Part B processes and many food manufacturing processes are not within the scope of the Environmental Permitting (England and Wales) Regulations 2016, for example. This fact, and the fact that it can be difficult to obtain suitable activity data from Government statistics, means that consultation with industry is the primary method used to gather data for this pollutant. There is an ongoing programme of stakeholder consultation which aims to contact each sector periodically and this may result in improvements for NMVOCs. While there have been many improvements in recent years, particularly to the biggest consumers of solvent (paints, inks, aerosol and non-aerosol consumer products, adhesives) there are other sectors (such as wood preservatives, agrochemicals, solvent extraction processes and foam blowing) where estimates are less certain and consultation with relevant trade bodies might allow improvements.

Improvements are also ongoing regarding estimating emissions from the transport and handling of dusty materials, e.g. grain, and emissions produced from commercial cooking processes. It is hoped that some estimates from these sources can be included in a future inventory.

Potential for improvements to estimates in the foundry sector are being investigated and we are working with industry to understand and obtain the most suitable data to estimate emissions.

New data has been received from the Scotch Whisky sector, which we plan to incorporate within the 2025 submission.

5. NFR 3: Agriculture

5.1. Classification of Activities and Sources

Classification of activities and sources relates the detailed NAEI source categories for agriculture used in the inventory to the equivalent NFR source categories. Some NAEI source categories are used only to describe emissions of greenhouse gases, therefore the methodologies used to produce estimates for these categories are not covered in this report.

Table 5-1 Mapping of NFR Source Categories to NAEI Source Categories: Agriculture

NFR Category		Pollutant coverage	NAEI Source	Source of EFs
3B1a	Manure management - Dairy cattle	NH_3, NO_X, NMVOCs, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - dairy cattle/waste	UK Factors or EMEP/EEA Guidebook[84]
3B1b	Manure management - Non-dairy cattle	NH_3, NO_X, NMVOCs, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - other cattle/waste	
3B2	Manure management - Sheep	NH_3, NO_X, NMVOCs, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - sheep/waste	
3B3	Manure management - Pigs	NH_3, NO_X, NMVOCs, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - pigs/waste	
3B4d	Manure management - Goats	NH_3, NO_X, NMVOCs, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - goats/manures	
3B4e	Manure management - Horses	NH_3, NO_X, NMVOCs, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - horses/manures	
3B4gi	Manure management - Laying hens	NH_3, NO_X, NMVOCs, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - laying hens/manures	
3B4gii	Manure management - Broilers	NH_3, NO_X, NMVOCs, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - broilers/manures	
3B4giii	Manure management - Turkeys	NH_3, NO_X, NMVOCs, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - turkeys/manures	
3B4giv	Manure management - Other poultry	NH_3, NO_X, NMVOCs, Ps$M_{2.5}$, PM_{10}, TSP	Agriculture livestock - other poultry/manures	
3B4h	Manure management - Other animals (please specify in IIR)	NH_3, NO_X, NMVOCs, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - deer/manures	
3Da1	Inorganic N-fertilizers (includes urea application)	NH_3, NO_X	Agricultural soils	UK factors (model-derived)

[84] Default Tier 1 EFs used for all other than NH_3 and NO_X.

NFR Category		Pollutant coverage	NAEI Source	Source of EFs
3Da2a	Livestock manure applied to soils	NH_3, NO_X, NMVOCs	Agriculture livestock - Animal manure applied to soils	UK factors (model-derived)
3Da2b	Sewage sludge applied to soils	NH_3, NO_X, PCBs	Application to land	UKCEH, 2018
3Da2c	Other organic fertilisers applied to soils (including compost)	NH_3, NO_X	Land spreading of manure-based and non-manure digestates	Tomlinson *et al.*, 2019
3Da3	Urine and dung deposited by grazing animals	NH_3, NO_X, NMVOCs	N-excretion on pasture range and paddock unspecified	UK factors or EMEP/EEA Guidebook[1]
3Da4	Crop residues	NO_X	Crop residues	UK factors (model-derived)
3Dc	Farm-level agricultural operations including storage, handling and transport of agricultural products	$PM_{2.5}$, PM_{10}, TSP	Agricultural soils	Literature sources
3De	Cultivated crops	NMVOCs	Cultivated crops	EMEP/EEA Guidebook
3Df	Use of pesticides	HCB	Agricultural pesticide use - chlorothalonil use	UK Factors Duiser et al, 1989 Sweetman, 2005 Bailey, 19998
			Agricultural pesticide use - chlorthal-dimethyl use	
			Agricultural pesticide use - quintozine	
3F	Field burning of agricultural residues	NH_3, NO_X, NMVOCs, Particulate Matter, PCDD/ PCDFs, PAHs, PCBs for 1990-1992 only	Field burning	EMEP/EEA Guidebook[1]

The following NFR source categories are key sources for major pollutants:

- 3B1a Manure Management of Dairy Cattle - NH_3, NMVOC
- 3B1b Manure Management of Non-Dairy Cattle - NH_3, NMVOC
- 3B4gi Manure Management of Laying Hens - TSP
- 3B4gii Manure Management of Broilers - PM_{10}
- 3B4giv Manure Management of Other Poultry - TSP, PM_{10}
- 3Da1 Use of Inorganic N-fertilisers - NH_3
- 3Da2a Application of Animal Manure to Soils - NH_3, NMVOCs
- 3Da2c Application of Digestate to Soils - NH_3
- 3Da3 Urine and Dung Deposited by Grazing Animals - NH_3
- 3Dc Farm-Level Agricultural Operations - PM_{10}, TSP
- 3Df Use of Pesticides - HCB

The UK has an important ruminant livestock sector, largely concentrated in the west of the country where soil and climatic conditions favour the production of grass over arable crops, which are predominantly grown in the east of the country. Dairy and beef cattle production are the most important sectors in terms of NH_3 emissions. Although there is a trend for increasing year-round housing systems for dairy cows, most dairy and beef cattle spend much of the year grazing at pasture, unlike in many other NW European countries. The NH_3 emission factor from grazing tends to be less than from housed animals with subsequent manure management, because of rapid infiltration of urine into the soil during grazing. Therefore, the implied emission factor for UK beef and dairy cattle may be lower than for other European countries where grazing is practised less. Cattle housing in the UK also differs from that in many other European countries in that for dairy cows slatted floor systems are uncommon in the UK (particularly England, although they are more prevalent in Scotland and Northern Ireland) and for beef cattle, straw-bedded solid manure systems are typical. Sheep are an important livestock sector, but as they spend the majority of the year outdoors, they are associated with low NH_3 emissions compared with cattle.

Numbers of cattle, sheep and pigs have declined substantially since 1990, partly through efficiency measures (i.e. greater production per animal) but also in response to economic drivers (Table 5-3). Poultry numbers have increased, with the poultry sector now representing the next most important livestock sector, in terms of NH_3 emissions, after cattle. Pig, poultry and dairy cow numbers decreased (by 3.0%, 2.9% and 0.4% respectively) between 2021 and 2022, whereas other cattle and sheep numbers increased slightly (both 0.5%).

Dominant crops grown are the cereals wheat and barley, and oilseed rape, representing approximately 72% of total arable crop area. Nitrogen (N) fertiliser use has decreased substantially since 1990, mostly because of lower rates being applied to grassland, although there has been little change in overall trend in total fertiliser N use since 2006 (Table 5-10). In 2020 there was a decrease in total fertiliser N use linked to a reduction in winter cereals being grown, due to poor weather. In 2021 total fertiliser N use increased relative to 2020, but remained less than that of previous years, at 94% of the 2019 value. In 2022 there was a 16.9% decrease in total fertiliser N use relative to 2021, which is linked to the increased cost of fertiliser in association with increased energy prices. The proportion of fertiliser N applied as urea and urea ammonium nitrate (UAN; with both fertiliser types associated with a much larger NH_3 emission than other fertiliser types) has generally increased since 1997, with their use linked to market prices. In 2022 approximately 27% of total fertiliser N use consisted of urea and UAN.

Although improvements in production efficiency have resulted in lower emission intensities for some products, until recently UK uptake of mitigation measures specifically targeted at abating NH_3 emissions from agriculture (e.g. low emission slurry spreading methods and inclusion of urease inhibitors with urea; Defra Farm Practices Surveys, the DAERA Survey of Nutrient Management Practices; Defra project AC0114; the British Survey of Fertiliser Practice) has been relatively slow. However, changes in regulations around manure management, particularly for Northern Ireland, have led to greater uptake of low emission slurry spreading methods for the year 2022 (see Table 5-9).

5.2. Activity Statistics

5.2.1. Livestock Statistics

National Agricultural Survey

Livestock numbers are obtained at agricultural holding level for England and each of the Devolved Administrations (DAs; Northern Ireland, Scotland and Wales) - based on annual returns to the June Agricultural Survey (Defra 2023a) and, for years from 2005 onwards, data from the Cattle Tracing

Service database is used to provide further detail on all cattle for England, Wales and Scotland (Jon Ellerbeck (2023) of Animal and Plant Health Agency and British Cattle Movement Service, 2022). For Northern Ireland, data are provided by DAERA. Each agricultural holding is categorised according to Robust Farm Type (RFT), a classification used across different UK surveys (e.g. Farm Business Survey), enabling linking of input or output datasets where appropriate. Each holding is also spatially located within a 10 x 10 km grid square for association with soil type and climate as appropriate.

Data are summed for England and the DAs to provide UK population data for the livestock categories and subcategories as used in the inventory compilation (see further details below). Calculating at the country-level by RFT allows for differences in management practices and/or environmental factors to be reflected in the emission estimates. These surveys:

- are considered the most complete and robust data sources for UK livestock numbers;
- have been relatively consistent over a long timescale;
- are structured to be representative of the UK agricultural sectors; and
- are associated with low uncertainties (actual values depending on year and livestock category).

Further details of compilation of livestock numbers across the time series are given in Dragosits *et al*. (2018) and in the Defra report for project AC0114 WP4.3.

Livestock Categorisation

The June survey data (Defra 2023a; and Cattle Tracing Scheme data) provide sub-categories within the major livestock categories, which are used as the basis for subsequent emission calculations (Table 5-2). For animals which are present for less than 1 year (e.g. broilers, finishing pigs) the survey data are assumed to represent the number of animal places and all subsequent calculations are performed on an animal place basis (e.g. N excretion calculations will account for the number of crop cycles within a year for broilers).

Detailed sector characterisation is included for the major livestock sectors (dairy, beef, sheep, pig and poultry) reflecting UK-specific livestock, environment and production characteristics. Dairy cattle are disaggregated into three production/breed types (large, medium, small), associated with different average milk yields for each year (high, medium, low) and into four sub-categories by age (Table 5-2). Live weights and growth rates for each production/breed type are defined based on a standard growth curve and annual data on calf birth weight and final mature cow weight (from slaughterhouse statistics; Defra 2023b). Beef cattle are disaggregated into 15 age bands, four breed types (Continental, lowland native, upland and dairy) and six sub-categories by role (Table 5-2), associated with different live weights, growth rates and management practices. Sheep are disaggregated into three production systems (hill, upland and lowland) associated with different livestock parameters and management practices, based on a survey by Wheeler *et al*. (2012). Growth-curves are used to allocate ewes and lambs to grass and stores at finishing. The annual average weight of ewes and slaughter weight of lambs are calculated separately for each country based on average carcase weights and a fixed killing-out percentage (weight of carcase as a percentage of the live weight before slaughter) of 46% and 44%, respectively. Pigs are disaggregated into six sub-categories (Table 5-2) representing the breeding herd, replacements and finishing pigs. Finishing pigs are subdivided into three categories according to live weight to reflect differences in diet and management practices. Poultry are disaggregated into eight subcategories (Table 5-2) to reflect differences in live weight, feeding and management practices.

Table 5-2 Livestock categories and sub-categories included in the NAEI

Livestock categories	Sub-categories
Dairy cattle	Dairy cows[1]

Livestock categories	Sub-categories
	Dairy heifers in calf[2]
	Dairy replacements > 1-year old[2]
	Dairy calves < 1-year old[2]
Beef cattle	Beef cows[2]
	Beef heifers for breeding[2]
	Breeding bulls[2]
	Beef females for slaughter[2]
	Steers[2]
	Cereal fed bulls[2]
Pigs	Sows
	Gilts
	Boars for service
	Finishing pigs >80 kg
	Finishing pigs 20-80 kg
	Weaners <20 kg
Sheep	Lamb
	Mature ewe
	Mature ram
Goats	Goats
Deer	Deer
Poultry	Laying hens
	Broilers
	Pullets
	Breeding flock
	Turkeys
	Ducks
	Geese
	Other poultry
Horses	Horses kept on agricultural holdings
	Professional horses[3]
	Other domestic horses[3]

[1]Reported under 3B1a (Dairy cattle); [2]Reported under 3B1b (Non-dairy cattle);[3]Reported under 6A.

Trends in UK livestock numbers are given in Table 5-3. Headline changes between 2021 and 2022 were a 3% decrease in pig numbers, a 2.9% decrease in total poultry, including a 3.6% decrease in broiler numbers and a 3.5% increase in laying hens, a 0.5% increase in sheep numbers and a very slight increase in total cattle numbers, with dairy cows decreasing by 0.4% and all other cattle increasing by 0.5%.

Table 5-3 Animal numbers over the 1990-2022 period (thousand animal places[1])

Livestock Categories	1990	2000	2005	2010	2020	2021	2022
Total cattle	12,125	11,048	10,698	10,014	9,429	9,444	9,476
Dairy cows	2,848	2,336	2,003	1,839	1,853	1,856	1,848
All other cattle	9,277	8,713	8,695	8,175	7,576	7,588	7,628
Sheep	45,475	43,154	36,140	31,724	33,427	33,641	33,817
Pigs	7,548	6,482	4,862	4,468	5,069	5,323	5,164
Total poultry	138,381	169,773	173,909	163,842	182,882	189,853	184,367
Laying hens	33,624	28,687	29,544	28,751	31,067	30,788	31,879
Broilers	73,944	105,689	111,475	105,309	120,047	126,584	122,006
Horses on agricultural holdings	202	287	346	312	236	231	220
Goat	98	74	95	93	112	111	111

Livestock Categories	1990	2000	2005	2010	2020	2021	2022
Deer	47	36	33	31	38	46	44

[1]Livestock numbers for pig, poultry and sheep are based on the number of occupied places at the time of survey

5.2.2. Nitrogen Excretion

The UK model for NH_3 emissions from agriculture uses the N flow approach, accounting for all nitrogen losses (NH_3, N_2O, NO, N_2) and transformations (mineralisation/immobilisation) through the manure management system with emission factors expressed as a proportion of the ammoniacal N in the manure for the given emission source (Webb and Misselbrook, 2004).

For cattle and sheep, N excretion is estimated using a mass balance approach based on estimates of dietary N intake, N output in product (milk, wool) and N retention in live weight gain. Production parameters including milk yield (Table 5-4), live weight and growth rates are system-specific for the dairy, beef and sheep production systems represented, as described above, and are reviewed and updated annually. Nitrogen intake is estimated from the feed dry matter (DM) intake per animal and the dietary protein content. Dry matter intake is determined using UK-specific energy balance equations (Thomas, 2004; AFRC, 1993), based on metabolisable energy (ME). The daily ME intake by the animal is assumed to correspond with the requirement to meet the needs of live weight gain, activity, milk, wool and foetus production. Standard dietary components have been defined and associated with the outdoor grazing and indoor housing periods for each production system. These include grazed grass (with and without clover), grass silage, maize silage, whole crop silage, hay and various concentrate formulations. Based on ME requirement and dietary ME content, daily DM intake is derived, and from the protein content of the diet the daily N intake is derived.

Table 5-4 Average milk yield (litres per cow) for each production system and for all UK dairy cows over the period 1990-2022

Dairy breed/production systems	1990	2000	2005	2010	2020	2021	2022
Large (high yield)	6,003	6,772	7,844	7,973	9,120	9,100	9,063
Medium (medium yield)	5,007	5,547	6,286	6,308	6,805	6,856	6,813
Small (low yield)	3,893	4,532	5,103	5,365	5,402	5,298	5,244
UK average	5,151	5,995	6,990	7,306	8,212	8,213	8,171

For pigs and poultry, N excretion values specific to UK livestock and production practices are derived from a report by Cottrill and Smith (2007), with more recent values for pig and poultry based on the data underlying Defra project report WT1568 (Defra, 2016). Livestock management and commercial feeding practices were reviewed in consultation with leading livestock advisers and specialist consultants, and all available research and industry data pertaining to feed inputs and product outputs for UK livestock production systems were also reviewed. The same N-balance approach as described above for the ruminant sectors was used for estimating N excretion. The approach was applied at the level of the individual animal, with an adjustment made according to the length of the production cycle and for empty periods of livestock housing, to provide an annual output factor per ‘animal place’. The latter is necessary to allow for non-productive time needed for cleaning and re-stocking the housing. Nutrition specialists provided typical input and performance data on which to base the calculations and, where possible, industry data was also considered. A time series from 1990 was established using expert judgement (Cottrill and Smith, ADAS) based on Defra project reports WT0715NVZ and WT1568. For pig and poultry, the increasing implementation of phase feeding, dietary synthetic amino acids and animal genetic advances resulting in improvements in feed efficiencies in the UK pig and poultry sectors have been reflected as a trend for decreasing N excretion from 1990 to 2016 (with values constant since then). For goats and deer, values are derived from the IPCC 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Tables 10.19 and 10A.5; IPCC 2019) for

Western Europe, as the best estimates for the UK. It has been assumed that there are no changes in N excretion over the time series for horses, goats and deer.

The time series for N excretion by different livestock categories is shown in Table 5-5. The proportion of N in livestock excretion assumed to be as ammoniacal N (the 'pool' from which ammonia volatilisation is assumed to take place), for livestock types other than cattle, was based on expert opinion and verified by comparing the modelled estimate of total N and ammoniacal N in manures at manure storage and spreading, with empirical data from on-farm measurements in the Manure analysis database (MANDE; Defra, 2003). For cattle, the excreted N is partitioned to urine and faecal N based on relationships given by Johnson *et al.*, 2016, and in subsequent N-flow modelling the urine N is assumed to be the ammoniacal N and the faecal N is assumed to be organic N. The ammoniacal N proportions assumed for livestock excreta are consistent with those assumed by other European countries (Reidy *et al.*, 2008; Reidy *et al.*, 2009).

Table 5-5 Nitrogen excretion values for livestock categories (kg N per animal place per year)

Livestock Category	1990	2000	2005	2010	2020	2021	2022
Dairy cows	85.5	93.5	102.4	104.5	118.2	118.7	118.0
Other cattle	39.8	43.2	44.7	45.7	44.5	44.5	44.2
Sows	23.6	21.4	20.6	20.8	21.1	21.1	21.1
Gilts	15.5	15.5	15.2	13.6	11.7	11.7	11.7
Boars	28.8	26.1	24.5	22.0	18.9	18.9	18.9
Fatteners (> 80 kg)	20.2	18.4	17.2	15.4	13.2	13.2	13.2
Fatteners (20 - 80 kg)	14.6	13.2	12.4	11.1	9.6	9.6	9.6
Weaners (<20 kg)	4.6	4.2	4.0	4.0	4.0	4.0	4.0
Ewes	8.3	8.6	8.6	8.3	8.8	8.8	8.7
Rams	11.3	11.4	11.3	11.1	11.4	11.3	11.3
Lambs	3.7	3.9	4.1	4.0	4.2	4.3	4.3
Goats	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Horses on agricultural holdings	50	50	50	50	50	50	50
Deer	29.3	29.3	29.3	29.3	29.3	29.3	29.3
Laying hens	0.87	0.80	0.77	0.76	0.74	0.73	0.74
Broilers	0.64	0.55	0.49	0.40	0.28	0.28	0.28
Turkeys	1.50	1.68	1.75	1.77	1.78	1.78	1.78
Pullets	0.42	0.36	0.34	0.35	0.36	0.36	0.36
Breeding flock	1.16	1.10	1.09	1.11	1.14	1.14	1.14
Ducks	1.30	1.52	1.57	1.40	1.20	1.20	1.20
Geese	1.30	1.52	1.57	1.40	1.20	1.20	1.20
Other poultry	1.30	1.52	1.57	1.40	1.20	1.20	1.20

5.2.3. Livestock Management Practices

A review of the literature on livestock housing and manure management practices (Nicholson *et. al.,* 2013), updated with survey data on manure spreading practices from the BSFP (BSFP, 2023), and data from DAERA statistics for NI (DAERA, 2022) was used as the basis for developing the 1990 to 2022 time series of livestock housing and manure management practices for England and each DA. From this a weighted average was derived for the UK. Underlying data sources include routine and ad-hoc surveys such as the Defra Farm Practices Surveys (Defra, 2023c) and published manure management surveys (Smith et al., 2000, 2001a, 2001b). Broad management categories (managed as slurry, farmyard manure (FYM) or outdoor excreta) are given in Table 5-6 for the major livestock categories. More detailed practice-specific data are applied at a country scale for each livestock category for the livestock housing, manure storage and manure application phases of the manure management continuum. Tonnages of poultry litter incinerated in each year were obtained directly from EPRL and Fibropower websites, with tonnage exported from Northern Ireland to be incinerated in Scotland and England provided by Tom McKeown, Moy Park.

Table 5-6 Manure management systems for livestock categories 1990-2022

Livestock Category	1990	2000	2005	2010	2020	2021	2022
Dairy cows							
% slurry	71	77	79	80	81	81	81
% FYM[1]	29	23	21	20	19	19	19
Beef cattle							
% slurry	36	42	41	41	41	42	41
% FYM[1]	64	58	59	59	59	58	59
Sows							
% slurry	63	54	38	40	41	42	43
% FYM[1]	19	16	36	21	21	20	20
% outdoors	18	30	26	39	38	38	37
Weaners							
% slurry	91	50	49	43	45	45	46
% FYM[1]	9	44	37	38	37	37	36
% outdoors	0	6	13	19	18	18	18
Finishing pigs							
% slurry	56	39	46	40	45	44	45
% FYM[1]	44	60	51	58	54	54	53
% outdoors	0	1	2	2	2	2	2
Laying hens							
% indoors	85	73	67	62	58	58	58
% outdoors	15	27	33	38	42	42	42
Broilers							
% indoors	100	99	95	93	92	92	93
% outdoors	0	1	5	7	8	8	7

[1]FYM is farmyard manure

Quantities of livestock manure being used in anaerobic digestion (Table 5-7) are estimated from data provided by the National Non-Food Crops Centre (2022) annual deployment report, a database listing operational, under-construction and proposed anaerobic digestion plant in the UK. Quantities of manure used as feedstock in anaerobic digestion have changed across the time series due to updated values from the NNFCC. Information in the database includes location, capacity, feedstock (inputs) types and feedstock quantities in five categories: manure, crops, crop wastes, food and other. Although co-digestion of two or more feedstocks is commonly practiced, for the purpose of the emission calculations each is treated individually. Manure as a feedstock is further categorised as cattle, pig, poultry, equine and miscellaneous animal.

For inventory calculations, the categories of equine and miscellaneous animal (i.e. not specifically identified) are summed and reallocated to cattle, pig and poultry based on the relative proportions of total manure (leaving housing) for those livestock types. Similarly, as cattle is not further defined, the relative proportions from the dairy and beef sectors are assumed to be in proportion to the total quantity of manure managed for those sectors. Within each livestock sector, for each livestock subcategory, the same proportions are applied to manure quantity going to anaerobic digestion as are applied to that sector as a whole. For cattle and pigs, slurry and farmyard manure are assumed to be equally applicable for anaerobic digestion, so have the same proportional implementation.

Table 5-7 Quantity of livestock manure (kt fresh weight) used as feedstock for anaerobic digestion 1990-2022

Manure type	1990	2000	2005	2010	2020	2021	2022
Cattle	0	8	8	44	824	828	828
Pig	0	0	12	18	319	319	319
Poultry	0	1	1	12	499	499	499
Misc. ‘animal’	0	0	1	66	1,002	1,008	1,008

A review of the implementation of specific ammonia mitigation methods over the time series was conducted as part of a Defra Inventory Implementation project and the estimated uptakes as included in the UK emission inventory are shown in Table 5-8 and Table 5-9. From 2020, increased uptake of slurry store covers and use of LESSE in Northern Ireland is assumed based on regulation associated with the Nutrient Action Programme (2019). The implementation of mitigation for finishing pig and broiler housing and pig slurry storage are based on the number of animals that would come under the EU Industrial Emissions Directive permitting requirement, and the mitigation methods included are assumed as proxy for those that would be required as Best Available Technology.

Table 5-8 Estimated uptake of ammonia mitigation methods for livestock housing and manure storage in UK agriculture

Mitigation	Emission source	% abatement	% implementation				
			1990	2005	2020	2021	2022
Part-slatted floor with reduced pit area	Finishing pig housing (slurry)	30	0	0	33	33	33
Litter drying	Broiler housing	60	0	0	72	72	72
Crust formation	Cattle slurry tanks/lagoons	50	80	80	80	80	80
Rigid (tent) cover	Pig slurry tanks	80	0	0	24	24	24
Floating cover	Pig slurry lagoons	60	0	1	24	24	24
Rigid cover[1]	Digestate tanks	80	100	100	100	100	100

[1]Assumption that best practice is applied and all post-digestion storage is covered

Table 5-9 Estimated uptake of ammonia mitigation methods for the applications of livestock manure, digestate and urea-based nitrogen fertilisers in UK agriculture

Mitigation	Emission source	% abatement	Country	% implementation				
				1990	2005	2020	2021	2022
Shallow injection	Cattle slurry	70	England	0	1	6	7	6
			Wales	0	1	6	7	6
			Scotland	0	1	6	7	6
			N. Ireland	0	0	0	0	0
Deep injection	Cattle slurry	90	England	0	0	3	2	2

Mitigation	Emission source	% abatement	Country	% implementation				
				1990	2005	2020	2021	2022
			Wales	0	0	3	2	2
			Scotland	0	0	3	2	2
			N. Ireland	0	1	1	1	1
Trailing shoe	Cattle slurry on grassland	60	England	1	4	12	15	18
			Wales	1	4	12	15	18
			Scotland	1	4	12	15	18
			N. Ireland	0	2	10	10	10
Trailing hose	Cattle slurry on arable	30	England	0	4	12	15	18
			Wales	0	4	12	15	18
			Scotland	0	4	12	15	18
			N. Ireland	0	6	35	38	40
Rapid incorporation[1]	Cattle slurry on arable	59	England	3	6	12	9	15
			Wales	3	6	12	9	15
			Scotland	3	6	12	9	15
			N. Ireland	3	6	9	8	8
Rapid incorporation[1]	Cattle FYM on arable	71	England	3	4	9	13	14
			Wales	3	4	9	13	14
			Scotland	3	4	9	13	14
			N. Ireland	3	4	9	13	14
Shallow injection	Pig slurry	70	England	0	3	26	23	20
			Wales	0	3	26	23	20
			Scotland	0	3	26	23	20
			N. Ireland	0	3	26	26	26
Deep injection	Pig slurry	90	England	0	0	0	0	0
			Wales	0	0	0	0	0
			Scotland	0	0	0	0	0
			N. Ireland	0	0	0	0	0
Trailing shoe	Pig slurry on grassland	60	England	0	13	32	28	31
			Wales	0	13	32	28	31
			Scotland	0	13	32	28	31
			N. Ireland	0	13	32	28	70
Trailing hose	Pig slurry on arable	30	England	0	13	32	28	31
			Wales	0	13	32	28	31
			Scotland	0	13	32	28	31
			N. Ireland	0	13	32	42	52
Rapid incorporation[1]	Pig slurry on arable	67	England	10	7	9	10	9
			Wales	10	7	9	10	9
			Scotland	10	7	9	10	9
			N. Ireland	10	7	9	10	10
Rapid incorporation[1]	Pig FYM on arable	71	England	10	6	9	13	14
			Wales	10	6	9	13	14
			Scotland	10	6	9	13	14
			N. Ireland	10	6	9	13	14
Rapid incorporation[1]	Poultry manure on arable	82	England	8	14	24	21	21
			Wales	8	14	24	21	21
			Scotland	8	14	24	21	21
			N. Ireland	8	14	24	21	21
Trailing hose	Digestate	30	England	0	20	72	72	72
			Wales	0	20	72	72	72
			Scotland	0	20	72	72	72

Mitigation	Emission source	% abatement	Country	% implementation				
				1990	2005	2020	2021	2022
			N. Ireland	0	20	72	72	72
Shallow injection	Digestate	70	England	0	8	28	28	28
			Wales	0	8	28	28	28
			Scotland	0	8	28	28	28
			N. Ireland	0	8	28	28	28
Urease inhibitor	Urea on arable	70	All countries	0	0	17	14	8
Urease inhibitor	UAN on arable	44	All countries	0	0	5	10	6
Urease inhibitor	Urea on grassland	70	All countries	0	0	18	15	15
Urease inhibitor	UAN on grassland	44	All countries	0	0	11	11	11

[1]Incorporated within 4h of application with plough, disc or tine

5.2.4. Synthetic Fertiliser Usage

Fertiliser usage in England, Wales and Scotland are derived from the annual British Survey of Fertiliser Practice for the appropriate cropping year (BSFP, 2023)[85] and for Northern Ireland from DAERA statistics (DAERA, 2022)[86], and these are used to derive total UK fertiliser N use for each year (Table 5-10). Estimates for total N use by fertiliser type are derived using the survey data for total fertiliser quantity used and survey data on the N content for each type.

Table 5-10 Total fertiliser N use (thousand tonnes) by land use and fertiliser type

	1990	2000	2005	2010	2015	2020	2021	2022
Total fertiliser N	1573	1356	1137	1100	1098	947	997	828
Total to tillage	732	701	638	666	685	533	594	547
As urea based fertiliser[1]	154	72	125	173	235	164	191	189
Total to grassland	840	656	499	434	413	414	403	281
As urea based fertiliser[1]	58	23	20	27	36	37	35	37

[1]Urea based fertiliser values includes all nitrogen contained within urea and urea ammonium nitrate (UAN). In previous years only the urea-N component of UAN was included here.

Total fertiliser N use has declined since 1990, particularly to grassland, although the decline had levelled out to some extent since 2006. The increase in fertiliser prices during 2022 in association with higher energy prices resulted in a sharp decrease in fertiliser applications to tillage (8%) and grassland (30%). Previously the N fertiliser use on cropland had fluctuated with weather conditions. There was a sharp decline (14%) between 2019 and 2020 due to very wet weather in autumn 2019 preventing the sowing of winter cereal crops, some of which were subsequently replaced with spring cereal crops associated with lower N application rates. This pattern has been seen before (e.g. 1992/93, 2000/2001 and 2013/14) and total N use generally increased again in the following year, as occurred in 2021.

Use of urea based fertilisers (urea *and* urea ammonium nitrate; UAN), which are associated with much higher ammonia emission factors, has increased as a proportion of total fertiliser N use on both cropland and grassland since 2005.

[85] https://www.gov.uk/government/collections/fertiliser-usage
[86] https://www.daera-ni.gov.uk/articles/fertiliser-statistics

The inclusion of urease inhibitors with urea-based fertilisers can reduce ammonia emissions associated with the use of urea-based fertiliser (Table 5-10). Records of urease inhibitor use from the British Survey of Fertiliser Practice (BSFP) began in 2018 and the assumption is that prior to 2018 the use of urease inhibitors with urea-based fertilisers was zero. In 2022 the percentage of urea fertiliser nitrogen applied with a urease inhibitor was 7.5% and 15.3% for UK arable and grassland crops respectively, and for UAN was 5.7% and 11.0% for UK arable and grassland crops respectively. Use of inhibitors is currently at a low level and there is large uncertainty in the surveyed uptake values which are aggregated each year to calculate running means. This uncertainty stems from farmer understanding of inhibitors and which products contain urease inhibitors, with improvements to the questions used in the 2022 BSFP indicating that the inventory is likely to over-estimate current use of urease inhibitors. Planned additional survey questions will increase the rigour of this data.

5.2.5. Use of Pesticides

Statistics relating to the sale and use of pesticides within the UK are published by FERA (Food and Environmental Research Agency) for England, Wales and Scotland (https://pusstats.fera.co.uk/data/current) and by Agri-Food and Biosciences Institute for Northern Ireland (AFBINI) (https://www.afbini.gov.uk/articles/pesticide-usage-monitoring-surveys). Hexachlorobenzene (HCB) occurs as an impurity or a by-product in the manufacture of several pesticides currently used in the UK (chlorothalonil) or used in the past (quintozene and chlorthal-dimethyl). Following the application to agricultural land, pesticides can volatilise from deposits on plants or soil into the atmosphere.

The UK's activity is calculated by multiplying the data from FERA by 70.2%, the fraction of new HCB that is emitted into atmosphere as opposed to soil or water (AEA Technology, 2009). Following quintozene and chlorthal-dimethyl being withdrawn from the authorised active substance list and then banned, HCB emission into atmosphere is only through the use of chlorothalonil.

Table 5-11 Total agricultural pesticide use in the UK (t)

	1990	1995	2000	2005	2010	2019	2020	2021	2022
Chlorothalonil	383	589	328	1,111	1,173	1,271	921	921	921
Chlorthal-dimethyl	34	23	5.6	5.8	4.5	0	0	0	0
Quintozene	0.3	0.2	3.2	0	0	0	0	0	0

Quintozene was withdrawn from the UK market in 2002 and its use had to cease within 18 months.

The emission factors used are given in Table 5-12. The Bailey, 2001 US EPA emission factor of 0.04 kg/t has been used for chlorothalonil between 1990 and 1998. Following new monitoring and sampling in 2010, which gave a weighted average of 0.008 kg/t (Whiting, 2011), emission factors were extrapolated for the period between 1999 and 2009. Benezon's (1999) emission factor based on a Canadian study has been used for quintozene has been scaled down across the time series from 1 kg/t to 0.5 kg/t (AEA Technology, 2009).

Table 5-12 Pesticides emission factors for HCB (kg/t)

	1990	1995	2000	2005	2010	2019	2020	2021	2022
Chlorothalonil	0.040	0.040	0.034	0.020	0.008	0.008	0.008	0.008	0.008
Chlorthal-dimethyl	3.00	3.00	3.00	3.00	3.00	NA	NA	NA	NA
Quintozene	1.00	0.84	0.69	NA	NA	NA	NA	NA	NA

Emission factors listed as 'NA' are such because no activity data/use of these pesticides exist in the respective years.

Although the pesticide use dataset is updated annually for Great Britain and every two years for Northern Ireland, the redistribution of emissions among air, land and water after the application of the pesticides is associated with some uncertainty. The application of Tier 3 emission factors, having confirmed the UK working concentrations of HCB from pesticides through the monitoring of in-use pesticides in 2010 (Whiting, 2011), has improved the reliability of HCB emissions estimates.

5.2.6. Field burning of Agricultural Residues

Burning of crop residues leads to the emission of atmospheric pollutants including: NH_3, NO_X, NMVOCs, SO_X, CO and PM including black carbon. Burning these residues will also give rise to emissions of heavy metals and PCDD/PCDF. Public pressure stemming from concerns over the effects on health of these emissions, together with the nuisance caused by smoke from stubble burning (e.g. reductions in visibility on main roads and motorways sometimes leading to serious accidents), were among the reasons for the ban on crop residue burning in the UK. In addition, there had been considerable losses of hedges, trees and wildlife (http://hansard.millbanksystems.com/commons/1989/nov/30/straw-and-stubble-burning).

Activity data sources are given in Table 5-13. The practice of burning old growth on a heather moor to encourage new growth for grazing (muirburn) means that heather, rough grass, bracken, gorse or vaccinium may be burned on some types of pasture. The burning season is from 1 October to 15 April for uplands, and from 1 November to 31 March for other land. As these are living plants they do not come under the category of 'crop residues', some emissions from these activities are currently captured under memo items, but currently limited by availability of suitable activity data and emission factors. This is an area of the inventory where we are considering potential improvements.

Table 5-13 Sources of activity data used for field burning of agricultural residues

Activity data	Source
Land areas for each type of crop burned	England: https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june Scotland: http://www.scotland.gov.uk/Publications/2012/09/1148/downloads Wales: http://wales.gov.uk/statistics-and-research/survey-agricultural-horticulture/?lang=en and John Bleasdale, Welsh Government Northern Ireland: https://www.daera-ni.gov.uk/news/final-results-june-agricultural-census-2016 and Paul Caskie, DARDNI
Average harvested yields of those crops	England: https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june Scotland: http://www.scotland.gov.uk/Publications/2012/09/1148/downloads Wales: http://wales.gov.uk/statistics-and-research/survey-agricultural-horticulture/?lang=en and John Bleasdale, Welsh Government Northern Ireland: https://www.daera-ni.gov.uk/news/final-results-june-agricultural-census-2016 and Paul Caskie, DARDNI
Ratio of crop residue to harvested crop	A Harvest Index approach was used to estimate the amount of crop residue (Williams, A.G.; Goglio, P. (2017). Crop Residues Management. Appendix F to Crop Sector Methods for the Enhanced GHG Inventory. Document produced under Defra project SCF0102 at Cranfield University. Access by request to adrian.williams@cranfield.ac.uk).
Fraction of the residue burned	These data are not reported in the UK.

5.3. NFR 3B: Emissions from Livestock Housing and Manure Management

NH_3

Agricultural sources are the highest emitting sources in the UK ammonia inventory, contributing 87% of total emissions in 2022. The UK uses a Tier 3 methodology to estimate ammonia emissions from manure management, with calculations for animal subcategories (Table 5-2) using detailed information on farm management practices (Defra, 2023c; DAERA, 2022) and country-specific emission factors for livestock housing (Table 5-14), manure storage (Table 5-15), manure spreading and grazing. For cattle production systems, emissions deriving from outdoor yards (hard standings) used for collecting cattle prior to milking or feeding cattle, are also accounted for. The UK uses a combined, coded (C#) greenhouse gas and ammonia emission model for the Agriculture sector with a high spatial resolution (where data allow) and sectoral detail. The model calculates the flow of total N and total ammoniacal nitrogen (TAN) through the livestock production and manure management system, using a mass-flow approach, as described by Webb and Misselbrook (2004). Ammonia EFs at each management stage are expressed as a percentage of the TAN present within that stage. Other N losses (gaseous as N_2, N_2O and NO and via N leaching) and transformations between organic and inorganic forms of N are also modelled at each stage. All N losses are assumed to occur from the TAN content of the manure at a given management stage. The N content of any added bedding material (0.005 kg of N per kg of bedding material used) is included in the manure N pool as organic N and an immobilisation of 40% of the TAN content of the manure is assumed for deep litter systems on bedding addition. Mineralisation of 10% of the organic N to TAN is assumed to occur during slurry storage. Higher mineralisation rates are applied to manures going to anaerobic digestion, with rates of 70% and 50% for cattle and pig slurry, respectively, and 50% for cattle and pig FYM and all types of poultry manure, to achieve a TAN content of the digestate of approximately 80% at the point of land application. NO-N and N_2-N losses associated with denitrification are estimated as a ratio of the estimated N_2O-N emissions (method described in the UK NIR), with ratios of 0.1 and 3 applied for NO-N and N_2-N, respectively. Leaching losses of N during field storage of FYM are estimated as 3% of the total manure N. Further details are provided in Carswell *et al.* (2023).

A range of abatement practices are included as appropriate throughout the model with associated emission reduction factors (Table 5-8). More detailed information on the derivation of UK-specific EF and mitigation reduction efficiencies for NH_3 are given in Carswell *et al*. (2023).

Table 5-14 Ammonia emission factors for livestock housing (as a % of the total ammoniacal N (TAN) excreted in the house)

Housing system	EF (% of TAN)	Standard error[a]
Cattle		
Cubicle houses - solid floor	27.7	3.85 (14)
Slatted floor housing	27.7 (same value as for solid floor cubicle house assumed)	
Deep litter (FYM)	16.8	1.97 (10)
Calves on deep litter	4.2	1.62 (2)
Pigs		
Dry sows on slats	27.5	6.91 (3)
Dry sows on straw	30.8	9.80 (9)
Farrowing sows on slats	28.6	3.02 (9)
Farrowing sows on straw	33.5	- (1)
Boars on straw	30.9 (same value as dry sows on straw assumed)	
Finishing pigs on slats	29.2	2.73 (18)
Finishing pigs on straw	19.6	5.13 (13)

Housing system	EF (% of TAN)	Standard error[a]
Weaners on slats	12.2	4.29 (4)
Weaners on straw	7.4	- (1)
Poultry		
Layers, deep pit (‘old’ cages, perchery)	35.6	8.14 (7)
Layers, free-range, single tier	20.1	5.85 (3)
Layers, free-range, multi-tier	10.7	3.37 (3)
Layers, ‘old’ cages with belt-cleaning	14.5	4.79 (5)
Layers, colony cages belt-cleaned	8.9	3.15 (3)
Broilers	9.9	0.93 (15)
Turkeys	36.2	30.53 (3)
All other poultry	14.1 (based on broilers and turkeys)	
Sheep, goats, deer and horses	16.8 (same value as for cattle deep litter)	

[a]Numbers in parentheses are the number of studies (or production cycle-years) on which the mean EF is based; “-“ indicates that the standard error was not calculated

Table 5-15 Ammonia emission factors for livestock manure storage (as a % of the total ammoniacal N (TAN) in the store)

Housing system	EF (% of TAN)	Uncertainty
Slurry		**95% CI[a]**
Cattle slurry - above-ground tank (no crust)	10	3.0
Cattle slurry - weeping wall	5	1.5
Cattle slurry - lagoon (no crust)	52	15.6
Cattle slurry - below-ground tank	5	1.5
Solid manure		**Standard error[b]**
Cattle FYM	26.3	8.28 (10)
Pig FYM	31.5	10.33 (6)
Sheep, goat, deer and horse FYM	26.3 (same value as for cattle FYM assumed)	
Layer manure	14.2	2.99 (8)
Broiler litter	9.6	2.69 (11)
Ducks	26.3 (same value as for cattle FYM assumed)	
Other poultry litter	9.6 (same value as for broiler litter assumed)	

[a]Default uncertainty bounds of ±30% for the 95% confidence interval (CI) are assumed; [b]Numbers in parentheses are the number of studies on which the mean EF are based

NO_X

Estimates of NO_X emissions from manure management were made using the same N-flow model (based on Webb and Misselbrook, 2004) as for NH_3 and N_2O. Emissions of NO_X at each manure management stage are assumed to be a factor of 0.1 of the N_2O emissions at each stage, based on the derivation (rather than the absolute values) of the EMEP/EEA Guidebook default values for NO emissions as presented in Table 3.10 (Chapter 3.B. Manure management; EMEP, 2023). The UK uses a combination of IPCC default and country-specific N_2O EF, as described in the UK NIR (Brown et al., 2023).

NMVOC

A Tier 2 approach has been used to estimate NMVOC emissions from manure management, applying Tier 2 EF as given in Tables 3.11 and 3.12 of the EMEP/EEA Guidebook (Chapter 3B Manure management; EMEP, 2023) to the UK-specific livestock numbers. This makes use of UK-specific data on: livestock housing periods for all livestock categories (Table 5-16), and gross energy intake by cattle (Table 5-17; calculated using the mass balance approach described above). UK-specific estimates of volatile solids (VS) excretion are used for sheep, based on diet and production characteristics, and default VS excretion rates are used for other livestock categories as given in Tables 10A.4 - 10A.9 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Chapter 10; IPCC, 2006). Values for Fraction silage and Fraction silage store of 0.50 and 0.25 are assumed as per the EMEP/EEA Guidebook.

Table 5-16 Livestock housing periods (days per year, weighted average across Devolved Administrations, livestock subcategories and production systems)

Livestock category	1990	2000	2005	2010	2020	2021	2022
Dairy cows	211	228	247	277	292	291	291
Dairy heifers	133	132	126	127	129	129	127
Dairy replacements	134	133	145	141	140	139	138
Dairy calves	139	139	139	137	138	137	138
Beef cows	189	189	189	189	189	189	189
Beef heifers	188	188	195	197	197	197	197
Beef steers	192	191	190	190	191	191	190
Beef females for slaughter	195	198	191	191	192	191	191
Cereal-fed beef	353	354	355	355	356	355	355
Bulls for breeding	195	194	187	188	189	189	189
Pigs (all categories)	365	365	365	365	365	365	365
Ewes	29	29	28	28	29	29	29
Rams	5	5	5	5	5	5	5
Lambs	23	22	22	22	22	22	22
Goats	30	30	30	30	30	30	30
Agricultural horses	91	91	91	91	91	91	91
Deer	91	91	91	91	91	91	91
Poultry (all categories)	365	365	365	365	365	365	365

Table 5-17 Gross energy intake by cattle (MJ/head/day)

Livestock category	1990	2000	2005	2010	2015	2020	2021	2022
Dairy cows	211.47	237.89	262.20	272.37	282.44	291.79	293.57	291.56
Other cattle	94.02	102.07	105.21	107.28	107.16	104.04	104.32	103.49

$PM_{2.5}$ and PM_{10}

$PM_{2.5}$ and PM_{10} emission estimates have been calculated using the UK agricultural activity data as described above. The emission estimates are based on assumed proportions of emissions which occur in the livestock building in line with the EMEP/EEA Guidebook. A Tier 1 methodology has been used (as the Guidebook no longer supports a Tier 2 methodology), and full details of the default factors used are given in the EMEP/EEA Guidebook.

The main source of PM emission is buildings housing livestock. These emissions originate mainly from feed, which accounts for 80 to 90 % of total PM emissions from the agriculture sector. Bedding materials such as straw or wood shavings can also give rise to airborne particles. Poultry and pig farms are the main agricultural sources of PM.

5.4. NFR 3D: Emissions from Soils

NH_3

Ammonia emissions from soils derive from direct excretal returns by grazing animals (including outdoor pigs and poultry as well as cattle, sheep, goats, horses and deer), from manure applications to land and from synthetic fertiliser N applications to land.

Emissions from grazing and outdoor livestock are estimated using UK-specific activity data (Defra Farm Practices Survey, Defra, 2023c, the DAERA Survey of Nutrient Management Practices, DAERA, 2022; the June Agricultural Survey, Defra 2023a; the December Agricultural Survey (1993 – 2010), the Cattle Tracing Scheme from the British Cattle Movement Service) on the proportion of livestock associated with grazing and the proportion of the year those livestock spend outdoors (Table 5-18) and UK-specific EF derived from experimental measurements (Table 5-19; more detail given in Carswell *et al*., 2023) .

In this submission the amount of time free-range poultry spend outdoors has been updated following discussions with industry experts and the Environment Agency, who are responsible for issuing permits to regulate intensive poultry farms, with a decrease from 20% to 10% of their time spent outdoors, affecting the entire timeseries (Table 5-18).

Table 5-18 UK livestock on outdoor systems and proportion of the time spent outdoors

Livestock category	% of UK total on outdoor systems					% of year spent outdoors				
	1990	2005	2020	2021	2022	1990	2005	2020	2021	2022
Dairy cows[1]	100	98	94	94	94	42	33	21	22	22
Other cattle[1]	96	95	97	97	97	50	49	50	50	50
Sheep	100	100	100	100	100	93	93	93	93	93
Goats	100	100	100	100	100	92	92	92	92	92
Horses	100	100	100	100	100	75	75	75	75	75
Deer	100	100	100	100	100	75	75	75	75	75
Sows	18	26	38	38	37	100	100	100	100	100
Finishing pigs	0	2	2	2	2	100	100	100	100	100
Weaners	0	13	18	18	18	100	100	100	100	100
Laying hens	15	33	42	42	42	10	10	10	10	10
Broilers	0	5	8	8	7	10	10	10	10	10

[1]Changes to % of year spent outdoors for dairy cows and other cattle across the timeseries, presented here, due to updated approach for calculating % of time spent outdoors, based on model outputs for excreta deposited whilst grazing.

Table 5-19 Ammonia emission factors (as % of TAN excreted) for livestock excreta returns at grazing

Livestock type	EF (% of TAN)	Uncertainty (95% CI)
Cattle	6.0	1.4
Sheep, goats, horses and deer	6.0	1.4
Outdoor pigs	25	7.5
Free-range poultry	35	15

Country-specific EFs are applied to different livestock manure types for emissions following application to land, with the default application method assumed to be broadcast spreading, based on the MANNER-NPK model (Nicholson et al., 2013) taking into account manure type, soil moisture, land use, slurry dry matter content and wind speed. Weighted UK NH_3 EF for each manure type (unmitigated) are given in Table 5-20. Low emission slurry application techniques and rapid soil incorporation are accounted for, with implementation rates and emission reduction factors applied as given in Table 5-9.

Table 5-20 UK weighted average ammonia emission factors (as % of TAN applied) for livestock manure applications to land (surface broadcast)

Livestock manure type	EF (% of TAN)	Uncertainty (95% CI)
Cattle slurry - to grassland May-Jul	52.5	8.4
Cattle slurry - to grassland Aug-Apr	28.2	4.5
Cattle slurry - to arable May-Jul	38.8	6.2
Cattle slurry - to arable Aug-Apr	20.9	3.4
Pig slurry	24.2	6.4
FYM (all types)	68.3	8.7
Poultry manure	52.3	7.1

For emissions from fertiliser applications to agricultural land, the UK follows a Tier 3 approach, using the simple process-based model of Misselbrook *et al*. (2004), modified according to data from the Defra-funded NT26 project. Each fertiliser type is associated with an EF_{max} value, which is then modified according to soil, weather and management factors. Soil placement of N fertiliser is categorised as an abatement measure. The relationships are applied at a 10 x 10 km grid level across the UK using land use (crop type), soil and climate data at that resolution combined with fertiliser application rates specific to crop types, derived from the British Survey of Fertiliser Practice (Farm Business Survey for Northern Ireland) for each year and region. The weighted emission factors for 2022 are given in Table 5-21.

Table 5-21 Ammonia emission factors from different fertiliser types

Fertiliser type	EF_{max} (as % of N applied)	Modifiers†	Weighted UK EF 2022 (NH_3-N emission as % N applied)	Quantity of N applied in 2022 (kt)
Ammonium nitrate	1.8	Rainfall	1.7	377
Ammonium sulphate and diammonium phosphate	45	Soil pH	2.5	14
Calcium ammonium nitrate	1.8	Rainfall	1.7	50
Urea	45	Application rate, rainfall, temperature	10.9	104
Urea ammonium nitrate	23	Application rate, rainfall, temperature	5.8	122
Other N fertiliser types	1.8	Rainfall	1.5	162

†Modifiers (refer to Misselbrook et al., 2004):

Soil pH: if calcareous soil, assume EF as for urea; if non-calcareous, assume EF as for ammonium nitrate
Application rate:
if <=30 kg N ha^{-1}, apply a modifier of 0.62 to EF_{max};
if >=150 kg N ha^{-1}, apply a modifier of 1 to EF_{max};
if between 30 and 150 kg N ha^{-1}, apply a modifier of ((0.0032 x rate) + 0.5238).
Rainfall - a modifier is applied based on the probability of high rainfall (>5mm within a 24h period) within 1, 2, 3, 4 or 5 days following application, with respective modifiers of 0.3, 0.5, 0.7, 0.8 and 0.9 applied to EF_{max}.
Temperature - apply a modifier, with the maximum value constrained to 1, of

$$RF_{temp} = e^{(0.1386 \times (T_{month} - T_{UKannual}))}/2$$

where $T_{UKannual}$ is the mean annual air temperature for the UK

An uncertainty bound to the EF_{max} values of ±0.3 x EF_{max} is suggested based on the measurements reported under the NT26 project.

NO_X

Emissions of NO_X from fertiliser, manure applications, digestate applications and grazing returns are assumed to be a factor of 0.4 and 0.6 of the N_2O emissions estimated for each source on grassland and arable land, respectively, based on the meta-analysis reported by Stehfest and Bouwman (2006). The UK applies country-specific N_2O EF for these emission sources as described in the NIR (Brown et al., 2023).

NMVOC

Emissions of NMVOCs from crops are estimated using the Tier 1 approach as described in the EMEP/EEA Guidebook, using crop-specific EF for wheat, rye, oilseed rape and grassland as given in Table 3.4 of the EMEP/EEA Guidebook (Chapter 3D Crop production and agricultural soils; EMEP, 2023) and the Tier 1 default EF of 0.86 kg NMVOCs ha^{-1} a^{-1} for all other crops.

PM

The UK estimates $PM_{2.5}$ and PM_{10} emissions from agriculture soil using the EMEP/EEA Guidebook EF (Chapter 3D Crop production and agricultural soils; EMEP, 2023); this covers the following stages of crop production: soil cultivation, harvesting, cleaning and drying. The main sources of PM emissions from soil are soil cultivation and crop harvesting, which together account for > 80% of total PM_{10} emissions from tillage land. These emissions originate at the sites where the tractors and other machinery operate and are thought to consist of a mixture of organic fragments from the crop and soil mineral and organic matter. Field operations may also lead to re-suspension of dust already settled (re-entrainment). Emissions of PM are dependent on climatic conditions, and in particular the moisture of the soil and crop surfaces.

Emissions are calculated by multiplying the cultivated area of each crop by an EF and by the number of times the emitting practice is carried out (EMEP, 2023). It is important to note that the PM emissions calculated are the amounts found immediately adjacent to the field operations. A substantial proportion of this emission will normally be deposited within a short distance of the location at which it is generated.

5.5. NFR 3Da2b: Emissions from Sewage Sludge Applied to Soils

The quantities of sewage sludge applied to land for each DA are provided by Ricardo from a combination of Environment Agencies and water companies (Table 5-22). The N content is assumed to be 3.6 % of the dry matter content. According to UKCEH (2017), 95% of sewage sludge is assumed to be applied as sludge cake and 5% as a liquid (based on ADAS, Brian Chambers, pers. comm., December 2006), with no change across the time series.

For the inventory model, the average RB209 TN contents for biosolids were used (four categories: digested cake, thermally dried, lime-stabilised and composted), assuming equal proportions of each, giving 3.7% on a dry matter basis. The TAN content is assumed to be 10% of the TN content (RB209) for sludge cake and 50% (assumed similar to livestock slurry) for liquid sludge.

No data have been collated regarding proportional split in application to grassland and arable land, so a simplistic assumption is made that it is applied approximately in proportion to the ratio of improved grassland area to arable land area at DA level. Based on 2010 land area values (and used across the time series for simplicity) this gives a proportional application to improved grassland of 50, 94, 71 and 93% for England, Wales, Scotland and Northern Ireland, respectively, with the remainder to arable.

The emission factors for the different sludge types were derived from the Manner model (ADAS, Brian Chambers pers. Comm. Dec 2006) as 6.5 and 16.0% of the total N content for sludge cake and liquid sludge, respectively. Expressing these as a percentage of the estimated TAN content therefore gives emission factors of 65 and 32% of applied TAN for sludge cake and liquid sludge, respectively.

Of the liquid sludge, 40% is assumed to be applied by deep injection (ADAS, Brian Chambers, pers. comm., December 2006), with an associated NH_3 emission reduction factor of 90%. It is assumed that none of the surface applied liquid sludge or the sewage sludge cake is rapidly incorporated into the soil.

Table 5-22 Application of sewage sludge to land (t DM/yr)

1990	2000	2005	2010	2015	2020	2021	2022
507,855	590,160	1,216,378	1,281,602	1,422,257	1,555,616	1,555,616	1,555,616

5.6. NFR 3Da2c: Emissions from Other Organic Fertilisers Applied to Soils (Including Compost)

Emissions from land spreading of manure-based and non-manure digestate are reported within other organic fertilisers applied to soils. Quantities of livestock manure being used in anaerobic digestion are estimated from data provided by the NNFCC annual deployment report, a database listing operational, under-construction and proposed anaerobic digestion plant in the UK. Information in the database includes location, capacity, feedstock (inputs) types and feedstock quantities in five categories: manure, crops, crop wastes, food and other. Although co-digestion of two or more feedstocks is commonly practiced, for the purpose of the emission calculations each is treated individually. Quantities of manure feedstock going to anaerobic digestion are given in Table 5-7 and those for non-manure feedstock in Table 5-23.

Table 5-23 Quantity of digestate (kt fresh weight) from anaerobic digestion of non-manure feedstocks 1990-2022; MSW = municipal solid waste

Manure type	1990	2000	2005	2010	2015	2020	2021	2022
Food & organic MSW	0	0	179	775	3,820	5,794	6,098	6,248
Crops and crop wastes	0	0	0	211	3,166	4,747	4,772	4,772
Other	0	0	103	107	658	978	978	978

The NH_3 emission factors for manure-based digestates are assumed to be the same as for the corresponding slurry (for cattle and pig), and for poultry manure digestates the value for pig slurry is applied (based on their having similar characteristics). Literature evidence on the effect of anaerobic digestion on ammonia emissions at land spreading compared with the corresponding livestock slurry is mixed, with differing effects of a lower dry matter content (potentially reducing emissions) but higher pH and TAN content (potentially increasing emissions).

Tomlinson et al. (2019) derived an NH_3 emission factor for surface broadcast digestate (across all types) of 34.7% of the applied N (range 15.4 - 54). Assuming 80% of total N to be in the TAN form, a revised emission factor of 43% of TAN applied (range 19 - 68) is derived for use in the agricultural inventory model.

Tomlinson et al. (2019) report that 67% (+/- 10%) of digestates are assumed to be band spread, 26% (+/- 10%) are assumed to be injected and only 7% (+/- 7%) are assumed to be broadcast, based on limited survey and expert opinion. For the agricultural emissions inventory, it is assumed that by 2018 all digestate was applied using low NH_3 emission application methods with an assumption of a linear increase in implementation from a zero baseline in 2000, and band spread assumed to be trailing hose (not trailing shoe). Ammonia emission reduction efficiencies associated with the different application methods are as for slurry applications, i.e. 30, 60 and 70% reduction for trailing hose, trailing shoe and shallow injection, respectively. It is assumed that none of the digestate applied to arable land is rapidly incorporated into the soil.

5.7. NFR 3F: Field Burning of Agricultural Residues

Emissions are influenced by factors that affect the combustion efficiency of the fire and also by the residue characteristics, including chemical composition and residue mass per unit area. The larger emissions tend to be produced at greater moisture contents (15 to 20 % wet basis).

The method follows that provided in the EMEP/EEA Guidebook (Chapter 3F, Field burning of agricultural wastes). The Tier 1 approach for emissions from field burning of agricultural residues uses the general equation:

$$E_{pollutant} = AR_{residue\_burnt} \cdot EF_{pollutant}$$

$E_{pollutant}$ = emission (E) of pollutant (kg);

$AR_{residue\_burnt}$ = activity rate (AR), mass of residue burnt (kg dry matter);

$EF_{pollutant}$ = emission factor (EF) for pollutant (kg/kg dry matter).

This equation is applied using annual national total amount of residue burnt. The default Tier 1 EFs are given in Tables 3-2, 3-3 and 3-4 of Chapter 3F of the EMEP/EEA Guidebook. Emission factor values for each pollutant are given for wheat and barley; the EF for wheat is also applied to oats and linseed in the UK calculations.

In the UK it is illegal to burn cereal straw and stubble and the residues of oilseed rape, peas and beans in the field, unless:

- It is for education or research purposes;
- It is in compliance with a notice served under the Plant Health (Great Britain) Order 1993 (e.g. to eliminate pests); or
- It is to dispose of broken bales and the remains of straw stacks.

As a result of stubble burning being a largely illegal practice since 1993, it is highly unlikely that a reliable dataset of activity data is available to estimate emissions from 3F. As a result, for years from 1994 onwards, the notation key, 'NE' is used.

5.8. Source Specific QA/QC and Verification

Data tables compiled as input to the inventory model are cross-checked for consistency and errors by a team member other than the compiler. Model output, including emission estimates, activity data and implied emission factors are checked against input data, against default emission factor values and checked for consistency with previous years. Trends in emission per sub-category and activity data are plotted (from 1990 - the present year) and the reasons for any large deviations are scrutinised.

NMVOCs, $PM_{2.5}$ and PM_{10} data are input and compiled by one member of Inventory Agency staff before being checked by another. Trends in sub-categories and overall emissions are plotted from 1990 to the present year and, again, any large deviations from trends are scrutinised.

Following compilation, the inventory spreadsheet and report are checked by the wider compilation team (Rothamsted, ADAS, Cranfield University and UKCEH), then sent to the central Inventory Agency and Defra for further checking prior to inclusion in the UK NAEI.

Informal reviews of key elements of the Agriculture sector GHG and ammonia inventory model were held in November 2018 with an experienced UNECE and UNFCCC Expert Reviewer, and in May 2019 with the German inventory compilation team at the Thünen Institute of Climate-Smart Agriculture in Braunschweig, the findings from which will inform future improvement priorities.

The UK also participates in the EAGER network (European Agricultural Gaseous Emissions Research) which has a strong focus on comparing approaches and parameter values used in the national NH_3 emission inventories of the participating countries (predominantly NW European). Two comparison exercises, conducted to verify the models, gave comparable estimates for slurry-based (Reidy *et al*., 2008) and solid manure based (Reidy *et al*., 2009) livestock production systems.

5.9. Recalculations in Agriculture (NFR 3)

Emissions from agriculture are recalculated when new information on emissions or activity data is obtained that is known to be applicable to previous years.

There were no methodological changes in the 1990-2022 submission. Parameter revisions/updates included:

- Nitrogen fertiliser activity data: small revisions to the reporting of estimates of nitrogen fertiliser type used in Northern Ireland (changed from calendar to agricultural year); replacement of provisional Northern Ireland 2021 fertiliser data with actual data; update of fertiliser rate to grass on dairy farm types in Scotland in 2021 (centred 3-year rolling average used so affects 2020 and 2021);
- Cattle N excretion: small changes associated with updated milk yield and slaughter weight data;
- Manure management activity data – Changes to amount of time spent outside for outdoor poultry from 20/80 (outdoor/indoor) to 10/90; housing EF updated for weaners and finishers on slats; Implementation of 'firm and funded' policy regarding covering of stores and increased use of LESSE in NI; updated time series for quantities of manure being processed by anaerobic digestion.

The impact of these recalculations on the estimate of historic NH_3 emissions (1990 and 2021) is shown in Table 5-24.

Table 5-24 Impact of recalculations (kt NH_3/y)

NFR code and Source	1990 (2023 submission)	1990 (2024 submission	2021 (2023 submission)	2021 (2024 submission)
3B1a	28.41	28.41	35.92	35.94
3B1b	37.33	36.97	33.68	33.77
3B2	2.64	2.64	2.14	2.14
3B3	27.98	27.75	11.55	11.48
3B4gi	9.63	9.66	3.38	3.57
3B4gii	5.62	5.62	2.60	2.61

NFR code and Source	1990 (2023 submission)	1990 (2024 submission	2021 (2023 submission)	2021 (2024 submission)
3B4giii	4.67	4.68	1.77	1.80
3B4giv	2.78	2.81	2.88	2.93
3Da1	59.43	51.63	36.20	37.57
3Da2a	76.24	77.28	59.26	59.21
3Da2b Sewage sludge applied to soils	1.53	1.53	4.67	4.67
3Da2c Other organic fertilisers applied to soils (including compost	0.00	0.00	16.44	16.23
3Da3	23.16	23.14	19.46	18.98

5.10. Planned Improvements in Agriculture (NFR 3)

The UK GHG agricultural inventory has recently undergone a major improvement program resulting in the adoption of a new coded (C#) inventory model with finer spatial, temporal and sectoral resolution in underlying calculations, implementation of a number of country-specific emission factors and improvements to activity data. Further planned improvements are more modest, but include:

- Review UK beef N excretion rates based on recent and ongoing research relating to beef animal energy requirements, feed intake and N retention.
- Continue to review the scientific literature to revise and refine UK-specific emission factors as relevant data arise.

6. NFR 5: Waste

6.1. Classification of Activities and Key Sources

Table 6-1 relates the detailed NAEI source categories for waste used in the inventory to the equivalent NFR source categories. NFR 4 source categories are key sources for one or more pollutants in the UK inventory in 2022:

- 5A is a key source for Hg;
- 5C1bv is a key source for Hg;
- 5C2 is a key source for PCDD/PCDF, $PM_{2.5}$ and PM_{10};
- 5E is a key source category for $PM_{2.5}$and PCDD/PCDF.

Table 6-1 Mapping of NFR Source Categories to NAEI Source Categories: Waste

NFR Category	Pollutant coverage	NAEI Source Category	Source of EFs
5A Biological treatment of waste - Solid waste disposal on land	NMVOCs, NH_3, Benzene, 1,3-butadiene TPM, PM_{10}, $PM_{2.5}$, Hg, PCDD/PCDFs and PCBs	Landfill	UK model and data from UK research (NMVOCs, benzene, 1,3-butadiene), literature factors quoted by UKCEH (NH_3) and IPCC Guidelines (TSP, PM_{10} and $PM_{2.5}$)
		Application to land	PCBs (Dyke et al., 1997) PCDD/PCDFs (HMIP, 1995)
		Waste disposal batteries (Hg)	Wenborn, 1998
		Waste disposal - electrical equipment (Hg)	Wenborn, 1998
		Waste disposal - lighting fluorescent tubes (Hg)	Wenborn, 1998
		Waste disposal - measurement and control equipment (Hg)	Wenborn, 1998
5B1 Biological treatment of waste - Composting	NH_3	Composting (NH_3)	Literature factors (UKCEH)
5B2 Biological treatment of waste - Anaerobic digestion at biogas facilities	NH_3	Process emissions from Anaerobic Digestion (NH_3)	Literature factors (Bell *et al.*, 2016; Cuhls *et al.*, 2010; Cumby *et al.*, 2005 quoted by UKCEH)
5C1a Municipal waste incineration (d)	All CLRTAP pollutants (except Se, Indeno(1,2,3-cd) pyrene)	Incineration	Operator reporting to regulators for PRTR and literature factors (EMEP/EEA, HMIP, US EPA)
5C1bi Industrial waste incineration (d)		Incineration - chemical waste	
		Other industrial combustion	
		Regeneration of activated carbon	

NFR Category	Pollutant coverage	NAEI Source Category	Source of EFs
5C1bii Hazardous waste incineration (d)		Incineration - hazardous waste	
5C1biii Clinical waste incineration (d)		Incineration - clinical waste	
5C1biv Sewage sludge incineration (d)		Incineration - sewage sludge	
5C1bv Cremation	NO_X, NMVOCs, SO_X, Particulate Matter, CO, Hg, PCDD/PCDFs and benzo[a]pyrene	Crematoria	UK research (CAMEO) and literature factors (EMEP/EEA, HMIP)
		Foot and mouth pyres	
		Incineration - animal carcases	
5C2 Open burning of waste	NO_X, NMVOCs, Particulate Matter, CO, POPs (except HCB)	Other industrial combustion	UK research and literature sources (Stewart *et al.*, Passant)
		Small-scale waste burning	
		Agricultural waste burning	
5D1 Domestic wastewater handling	NMVOCs	Sewage sludge decomposition	UK industry research
5D2 Industrial wastewater handling		Industrial wastewater treatment	
5E Other waste	PCDD/PCDFs and PCBs	Regeneration of activated carbon	Literature factors (Wichmann, UKCEH, Dyke *et al., 1997*)
		RDF manufacture (PCB)	
	NO_X, NMVOCs, Particulate Matter, CO, and POPs (except HCB)	Accidental fires - dwellings	US EPA Factors alongside UK Factors supported by the UK Toxic Organic MicroPollutant (TOMPs) ambient monitoring data
		Accidental fires - other buildings	
		Accidental fires - vehicles	
	CO, Particulate Matter, PAHs, PCDD/PCDFs, PCBs	Bonfire night	UK Factors

6.2. Activity Statistics

Accredited Official Statistics on waste sector activities are limited in coverage and detail across the time series.

However, over recent years, the completeness and accuracy has improved and the UK has higher quality data now than it did in the earlier parts of the time series. There are some datasets that are of lower quality than others. For example, the number of accidental fires will likely always be uncertain.

6.3. NFR 5A: Landfill

6.3.1. Waste to Landfill

Waste data reporting for later years are more comprehensive and the Inventory Agency obtains annual statistics on landfill waste which extend back to 1945. Whilst earlier data is much less reliable, the nature of landfill processes means that the influence of these uncertainties on calculated emissions in the latest year is minimal.

The UK approach to calculating emissions from landfills uses a methodology based on national data for waste quantities, composition, properties and disposal practices over several decades. Records of individual waste consignments treated and disposed, together with European Waste Category (EWC) codes are compiled by the regulatory authorities in the Devolved Administrations and as such are considered to be of good quality:

- Data on waste consignments landfilled in England for the period 2006 to 2022 are published by the Environment Agency;
- Data on waste consignments landfilled in Scotland for the period 2005 to 2022 are published by the Scottish Environmental Protection Agency;
- Data on waste consignments landfilled in Wales for the period 2006 to 2022 are published by Natural Resources Wales;
- Data on waste consignments landfilled in Northern Ireland for the period 2008 to 2022 were provided by the Northern Ireland Environment Agency.

The composition of waste landfilled was evaluated by allocating each EWC code to one of the categories used in the UK model (‘Municipal’ or ‘Commercial and Industrial’ waste category), as set out in Table 6-2.

Table 6-2 Waste categories used in the UK landfill model

Municipal waste category	Commercial & Industrial waste category
Household & similar paper	Non-inert Fines
Household & similar card	Household inert materials
Nappies	Commercial/industrial paper and card
Household & similar textiles and footwear	Commercial/industrial food; abattoir waste
Miscellaneous combustible	Food effluent/biodegradable industrial sludges
Wood	Construction & Demolition waste
Food	Sewage sludge
Garden	Commercial textiles / Carpet and Underlay
Soil and other organic	Commercial sanitary
Furniture	Commercial inert materials
Mattresses	

For two EWC codes, it was not possible to allocate an individual category to the waste materials. These EWC codes are 19.12.12 (residues from waste sorting) and 20.03.01 (mixed municipal waste). Wastes with these codes were allocated in accordance with the findings of a survey carried out on behalf of Defra (Resource Futures, 2012), as set out in Table 6-3.

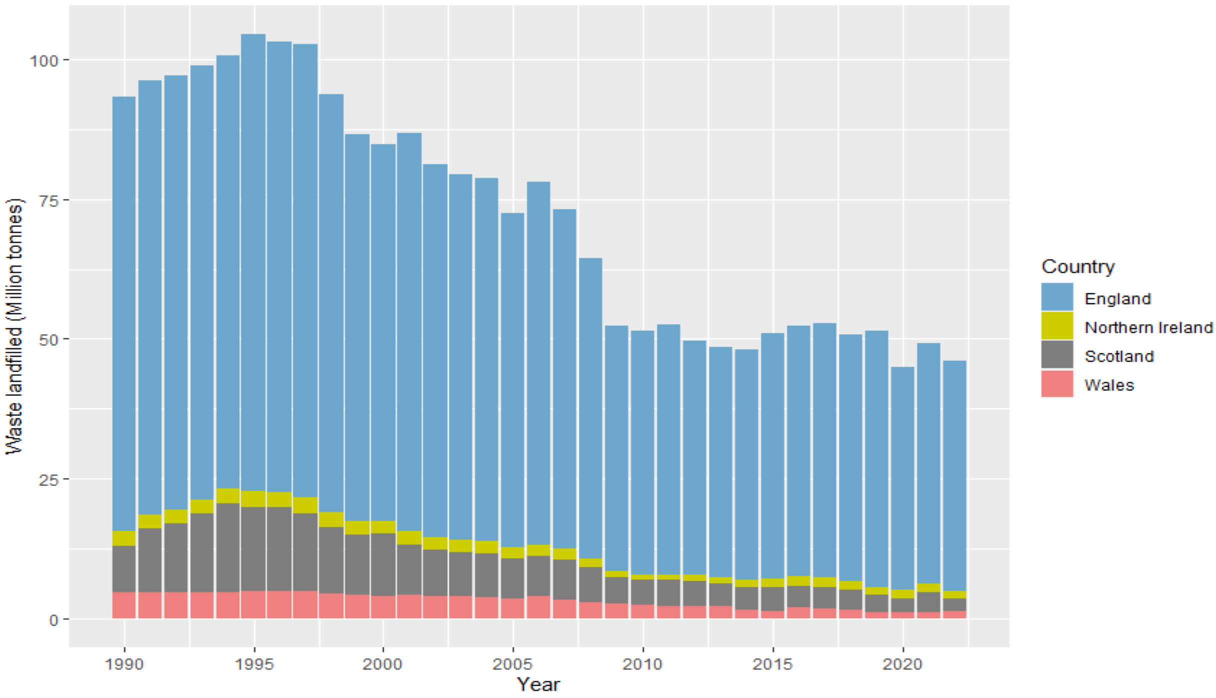
Table 6-3 Composition of waste sorting residues and mixed municipal waste

Material	EWC code 19.12.12 (residues from waste sorting)	EWC code 20.03.01 (mixed municipal waste)
Paper	10.3%	10.6%
Card	9.1%	7.7%
Plastic film	9.4%	8.4%
Dense plastics	13.2%	9.6%
Sanitary waste	1.3%	3.1%
Wood	10.0%	5.3%
Textiles and shoes	5.9%	5.6%
Glass	1.3%	3.0%
Food waste	8.2%	21.3%
Garden waste	1.8%	3.5%
Other organic	1.3%	2.1%
Metals	3.2%	3.7%
WEEE	1.4%	1.5%
Haz waste and batteries	1.1%	0.9%
Carpet, underlay & furniture	7.0%	5.0%
Other combustibles	2.7%	1.4%
Bricks, plaster and soil	7.9%	4.1%
Other non-combustible	1.7%	1.5%
Fines <10mm	3.3%	1.8%
Total	100%	100%

For years prior to 2005-2008, the quantities of waste landfilled and its composition were taken from a report compiled and peer-reviewed on behalf of the UK Government (Eunomia, 2011).

In recent years, improvements in waste management in the UK have resulted in a reduction in the quantity of waste landfilled and changes to the composition of waste as the recovery of recyclable materials has improved. This has been driven by a combination of measures, including setting recycling targets for local authorities; uptake of recycling behaviours; investment in recycling infrastructure and services; and increasing the cost of landfill via the landfill tax. The quantities of waste landfilled in the UK between 1990 and 2022 are shown in Figure 6-1.

Figure 6-1 Quantities of waste landfilled in the UK, 1990 to 2022



The quantity of waste landfilled in the UK peaked in 1995 and steadily reduced to less than half of this quantity by 2010. Quantities of waste landfilled in the UK have been relatively static since 2009. Since 1995, the proportion of biodegradable materials in residual waste landfilled, such as paper, card and food waste, has continued to decline. Like many other areas of the NAEI, this sector experienced a dip in 2020 as a result of the COVID-19 pandemic.

6.3.2. Estimating Emissions from Landfill

Landfill emission estimates of methane are based on a UK first-order decay model (MELMod) that has been developed by the Inventory Agency to estimate the methane emissions from UK landfills. The landfill model uses activity data comprising:

- Annual data on waste consignments disposed to UK landfills since 2005 - 2008, including information on their composition, as described in Section 6.3.1 to enable separate factors to be applied to reflect the degradable organic content of the different waste streams.
- Historical data on waste disposed to UK landfills and its composition prior to 2005 - 2008, as described in Section 6.3.1.

The model generates estimates of the methane production from landfill waste. Landfill operators are required to assess and, where practicable, collect and burn landfill gas generated at operational and recently closed landfill sites. However, it is not practical to do this at every landfill site, and landfill gas collection is never completely effective. Methane which is not collected in this way is assumed to be released via the landfill surface to the atmosphere. Some oxidation of methane takes place as the methane passes through the landfill surface layers. Further calculations are therefore carried out to estimate:

- the quantity of methane captured and combusted in landfill gas engines. This is based on Accredited Official Statistics for electricity generation from the combustion of landfill gas, combined with the assumed efficiency of landfill gas engines. The results of this calculation are considered to be of good quality;

- the quantity of methane captured and flared. This is based on individual site reports from operators. In circumstances where site-specific data are not available, no account is taken of landfill methane flaring. Hence, the calculation of methane flaring is conservative, in that the quantity of methane captured and flared is likely to be underestimated. Consequently, this will tend to over-estimate the quantity of methane released to the atmosphere;
- the proportion of remaining methane oxidised in the surface layers of the landfill. It is assumed that 10% of the remaining methane is oxidised in the landfill surface, following the recommended approach for greenhouse gas inventories. Studies carried out at a small number of UK landfills are consistent with this figure. The results of this calculation are considered to be of reasonable quality.

Combining the total methane generation estimate with the methane captured and oxidised enables an estimate to be derived for the total quantity of methane emitted to atmosphere annually from UK landfills.

Using the model outputs, estimates of ammonia, NMVOCs, benzene, 1,3-butadiene, TSP, PM_{10} and $PM_{2.5}$ are calculated by assuming a fixed ratio of the other released substances to methane in landfill gas emissions which is assumed to be constant across the time series for all substances. The factors used in this calculation were taken from the EMEP/EEA Guidebook supplemented by published data relevant to the UK.[87,88] The factors used are as follows:

Table 6-4 Emission factors for landfill emissions

Substance	Value	Units	Reference
NMVOC	$3.6x10^{-3}$	t NMVOCs / t CH_4	EMEP/EEA Guidebook, based on Broomfield *et al*., (2010)
benzene	$5.3x10^{-5}$	t benzene / t CH_4	Based on Parker *et al*., (2005)
1,3-butadiene	$5.8x10^{-8}$	t benzene / t CH_4	Based on Parker *et al*., (2005)
TSP	$4.6x10^{-4}$	kg/Mg waste landfilled	Inventory guidelines (EMEP/EEA) quoting AP-42 (US EPA, 2009)
PM_{10}	$2.2x10^{-4}$	kg/Mg waste landfilled	Inventory guidelines (EMEP/EEA) quoting AP-42 (US EPA, 2009)
$PM_{2.5}$	$3.3x10^{-5}$	kg/Mg waste landfilled	Inventory guidelines (EMEP/EEA) quoting AP-42 (US EPA, 2009)

Ammonia emissions are estimated using emission factors provided by the United Kingdom Centre of Ecology and Hydrology (UKCEH, 2023). Following an in-depth methodological review conducted for the 2018 inventory (Tomlinson *et al*., 2019), landfilled materials data are now (2018 onwards) obtained from Waste Data Interrogator (WDI) systems, which are (broadly) a collation of individual data returns from most waste processing sites in the UK (a small percentage of sites with waste exemptions are not required to file returns). Data from the WDI releases for England and Wales, statistical releases for Scotland (derived from a WDI-style database) and data extracted from a WDI system in Northern Ireland are aggregated into six waste categories, each of which is assigned a nitrogen content range, via the European Waste Catalogue coding system (EWC), to produce an estimate of the quantity of nitrogen going to each landfill site. This method also extracts the large quantities of soils and

[87] Broomfield M, Davies J, Furmston P, Levy L, Pollard SJT, Smith R (2010). "*Exposure Assessment of Landfill Sites Volume 1: Main report.*" Environment Agency, Bristol. Report: P1-396/R.

[88] Parker T, Hillier J, Kelly S, and O'Leary S (2005). "*Quantification of trace components in landfill gas,*" Environment Agency, Bristol.

construction wastes that go to landfill, but these materials are considered to be inert for the purposes of emissions estimates. This method also changes the focus of emissions to an aerobic approach similar to composting; materials at the uncovered open landfill face are subject to volatilisation in contact with air. The assumption is made that all inputs are exposed to air at some point in their lifetime and the emission factor for this is 0.1 - 1% of total nitrogen volatilised as NH_3 (Brandstätter *et al*., 2015 and He *et al*., 2011). The 2022 best estimate emission factor is 0.04 kg NH_3-N/t of landfilled materials.

Emissions of mercury from waste disposal of batteries, electrical equipment, fluorescent lighting tubes and monitoring and control equipment, such as thermometers, are calculated based on emission factors given by Atkins (Atkins 1997) and, from 1996 onwards, derived from UK research (Wenborn *et al.*, 1998). The report by Atkins proposed a consumption rate for mercury in 1990 as follows:

- Batteries 0.22 g per person per annum;
- Measurement and control equipment: 0.32 g per person per annum;
- Fluorescent lighting: 0.04 g per person per annum;
- Electrical equipment: 0.11 g per person per annum.

The trends in consumption between 1990 and 1995, suggested in the report, are used to generate estimates for consumption in later years. A conservative assumption that all the mercury consumption has the potential to be emitted the same year is used to estimate emissions. The methodology firstly considers how much of the mercury is likely to be released due to accidental breakages and then how much of the rest is contained in products that are disposed of, either to incinerators or landfills or in metallic wastes that are processed at electric arc furnaces to recover steel. Estimates for waste products sent for incineration are already included in sectors 1A1a and 5C1, while estimates for metal processed at electric arc steelworks are reported in sector 2C1. Therefore, only emissions from landfill sites and from 'accidental breaking' of mercury-containing products are included in sector 5A. All mercury is assumed emitted in the case of products that are accidentally broken, whereas only 5% of the mercury is assumed to be released from products that are sent to landfill. Since most waste containing mercury in the UK is landfilled, it is assumed that a notable proportion of the mercury used in products is stored indefinitely in landfill sites. The per capita emission rates for the four types of products have decreased over time on the assumption that, based on the trends for 1990-1995 given in WS Atkins' report, there is a declining use of mercury-containing products, as set out in the requirements of the Waste Batteries and Accumulators Regulations[89]. No changes in disposal routes or abatement of those disposal processes have been expected to happen, although in the case of disposal routes, this is probably a worst-case assumption (since incineration rates have increased substantially since the Atkins report was published).

Separate emission factors for PCDD/F from sector 5A are applied for methane/landfill gas escaping directly from landfills and methane/landfill gas flared from landfill: these are 1.1×10^{-3} g I-TEQ/kt and 7.0×10^{-4} g I-TEQ/kt, respectively. These emission factors were originally proposed in a study commissioned by one of the UK regulators (HMIP) in 1995. The emission factor for PCB from landfill (8.0×10^{-4} kg/kt) is taken from a UK literature source (Dyke *et al.*, 1997).

6.4. NFR 5B: Composting and Anaerobic Digestion

Emissions of ammonia from composting and anaerobic digestion are based on Accredited Official Statistics for these activities and research conducted by the United Kingdom Centre of Ecology and Hydrology.

[89] https://www.gov.uk/guidance/batteries

The basic information and evolution in the inventoried period on the data of the composting activity is shown in Table 6-5. Activity data refer to net inflows to the composting process and are expressed in megagrams (Mg).

Table 6-5 Inputs to composting processes (Amounts in Mg)

Year	Non-household Waste	Household Waste
1990	0	1,372,646
1995	1,145,181	1,425,861
2000	2,290,361	1,479,141
2005	3,435,542	1,528,918
2010	4,896,811	1,590,943
2015	5,921,077	1,639,811
2018	6,347,498	1,671,946
2019	5,510,012	1,686,982
2020	5,487,268	1,691,165
2021	5,821,476	1,704,868
2022	4,396,227	1,712,386

NH_3 emissions associated with composting exhibit an upward trend throughout the inventory period, which levelled off in recent years and underwent a decrease from 2018 to 2022. The notable increase in NH_3 emissions for sector 5B1 since 1997 is determined by the progressive increase in the amount of non-household composted waste.

Due to limited scientific information regarding emissions or emission factors from home-based (i.e. at private dwellings) composting techniques, the EF for open systems treating green waste at permitted composting facilities is used for household composting. The best estimate EF of 0.34 kg NH_3-N/t of fresh matter composted (range 0.14 - 0.55), which remains unchanged and constant across the whole time series. Activity data are based on the methodology in Eades *et al.* (2020) where quantities of garden compost generated (with a rural-urban split) was extrapolated to the UK scale using household data (ONS 2023).

The emission factor for non-household composting is based on multiple factors such as nitrogen content, types of waste and type of composting facility. This means the emission factor varies between years based on waste flows, number of inputs and the compost facilities themselves. Following a methodological review conducted for the 2018 inventory (Tomlinson *et al*., 2019), activity data for permitted composting are divided into 'green', the organic fraction of municipal solid waste ('OFMSW'), and 'other' inputs (water treatment sludge, cardboard etc.), which are further assigned to open (e.g. windrow) and closed systems (e.g. in-vessel). As the composting method is an important variable in determining emissions, all six combinations of activity data and compost system have a separate EF (Tomlinson *et al*., 2019). Since 'other' waste is assumed to be closer in nitrogen content to green waste than OFMSW, it is therefore assigned the same EFs as green waste. Amlinger *et al*. (2008) noted that using the estimated dry matter (DM) content of compost inputs to calculate emissions can increase uncertainty when using it alongside already uncertain EFs. Therefore, the new methodology uses EFs that consider kg NH_3-N emissions as a ratio of the initial fresh input (not DM). This is a shift away from assumed fractions of green and kitchen wastes used to apportion the quantity that was sent to composting facilities in 2017 (UKCEH, 2018).

In the 2022 inventory, the overall EF for composting at permitted sites is 0.62 kg NH_3-N/t input fresh weight (range 0.51 - 0.73), a ~1% increase from 2021. Table 6-6 lists the implied emission factors for recent years (note - EFs are expressed as ammonia concentration as nitrogen (NH_3-N) and not ammonia (NH_3)).

Table 6-6 NH_3 **implied emission factors for non-household composting in recent years**

Year	Implied Emission Factor	EF Units
2022	0.618	kg NH_3-N/t fresh weight
2021	0.613	kg NH_3-N/t fresh weight
2020	0.620	kg NH_3-N/t fresh weight
2019	0.595	kg NH_3-N/t fresh weight
2018	0.624	kg NH_3-N/t fresh weight
2017	0.637	kg NH_3-N/t fresh weight
2016	0.624	kg NH_3-N/t fresh weight
2015	0.637	kg NH_3-N/t fresh weight
2010	0.587	kg NH_3-N/t fresh weight
2005	0.572	kg NH_3-N/t fresh weight

NH_3 emissions associated with anaerobic digestion (AnD) are reported in the following NFR categories:

- Process (fugitive and storage) emissions from AnD are reported in '5B2 Biological treatment of waste – Anaerobic digestion at biogas facilities'
- Emissions from land spreading of digestates, other than manure digestates, are reported in 3Da2c, "Other organic fertilisers applied to soils (including compost)"

Emission factors calculated for fugitive and storage emissions at AnD plant are based on a thorough review of relevant literature (Bell *et al*., 2016 & Cuhls *et al*., 2010).

For the storage of digestates, consideration is given to possible separation of digestates into liquids and fibrous solids and whether the site is PAS110 accredited. Separation, when used, and the removal of solids from the 'whole' digestate product, producing 'liquid' and 'fibre' fractions. The liquid fraction must be stored in a tank (covered or not) while the fibrous fractions may be stored in heaps similar to composted materials. The PAS110 accreditation scheme carries a recommendation to cover all digestate products to comply with the scheme and so the split of materials to PAS110 accredited sites is taken into consideration. The EF for storage of digestates is a combination of

i. ~25% (+/- 10%) of digestates are produced by PAS110 registered AnD plant;

ii. ~70% (+/- 10%) of materials remain as whole digestate, ~22% (+/- 10%) are in liquid form, with the remaining ~8% (+/- 8%) as fibre solids;

iii. 100% of PAS110 digestates (whole, liquid or fibre) are under covered storage, 70% of non-PAS110 whole/liquid digestates under covered storage and 50% of non-PAS110 fibre digestates under covered storage.

Any covered storage is assumed to have an effective membrane for emission mitigation. As there are no data to inform otherwise, the emission factor is set to be the same as that for storage of inputs (combination of expert opinion, personal communication and surveys (UKCEH 2022)). The emission factor for the storage of digestates is 0.09 kg NH_3-N/t fresh weight digestates, and is dependent on the feedstock composition (i.e. feedstock with a higher nitrogen content per tonne will result in a higher EF per tonne feedstock).

The best estimate emission factor for fugitive and storage emissions at UK AnD plant (weighted average) is 0.08 kg NH_3-N/ t fresh weight feedstocks (range 0.04 – 0.14 kg/t).

The amounts of materials treated in UK AnD plant are considerable, and this source has been growing rapidly from 2008, though has undergone slower growth since 2017 than in preceding years. New NH_3 emission sources from anaerobic digestion are evaluated annually. The comprehensive database for AnD sites still contains 621 plants operational, as it did in 2021, that are not dedicated to brewery or vegetable washing wastes (NNFCC, 2022). Activity data for this compilation cycle was extrapolated from previous years. It should be noted that as a new AnD database is released every year, the historic information for all plants is updated (e.g. opening year and feedstock quantity). This will inherently make previous estimates for inputs out of date as the information attached to a site becomes more reliable, having a stronger effect on more recent years. The reported inputs to each site in NNFCC provide an accurate estimate of the actual tonnes inputted by feedstock category, compared with previously available datasets, which utilised the capacity of the site as the presumed input (in the absence of quantitative input data). Furthermore, input materials to each site are reported as quantities for 'manures', 'crops', 'food' and 'other' for each site, thereby reducing the uncertainty when estimating category proportions. In the NNFCC dataset, multiple manure types may still be listed in the inputs, with an aggregate 'manure' input total. This allows input materials, and therefore resulting digestates, to be characterised , and also enables more accurate estimation of manure-based digestates.

These plants are estimated to have processed 15,335 kt of materials (fresh weight) during 2022, an increase of approximately 2% from 2021, using the latest database. Approximately 82% of input materials to AnD were from non-manure sources, such as crops and food wastes, very similar to that in 2021. As in previous years, large volumes of materials (approx. 1,856 kt at 30 sites) were then removed from the non-farm-based input stream after it was established: they did not enter the AnD process as characterised in this inventory. These materials were predominantly distillery and brewery wastes (and some vegetable washings) and were not included in emissions estimates as they are likely to be processed in other ways. These distillery and brewery wastes have also been removed from the historic timeline for AnD. For estimating fugitive and storage emissions, all materials that are processed by AnD are included in the calculations - aside from manure and slurries - whereas for estimating land spreading emissions for digestate, all products were excluded, to avoid double-counting with the agricultural emissions inventory.

6.5. NFR 5C: Incineration of Waste

The quantities of waste-derived fuels used for electricity and heat generation are reported in DUKES (DESNZ, 2023a). These data are useful for the derivation of emission inventory estimates for incinerators burning municipal solid waste (MSW), since energy has been recovered at all sites burning MSW since 1997 and for at least some sites back to 1990. However, it is also necessary to estimate how much MSW was incinerated without energy recovery, since this is not reported in DUKES.

The distinction between incineration of MSW with energy recovery and incineration without energy recovery is important because emissions from the former are reported in NFR 1A1a, whereas emissions from the latter are reported in 5C1a. However, the same methods are used for estimating emissions: emission factors are derived that cover all MSW incineration and these are then used for reporting of emissions in both 1A1a and 5C1a. In the NAEI, MSW incineration in the 1990-1996 period is estimated to have been 2.9 Mt/annum, although this is almost certainly conservative for at least some of that period. The Royal Commission on Environmental Pollution (RCEP, 1993) estimated that 'about 2.5 million tonnes' of MSW were incinerated at that time and presented a list of operational incinerators with an aggregate capacity of about 2.7 Mt. Many smaller sites closed between 1993 and 1997 because it was not considered viable to upgrade them to required environmental standards, so it is therefore likely that the quantity of waste incinerated fell after 1993. In the absence of more reliable figures for the 1990-1996 period, the figure of 2.9 Mt is retained. By 1997, all remaining incinerators recovered energy, and DUKES figures for that year can be converted into an estimate of

2.1 Mt of waste incinerated. Since 1997, the use of MSW to generate energy has increased with many new plants being built, but emissions from all of these plants are reported in 1A1a.

All UK facilities that incinerate MSW, chemical waste, or sewage sludge are regulated under IED or under the Urban Waste Water Treatment Directive. In addition, we believe that almost all clinical and other waste incineration is also carried out at regulated plants in this way. A number of very small incinerators may be regulated by local authorities, but tonnages of waste and emissions are likely to be minimal. All operators of the IED-regulated sites are required to report annual estimates of emissions to their respective regulator, however data on the quantity of waste incinerated by LA incinerators is limited. Wherever possible, these emissions are used directly in the national inventory, however the scarcity of reported data for some pollutants makes this approach impossible - typically for the smaller incinerators burning clinical waste and sewage sludge. In these cases, literature emission factors are used. Even in cases where reported data are used, some incinerators are likely to report emissions as below reporting thresholds, and so the NAEI generates estimates for the emissions at those sites based on previous plant performance, activity data for waste burned and/or emission factors. This gap-filling increases the uncertainty of the estimates. Emissions for the early part of the time series (prior to operator reporting which began in 1998) are generated using literature emission factors which reflect the lower level of emission control in that period.

Emissions from clinical waste incinerators are estimated from a combination of data reported to the Pollution Inventory (EA, 2023a), supplemented using literature-based emission factors, largely taken from the EMEP/EEA Guidebook. The quantity of waste burnt annually is also estimated, these estimates being based on information provided in the sources shown in Table 6-7:

Table 6-7 Sources of data on waste burnt in clinical waste incinerators*

Years	Source
1991	RCEP, 1993
1997	Wenborn *et al.*, 1998
2002	Entec, 2003
2006-2022	Environment Agency, waste disposal data for individual sites in England (2006 – 2022) and Wales (2006-2022)
2018-2022	Natural Resources Wales, waste disposal data for individual sites in Wales
2004-2013 2015-2022	Scottish Environment Protection Agency, estimates of total clinical waste incinerated in Scotland

* No operational clinical waste incinerator was identified in Northern Ireland.

Interpolation between the various estimates is used to gap-fill the activity data time series. It should be noted that emission estimates for clinical waste incineration are based on a Tier 3 type approach. Emissions at many sites show large inter-annual variation due to changes in how often incinerators are used, the composition of the waste incinerated and the efficiency of the incinerator.

The majority of emissions from chemical waste incinerators are estimated based on analysis of data reported to the Pollution Inventory (EA, 2023a). Benzene is based on emission factors from US EPA 42 profiles, whilst PAH is derived from Parma *et al*. (1995) atmospheric guidelines for POPs published by External Affairs Canada. The activity data is derived partially from data on waste burnt at operational sites. Waste tonnages burnt at the largest individual chemical waste incinerators for the period 2006 - 2022 have been obtained from the Environment Agency, but the quantity of chemical waste burnt at smaller plant must then be estimated by the NAEI, based on the capacity of those sites. For the earlier part of the time series, the estimates of waste burnt are shown in Table 6-8:

Table 6-8 Sources of data and quantities of waste burnt in chemical waste incinerators

Years	Source
1993	290,000 tonnes (HMIP, 1995)
2002	284,000 tonnes (Entec, 2003)

The HMIP figure is assumed to also be applicable for 1990-1992, and data for the years 1994-2001 is then generated by interpolating between the HMIP and Entec figures. Activity data for the period 2003-2005 is generated by interpolating between the Entec figure of 284,000 tonnes and the NAEI estimate for 2006 of 177,000 tonnes.

Emissions from sewage sludge incinerators are estimated from a combination of data reported to the Pollution Inventory (PI) (EA, 2023a) and Scottish Pollutant Release Inventory (SPRI) (SEPA, 2023a), supplemented with the use of literature-based emission factors where the PRTR-reported data are incomplete. Emissions of NO_X are estimated using PI and SPRI data while emissions of all other pollutants are estimated from literature-based emission factors, taken from the EMEP/EEA Guidebook. The quantity of waste burnt annually is estimated based on annual activity data from environmental regulators (EA, 2023b and SEPA, 2023b) or plant capacity information where annual activity data are not available. The quantity of waste burnt annually in previous years is estimated using data from various sources as shown in Table 6-9:

Table 6-9 Sources of data on sewage sludge burnt in sewage sludge incinerators*

Years	Source
1990	RCEP, 1993
1991-1998	Digest of Environmental Statistics (Defra, 2004)
2006-2022	Environment Agency, waste disposal data for individual sites in England and Wales (Wales up to and including 2017)
2009	NI Water, capacity information of a sewage sludge incinerator in Belfast[90]
2018-2022	Natural Resources Wales, waste disposal data for individual sites in Wales
2013, 2015, 2017 - 2022	Scottish Environment Protection Agency, estimate of total sewage sludge incinerated in Scotland

Interpolation between the various estimates is used to fill the gaps in the activity data time series.

Animal carcass incinerators - Emission estimates for animal carcass incinerators are taken directly from a Defra-funded study (AEA Technology, 2002) and are based on emissions monitoring carried out at a cross section of incineration plant. No activity data are available and so the emission estimates given in this report are assumed to apply for all years. The NAEI has also reviewed data on the small proportion of animal carcass incinerators that are covered in the PI (EA, 2023a); there is insufficient new data to warrant a revision to the estimates from the 2002 report, without more detailed industry-focussed research and consultation.

Crematoria - Emissions are predominantly based on literature-based emission factors, expressed as emissions per corpse (US EPA, 2009). Data on the annual number of cremations is available from The Cremation Society of Great Britain (2022). Mercury emission estimates are based on calculations using UK population (ONS, 2023f) and dental record data (2009 Dental Health Survey) produced by the UK National Health Service (NHS). The method to estimate mercury emission factors take account of the impacts of the Crematoria Abatement of Mercury Emissions Organisation (CAMEO) scheme, through which a rolling programme of mercury emissions abatement at UK crematoria has been implemented to achieve industry-wide targets. Emission factors for PCDD/PCDF are also calculated depending on the level of abatement within UK crematoria (CAMEO, 2016).

[90] https://www.niwater.com/belfast-sludge-incinerators/

Municipal waste incinerators - Emissions from municipal waste incinerators in the UK have been zero since 1997, as new regulations in 1996, such as the EU Landfill Directive, required that existing plant were closed down if they did not meet new emission limits. Emissions from plant operated using incineration with energy recovery, i.e. generating heat or power, are reported within NFR 1A1a. There were still emissions from Gibraltar until 2000. Estimates of emissions from MSW incineration up to 1996 are reported under NFR 5C1a and are generally based on Pollution Inventory data for the period 1993-1997 with use of literature factors for the period 1990-1992 to reflect the higher emissions likely from UK MSW incinerators in that period, before plant shutdowns and upgrades occurred in the 1993-1995 period. The inventory uses the emissions data that the operators submit for inclusion in the PI (in England and Wales) and the Scottish Pollutant Release Inventory (for the one or two sites in Scotland). The data that these operators submit can be based on measurements, calculations etc. and it is assumed that the data available to the process operator on site-specific factors, such as abatement and quantities and types of waste burnt, are the most appropriate. In addition, the operator would need to monitor emissions of most pollutants on at least a periodic basis and some continuously, so they would also have site-specific data on emission rates, considered better than default emission factors.

Table 6-10 shows the activities as inputs into the incineration waste process. The NAEI does not have activity data for the incineration of animal carcasses: instead, emission estimates are taken directly from AEA Technology (2002). In the case of incineration of clinical, chemical and municipal wastes, the quantity of waste incinerated has decreased over time due to the closure of many incineration sites. For sewage sludge incineration, quantities increased substantially between 1995 and 2000 as a result of the construction of a number of sewage sludge incinerators, for example those at Beckton and Crossness sewage treatment works started operation in 1998. In recent years, a number of sewage sludge incinerators have ceased operation and quantities of sewage sludge incinerated have fallen again.

Table 6-10 Inputs into waste incineration processes in the UK

Year	Clinical waste (Mt)	Chemical waste (Mt)	Sewage sludge (Mt)	Crematoria (Million Cremations)	Municipal waste(Mt)
1990	0.35	0.29	0.08	0.44	2.1
1995	0.27	0.29	0.08	0.45	1
2000	0.25	0.29	0.19	0.44	0
2005	0.14	0.21	0.22	0.42	0
2010	0.11	0.15	0.23	0.41	0
2015	0.09	0.16	0.17	0.46	0
2019	0.10	0.14	0.09	0.47	0
2020	0.09	0.15	0.07	0.54	0
2021	0.08	0.13	0.07	0.53	0
2022	0.08	0.13	0.08	0.53	0

6.5.1. NFR 5C2: Open Burning of Waste

Emission estimates in the NAEI from small-scale waste burning comprise emissions from combustion of agricultural, commercial and domestic waste (including garden bonfires and domestic grates), and emissions from disposal by burning of untreated and treated waste wood (i.e. treated with fungicides and used in construction). For all sources, the activity data are not routinely collected as annual statistics across the time series. Instead, the NAEI generates the time series estimates of activity based on available survey data and published statistics, together with proxy data to extrapolate across years where data are missing. The activity estimates incorporate results from a national waste burning habits survey of a thousand UK households completed on behalf of Defra in 2010 (Whiting *et al*., 2011) and from the UK domestic burning survey (Defra, 2020) which looked into households' burning behaviour. The UK methodology includes:

(a) statistics for domestic outdoor burning which covers the burning substances including wood and waste on bonfires, chimeneas and firepits. The burning of coal and charcoal on barbeques is covered in 1A4bi;

(b) statistics on households with/without central heating using solid fuel as main fuel on open fires, and assumptions about waste wood arisings for indoor domestic burning;

(c) time series for industrial, commercial, construction and demolition waste arisings.

The emission factors for emissions of copper, chromium and arsenic from treated wood are taken from a UK study (Passant *et al*., 2004). Emissions of PCDD/PCDFs and PCBs from all the small-scale burning sources are based on composite factors derived from estimates of the individual waste types burnt and factors for specific waste types from UK research (Coleman *et al*., 2001 and Perry, 2002).

The PCDD/PCDF emission factors for small-scale waste burning used in the NAEI have also been reviewed against the EMEP/EEA Guidebook. The Guidebook refers users to the US EPA guidance for waste other than agriculture waste. The UK factors for domestic waste burning and bonfires were based on a UK study published in 2001 and are more recent than the US EPA AP42 guidance, thus they are considered the most representative of UK emissions. Emissions of NO_X, PM_{10} and NMVOCs from small-scale waste burning sources are based on composite factors derived from estimates of the individual waste types burnt and factors for specific waste types from UK and US research (US EPA, 2004 and Perry, 2002).

The burning of agricultural waste was regulated in 2006, and farmers subsequently had the options of i) applying for waste management licences or licence exemptions if they wanted to continue dealing with wastes on site, ii) taking their waste to a licenced disposal site, or iii) getting an authorised waste contractor to remove their waste. As a result, the quantities of waste burnt on farm sites declined by 97% between 2005 and 2008.

Table 6-11 provides a time series of activities for the burning of agriculture and domestic waste since 1990.

Table 6-11 Inputs in the agriculture and open burning of waste

Year	Agricultural Waste Burning (kt)	Other Open Waste Burning (kt)
1990	97.8	341
1995	97.8	313
2000	97.8	304
2005	97.8	284
2010	2.93	270
2015	2.93	270
2018	2.93	277
2019	2.93	278
2020	2.93	276
2021	2.93	278
2022	2.93	279

6.6. NFR 5D: Wastewater

The emission estimates of ammonia from sewage treatment are taken from data provided by the United Kingdom Centre of Ecology and Hydrology (UKCEH, 2022). Sewage treatment emissions were unchanged from previous year estimates, at 1.2 kt NH_3-N/yr (Lee and Dollard, 1994). Emissions from sewage sludge disposal to land are reported under sector 3Da2b, apart from sewage sludge used for land reclamation, which is reported under 5D1.

NMVOC emissions from municipal wastewater treatment (WWT) plant are estimated using the Tier 1 method given in the EMEP/EEA Guidebook. The approach uses the default emission factor (15 mg NMVOC/m^3 wastewater handled) and activity data estimates based on a time series of wastewater generated from residential properties for treatment from the UK water companies.

Activity data for industrial wastewater are expressed as amount of chemical oxygen demand (COD)/year and a method specific to industrial WWT is not available. An EF was derived from the NMVOC:CH_4 ratio for municipal WWT as a best estimate. Although the NMVOC:CH_4 ratio for residential WWT varies somewhat over time, the average ratio for 2011 to the latest year was chosen as a conservative value. This was applied to the derived CH_4 EF from industrial WWT to generate the EF for NMVOCs from that source. NMVOC emissions from residential and industrial WWT are reported under sector 5D1 and 5D2, respectively. The resulting emissions are minor in the UK context.

6.7. NFR 5E: Other Waste

NFR category 5E - 'Other' captures those sources not covered in other parts of the waste sector of the inventory. National fire statistics produced by the ONS are used to provide data on the number and type of incident the UK fire and rescue services are required to attend to annually, disaggregated by buildings and vehicles.

Additional activity data and estimates for quantities of material burnt for bonfires are based on the UK Inventory agencies' estimates for the UK. These estimates carry a higher level of uncertainty due to the lack of viable UK statistical data.

Accidental Fires

UK Accredited Official Statistics provide data on the number and type of fires which the UK fire and rescue services attend annually. This provides disaggregation to type of incident (dwelling, other building, and vehicle) and for some, but not all years, provides further detail on scale of the fire. The data do not specify the quantity of material destroyed. For dwellings and other buildings, the most detailed statistics are available for the period 1987-2007 and 2010-2013, and for the remaining years in the time series the Inventory Agency has constructed and used a set of profiles to help predict the scale of the fire (contained to one room, whole room destroyed, whole building destroyed) based on the detailed statistics for the years where those are available. A similar combination of detailed statistics and extrapolation for the earliest and latest part of the time series is necessary for vehicle fires (detailed statistics broken down by vehicle type available for 1985-2007 only). The inventory approach is then to make assumptions based on the scale of the fire for how much material has been destroyed. For example, for fires described in the statistics as confined to a single item, the assumption is that 1 kg of materials is combusted. Applying this approach to the UK fire statistics allows the Inventory Agency to generate activity data in the form of material burnt, which will cover a range of material types (wood, plastic, textiles etc.). Literature emission factors for all pollutants under this source are then used to estimate emissions to air based on factors taken from the US EPA (2004) excluding PAHs, which make use of UK research by Coleman (2001) supported by UK ambient monitoring data.

Emissions from vegetation fires (including forest fires and muirburn) are also estimated, but are not reported as waste sector emissions due to being considered natural emission sources. Instead, these are reported as a memo item.

Bonfire Night

The celebration of Bonfire night in the UK (5th November) is treated as a separate source from other domestic burning events due to the large-scale organised nature of the event (predominately public firework displays) and potential air quality impact over a short period of time. Backyard burning of waste and other bonfires throughout the year are also reported under NFR 5.

Emission estimates for Bonfire night are based on the Inventory Agency estimates of the quantity of material burnt in bonfires and firework displays. Since the 2019 submission, emission factors from the EMEP/EEA Guidebook have been used, as they are assumed to be more reliable than the previous UK factors. Emission factors for domestic wood fires (in the case of CO and PM_{10}), for domestic combustion of wood (in the case of PAHs), and for disposal of wood waste through open burning (in the case of PCDD/PCDFs and PCBs) are used to generate emission estimates.

6.8. Source Specific QA/QC and Verification

Many of the emission estimates reported in NFR 5 are based on facility-specific emissions reported to the PI, SPRI and NIPI, under EPR regulation. Section 3.1.7 discusses QA/QC issues regarding these data.

The emission estimates for NFR 5A (landfill waste) are not directly verified, but the model (MELMod) upon which the air quality pollutant estimates are based is designed and used specifically to estimate methane emissions from landfills. This model and the associated calculations were audited for the purposes of the UNFCCC inventory for 2013, resulting in improvements to the calculation of landfill methane collection and combustion. Additionally, MELMod was subject to a further peer review process in 2014 (Golder Associates, 2014). In the light of this peer review, changes were made to the assumed efficiency of landfill gas engines. The landfill methane inventory for the 2019 submission was cross-checked against the inventory that would be obtained by using the IPCC Tier 1 methodology for calculating landfill methane emissions, using identical inputs as far as possible, and was found to be consistent (Brown *et. al*. 2023).

The remaining source categories are covered by the general QA/QC, please refer to Section 1.6.

6.9. Recalculations in Waste (NFR 5)

As part of the continuous update of the methodology for estimating NH_3 from anaerobic digestion (both site-based processes and land-spreading of digestates), composting and landfill sites, changes in emissions estimates for the 2023 submission are summarised below:

- A methodology outlined in Eades et al. (2020) was utilised to re-estimate the quantity of wastes composted at household for this year’s compilation and led to minimal revision in recent years’ emissions.
- Updates to composting materials at permitted composting sites resulted in changes to calculated emissions across the timeseries.
- Minor updates to the amount of open burning waste in 2020 and 2021 resulted in minimal revised emissions.
- Updated crematoria abatement percentages and revised number of cremations for 2021 led to a minor revision in emissions.

- Updates to the material sent to landfill using waste data interrogator statistics that were not available at the time of reporting last year were incorporated into the inventory.

6.10. Planned Improvements in Waste (NFR 5)

The NAEI team operate a continuous improvement programme that spans all sources sectors of the inventory. Among the inventory improvements foreseen, consideration is given on the one hand to improvements influencing the whole system of the national inventory and, on the other hand, improvements aimed at specific activity sectors.

Defra are currently analysing the results from survey work conducted in 2022 and 2023 into the prevalence and use of domestic solid fuels across the UK. It is anticipated that outputs from the current survey will provide better activity data by technology and feed into compilation of the inventory in the 2025 submission. We intend to revisit the previous survey along with the result of the current survey to assess where information can be used to improve estimates of domestic outdoor burning

7. NFR 6: Other

Table 7-1 Mapping of NFR Source Categories to NAEI Source Categories: Other Sources

NFR Category	Pollutant coverage	NAEI Source Category	Source of EFs
6A Other (included in national total for entire territory)	NO_X, NMVOCs, Particulate Matter, NH_3	Non-agriculture livestock - horses wastes	UK Factors
		Professional horse wastes	
	NH_3	Infant emissions from nappies	UK Factors
		Domestic pets	UK Factors
		Domestic garden fertiliser application	Literature sources
		Park and garden, golf courses fertiliser application	

7.1. Classification of Activities and Sources

NFR source category 6A is a key source for NH_3.

7.2. Activity Statistics

NFR category 6 - 'Other' captures those sources not covered in other parts of the inventory.

The horse population estimate for the UK is divided into three categories for transparency reasons:

1. 'normal' (i.e. non-professional) horses located on agricultural holdings (and counted in the agricultural census) - emissions from this category are reported under NFR 3: Agriculture;
2. 'normal' privately owned horses (not counted in the agricultural census) - emissions from this category are reported under NFR 6A: Other;
3. professional horses (i.e. horses on a higher protein diet) - emissions from this category are reported under NFR 6A: Other.

The UK population estimate for horses are derived from holding level data in the June Agricultural Survey. Missing data for some years were gap-filled using data from other years as described in Defra AC0114. No new population data for professional horses or 'normal' privately owned horses were found for the year 20221 and thus it was assumed to remain at the 2015 level. The agricultural horse population (category 1, above) has decreased between 2021 and 2022.

For the year 2022, the UK population estimate for cats and dogs was based on data from UK CEH (UKCEH, 2023). It shows that the UK population estimate for dogs has increased decreased from 13 million in 2021 to 122 million in 2022 whilst and cats have also decreased, from 12 million in 2021 to 11 million in 2022. The UK population of domestic chickens has decreased slightly to an estimated 1.6 million in 2022.

Ammonia emissions linked to infants' nappies, fertiliser applied to parks and gardens and golf courses are based on the UK Inventory agencies' estimates for the UK. These estimates carry a higher level of uncertainty due to the lack of viable UK statistical data.

7.3. Methods for Estimating Emissions

Professional and privately-owned horses (i.e. all equines not recorded on agricultural premises)

NH_3 emissions from professional horses and 'normal' privately owned horses were taken from the latest submission of the agricultural inventory (Carswell *et al.*, 2023). These data reflect the N-flow methodology (Box 3) used for horse emission estimates.

Box 3 - N-flow methodology for estimating NH_3 emissions from professional and domestic horses

Professional horses are assumed to be on a higher nutritional plane than other horses, and are therefore assumed to have a greater N excretion (129 kg/head/y compared to 50 kg/head/y). The total ammoniacal N (TAN) content of horse excreta (all categories) is assumed to be 60% of total N excreted. The N flow model is used, as for agricultural livestock categories, to estimate ammonia emissions at each stage of horse/manure management (including grazing, housing, manure storage and manure application to land). Professional horses are assumed to spend 50% of the year housed, while for domestic horses the assumption is 25% of the year housed. All housing is assumed to be straw deep litter system receiving 6 kg of straw per head per day, with manure subsequently being managed as farmyard manure (FYM). Emission factors (expressed as kg NH_3-N loss per kg TAN) at housing, storage and land application are assumed to be the same as for cattle FYM. No mitigation practices are assumed and all horse FYM is assumed to be spread to grassland and not incorporated. The emission factor for horses at grazing (expressed as % of TAN excreted) is assumed to be the same as that for cattle and sheep.

For horses kept by professionals, the best estimate emission factor remains at 16.1 kg NH_3-N $horse^{-1}$ (range 14.5-17.8). For 'normal' privately owned horses, the best estimate emission factor remains 3.9 kg NH_3-N $horse^{-1}$ (range 3.5 - 4.3).

Activity data and ammonia emission factors for domestic and professional horses are displayed in Table 7-2

Table 7-2 Activity data and NH_3 emission factors for professional and domestic horses from 1990-2022

Year	Activity Name	Activity (thousand heads)	Emission Factor (kt / thousand heads)
1990	Domestic Horses	305.5	0.005
	Professional Horses	62.2	0.020
1991	Domestic Horses	320.8	0.005
	Professional Horses	62.2	0.020
1992	Domestic Horses	337.3	0.005
	Professional Horses	62.2	0.020
1993	Domestic Horses	326.8	0.005
	Professional Horses	62.2	0.020
1994	Domestic Horses	338.7	0.005
	Professional Horses	62.2	0.020
1995	Domestic Horses	348.3	0.005
	Professional Horses	62.2	0.020
1996	Domestic Horses	439.7	0.005

Year	Activity Name	Activity (thousand heads)	Emission Factor (kt / thousand heads)
	Professional Horses	62.2	0.020
1997	Domestic Horses	547.7	0.005
	Professional Horses	62.2	0.020
1998	Domestic Horses	653.3	0.005
	Professional Horses	62.2	0.019
1999	Domestic Horses	679.7	0.005
	Professional Horses	66.3	0.019
2000	Domestic Horses	649.1	0.005
	Professional Horses	70.5	0.019
2001	Domestic Horses	649.1	0.005
	Professional Horses	74.6	0.019
2002	Domestic Horses	632.3	0.005
	Professional Horses	78.7	0.019
2003	Domestic Horses	641.1	0.005
	Professional Horses	82.9	0.019
2004	Domestic Horses	613.0	0.005
	Professional Horses	87.0	0.019
2005	Domestic Horses	599.1	0.005
	Professional Horses	91.2	0.019
2006	Domestic Horses	554.5	0.005
	Professional Horses	91.2	0.019
2007	Domestic Horses	556.2	0.005
	Professional Horses	91.2	0.019
2008	Domestic Horses	567.2	0.005
	Professional Horses	91.2	0.019
2009	Domestic Horses	558.1	0.005
	Professional Horses	91.2	0.019
2010	Domestic Horses	620.8	0.005
	Professional Horses	91.2	0.019
2011	Domestic Horses	610.9	0.005
	Professional Horses	90.4	0.019
2012	Domestic Horses	600.5	0.005
	Professional Horses	89.5	0.019
2013	Domestic Horses	613.9	0.005
	Professional Horses	88.7	0.019
2014	Domestic Horses	595.8	0.005
	Professional Horses	87.9	0.019
2015	Domestic Horses	608.2	0.005
	Professional Horses	87.1	0.019
2016	Domestic Horses	608.2	0.005
	Professional Horses	87.1	0.019
2017	Domestic Horses	608.2	0.005
	Professional Horses	87.1	0.019
2018	Domestic Horses	608.2	0.005
	Professional Horses	87.1	0.019
2019	Domestic Horses	608.2	0.005
	Professional Horses	87.1	0.019
2020	Domestic Horses	608.2	0.005
	Professional Horses	87.1	0.019
2021	Domestic Horses	608.2	0.005
	Professional Horses	87.1	0.019
2022	Domestic Horses	608.2	0.005

Year	Activity Name	Activity (thousand heads)	Emission Factor (kt / thousand heads)
	Professional Horses	87.1	0.019

NO_X and NMVOC emissions from horses were also taken from the latest submission of the agricultural inventory (Carswell *et al.*, 2023). These emissions were estimated using the latest EMEP/EEA Guidebook methods; for NO_X it is based on the Tier 3 N-flow approach while the Tier 1 method was used for NMVOCs.

Infant Emissions from Nappies

The emission estimate for ammonia from infants' nappies is based on research by the United Kingdom Centre of Ecology and Hydrology (UKCEH, 2023). The approach uses population data for the under 4 years of age group and assumed generation rates for sewage which equates to kt of NH_3 per head of population. The best estimate emission factor for infants less than 1-year-old is 11.7 g NH_3-N per infant (range 2.4 - 54.2) and the best estimate emission factor for infants between 1 and 3 years old is 14.6 g NH_3-N per infant (range 3.0 - 67.8).

Domestic Pets

Ammonia emission estimates for domestic pets are provided by the United Kingdom Centre of Ecology and Hydrology (UKCEH, 2023), based on the UK population estimates for cats and dogs and an emission estimate per animal. The best estimate emission factor for dogs is 0.64 kg NH_3-N per animal (range 0.30 - 1.01). The best estimate emission factor for cats is 0.11 kg NH_3-N per animal (range 0.05 - 0.16), this is based on the urinary excretion rate of a cat being 0.91 kg urinary N cat^{-1} yr^{-1}. The excretion rate itself is derived from assuming a diet of 500 mg kg^{-1} bodyweight d^{-1} for a 5 kg cat (Sutton, *et. al*., 2000).

Golf courses, parks and gardens

Ammonia emission estimates for this category are provided by the United Kingdom Centre of Ecology and Hydrology (UKCEH, 2023).The average NH_3 volatilisation rate for fertiliser application was kept in line with the emission factors for fertiliser application to agricultural grassland from the UK inventory for 2015 (Misselbrook *et. al*. 2016) due to the unavailability of updated figures. For parks and gardens, an average of all fertiliser types was used rather than just ammonium sulphate and di-ammonium phosphate. Similarly, for golf courses, the average of all fertiliser types was used (instead of only ammonium nitrate), including the usage of some N-rich urea. The best estimate emission factor for parks and gardens is 0.7 kg NH_3-/ha (range 0.2- 1.4). For golf courses, the best estimate emission factor is 0.7 kg NH_3-N/ ha (range 0.4-1.2).

It is estimated that around 61 kt (range 50 - 80 kt) of non-agricultural fertilizers are used by domestic households every year in the UK, as reported by Datamonitor (1998). To calculate NH_3 emissions, the assumed average N content is 15% while the volatilisation rate is 2.5% (range 1% - 4%), in line with fertilizers used in parks and gardens (from Misselbrook *et al*., 2016).

Emission factors and activity data are available on the NAEI website: http://naei.beis.gov.uk/data/

7.4. Source Specific QA/QC and Verification

Many of the emission estimates reported in NFR category 6 come from sources with less well-defined activity data and emission factors based on literature. Where possible Accredited Official Statistics have been used to help better define the sources with in-built QA/QC from the data utilised.

7.5. Recalculations in “Other” (NFR 6)

There are no significant recalculations in NFR 6A for the 2023 submission.

7.6. Planned Improvements in “Other” (NFR 6)

There are currently no future planned improvements in the NFR 6 sector.

8. Recalculations and Methodology Changes

Sector specific recalculations are described within each of the relevant chapters. These chapters should be referred to for details of recalculations and method changes. This chapter summarises the impact of these changes on the emissions totals and highlights the largest changes for each pollutant. All data comparisons presented here compare data in the latest (2024) submission with the previous (2023) submission, for the calendar year specified (i.e. the year in which the emissions occurred).

Table 8-1 Overview of the recalculations in the main pollutants

Pollutant	Absolute change between 2023 and 2024 submission for the 2021 reporting year (kt)	Percentage change between 2023 and 2024 submission for the 2021 reporting year	Main reason for recalculation
NO_X	-10.29	- 1.5%	Disaggregation of burning oil use (1A2gviii, 1A4ai and 1A4ci), allowing use of more sector appropriate emission factors.
CO	+16.45	+1.3%	Updating road transport methodology to use COPERT 5.6 rather than 5.4 (1A3bi).
NMVOC	+11.04	+1.4 %	Updating road transport methodology to use COPERT 5.6 rather than 5.4 (1A3bi).
SO_X	-7.79	- 6.2%	Revised DUKES activity data[85] and disaggregated burning oil use from industrial use into commercial and public sectors (1A2gviii) allowing use of more sector appropriate emission factors.
NH_3	+1.51	+0.6%	Multiple small changes.
$PM_{2.5}$	-17.18	-20.6%	$PM_{2.5}$ is now fully integrated within the Industrial Scale Combustion Model (1A2gviii), thus uses more technology specific emission factors. The domestic combustion model now more accurately allocates increased wood use in more recent years to newer installations.

Throughout the NAEI, emission estimates are updated annually across the full timeseries in response to new research and revisions to data sources – in particular revisions to UK Energy Statistics, provided by DUKES[91]. Cross-cutting recalculations, with respect to either or both of sectors and pollutants, this year relate to revisions to the Industrial Scale Combustion model and migrating pollutants to use a Tier 2 approach, or updates to COPERT modelling (updates from Version 5.4 to Version 5.6).

[91] https://assets.publishing.service.gov.uk/media/64f1fcba9ee0f2000db7bdd8/DUKES_2023_Chapters_1-7.pdf

8.1. NO_X

Total NO_X emissions have been revised down by 10.29 kilotonnes (-1.5%) for the calendar year 2021 between the 2023 and 2024 UK inventory submissions. The main contributors to recalculations in NO_X emissions are explained below:

- Emissions from 1A2gviii (Stationary combustion in manufacturing industries and construction: Other) in 2021 have decreased, while 1A4ai and 1A4ci (Commercial/Institutional: Stationary and Agriculture/Forestry/Fishing: Stationary respectively) emissions have increased, for an overall revision of -15.7 kilotonnes due to re-allocation of a proportion of burning oil. The change in emissions is as a result of lower emission factors being used for 1A4 during the reallocation. There have also been revision to DUKES in this sector, accounting for some revisions.
- 1A3b (Road transport) emissions have increased by 15.4 kilotonnes in 2021 due to using COPERT 5.6 rather than COPERT 5.4 which was used in NAEI21. The change is driven by increases in emission factors and emissions from cold start and degradation.
- 1A4bi (Residential: Stationary) emissions have been revised down by 8.0 kilotonnes due to implementing a split in technologies for natural gas fired water boilers, hence adjusting the weighted emission factor.
- 1A2gvii (Mobile combustion in manufacturing industries and construction) emissions in 2021 have decreased by 4.8 kilotonnes due to disaggregating emissions into a range of categories, in line with the technology type used in different industries. For example, emissions in 1A4aii and 1A3eii (Commercial/Institutional: Mobile and Other Mobile Transport) have increased by 3.7 kilotonnes and 3.0 kilotonnes respectively.
- 1A3dii (National navigation shipping) emissions have decreased by 2.7 kilotonnes in 2021 as a result of implemented a recent NO_X efficiency factor, in line with Scarbrough et al. (2017).
- 2H1 (Pulp and paper industry) emissions have been revised down by 1.2 kilotonnes, due to recalculations for paper processing where the estimates have been upgraded from the EMEP/EEA Guidebook Tier 1 to (technology-specific) Tier 2 emission factors. This results in reductions of 98% to 100% in various years across the time series. These Tier 2 emission factors are applicable for the UK, since papermills within the territory use mechanical pulping (and used neutral sulphite semi-chemical pulping in the past); these types of pulp production methods have much lower or zero emissions compared with the Kraft process which is assumed for the Tier 1 emission factors previously used.

8.2. NMVOCs

Total NMVOC emissions have been revised up by 11.04 kilotonnes (+1.4%) for the calendar year 2021 between the 2023 and 2024 UK inventory submission. The largest changes for this pollutant are:

- 1A3bi (Road transport: Passenger cars) emissions have been revised upwards by 7.2 kilotonnes. The increase in emissions is due to the migration from COPERT 5.4 to 5.6, particularly impacting emission factors from cold starts in petrol cars.
- Emissions for the sector 1A2gviii (Stationary combustion in manufacturing industries and construction: Other) have been revised up by 3.4 kilotonnes in 2021, this is largely due to including NMVOCs within the expanded Industrial Scale Combustion model, which included replacing an old US EPA emission factor with a T2 EMEP/EEA Guidebook method.

The impact of the higher emission factor now used for gas combustion is offset partially by the impact of the lower emission factor now used for biomass combustion, also as a result of migrating the calculations to a T2 method.

- 1A4ai (Commercial/Institutional: Stationary) emissions have increased by 3.5 kilotonnes, due to the inclusion of NMVOCs within the Industrial Scale Combustion model. The most significant change in this sector is for public and miscellaneous gas combustion where the US EPA emission factor has been replaced with EMEP/EEA Guidebook emission factors.
- 2D3a (Domestic solvent use including fungicides) emissions have been revised down by 2.0 kilotonnes due to two main contributors. The addition of professional consumption of cleaning products as an emission source leads to an increase of 12.4 kilotonnes. This is counteracted by the removal of a long-term double count of aerosol usage within the paint and adhesive sectors following collaboration with industry. This particular change leads to a decrease of 14.2 kilotonnes.
- 2H2 (Food and beverages industry) saw emissions decrease by 2.1 kilotonnes in 2021 as up-to-date agriculture statistics and family consumption of food was updated.

8.3. SO_X

Total SO_X emissions have been revised down by 7.79 kilotonnes (-6.2%) for the calendar year 2021 between the 2023 and 2024 UK inventory submissions. The largest of these changes are:

- Emissions from 1A2gviii (Stationary combustion in manufacturing industries and construction: Other) have decreased by 3.2 kilotonnes due to revised fuel use data from DUKES, and other contributing factors including disaggregating burning oil use from industrial use into commercial and public sectors, thus allowing the use of more sector appropriate emission factors.
- 2H1 (Pulp and paper industry) emissions have been revised down by 2.4 kilotonnes, largely due to paper production being split into two processes, as discussed in the changes to NO_X.
- 1A2d (Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print) emissions have been revised down by 2.0 kilotonnes, due to DUKES revisions, in particular, the revision of coal use.

8.4. NH_3

Total NH_3 emissions have been revised up by 1.51 kilotonnes (0.6%) for the calendar year 2021 between the 2023 and 2024 UK inventory submission. The increase in emissions is driven by smaller changes in multiple NFR sectors. The main changes with respect to ammonia are:

- 3Da1 (Inorganic N-fertilizers (includes also urea application) emissions have been revised up 1.4 kilotonnes, as a result of increases in arable fertiliser due to small revisions from DAERA (NI) in the surveyed quantities of nitrogen fertiliser types.
- 1A1a (Public electricity and heat production) emissions have been revised up by 0.2 kilotonnes as a result of now including an NH_3 emission factor for wood combustion in power stations.
- Emissions of Ammonia from 3B4gi and 3Da3 (Manure management - Laying hens and Urine and dung deposited by grazing animals respectively) have increased by 0.2 kilotonnes due to updated ratio of time spent outdoors for outdoor poultry for the time

series. Updates to 3B4gi have also included changes to manure diverted to incineration and anaerobic digestion.

- 5B1 (Biological treatment of waste – Composting) emissions have been revised up by 0.4 kilotonnes due to revisions to composting data.

8.5. PM_{10} and $PM_{2.5}$

Between the 2023 and 2024 UK inventory submission, total PM_{10} emissions have been revised down by 18.16 kilotonnes (-12.6%) for the calendar year 2021. Total $PM_{2.5}$ emissions have been revised down by 17.18 kilotonnes (-20.6%) for the calendar year 2021 between the 2023 and 2024 UK inventory submission. The top contributors to these changes are:

- 1A2gviii (Stationary combustion in manufacturing industries and construction: Other) emissions have been revised down by 11.7 and 11.9 kilotonnes for $PM_{2.5}$ and PM_{10} respectively. This is due to $PM_{2.5}$ being fully integrated into the Industrial Scale Combustion Model enabling the split of large, medium and small combustion plant to be taken into account, hence applying more representative EMEP/EEA Guidebook emission factors in particular for biomass, coal, natural gas and other fuels.

  In particular, combustion of solid biomass within the industrial sector now utilises the Tier 2 emission factors for automatic boilers, as opposed to previous Tier 1 emission factors – this emission factor is appropriate to use due to the rapid growth in biomass combustion in recent years suggesting that the technology in use is likely to be the more modern, automatic fed boilers, as opposed to older manually fed boilers. In addition, there are revisions to activity data for liquid fuels and biomass. Finally, there is correction of a small double count in the previous submission relating to industrial wood use in the sector, as these emissions, arise from the chipboard sector, which are captured in 2I.
- 1A4bi (Stationary Residential combustion) emissions have been revised downwards by 3.1 and 3.2 kilotonnes for $PM_{2.5}$ and PM_{10} respectively. This is due to improvements to the Domestic Combustion model to take into account stove sales and heating degree days. This is to align with the methodology used in Accredited Official Energy Statistics to separate year to year changes in heating demand (heating degree days) and new appliance installations. In the 2024 UK inventory submission, growth in wood use is allocated more appropriately between newer, less emitting appliances and existing appliances, therefore applying the most reasonable emission factors. For 2021, there was an increase in wood use (compared to the previous year) from both heating demand and new installations but the greater part of this increase was from use allocated to new appliances. The PM_{10} and $PM_{2.5}$ emission factors from wood use in these new installations are lower than emission factors for the existing technology and the combined effect was a reduction in emission estimates.
- 1A2d (Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print) emissions have also seen a reduction, $PM_{2.5}$ and PM_{10} emissions have been revised down by 1.4 and 1.4 kilotonnes respectively, as a result of the changes made to the Industrial Scale Combustion Model as described previously.

8.6. CO

Total CO emissions have been revised up by 16.45 kilotonnes (+1.3%) for the calendar year 2021 between the 2023 and 2024 UK inventory submission. This overall change is made up of two main changes:

- 1A3bi (Road transport: Passenger cars) emissions have been revised up by 61.5 kilotonnes for the calendar year 2021. This is due to updating the methodology to use COPERT 5.6 rather than 5.4. The main contributions to the differences are revised cold start emission factors for petrol vehicles in COPERT 5.6 compared to 5.4. Additionally, COPERT 5.6 now includes degradation emission factors for the hot exhaust component of emissions.
- 1A2gviii and 1A2d (Stationary combustion in manufacturing industries and construction: Other and Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print respectively) emissions have been revised down by a combined 38.6 kilotonnes due to incorporating CO within the Industrial Scale Combustion model, enabling a split of large, medium and small combustion plants to be taken into account, hence applying more representative guidebook emission factors throughout. Smaller changes are also seen in 1A2gviii due to revisions in DUKES.
- 2H1(Pulp and paper industry) emissions have decreased by 6.6 kilotonnes as a result of using Tier 2 emission factors for mechanical pulping and NSSC processes, as described in the changes to NO_X.

8.7. Black Carbon

Total Black Carbon emissions have been revised down by 3.84 kilotonnes (-23.5%) for the calendar year 2021 between the 2023 and 2024 UK inventory submissions. The main contributors to this change are given below. The reasons are identical to the for revisions PM_{10} and $PM_{2.5}$ emissions, please refer to the section above for further detail:

- Emissions for 1A2gviii and 1A2d (Stationary combustion in manufacturing industries and construction: Other and Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print respectively) have been revised down by a combined 3.9 kilotonnes, the main contribution to this change is migrating Black Carbon into the Industrial Scale Combustion model, thereby allowing use of a Tier 2 method.
- 1A4ai (Commercial/Institutional: Stationary) emissions have been revised up 0.4 kilotonnes due to disaggregation of burning oil into appropriate sectors, allowing for more appropriate emission factors to be applied.

8.8. Metals

In this submission, individual metal emissions have been recalculated for a variety of reasons explained below. The emissions for all metals have been impacted by at least 2% of the National Total, with exception to cadmium (-0.09t, -1.8%).

- Total arsenic, chromium, copper and lead emissions have been revised up by 0.3 tonnes (+2.1%) for arsenic, 0.2 tonnes (+2.2%) for selenium, 5.5 tonnes (+12.9%) for chromium, 119.0 tonnes (+21.7%) for copper, and 16.9 tonnes (14.7%) for lead. These increases in emissions are predominantly due to implementing updated emission factors from COPERT 5.6 for brake and tyre wear (1A3bvi).

- Nickel emissions have been revised upwards by 19.8 tonnes (+26.6%) this year. The increase in emissions is predominantly due to including emissions from the combustion of the petroleum coke proportion in SSF (1A4bi, Residential: Stationary). The increases in arsenic and selenium emissions are also impacted by the inclusion of this source.
- Total mercury emissions have been revised up by 0.2 tonnes (+4.5%). The increase in emissions is driven by the inclusion of metal emission factors for natural gas use, particularly impacting industrial combustion sectors (1A2). Emissions are offset by reductions to the cremation sector by accounting for up-to-date figures on crematoria abatement (5C1bv, Cremation).
- The total emissions for zinc have been revised up by 13.3 tonnes (+2.6%) for the calendar year 2021. The increase in emissions is predominantly due to implementing updated emission factors from COPERT 5.6 for brake and tyre wear (1A3bvi, Road transport: Automobile tyre and brake wear). This is offset by a decrease in emissions as a result of removing a double count between 1A2gviii and 2I (Stationary combustion in manufacturing industries and construction: Other and Wood processing respectively), with the latter being retained as it is calculated through a more accurate Tier 3 method for the chipboard sector.
- Emissions of cadmium are notably impacted by the inclusion of commercial use of biomass being reallocated from 1A2gviii (Stationary combustion in manufacturing industries and construction: Other) to 1A4ai (Commercial/Institutional: Stationary).

8.9. POPs

The PAHs have all seen recalculations for the 2021 calendar year:

- Benzo[a]pyrene saw an increase of 0.2 tonnes (+3.2%)
- Benzo[b]fluoranthene increased by 0.3 tonnes (+3.7%)
- Benzo[k]fluoranthene increased by 0.1 tonnes (+3.1%)
- Indeno[123-cd]pyrene increased by 0.1 tonnes (+3.4%).

The main reason, accounting for almost all of the increases across the PAHs, was a recalculation driven by revisions to DUKES for the solid smokeless fuel use within the residential sector (1A4bi, Residential: Stationary), as well as the improvement to apportion more reliable activity data to differing appliance types.

Overall dioxins and furans have been revised down by 1.5 g ITEQ (-1.3%). The decrease in emissions is driven by migrating the calculation of emissions of Dioxins from industrial combustion (1A2, stationary combustion) to a more detailed T2 model. This is offset by revisions to DUKES to the residential sector (1A4bi).

HCB emissions in 2021 have been revised upwards by 1.0 kg (+2.5%), Driven by DUKES recalculations for MSW use in power generation (1A1a, Public electricity and heat production).

PCBs have had minimal changes, with an increase of 0.2 kg (+0.1%) as a result of minor DUKES recalculations.

9. Emission Projections

The UK has emission reduction commitments (ERCs) for five pollutants ($PM_{2.5}$, NO_X, SO_X, NH_3, NMVOC) under the 2018 NECR[92] and the CLRTAP Gothenburg Protocol[93]. Projected emissions are compiled by the Inventory Agency to enable comparisons with these commitments. Emission projections are required under the Gothenburg Protocol every 4 years starting from 2015 while reporting of projections is required every 2 years under the NECR.

The dataset presented here is based on the latest version of the UK inventory (the 1990-2022 NAEI), as submitted under NECR and CLRTAP on 14th February 2024 The projections rely upon data from numerous sources, key among which are the updated Energy and Emissions Projections, published by DESNZ in November 2023[94], data from DfT, including updated Road Traffic Forecasts, agriculture forecasts based on the Scenario Modelling Tool (SMT, Defra project AQ0978) and other forecasts. Further details of data and assumptions are given in section 3.

As of this, the 2024 submission, the territorial scope of the projections are reported on the same scope as the historic inventory – in that both the UK and Gibraltar are considered.

The projections are prepared in line with international guidance for 'with existing measures' which only take account, as far as is possible, of 'firm and funded' measures and therefore largely do not take into account policies or measures that are still in development. One exception is for Port Talbot and Scunthorpe steelworks where we assume that current proposals by the operators are carried out. 'Firm and funded' or 'Adopted' policies or measures are defined by the EMEP/EEA Guidebook as 'those for which an official government decision has been made and there is a clear commitment to proceed with implementation'.

The projections are subject to uncertainty from a combination of sources, including but not limited to:

- Uncertainties in the historic emissions data;
- Uncertainties in the projections of future activities and technologies.
- Uncertainties in the future emission factors, particularly from stationary sources, e.g. industry

The emission projections therefore show a best estimate of the likely trajectories for UK emissions to 2050, if no further action is taken, beyond the measures already in place.

9.1. Overview of Data and Input Assumptions

The UK projections are compiled in line with the 2019 EMEP/EEA guidebook. They take, as their starting point, the estimates of the latest historical time series (i.e. 2022 from the 2024 submission of the NAEI) which are then extrapolated into the future, taking into account forecasts of energy consumption, road traffic, and other activity data, as well as assumptions about the impact of environmental policies and

92 The NECD has been transposed into UK law via the 232/2018 - European Union (National Emission Ceilings) Regulations 2018, see The National Emission Ceilings Regulations 2018 (legislation.gov.uk)

93 See http://www.ceip.at/ms/ceip_home1/ceip_home/reporting_instructions/reporting_programme/ for reporting requirements of estimating and reporting emissions data under the CLRTAP.

94 https://www.gov.uk/government/collections/energy-and-emissions-projections Note that a separate file is provided to the Inventory Agency to support the projections, this was provided January 2024 and is based on the published projections.

measures on emissions. For more details about the data and methodology used to compile the historical time series data please see the relevant sector specific chapters.

As part of the projections compilation, we also take account of events outside the historic time series, for example known plant closures or significant events that might have occurred in the preceding year.

The following sector specific sections give details on this modelling.

9.1.1. Standard Approach

The projections are based on the latest version of the UK inventory (available on the NAEI website). Data from this inventory are used as a baseline for the projections:

- Activity data from the most up to date time series, are used as the starting point for activity projections for 2025, 2030, 2035, 2040, 2045 and 2050 by applying suitable assumptions about the growth or decline in each activity.
- Emission factors for 2022 are assumed to be appropriate for future years as well, unless we have data to indicate that emission reductions will occur, for example due to regulation or through improvements in technology.

Typically, the latest year in the historic time series is used as the starting point for the projections. For this set of projections, this is 2022. However, other years may be used as the starting point in the projection calculations, depending upon the data and assumptions being applied. For example, the projections in a few areas rely upon information supplied by various trade bodies during 2018 and 2019 and most of this information requires the use of 2017 figures from the latest inventory. Note, however, that the projections will still be consistent with the latest inventory submission.

Table 9-1 below summarises the Government statistics and other annually available datasets that are inputs for the emission projections.

Table 9-1 Government statistics and other annual inputs for the emission projections

Sector	Data Type	Dataset	Coverage	Data Provider	Publication date
Energy including transport	Energy use projections	Updated Energy and Emissions Projections	2022-2050	DESNZ, EEP team	November 2023. Supporting file supplied directly January 2024.
Industry	GDP projections				
Cross-cutting	Projected population & household numbers				
Industry, off-road vehicle	Industry sector growth indices				
Oil & gas	Production forecasts	UK crude oil and gas production forecasts	1998-2050	North Sea Transition Authority	August 2023
Agriculture	Emission projections	Scenario Modelling Tool (SMT, Defra project AQ0978)	2022-2040	Rothamsted	Currently unpublished

Sector	Data Type	Dataset	Coverage	Data Provider	Publication date
	Activity data projections	UK Agricultural Market Model (UKAMM) 2024	2023-2032	Defra	Currently unpublished[95]
Road Transport	Data related to future activity levels for road transport	Road Traffic Forecasts for Great Britain (GB)	2015-2050 (5-year intervals)	DfT	Bespoke data/ unpublished January 2023
		Car and LGVs mileage splits by fuel type	2015-2050	DfT	Bespoke data/ unpublished January 2024
		UK New Car and LCV Registrations Outlook to 2024	2023-2025	SMMT	October 2023
		Traffic and fleet composition projections data for London	2008-2030 (traffic), 2008-2050 (fleet)	TfL	Bespoke data/ unpublished January 2023 (traffic) and January 2024 (fleet)
Aviation	Fuel demand projections	Jet Zero (High ambition scenario)	2030-2050 (Data prior to 2030 is interpolated)	DfT	2023
Off-road machinery: domestic	Household and Industry projections	Updated Energy and Emissions Projections	2022-2050	DESNZ, EEP team	November 2023. Supporting file supplied directly January 2024.
Off-road machinery: airport	Passenger numbers	UK aviation forecasts 2017	2016, 2020, 2030, 2035 and 2040	DfT	2017
Rail	Activity projections	Rail Emissions Model (REM)	2013-2049	DfT	Bespoke data/ unpublished provided in 2016
		Updated Energy and Emissions Projections	2022-2050	DESNZ, EEP team	November 2023. Supporting file supplied directly January 2024.
Shipping	Emission projections	Scarbrough *et al.* (2017)	2025 and 2030	NAEI	2017
Waste	Methane emission projections	Non-CO_2 GHG Projections	2010-2030	BEIS	2015

[95] For further information about the UK Agricultural Market Model (UKAMM) please visit https://www.gov.uk/government/publications/uk-agricultural-market-model-ukamm

Sector	Data Type	Dataset	Coverage	Data Provider	Publication date
	Ammonia emission projections from anaerobic digestion	Electricity generated from anaerobic digestion	2020-2030	DESNZ (DUKES)	2020

In addition to the Government data and scientific studies referred to in Table 9-1, information provided on an ad-hoc basis from certain industrial trade associations, following extensive consultation with industry by Defra in particular, and by Ricardo is also used. Organisations providing information related to projections include:

- British Adhesives and Sealants Association (BASA)
- British Aerosol Manufacturers Association (BAMA)
- British Ceramics Confederation (BCC)
- British Coatings Federation (BCF)
- British Glass (BG)
- Chemical Industries Association (CIA)
- Mineral Products Association (MPA)

To produce emission projections, it is necessary to generate projections of activity, and to decide what emission factors are appropriate for the future. Most of the activity projections including almost all related to fuel consumption and many relating to industrial processes are based on data given in the annual 'Updated Energy and Emissions Projections' (EEP) dataset produced by DESNZ. A summary report and annexes, published in late 2023, give an overview of methods and assumptions used in EEP. These documents can be obtained from https://www.gov.uk/government/collections/energy-and-emissions-projections.

These energy projections include the impact on fuel consumption of emission source regulation, including the UK Emission Trading Scheme (ETS) and under the Environmental Permitting Regulations (EPR).

The EEP data we receive are for the central 'Reference' scenario, and include the following for 2025, 2030, 2035, 2040, 2045 and 2050:

- sectoral projections for use of each fuel type (coal, fuel oil, gas oil, gas, biomass) by major industrial sub-sectors such as power stations, refineries, oil and gas production and steelmaking;
- higher-level projections for use of each fuel type (coal, fuel oil, gas oil, gas, biomass) for the rest of industry combined, and for non-industrial and residential sectors;
- some additional indices that relate to output from various industrial sub-sectors, such as food and drink manufacture, non-ferrous metals etc.;
- projected household numbers and GDP.

These forecast data from DESNZ are used to generate our own estimates of activity data for the years to 2050, as required for the inventory forecasts, for almost all NAEI stationary combustion source categories and for many industrial process-related source categories. The GDP and population projections are used to forecast activity for non-combustion sources where use of such broad indicators is considered more reliable than the sector-specific data in the EEP dataset. For example, domestic products such as aerosols are sources of NMVOC emissions and for this source, population is considered to be a more reliable indicator of future consumption than, say EEP drivers for the chemical sector. For a handful of minor combustion source categories relating to use of fuels in narrowly-defined sectors, we may consider the use of any of the EEP forecasts less ideal, and so in these cases we would assume no change in fuel use from the base year onwards. Similarly, for industrial processes where there are only one or a few sites operating that type of process, we generally assume that activity remains constant unless we have information indicating either closures of sites or proposals to increase capacity or to construct new sites.

Details of assumptions and data that are specific for sub-sectors of the inventory are given below in Table 9-2. In this table, the methods given are:

- WM 'with measures' i.e. including the impact of regulations or other actions that seek to reduce emissions
- WoM 'without measures' i.e. assuming no impacts from regulations or other actions.

Measures are included wherever the data is available to support this - without measures calculations imply a lack of available data. Within a reporting category, there may be some emission sources for which it has been possible to project the impact of measures, and other sources where this is not the case. These are labelled as WoM/WM in the table below.

Table 9-2 Summary of assumptions for emission projections by NFR category

NFR Category	NFR Name	Method	Comments
1A1a	Energy industries (Combustion in power plants & Energy Production)	WM	All regulated. Projections assume power plants either meet IED limits for NO_X, SO_X, PM or else continue to emit at current levels if these levels appear to be below that required by IED.
1A1b	Energy industries (Combustion in power plants & Energy Production)	WM	All regulated. Permit review documents from 2018 indicated that refinery sites were often already compliant with BAT conclusions or else could become compliant subsequently but within the timeframe covered by the historical inventory. Since the historical inventory uses emissions data from operators, it can be assumed that these emissions will reflect all improvements made to ensure compliance with the BAT conclusions and it is assumed there are no further reductions.
1A1c	Energy industries (Combustion in power plants & Energy Production)	WoM /WM	All regulated. In general, no projection of emission factors. Due to lack of data on current level of emission control and information on how this will change in the future we assume factors do not change after the projection base year. The sole exception relates to emissions from coke ovens which will cease due to the closure of all coke ovens before 2025.
1A2b, 1A2c, 1A2d, 1A2e, 1A2f, 1A2gviii	Manufacturing Industries and Construction (Combustion in industry including Mobile)	WoM /WM	Partly regulated. Guidebook emission factors are used & these are held constant across both the historical time series and the projections. Permit reviews for cement & lime kilns (both 1A2f) indicated improvements were needed to achieve compliance with BATC but these improvements should be included in historical estimates due to the use of operator-reported emissions data through to 2022. It is assumed there are no further reductions in emission factors for either the cement or the lime sector.
1A3b	Road Transport	WM	All regulated (except non-exhaust emissions). Relatively sophisticated forecasts which take account of changes in traffic and technologies.
1A3a, 1A3c, 1A3dii, 1A3eii, 1A2gvii, 1A4bii, 1A4cii, 1A4ciii, 1A5b	Other transport (aviation, off-road mobile machinery, navigation, rail etc.)	WoM /WM	Mostly regulated. Relatively simple forecasts using proxy data to project activity data.
1A4a/1A4c	Other sectors (Commercial, institutional, agriculture and fishing stationary)	WoM	Partly regulated. We use Guidebook emission factors and these are held constant across the historical time series & in the projections.

NFR Category	NFR Name	Meth od	Comments
1A4b	Domestic Combustion	WM	An integrated appliance turnover model is used to forecast the split by technology used to combust solid, gaseous, and liquid fuels. The most advanced technologies modelled are Eco-Design appliances and are estimated for all fuel types. The projections also take account of the prohibition on the sale of house coal and restrictions on the sale of wet wood in England, introduced by the Air Quality (Domestic Solid Fuels Standards) (England) Regulations 2020.
1B1b	Coke ovens	WoM /WM	Regulated. All coke ovens at Scunthorpe are now closed and we assume that ovens at Port Talbot will close in 2024, thus there will be no emissions from this source from 2025 onwards.
2A	Mineral Processes	WoM /WM	Mostly regulated processes. Generally, WoM due to lack of data on current level of emission control and information on how this will change in the future so emission factors for 2025-2050 are assumed to be the same as in the base year. Industry have provided data for projections of dust emissions from the production of flat glass, container glass and continuous filament glass fibres.
2B	Chemical Processes	WoM /WM	Regulated processes. Generally, WoM due to lack of data on current level of emission control and information on how this will change in the future so emission factors for 2025-2050 are assumed to be the same as in the base year. However, industry have provided conservative estimates of reductions in NMVOC emissions from a small number of large-scale organic chemical processes and these have been adopted as a conservative estimate of reductions. In practice, other sites will likely reduce emissions in order to comply with regulation and so larger reductions are likely.
1A2a, 2C1	Combustion in iron & steel sector; Processes in steelmaking	WM	Mostly regulated processes. The operators of the Scunthorpe & Port Talbot steelworks have each proposed to close the current oxygen steelmaking processes at their sites and replace with steel production using electric arc furnaces. We have assumed that this does occur and that oxygen steelmaking ends in 2024 at Port Talbot and in 2025 at Scunthorpe. That would mean that emissions from some of the sources reported in 1A2a and 2C1 no longer occur after those dates. Closure of coke ovens, blast furnaces & oxygen furnaces also mean that process off-gases which are currently used as fuels on site in boilers and rolling mill furnaces have to be replaced by other fuels. We assume natural gas is used. We have estimated emissions from the proposed new electric arc furnaces using Guidebook factors. Emission factors for operations at other iron & steel sector sites are assumed to remain unchanged over the 2022-2050 period.

NFR Category	NFR Name	Meth od	Comments
2D	Solvent	WoM / WM	Mixture of regulated industries and consumer product use. Emission factors for 2025-2050 are generally assumed to be the same as in the (2020) base year. Almost all industrial solvent use has been regulated in the UK since the mid-1990s and emissions in many sectors have reduced substantially since 1990. The potential for further reductions is therefore often quite limited. In a number of important instances (use of paints, printing inks, adhesives, and sealants), trade bodies have provided forecasts extending to 2030 (BASA) or 2050 (BCF) and these have been adopted for the UK projections. Emissions from other industrial uses of solvent have generally been assumed to remain fairly constant, in the absence of any data from industry. We have assumed no reduction in emission rates for solvent use in non-coatings related consumer products (such as household products and cosmetics) in the absence of any regulation that explicitly drives reductions in NMVOC content.
2G, 2H	Other product use	WoM	Mostly not regulated and so the potential for reduction without additional measures is low and WoM forecasts are therefore currently acceptable.
2I	Industrial Processes	WoM	Regulated processes. Assumed to be fully controlled already so no further change assumed.
3	Agriculture	WM	Projections calculated using the Scenario Modelling Tool (SMT, Defra project ECM 55618) based on the year of 2022 of NAEI. Activity data projections for livestock numbers, milk yield and crop areas production to 2032 were derived from the UK Agriculture Market Model (2024), and for quantities of digestate to be applied to land to 2035 by Ricardo, based on energy production projections.
5	Waste	WoM	Partly regulated. Due to lack of data on current level of emission control and information on how this will change in the future, mostly assume no change in emission factors but there are some sectors (NMVOCs from landfill) where there is some modelling.
6	Other (included in National Total for Entire Territory)	WoM	Sources are generally uncontrolled so WoM is acceptable.

For most industrial sources, emissions of air quality pollutants have been regulated for several decades. While we have had, for many years, a lot of information on the historical emissions at these sites (via operator reporting to regulators under the EPR for the PRTR, and via operators themselves), we have until recently had almost no information on the emission limit values (ELVs) and other conditions placed on individual operators to achieve those annual emissions. Additionally, previously we have had little information on the requirements that are being placed on those individual operators in order to ensure compliance with regulations. In the last few years more information has become available as regulators have published permits and BAT decision documents online for some processes. These are large documents which contain much detail on the processes being regulated: the process technology; techniques used to control emissions; current ELVs and other conditions of operation; improvements that might be needed to comply in future. The documents may also provide estimates of the reductions in emissions that would result from future improvements but not always.

Nonetheless the information contained in the documents can be used to develop simple projections that take account of planned/proposed improvements. To date, permit reviews do not seem to have been published for all permitted sites. Of those that are published, we have prioritised the analysis of documents for cement kilns, lime kilns, refineries, oxygen steelworks, electric arc steelworks (for which we have documents for only 2 out of 6 sites) and non-ferrous metal processes. This prioritisation was on the basis that these were the most significant sectors for which we had no existing method for incorporating the impact of existing policies and measures. Documentation for further processes may become available in future, allowing us to better understand the potential for reductions at those sites also.

For sectors where we have been able to obtain and review documents, it was then previously possible to generate simple projections that took account of the 'current' level of compliance and improvements necessary to comply where this did not already occur. However, the BAT review documents that were reviewed were all produced at least 3 years ago and so the improvements identified are almost all things that would have had to be done before 2022 i.e. the impact of those improvements will be shown in the historical part of the NAEI and does not need to be modelled in the projections. We have not gathered data from permit reviews for other sectors, such as for large combustion plant in 1A2/1A4a/1A4c, energy from waste plant, and most chemical sector process sources, and in the case of some sectors and some sites, permit reviews may not even have taken place. For these sectors, the lack of detailed information on current compliance levels and required improvements means we have to assume a somewhat 'worst-case' scenario where emission factors in future years are the same as in the base year. This is less of an issue for NH_3, where combustion and processes are minor sources, or for SO_X where changes in fuel use, included through the use of EEP data, are likely to have a far greater impact than changes in emission factors. It could be a more substantial issue for the remaining pollutants simply because stationary combustion and processes are highly important sources. Emission projections might therefore be somewhat conservative for these pollutants.

Further detail on projections is given in the following sections.

9.2. Description of Sectoral Projections

9.2.1. NFR 1A1a: Power Stations

The EEP dataset contains detailed forecasts for fossil-fuel fired power stations, previously including site-by-site figures for coal-fired power stations. However, the last operational station is assumed to close in 2024 and so no power stations are forecast in EEP to still be burning coal in 2025 or thereafter i.e. all will have closed or have been converted to burn other fuels. Projections for other fuels such as natural gas and oils are UK-wide figures rather than being disaggregated into consumption at individual sites.

Almost all of the UK sites which are treated as fossil fuel-burning power stations in the UK inventory are sufficiently large to be regulated under EPR and to report historical emissions in the inventories maintained by regulators. The exceptions will be a number of small generating stations located on Scottish islands. Historical emissions and fuel use data can be used to generate emission factors for power stations in the base year, and these factors can be compared with those that would be expected for plant that are compliant with EPR. This analysis suggests that gas-fired UK power stations typically already meet EPR limits for NO_X and particulate matter.

For projections, we adopt the trends in fuel consumption for 2025 to 2050 given in the EEP dataset, and then applied pollutant specific assumptions.

For NO_X, we use the lower of:

- The base year (2022) emission factor, or
- An emission factor consistent with ELVs appropriate under EPR.

As already mentioned, UK gas-fired power stations as a group appear to be operating within the limits specified in EPR, so future changes in emissions are solely due to changes in fuel consumption.

Factors for NMVOCs, SO_2 and $PM_{2.5}$/PM_{10} are held constant into the future and so emission projections only reflect changes in fuel use. Gas-fired power stations are a relatively minor source of these emissions and so we regard the generation of more sophisticated projections for these pollutants as a low priority at this time.

EEP provides a full breakdown of electricity generation from renewable sources, including details for thermal renewables. The previous projections were based on the National Grid's Future Energy Scenarios (FES) as this level of breakdown was not provided by the EEP NZ. Emission factors for renewable energy sources are held constant at 2022 levels since we have no data that support a change to the factors. A comparison of current NO_X emission factors for wood stations with factors that are consistent with the requirements of IED suggests that UK biomass stations are already compliant. In the case of power generation using engines burning biogases (landfill gas, sewage gas, gas from anaerobic digestion of other wastes), we use the same literature factors both for the historical inventory and for the projections.

9.2.2. NFR 1A1b/1A1c Other Energy Industries and 1B Fugitive Emissions

The EEP dataset contains specific forecasts for fuels used by refineries, and for natural gas used by the offshore oil and gas industry, and these provide the trends used in NAEI projections. For other sectors within 1A1c (such as downstream gas facilities such as gas compressor stations), EEP does not have separate forecasts and so we use trends for the broad 'industry' category.

Emission factors for many of the sources covered by 1A1b and 1A1c are held constant at base year (2022) levels. Previously some simple modelling was done to reflect the requirement at some refinery sites to achieve compliance with regard to emissions of SO_X, NMVOCs and PM, however any improvements should now have been made and so factors are now kept constant from 2022 to 2050.

9.2.3. NFR 1A2/1A4a/1A4c: Other Stationary Combustion

EEP is used to produce estimates of fuel use for 2025 onwards. EEP only has relatively broad categories of industrial fuel use and these have to be used for all of the detailed sectors in the NAEI i.e. all of these categories are assumed to follow the same trend as the broad category in EEP.

The historical method in the NAEI for these sources is to use Tier 1 or Tier 2 emission factors from the 2019 EMEP/EEA Guidebook. Tier 2 factors are used for pollutants including NO_X, NMVOCs, $PM_{2.5}$ and PM_{10}, while Tier 1 factors are used for other pollutants. The method for NO_X and PM_{10} also makes use of some Tier 3 data i.e. emissions reported by operators for individual large sites. The use of a Tier 1 method does not allow any account to be taken of abatement. The higher tier method for NO_X and PM_{10} also does not currently allow any projection of emission factors, so the historical factors for 2022 are also retained through to 2050. More data on the compliance status of individual large sites and more detailed modelling of medium-sized plant would be required to develop projections that took full account of measures.

For cement kilns and lime kilns we also take account of any known closures and any improvement conditions that we have evidence for (though these particular sectors should already have complied with BAT conclusions i.e. should already be using BAT). We are aware of one cement kiln that was mothballed in 2020 and this site is assumed to effectively be permanently closed, so emissions from the sector are assumed to be slightly lower in future years because of the closure of this site.

The use of biomass as a non-residential fuel is forecast to continue increasing slowly in EEP[96] until just after 2030 with decreasing consumption from then onwards then predicted by DESNZ. In order to produce future emission factors, we have assumed that any growth in consumption (i.e. between 2022 and 2030) must be due to new biomass-fired plant which are brought into operation after the base year, for example in response to the UK Government's Renewable Heat Incentive (RHI). Emission factors for these new plants are taken either from the latest EMEP/EEA Guidebook (using factors for automatic boilers burning wood) or from the minimum standard for particulate matter or NO_X required under RHI. For some pollutants (NMVOCs, PM_{10}, $PM_{2.5}$), this results in a decrease in the overall emission factor over time as the new plant should be capable of emitting lower levels of pollutants. However, for NO_X, emission factors for newer appliances will be slightly higher than those for the existing population of combustion plant, so the aggregate emission factor used for the sector as a whole rises over time. This is consistent with higher temperatures and improved combustion efficiency in modern appliances which would be expected to reduce PM (and CO and NMVOC) but which might be expected to increase NO_X somewhat. Between 2030 and 2035, biomass consumption is predicted in EEP to peak and thereafter it declines. We therefore assume that once this decline begins, that the population of biomass-burning plant will also decrease over time and that there will be few, if any new plant. Therefore, factors calculated for 2035 are also used for 2040-2050.

9.2.4. NFR 1A3b: Road transport

The methodologies used to calculate the road transport emissions projections are consistent with those used in the historic inventory and are described in Section 3.3 of this report.

The key input data and assumptions include:

- DfT's road traffic forecasts for Great Britain[97] – projected vehicle kilometres were derived by applying DfT's "core" scenario traffic growth rates relative to the 2015 inventory year as this is the only year that has available data for both historic years and projected years from projected vehicle kilometres. Traffic forecasts for GB reflect the Renewable Transport Fuel Obligation (RTFO), latest fuel efficiency policies for cars, vans, HGVs and PSVs (buses), rail electrification and active travel spending. However, the traffic forecasts do not include the measures to phase out Internal Combustion Engines (ICE) vehicles from 2035. Additionally, DfT provided updated assumptions relating to the mileage splits by fuel type for cars, LGVs and buses which are consistent with the reference case for DESNZ' Energy and Emissions Projections 2022 (https://www.gov.uk/government/publications/energy-and-emissions-projections-2022-to-2040)[98]. The policies for the EEP projections are provided in Annex D of that publication. These transport policies include a reduced ambition on the uptake of electric vehicles relative to the previously used projections.
- DfT's future sales of cars – updated forecasts were provided by DfT which assume all currently firm and funded policies as listed above.
- For Northern Ireland (NI), traffic is assumed to follow the GB growth rates due to lack of suitable traffic projections data for NI.
- For London, traffic projections up to 2030 are based on TfL's current reference case and were provided by Transport for London in January 2024. These forecasts were used as an index to derive growth factors which were applied to DfT's London vkm for historic years. Updated

[96] https://www.gov.uk/government/publications/energy-and-emissions-projections-2021-to-2040
[97] Personal communication, Road Traffic Forecasts for Great Britain, Transport Appraisal and Strategic Modelling, Department for Transport, January 2023. Informed that there was no update for January 2024 relative to the January 2023 version.
[98] DfT (2023b), personal communication, Environmental Analysis, Environment and Future Mobility, Department for Transport, January 2023.

forecasts up to 2050 on future vehicle fleet composition data for London were also provided by TfL in January 2024. These fleet forecasts account for zero emissions from TfL Buses by 2034 (consistent with current business plan), uptake of zero emission capable (ZEC) and zero emission (ZE) taxis, and now account for the London-wide ULEZ. Additionally, these fleet compositions are based on a zero emissions path for 2050 and the Consumer Acceptance scenario on the ICE phase out of ICE sales from 2035 and the consequently increased level of EV uptake.

- The impacts from COVID-19 pandemic have not been considered in the UK's projections for 2025, 2030, 2040, and 2050.

One of the main uncertainties for road transport projections this year is from the lack of planned pathways to account for the phaseout of the ICE vehicles in the UK from 2035. Currently we assume that road traffic by 2025 will have not been impacted by the pandemic.

9.2.5. NFR 1A3a,c,d,e: Other Transport and Non-Road Mobile sources

Aviation (1A3a)

Activity data for domestic and international aviation are projected to align with DfT's Jet Zero Strategy "High Ambition Scenario" fuel consumption forecast (DfT, 2022)[99] from 2030 to 2050. The base year (2022) is aligned to actual DUKES data. Intermediate years (notably 2025) are interpolated between DUKES and DfT data to account for the impacts of the COVID-19 pandemic. Activity data for military aviation are held constant at 2022 levels (emissions from this source are reported under 1A5b).

Emission factors for all pollutants are held constant at 2022 levels.

Non-road mobile sources (1A2gvii, 1A3eii, 1A4bii, 1A4cii)

Machinery or engine-specific fuel consumption and emission factors (g/kWh) are taken from the latest EMEP/EEA Guidebook. Emission factors for more modern machinery are based on engine or machinery-specific emission limits established in the EU Non-Road Mobile Machinery (NRMM) Directives. Unlike in previous projections iterations, emission factors for engines meeting Stage V limits, introduced from 2019, have been introduced into the projections.

Activity data are derived from bottom-up estimates of population and hours of use of equipment in 2018, following a major improvement update to the sector. Various proxy statistics are used as activity drivers for different groups of machinery types to estimate the turnover in the off-road engine fleet and emissions and fuel consumption in future years relative to the latest 2022 base year. For machinery used in industry, a DESNZ sector-weighted energy projections driver for industry is used; for machinery used in construction the DESNZ energy projections driver for 'construction' is used; for machinery used in quarrying the DESNZ energy projections driver for 'Non-metallic mineral products' is used. For machinery used in agriculture, the activity driver is held constant at 2022 levels. For domestic house and garden machinery, a driver based on future trends in the number of households from the DESNZ energy projections is used. For machinery used in airports, projections in the number of terminal passengers at UK airports are used. Projections from 2030 to 2050 are taken from DfT's Jet Zero Strategy forecasts (DfT, 2022), the base year (2022) is aligned to actual CAA annual statistics, and the intermediate years (notably 2025) are interpolated between CAA and DfT data to account for the

[99] Jet Zero Strategy. DfT, 2022. https://www.gov.uk/government/publications/jet-zero-strategy-delivering-net-zero-aviation-by-2050

impacts of the COVID-19 pandemic. This method is used as the Jet Zero Strategy forecast doesn't account for the impact of the pandemic. For further information see Aviation.

The EU Fuel Quality Directive (2009/30/EC) has required fuels used in non-road mobile machinery to have a maximum sulphur content of 10ppm since 2011. Apart from this Directive, and including the EU NRMM Directives up to Stage V, no specific emission reduction policies and measures are taken into account for the off-road sector.

The main uncertainty for the machinery used in construction and the machinery used at UK airports lies with how the UK activities will recover by 2025 and beyond due to the impact from COVID-19 pandemic. The DESNZ EEP2022 dataset predicted that construction activity would not yet have returned to pre-pandemic levels by 2025.

Rail (1A3c)

Energy consumption forecasts for intercity and regional passenger and freight trains are taken from the Rail Emissions Model (REM) developed by DfT (2016)[100]. These are normalised to DESNZ EEP 2023 energy projections for total gas oil (diesel) used in the rail sector to provide separate activity drivers for passenger and freight train types. Those activity drivers are used to scale 2022 historic fuel consumption to estimate future energy consumption.

Taking into account the current fleet structure, the projections consider how this might change in future years for the intercity, regional passenger and freight diesel rail fleets as they approach compliance with Stage IIIB emission limits and an increased proportion of electrification. The projections account for the EU Fuel Quality Directive (2009/30/EC) which has required fuels used by railways to have a maximum sulphur content of 10ppm from 2012.

Inland waterways (1A3dii)

For the activity data, proxy statistics are used to estimate activities for the latest reported historic year and projected years. The emission factors for all projected years are assumed to remain constant at the emission factor values for the latest reported historic year, currently 2022. For future activities by inland waterways, the latest DESNZ sector-weighted energy projections driver for industry is used, re-based to the latest 2022 inventory year. The projections account for the EU Fuel Quality Directive (2009/30/EC) which has required fuels used by inland waterways to have a maximum sulphur content of 10ppm from 2011. Recalculations occur due to the application of updated EEP 2023 projections drivers, updated proxy data for scaling the historic years, and rebasing to 2022.

Shipping (1A3dii)

The method for forecasting emissions from shipping is described in the forecasting section of the report on the methodology for estimating emissions from shipping by Scarbrough et al. (2017)[101].

Activity projections are based on examination of recent trends in port activity shown in DfT statistics, Government forecasts of national demand for port capacity with growth factors for different vessel types carried out by MDS Transmodal and the growth rates forecast at each of 7 individual ports based on port Master Plans. The activity projections are re-based to the total UK domestic shipping fuel consumption estimated for the latest year in the inventory, 2022. Activity growth is compensated for by increases in shipping transport fuel efficiency improvements over time in response to financial and regulatory drivers, namely the IMO Energy Efficiency Design Index (EEDI) requirements for new ships.

[100] DfT (2016), personal communication, Rail Analysis: Services, Strategy, Infrastructure and Modelling, Department for Transport, 2016
[101] https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1712140936_ED61406_NAEI_shipping_report_12Dec2017.pdf

The relevant fuel sulphur requirements from MARPOL Annex VI and from The Merchant Shipping and Other Transport (Environmental Protection) Regulations[102] are taken into account. Within Sulphur Emission Control Areas (SECAs), fuel sulphur content is limited to 0.1% from January 2015. To achieve this, any HFO consumption in a SECA is assumed to switch to MDO consumption from 2015 onwards. Sulphur is limited to 0.1% for vessels at berth. Any HFO consumption out of SECA is assumed to switch to 0.5% sulphur HFO from 2020. This leads to a reduction in factors for SO_X and $PM_{2.5}$ emissions from shipping.

Future NO_X emissions factors reduce over time firstly due to continued turnover in the fleet leading to larger proportions of vessels with more recent engines which meet later (more stringent) NO_X emission tiers under the IMO MARPOL Annex VI NO_X Technical Code for ship engines; and secondly, due to the NO_X ECA designation of the North Sea and English Channel agreed by the IMO with Tier 3 NO_X emission reduction requirements placed on engines in ships constructed from 2022. It is assumed that this will be partially achieved by switching to LNG which will also lead to further reductions in $PM_{2.5}$.

9.2.6. NFR 1A4bi: Stationary Domestic combustion

Projections of emissions from domestic combustion are carried out in the integrated domestic combustion model and extend the historical approach using projected trends from the EEP. The historical approach, as described in **3.4.5** utilises data from the Domestic Burning Survey (2020) and preceding surveys to develop age profiles for appliances used for solid, gaseous, and liquid fuel combustion. Data from the DBS and ECUK datasets are used to portion activity across appliance types through to the latest historical inventory year, the major fuels used in domestic combustion are projected using the EEP data.

Restrictions on the sale of coal and wet wood in England are taken account of in the projections through the following approach:

- The England share of coal and wet wood are estimated using the 2023 release of the Devolved Administration (DA) inventories output (the DA inventories are not published until the summer each year, after the projections)
- All England coal use is transposed into solid smokeless fuel use (100% compliance of the ban) from 2022
- England wet wood activity is transferred into dry and seasoned wood activity, depending on split of activity in the latest inventory year. This ban is assumed to achieve a 65% compliance rate (in terms of quantity of wet wood burned) by 2025, and a 70% compliance rate by 2030. Beyond 2030, no further change in compliance is assumed.

Emission factors used are obtained from the integrated domestic combustion model which generally decrease over time, as newer, lower emitting technologies penetrate the appliance mix.

9.2.7. NFR 2A: Mineral Processes

Emissions from manufacture of bricks, ceramics, and glass, quarrying and construction are reported in NFR 2A. Industrial trade bodies representing the brick/ceramics sector and manufacture of flat/container/continuous filament glass have proposed growth rates or future activity estimates for their sectors. For other sub-sectors of the glass industry, and for quarrying and construction, we have used trends given in EEP for the 'other minerals and mineral processing' and 'construction and other industry' sectors respectively in order to forecast activity levels in 2025 to 2050.

The glass industry has provided estimates of future levels of dust emissions which take account of the fitting of particulate matter abatement systems at those remaining glass kilns that are unabated. These

[102] The Merchant Shipping and Other Transport (Environmental Protection) (Amendment) (EU Exit) Regulations 2019 (legislation.gov.uk)

estimates have been used to generate emission factors for 2025-2050. The glass industry also suggested emission estimates for NO_X and SO_X in 2025-2040, however, because glass kilns are not included as a separate source in the UK inventory, it has not been possible to incorporate these forecasts in the UK emission projections. For these pollutants and for all other sources within 2A, factors have been held at the same level as in 2022 in the absence of any information on changes in abatement.

9.2.8. NFR 2B: Chemical Processes

The chemical industry is represented in the NAEI using a combination of general categories, covering multiple sites, and highly specific categories that often relate to only one or two sites in the UK. As a general rule, we use the trend in EEP for 'chemicals and man-made fibres' for the former, and generally assume no change in activity for the latter unless we have specific information on either closures, plant expansions or new plants. The rationale for this is that we assume that all plants operating in the base year will be operating fairly close to their design capacity and that substantial changes in activity will only occur through closure of sites and/or construction of new or larger plants.

Historical emission estimates for NFR 2B are all based on Tier 3 type methods i.e. site-specific emissions data. However, we have no information on any abatement currently in place or any information on any changes in abatement that might be required in future. Therefore, our default assumption is to assume that emission factors for the 2022 base year are appropriate for 2025-2050 also. Previously the only exception to this was for NMVOC emissions from large-scale organic chemical processes. Here, the trade body collected information from members which indicated that operators of two sites expected to reduce NMVOC emissions by 1.1 kt by 2022, while another operator expected no change in the future. The trade body recommended this 1.1 kt figure be used as an assumption for the total reduction from the sector, while highlighting that it is likely to be a substantial underestimate since it was based on only 3 out of more than 25 sites. However, 2022 is now covered by the historical NAEI and so we have therefore assumed that any reductions that did ultimately occur for NMVOC emissions from NFR 2B will be reflected in the historical NAEI (which uses operator-reported emissions data from the PI etc).

9.2.9. NFR 2C: Metal Processes

Emissions reported in 2C are dominated by those emissions from manufacture of steel, either in integrated works, or using electric arc furnaces. There is relatively little production of primary non-ferrous metals in the UK. The UK now has only two integrated steelworks and four large electric arc steelworks.

In 2023, the last coke ovens at the Scunthorpe Steelworks were closed. There have also been proposals regarding future operations at both of the integrated steelmaking sites in the UK.

In Port Talbot, the operator, Tata Steel, has proposed the closure of the blast furnaces (BF), basic oxygen furnaces (BOF), sinter plant, coke ovens, and some of the downstream operations including the cold rolling mills (including annealing furnaces). The BF-BOF steelmaking route at Port Talbot would then be replaced with a single electric arc furnace (EAF) with annual capacity of ~3 million tonnes. Based on information in the public domain regarding the current proposals, we have assumed that the blast furnaces and associated plants are shut by the end of 2024. The hot rolling mill is assumed to continue operating, initially using imported steel and then using steel from the EAF which we have assumed will become operational no earlier than 2027. We have not found any information on plans for the power plant but the closure of the blast furnaces in 2024 would mean that blast furnace gas (BFG) is no longer available as a fuel. Since the proposals seem to envisage no steel production in 2025, we have assumed that the power plant boilers are not operated in that year but that they are returned to service once the EAF begins production. Currently the boilers mainly burn BFG and natural gas and we assume in 2030 and thereafter only natural gas is burnt. Rolling mill furnaces currently mainly burn coke oven gas (COG) and natural gas but COG will no longer be available if the coke ovens close in 2024, so we assume natural gas is the only fuel burnt.

Similar plans have been proposed by British Steel for the Scunthorpe steelmaking facility[103]. British Steel shut the last operating coke ovens in June 2023. The plans are to build two new EAFs, one at Scunthorpe and the other one at Lazenby on Teesside. Plans were submitted to the local authority in early 2024[104]. Under the current proposal, the blast furnaces and the remaining associated plants will be operational until the new EAFs are commissioned towards the end of 2025. From the available sources in the planning application of British Steel, the capacity of the EAFs at Scunthorpe and Teesside are 130 and 100 tonnes respectively. It has been assumed that these furnace capacities translate into annual capacities of 1.5 and 1.2 million tonnes per annum respectively. As with Port Talbot, there is less certainty regarding the site boilers and we have assumed these continue to operate continuously, albeit with a change to using natural gas only after closure of the blast furnaces. Rolling mill furnaces are also assumed to remain operational, again only using natural gas.

Activity forecasts for the main fuel-related sources at other iron and steel industry works are then based on EEP fuel use forecasts. We have assumed that the changes in fuels for the Port Talbot and Scunthorpe boilers and rolling mill furnaces does not affect the emissions of NO_X and $PM_{2.5}$ but we do take account of the much lower emissions of SO_2 that would result from ceasing to burn process off-gases. The assumption of constant NO_X and $PM_{2.5}$ emission factors despite the change in fuels for the boilers and furnaces is because of a lack of information indicating what change would occur. Emission limit values (ELVs) for the boiler and furnace stacks could potentially be revised by regulators with changes in the fuels used but it is not clear if current releases are below the level of any future ELVs.

There is also little clarity on dust emissions from the storage areas of the two steelworks. At the moment it is assumed that dust emissions occur due to the presence of large stockpiles of iron ore. Our assumption is that stockpiles will not necessarily disappear at the point that the blast furnaces close – instead it is possible that some small amounts of iron ore could remain on site, at least for a period. Other materials such as coal and fluxes are currently also stored and materials will continue to be stored for the electric arc furnaces. However, we have assumed that once the blast furnaces close, there will no longer be stockpiles of iron ore which are continuously being added to or removed to be fed to the sinter plant and that therefore any piles that remain can be kept wetted or have their surfaces coated so as to minimise emissions. We therefore have assumed that dust from stockpiles ceases after closure of the blast furnaces at each site.

We have included assumptions for a few operations that are directly associated with the two steelworks (such as a works grinding blast furnace slag at Port Talbot) although emissions from these sites are relatively trivial.

The assumptions detailed above, based on information in the public domain, are uncertain since the final shape of plans at each site has yet to announced. There is also uncertainty regarding the wider impact of any changes – what other sites or plant might either be closed down or perhaps built. All of the assumptions for Scunthorpe and Port Talbot will need to be reviewed for the next iteration of the projections.

For other electric arc furnace sites and other metal industry process sources we adopt the trends given in EEP for 'iron and steel', 'non-ferrous metals' or 'engineering and allied industries'.

[103] See https://britishsteel.co.uk/media/mwnp344v/british-steel-proposals.pdf
[104] https://apps.northlincs.gov.uk/application/pa-2024-123, accessed on 16/02/2024

9.2.10. NFR 2D: Solvent Use

Solvent use can be split into that which is consumed by industry in various manufacturing processes, and that which is in consumer products such as paints and cosmetics, used by the general public. In the former case, it is possible to regulate that use in a number of ways and substantial reductions in levels of emissions have in fact been made since the mid-1990s as a result of regulation introduced both by the UK, and later by the EU. In the case of solvent use in consumer products, emissions can only be reduced by eliminating or reducing the levels of solvent in those products, and since there has been comparatively little regulation specifically of the NMVOC content of many of these consumer products, we have assumed that emissions have not reduced to the same extent.

Due to the notable reductions in NMVOC emissions from industrial solvent use since the late-1990s, we consider that further large reductions are unlikely in many sectors. Many of the largest industrial users of solvent have installed abatement equipment to reduce NMVOC emissions and should already be compliant with IED. In most sectors it is likely that there will continue to be modest reductions in emissions over time as business develops improvements in processes or reformulates products to reduce the need for solvents. However, quantifying any changes is difficult and so for many sectors we adopt the conservative approach of assuming no change in emission factors between 2020-2040. For some of the most important sectors, we do have information from industry:

- The British Coatings Federation (BCF) has provided estimates for NMVOC emissions in 2030 and 2050 from the use of decorative paints, industrial paints, and inks, which we have used as a basis for forecasts. The BCF do expect further reductions in solvent content of certain types of coating in the period from 2025 to 2040, and also expect some reductions in sales of some coatings due to changes in the market.
- The British Adhesives and Sealants Association (BASA) have provided NMVOC forecasts to 2030 for both industrial and consumer/DIY adhesives. As with the BCF data, BASA predict changes in the markets for different types of adhesive formulation although the overall impact on NMVOC emissions is relatively small.
- For non-aerosol consumer products, we have estimated consumption to 2023 for many categories of product, these estimates having been developed by market research organisation Euromonitor. For the period from 2024 onwards, we assume the same average annual change as is predicted for the 2019-2023 period. Emission factors for each category of product are assumed to remain unchanged to 2050.
- For aerosols, the British Aerosol Manufacturers Association (BAMA) have indicated that assuming that emissions change in line with population is a reasonable approach in the absence of detailed data.

The information from BCF, BASA, Euromonitor and BAMA covers a large proportion of emissions reported in 2D3 (roughly 60% in 2020). Emission factors for the remaining sectors are assumed to remain constant in the absence of information from industry: as indicated above, this is likely to be conservative but unlikely to lead to a large overestimation due to the fact that significant industrial solvent users are already regulated and have been for many years.

9.2.11. NFR 2G: Other Product Use

The sources in NFR 2G include fireworks and cigarettes. Following the closure of the last UK manufacturer, all fireworks are now imported and import figures confirm that demand was higher in 2022 than in 2020, although not as high as 2019 levels. We have projected use of fireworks based on population and from a 2022 baseline.

For cigarettes, consumption has been in steady decline in the UK for decades and the overall downward trend seen over the past two decades is assumed to continue. The historical trend in tobacco consumption equates to an annual reduction in tobacco consumption of about 2.4%. As with fireworks, emission factors are held constant.

9.2.12. NFR 2H: Food, Drink Manufacture and Paper Production

The food and drink sector is a substantial contributor to NMVOC emissions, mainly due to the ethanol emissions associated with the manufacture of alcoholic drinks, but also due to other sources such as baking and cooking and processing of meats, fats, oils and animal feeds. NMVOC emissions from these sources are not regulated and so emission factors for 2022 are considered equally appropriate for 2025-2050. Activity projections generally rely on the EEP industrial output projection for the food, drink and tobacco sector.

9.2.13. NFR 2I: Wood Products Manufacture

Historical emission estimates for NMVOCs from processes manufacturing fibreboard, chipboard and similar wood products are based on site-specific emissions data. We have no information on any abatement currently in place or any information on any changes in abatement that might be required in future at these sites and therefore, as a conservative approach, assume that 2022 emission factors are also appropriate for 2025 onwards. The trend given in EEP for the 'construction and other industry' sector have been used to forecast activity levels in 2025-2050.

9.2.14. NFR 3: Agriculture

Air quality pollutant emission projections have been made for the UK Agriculture sector for the years 2023-2040 using the Scenario Modelling Tool (SMT, Defra project ECM 55618) to provide scaled projections based on the year 2022 of the 2024 UK inventory submission The years 2041 to 2050 are currently rolled from the 2040 output from the SMT, i.e. emissions are flatlined.

Activity data projections for livestock numbers, milk yield and crop areas to 2032 were supplied by Defra (January 2024) using the UK Agricultural Market Model (UKAMM), and for quantities of digestate to be applied to land to 2035 by Ricardo, based on energy production projections. The UKAMM provides projections at the UK level, therefore the same scalars were applied for livestock numbers, milk yield and crop areas across all Devolved Administrations.
Summary projections of the air quality pollutant emissions are given in Table 9-3Table 9-3 Summary air quality pollutant emission projections (kt pollutant) to 2040 for the UK Agriculture sector, showing a 0.5% decrease in ammonia emissions between 2022 and 2040, due to the combination of a projected decrease in cattle and sheep livestock numbers, projected decreases in emissions from manure spreading (based on assumptions around increased uptake of spreading mitigation methods), being offset by increased emissions from digestate being spread to land.

Agriculture is the dominant source of ammonia emissions in the UK; the trend in ammonia emissions from agriculture from 1990 and projected to 2040 is given in Figure 9-1. No further change is currently projected from 2040 to 2050. Baselines for 1990 and 2005 are shown, relevant to the previous NECR and current revised NECR emission ceilings target setting process. An estimated emission reduction of 19.3% is projected for the agriculture sector between 1990 and 2040, and just a 4.9% reduction between 2005 to 2040.

The underlying trends in activity data for livestock numbers, nitrogen fertiliser use and quantity of digestate spread to land are given in Figure 9-2, Figure 9-3 and Figure 9-4.

The reduction in ammonia emissions over the period 1990-2008 can clearly be linked to declining livestock numbers across most livestock sectors and to a reduction in the use of fertiliser nitrogen. The 2013-2018 period saw an upturn in emissions which was largely a result of increasing livestock numbers, increasing milk yield (and hence nitrogen excretion) in dairy cows, increasing quantities of digestate being applied to land and an increase in the proportion of nitrogen fertiliser that is applied as urea, which is associated with a much higher emission factor than other fertiliser types. Between 2021 and 2022 nitrogen fertiliser use declined by 16.9% (Figure 9-3; which is associated with the increased fertiliser prices caused by higher energy prices in 2022), the projections from 2023 assume that fertiliser rates to crop and grassland in future years will remain the same as for 2022. This may prove unrealistic if there is a later reduction in fertiliser prices and rates of application consequently increase. Projected emissions remain relatively constant to 2040 with increasing digestate application, offset to some extent by declining cattle and sheep numbers and increased uptake of low emission slurry spreading equipment (LESSE) as an ammonia mitigation method.

The projections include increased uptake of mitigation methods as detailed by the Northern Ireland, Scottish and Welsh governments and described in full below (Section 4). Greater uptake of LESSE methods and incorporation of manures into bare soils has a direct effect on ammonia emissions from spreading, declining by 10.3% between 2022 and 2040.

Table 9-3 Summary air quality pollutant emission projections (kt pollutant) to 2040 for the UK Agriculture sector

Pollutant	2022	2025	2030	2035	2040
NH_3	226.56	223.49	226.29	225.41	225.39
NO_X	24.09	24.29	24.47	24.41	24.41
$PM_{2.5}$	2.75	2.72	2.67	2.64	2.64
NMVOC	131.93	130.01	126.73	125.17	125.17

Figure 9-1 Trend and projections for ammonia emissions from UK agriculture, 1990 – 2040; horizontal grey lines are the emission totals for the base years 1990 and 2005

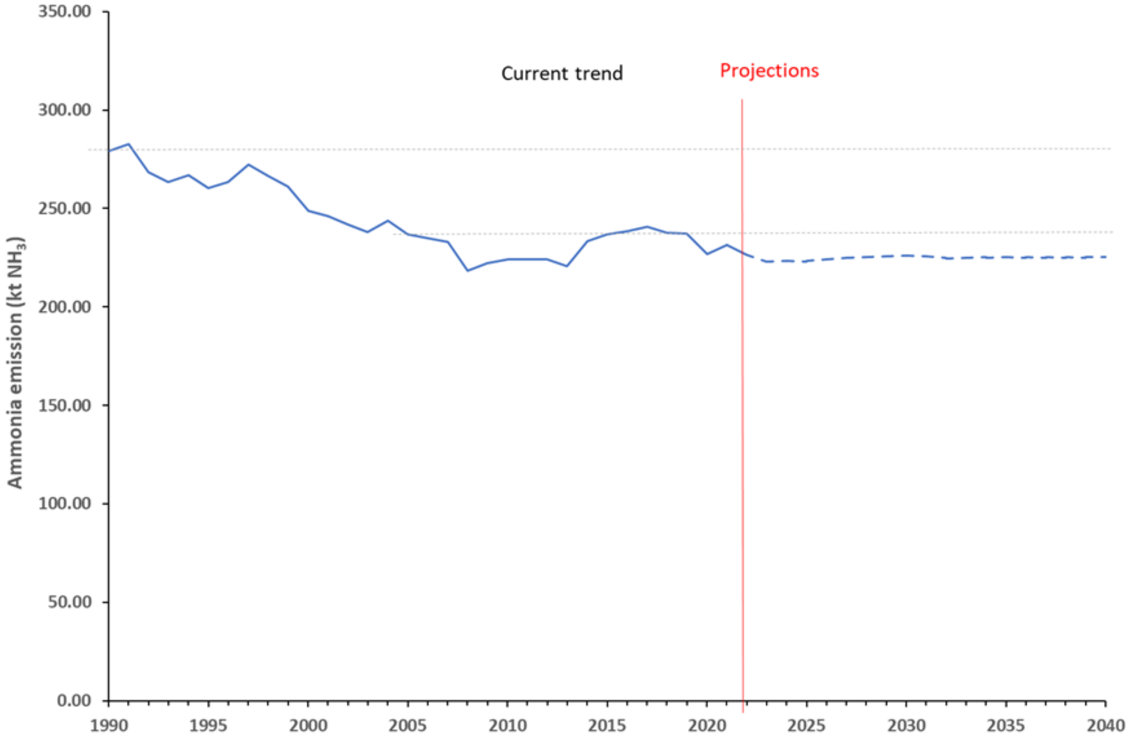


Figure 9-2 Trend and projections in UK livestock numbers, 1990 – 2040

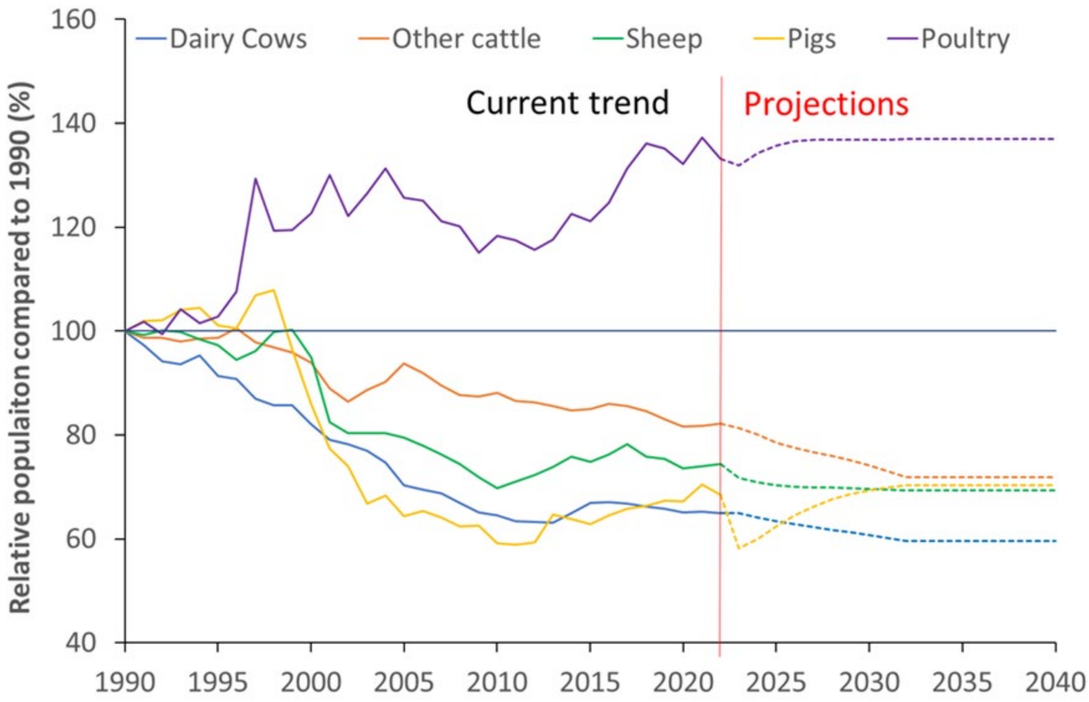


Figure 9-3 Trend and projections in UK fertiliser nitrogen use, 1990 – 2040

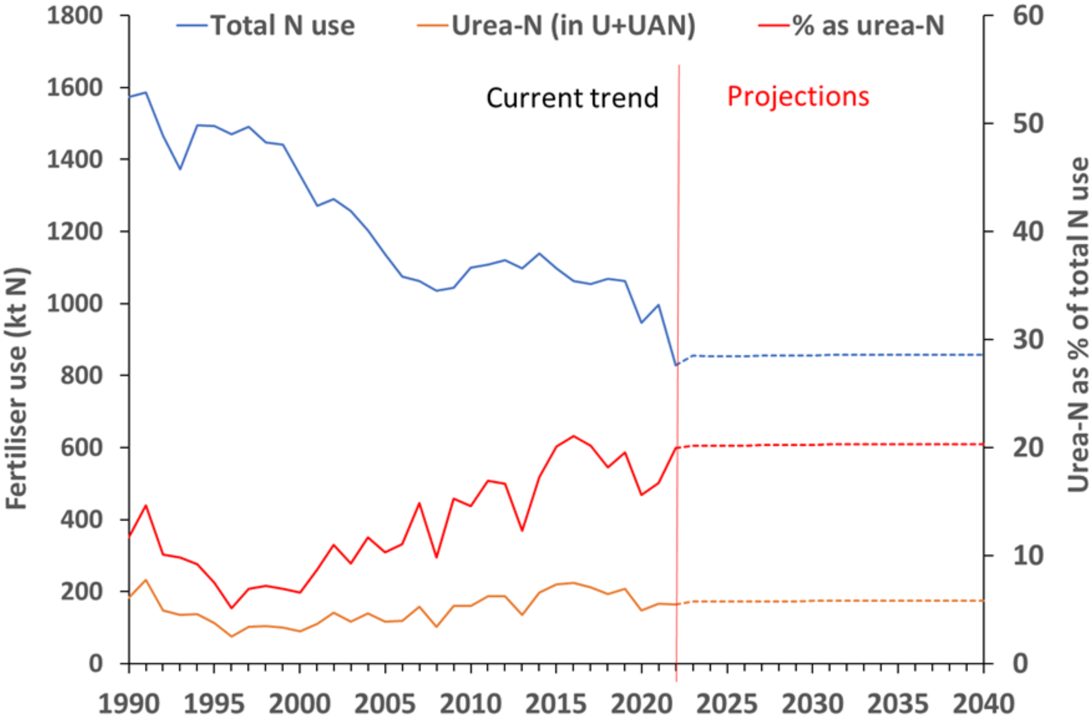
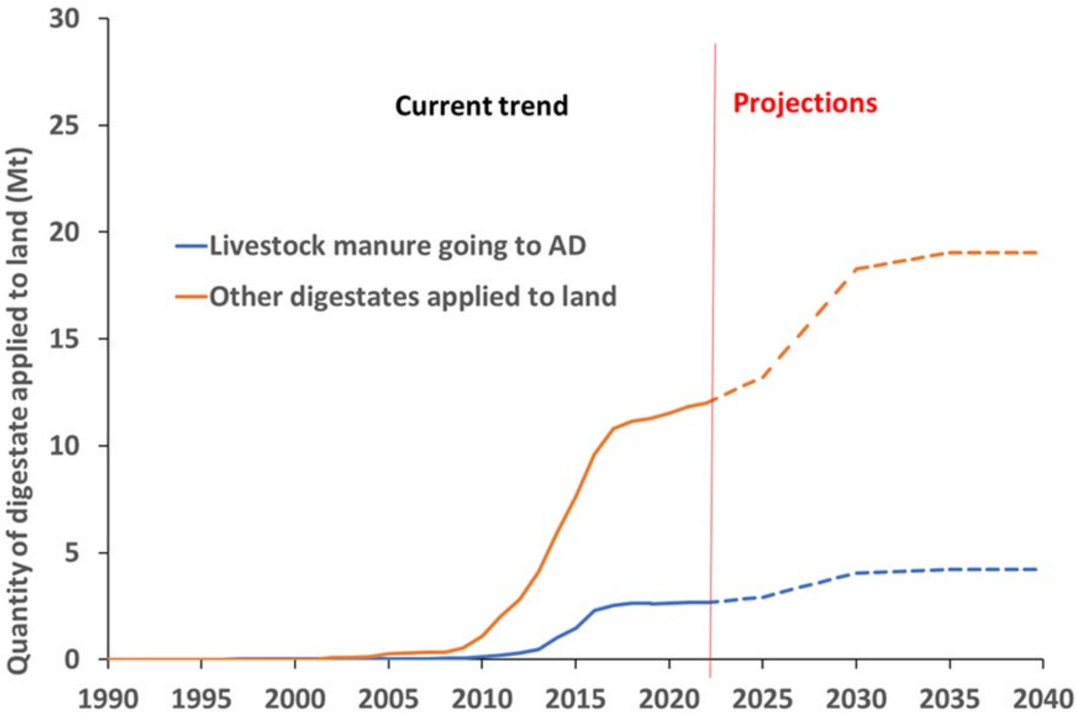


Figure 9-4 Trend and projections for digestate application to land in the UK, 1990 - 2040



9.2.14.1. Notes on methodology

Livestock numbers

Livestock number projections from 2023 to 2032 for major livestock categories (dairy cows, beef cows, ewes, total pigs, total poultry) were given by Defra (UKAMM, 2024) at the UK level, with scalars derived for each livestock category between a 2022 baseline and subsequent projection years. These scalars were applied in the SMT to the SMT 2022 baseline numbers. Numbers of young cattle and lambs were scaled in proportion to the provided numbers of breeding animals.

For years 2033-2040, livestock numbers were flat-lined at the 2032 values. Livestock subcategory numbers within cattle, sheep, pigs and poultry were assumed to remain at the same ratio as for 2032 for each of the subsequent projection years.

No projections were made in UKAMM for numbers of horses, goats or deer (these are minor livestock categories); 2023-2040 numbers for these categories were kept at a constant value corresponding to the 2022 numbers.

Dairy cow milk yield

Milk yield projections were provided by Defra (UKAMM, 2024) at the UK level. For the period 2033-2040, milk yield was kept constant at the projected 2032 value.

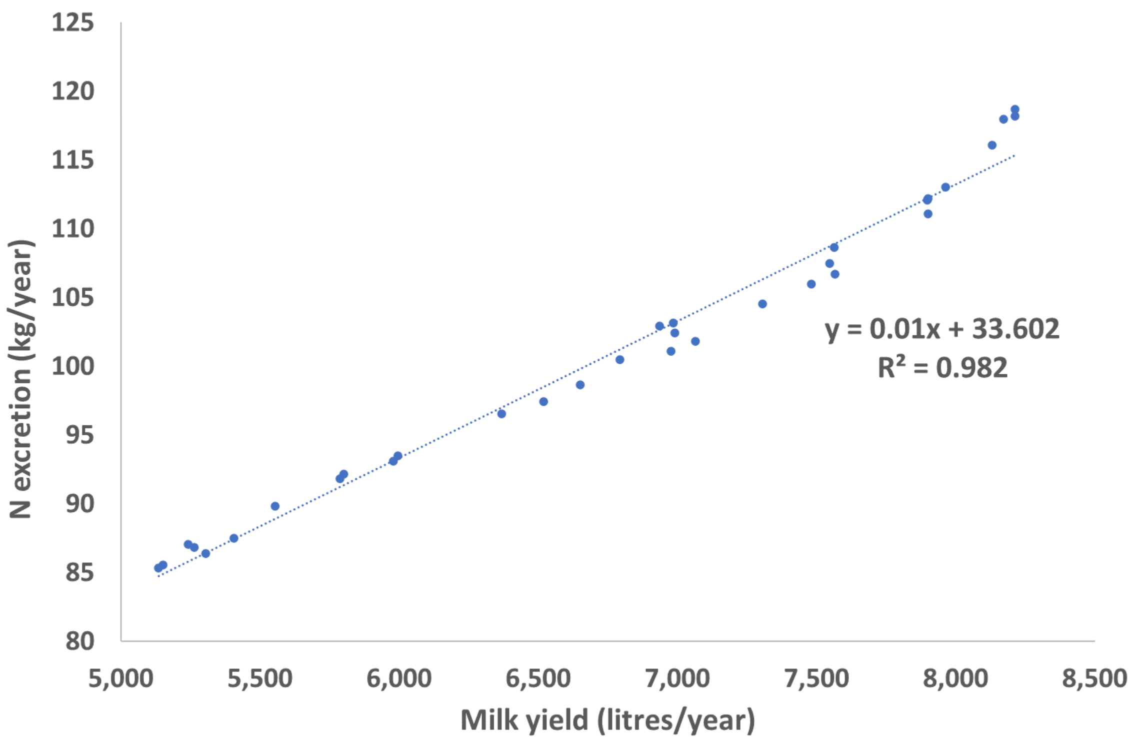
N excretion by livestock

For all livestock except dairy cows, annual N excretion for the years 2023-2040 was assumed to be the same as the 2022 value. For dairy cows, a historical relationship between dairy cow milk yield and N excretion was derived (Table 9-4). A scalar based on this relationship and the projected milk yield per dairy cow (Figure 9-5) was applied to dairy cow N excretion to reflect the projected increase in milk yield.

Table 9-4 Nitrogen excretion scalars applied in the SMT for dairy cows

	2023	2025	2030
Scalar	0.992	1.021	1.052

Figure 9-5 Relationship between dairy cow N excretion and milk yield, based on UK inventory values 1990 – 2022



Crop areas and fertiliser N use

The UKAMM projections did not include any explicit projections for total fertiliser N use. Projections of crop area were included for some major crops (wheat, barley, oats, and sugar beet and oilseed rape) for the period 2023-2032 and these were used to generate projections of total N use based on the existing inventory N application rates per crop for 2022. For the period 2033-2040, fertiliser N use values were kept constant at the 2032 value, which was based on the UKAMM crop area projections for that year. The types of fertiliser in use and the use of urease inhibitors with urea fertiliser applications were kept at 2022 values for the period 2023-2040.

Manure management systems

The proportion of manure from each livestock category managed according to the different manure management systems was kept constant at the 2022 value for the period 2023-2040.

Implementation of mitigation methods

The projections presented include increased uptake of mitigation methods as detailed by the Northern Ireland, Scottish and Welsh governments. The Nutrients Action Plan for NI (https://www.daera-ni.gov.uk/publications/nutrient-action-programme-regulations-northern-ireland-2019-22-and-associated-documents) and the Farming and Water Scotland document (https://www.farmingandwaterscotland.org/wp-content/uploads/2022/11/KTR8Organic-fertiliser.pdf) set out regulations for the land application of slurries and digestate. The rules state that Low Emission Slurry Spreading Equipment (LESSE; consisting of bandspreading, dribble bar, trailing hose, trailing shoe or soil injection methods and including soil incorporation in Northern Ireland) must be used for all digestate application to land which is already implemented in the current inventory. Additionally, the use of LESSE for all slurry spread by contractors and on large cattle farms (with > 100 dairy cows or > 200 beef cattle) and pig farms (with > 800 sows or fatteners) in Northern Ireland and Scotland, from 2022 and 2023 respectively, has been added as a mitigation measure in the projections.

The increased use of LESSE has been represented by increasing the use of trailing hose equipment, which has a higher emission reduction factor than conventional practice but is not the most effective of the LESSE methods. Further mitigation could be achieved by increased use of trailing shoe equipment (on grassland) or injectors. In Scotland the current rules for large pig and cattle farms will apply to all slurry on farms of all sizes from 2027. No end date for achieving 100% of slurry spreading using LESSE has been set for Northern Ireland, therefore minimum uptake under the new regulations was assumed to be reached by 2030. In Wales under the Control of Agricultural Pollution Regulations (https://www.gov.wales/water-resources-control-agricultural-pollution-wales-regulations-2021-guidance-farmers-and-land) any organic manure applied to bare soils must be incorporated within 24 hours under most circumstances. Projected changes in the uptake of mitigation methods are included in Table 9-5. Greater uptake of LESSE methods and incorporation of manures into bare soils has a direct effect on ammonia emissions from spreading, declining by 10.3% between 2022 and 2040.

From 1st April 2024 businesses that abide by the Red Tractor Standards and intend to use fertilisers containing urea will be required to apply only protected/inhibited fertilisers outside of a permitted window of 15th Jan to 31st Mar. The use of unprotected/uninhibited fertiliser between 1st April and the last application in autumn will require agronomic justification provided by FACTS-qualified farm personnel or advice specific to the crop provided by a FACTS-qualified advisor. This voluntary standard which applies only in England might be expected to increase the uptake of protected/inhibited urea fertiliser, but the scale of the outcome is uncertain and has therefore not been included in these projections.

Table 9-5 Assumed changes to uptake of manure spreading mitigation measures for Northern Ireland, Scotland and Wales (no new regulations have been applied to England)

Country	Livestock and land use	Mitigation measure	Current implementation rates (% of manure)	Projected implementation (% of manure)							
			2022	2023	2024	2025	2026	2027	2028	2029	2030
Northern Ireland											
	Dairy slurry to grassland	LESSE	62.1	64.6	67.0	69.5	72.0	74.4	76.9	79.4	81.8
	Dairy slurry to arable	LESSE	41.3	43.7	46.2	48.7	51.1	53.6	56.1	58.5	61.0
	Dairy slurry to arable	Incorporation	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8
	Dairy slurry to arable	Current total uptake	62.1	64.6	67.0	69.5	72.0	74.4	76.9	79.4	81.8
	Beef slurry to grassland	LESSE	52.0	53.2	54.5	55.7	57.0	58.2	59.4	60.7	61.9
	Beef slurry to arable	LESSE	24.4	25.6	26.9	28.1	29.3	30.6	31.8	33.1	34.3
	Beef slurry to arable	Incorporation	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6
	Beef slurry to arable	Current total uptake	52.0	53.2	54.5	55.7	57.0	58.2	59.4	60.7	61.9
	Pig slurry to grassland	LESSE	95.8	96.1	96.3	96.6	96.9	97.2	97.4	97.7	98.0
	Pig slurry to arable	LESSE	78.5	78.8	79.1	79.3	79.6	79.9	80.2	80.4	80.7
	Pig slurry to arable	Incorporation	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3
	Pig slurry to arable	Current total uptake	95.8	96.1	96.3	96.6	96.9	97.2	97.4	97.7	98.0
Scotland											
	Dairy slurry to grassland	LESSE	25.7	93.3	95.0	96.6	98.3	100.0	100.0	100.0	100.0
	Dairy slurry to arable	LESSE	25.7	70.0	77.5	85.0	92.5	100.0	100.0	100.0	100.0
	Dairy slurry to arable	Incorporation	29.1	23.3	17.5	11.7	5.8	0.0	0.0	0.0	0.0
	Dairy slurry to arable	Current total uptake	54.8	93.3	95.0	96.6	98.3	100.0	100.0	100.0	100.0

	Beef slurry to grassland	LESSE	25.7	65.4	74.0	82.7	91.3	100.0	100.0	100.0	100.0
	Beef slurry to arable	LESSE	25.7	42.1	56.6	71.0	85.5	100.0	100.0	100.0	100.0
	Beef slurry to arable	Incorporation	29.1	23.3	17.5	11.7	5.8	0.0	0.0	0.0	0.0
	Beef slurry to arable	Current total uptake	54.8	65.4	74.0	82.7	91.3	100.0	100.0	100.0	100.0
	Pig slurry to grassland	LESSE	51.3	94.2	95.7	97.1	98.6	100.0	100.0	100.0	100.0
	Pig slurry to arable	LESSE	51.3	82.9	87.2	91.5	95.7	100.0	100.0	100.0	100.0
	Pig slurry to arable	Incorporation	14.1	11.3	8.4	5.6	2.8	0.0	0.0	0.0	0.0
	Pig slurry to arable	Current total uptake	65.4	94.2	95.7	97.1	98.6	100.0	100.0	100.0	100.0
Wales											
	Dairy slurry to arable	LESSE	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7
	Dairy slurry to arable	Incorporation	29.1	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
	Dairy slurry to arable	Current total uptake	54.8	75.7	75.7	75.7	75.7	75.7	75.7	75.7	75.7
	Dairy FYM to arable	Incorporation	50.7	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
	Beef slurry to arable	LESSE	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7
	Beef slurry to arable	Incorporation	29.1	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
	Beef slurry to arable	Current total uptake	54.8	75.7	75.7	75.7	75.7	75.7	75.7	75.7	75.7
	Beef FYM to arable	Incorporation	50.7	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
	Pig slurry to arable	LESSE	51.3	51.3	51.3	51.3	51.3	51.3	51.3	51.3	51.3
	Pig slurry to arable	Incorporation	14.1	48.7	48.7	48.7	48.7	48.7	48.7	48.7	48.7
	Pig slurry to arable	Current total uptake	65.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Pig FYM to arable	Incorporation	50.7	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
	Poultry manure to arable	Incorporation	53.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0

Uncertainties

Fertiliser use – in addition to uncertainties in total fertiliser N use, emission projections are very sensitive to changes in the relative proportion of different fertiliser types (urea in particular). Future updates would benefit from industry forecasts regarding urea use (and use of urease inhibitors), if available, and/or providing scenarios based around probable uncertainty bounds.

Livestock management practice data – projections presented here assume no changes in livestock and manure management practices (e.g. feeding practices, housing types, housing periods, manure storage methods). Future updates would benefit from industry forecasts regarding management practices, if available, and/or providing scenarios based around probable uncertainty bounds.

Emission factors – all emission factors (or algorithms determining emission factors) remain constant over the projections period and no potential influences of any climate changes have been factored in.

9.2.15. NFR 5: Waste

Emissions of NMVOCs from landfills have been projected from emission projections for methane. These are available from BEIS (now DESNZ) (at https://www.gov.uk/government/statistical-data-sets/non-co2-greenhouse-gas-emissions-projections-report-summer-2015) and they are converted into NMVOC projections by assuming that NMVOC emissions continue to have the same relationship to methane emissions as in the 2022 base year. The BEIS projections for methane assume that quantities of waste sent to landfill decline over time as a result of the Landfill (England and Wales) Regulations 2002, and that there are also small improvements in landfills which reduce methane emissions. A similar approach is used for emissions of NH_3 and particulate matter with emissions in 2025-2040 assumed to follow the exact same trend as methane. Emissions from this source between 2040 to 2050 are flat-lined in lieu of alternative data. It is planned to updated the projections for the landfill sector using the most recent data available.

Emissions from composting, both by households and at waste disposal sites are also based on the BEIS methane emission projections, with trends for ammonia emissions assumed to follow the same trend as given for methane.

Projected ammonia emissions from anaerobic digestion (AnD) have been calculated based on data in DUKES for historical electricity generation from AnD in 2013 – 2022, and with the assumption that electricity generation from this sector is expected to grow, in line with the Government's objectives, as set out in Defra's "Anaerobic Digestion Strategy and Action Plan" (2011) and BEIS' "Consultation Stage IA: Future Support for Low Carbon Heat" (2020).

Based on the most recent data and literature available, the best estimate emission factor for fugitive and storage emissions at UK AnD plants (weighted average) is 0.08 kg NH_3-N/ t fresh weight feedstocks (range 0.04 – 0.14 kg/t) (Tomlinson et al., 2019). The 2022 emissions estimate has been used as the baseline for the projected emissions. All inputs to AnD plants that were classed as manure or slurry, along with all digestate production, were not used to calculate emissions from storage and processing at AnD plants in 2022. This information was used instead within the agricultural inventory.

For waste incineration, we have assumed that activity levels are proportional to population (in the case of clinical waste incineration and cremation), stay constant (in the case of sewage sludge incineration and animal carcass incineration, or are proportional to chemical sector output (in the case of chemical waste incineration).

Note that sewage could realistically be assumed to grow with population, but the UK only incinerates sewage sludge at a handful of sites and because we are not aware of any further incinerators being planned, we assume constant activity in this sector. We have no information on any abatement currently in place at any of the incinerator sites or any information on any changes in abatement that might be required in future and therefore, as a conservative approach, we assume that 2022 emission factors are also appropriate for future years.

Emissions from small-scale waste burning, such as burning of waste on open grate fires and outside, on garden bonfires, is assumed to stay constant at 2022 levels.

Emission factors for waste-water treatment are held constant at 2022 levels but the level of activity is assumed to change: in line with population growth for public sewage treatment works, and in line with growth in the food, drink and tobacco sector for industrial waste-water plant.

9.2.16. NFR 6A: Other (Included in National Total for Entire Territory)

The projections in this sector are derived by scaling the latest inventory year, 2022, with projected population figures provided by DESNZ (EEP 2022).

Emissions of non-agricultural horses are assumed to be constant from 2022 onwards.

9.3. Progress Against UK Air Quality Emission Commitments

The emission projections take account of measures in place as far as is possible, given the data available, but do not reflect measures which are still in development (as per the EMEP/EEA Guidebook requirements for projections 'with existing measures').

The Gothenburg Protocol sets emission reduction commitments (ERCs) for NO_X, SO_X, NMVOCs, NH_3 and for $PM_{2.5}$ to be achieved in 2020 and beyond. The NECR sets emission reduction commitments for 2020 to 2029 (in line with the Gothenburg Protocol commitments – though the totals for compliance differ slightly for NMVOCs and NO_X as is explained below) as well as more stringent emission reduction commitments for 2030 (and in each subsequent year) for the same air pollutants. These are ambitious reduction commitments, which aim to reduce the health impacts of poor air quality by half by 2030.

Table 9-5 shows how the latest emission totals compare with 2020 to 2029 emission reduction commitments (ERCs) based on applying the NECR and Gothenburg Protocol ERCs to the current 2005 baseline. The National Totals used for compliance assessment under the NECR and Gothenburg Protocol differ. Under the NECR, NMVOCs and NO_X emissions from 3B (Manure Management) and 3D (Crop Production and Agricultural Soils) are not accounted in the National Total for the purpose of complying with the 2020 to 2029 (or 2030) emission reduction commitments. Under the Gothenburg Protocol these exceptions are not valid, and the National Totals include emissions of subsectors including 3B and 3D. Thus, emissions of NMVOCs and NO_X are displayed in two separate columns, one column showing emissions excluding emissions from 3B and 3D (NO_X *(exclude 3B and 3D)*, *NMVOCs (exclude 3B and 3D)*) and one column showing total emissions (*NMVOCs*, NO_X).

The progress made towards the 2020 - 2029 ERCs has been shown in two ways. Firstly, the reduction achieved in emissions between the 2005 base year and 2020 has been shown as a percentage of the reduction required to meet the ERCs (see row 'Progress to date towards 2020 – 2029 ERC'). Secondly, the row 'Emission reduction required from 2022' shows the amount of reduction required by 2025 from current (i.e. 2022) emissions to reach the 2020 - 2029 commitment. This shows that the reductions required to meet the estimated 2020 - 2029 ERCs for SO_X, NO_X, and NMVOC emissions have been achieved in 2022.

Emissions of NH_3 were at similar levels in both 2005 and 2020/2022 so further reductions would be required to meet the 2020 – 2029 and 2030 ERCs. It should be noted that the National Compliance Totals for NH_3 for all years, as shown in Table 9-5 and Table 9-6 do take account of the 2022 emission adjustment application[105]. As such the 2020-2029 and 2030 ERCs were applied to the adjusted 2005 National Compliance Total to calculate the ERCs for 2020-2029 and 2030.

Similarly Table 9-6 shows how the latest emission totals compare with 2030 based on applying the NECR 2030 ERCs to the current 2005 baseline.

Table 9-5 Comparison of UK projected 2025 national emissions with the 2020 - 2029 NECR / Gothenburg ERCs.[106]

Pollutant	NH_3 [c]	NO_X (as NO2) (exclude 3B and 3D)[b]	NO_X *(as NO2)*	SO_X (as SO2)	NMVOCs (exclude 3B and 3D)[b]	NMVOCs [c]	$PM_{2.5}$
2005 National Compliance Total, kilotonnes	280.48	1,695.70	1,724.94	781.83	1,123.42	1,239.20	109.48
2022 National Compliance Total, kilotonnes	246.14	619.21	643.30	120.23	623.66	755.59	64.89
Emission reduction commitment (ERC)	8%	55%	55%	59%	32%	32%	30%
2020 - 2029 target, kilotonnes[d]	258.04	763.06	776.23	320.55	763.92	842.66	76.63
Progress to date towards 2020 - 2029 ERCs	153%	115%	114%	143%	139%	122%	136%
Emission reduction required to date from 2020 onwards	0	0	0	0	0	0	0
Projected 2025 National Total, kilotonnes	241.96	550.94	575.23	106.64	622.01	752.03	62.86
Above or below 2020 - 2029 targets in 2025, kilotonnes	-16.08	-212.12	-201.00	-213.91	-141.91	-90.63	-13.77

[a] Figures presented in this table for NH_3 take account of the approved adjustment regarding NFR sector 3Da2c.

[b] The NMVOCs and NO_X figures quoted in this column exclude emissions from 3B and 3D. Under the NECR, NMVOCs and NO_X emissions from 3B and 3D are not accounted in the National Total for the purpose of complying with the 2020-29 (or 2030) emission reduction commitments.

[c] Under the Gothenburg Protocol NMVOCs and NO_X emissions from 3B and 3D are counted in the National Total for the purpose of complying with the 2020 (and beyond) emission reduction commitments.

[d] The 2020-29 and 2030 emission reduction commitments have been calculated using the 2005 emissions of the current inventory submission as the base year.

[105] https://uk-air.defra.gov.uk/reports/cat09/2203151457_UK_Annex_IIa_to_ECE-EB.Air130_Adjustment_Application_2022Submission_v1.xlsx

[106] Emissions are rounded.

Table 9-6 Comparison of UK projected 2030 national emissions with the 2030 NECR ERCs.[107]

Pollutant	NH_3[a]	NO_X (as NO2) (exclude 3B and 3D)[b]	SO_X (as SO2)	NMVOCs (exclude 3B and 3D)[b]	$PM_{2.5}$
2005 National Compliance Total, kilotonnes	280.48	1,695.70	781.83	1,123.42	109.48
2022 National Compliance Total, kilotonnes	246.14	619.21	120.23	623.66	64.89
Emission reduction commitment	16%	73%	88%	39%	46%
2030 target, kilotonnes[c]	235.60	457.84	93.82	685.29	59.12
Progress to date towards 2030 reductions	77%	87%	96%	114%	89%
Emission reduction required from 2022	10.54	161.37	26.41	0.00	5.77
Projected 2030 National Total, kilotonnes	239.64	434.34	101.85	617.37	60.38
Above or below 2030 targets by, kilotonnes	**4.04**	-23.50	**8.03**	-67.92	**1.26**

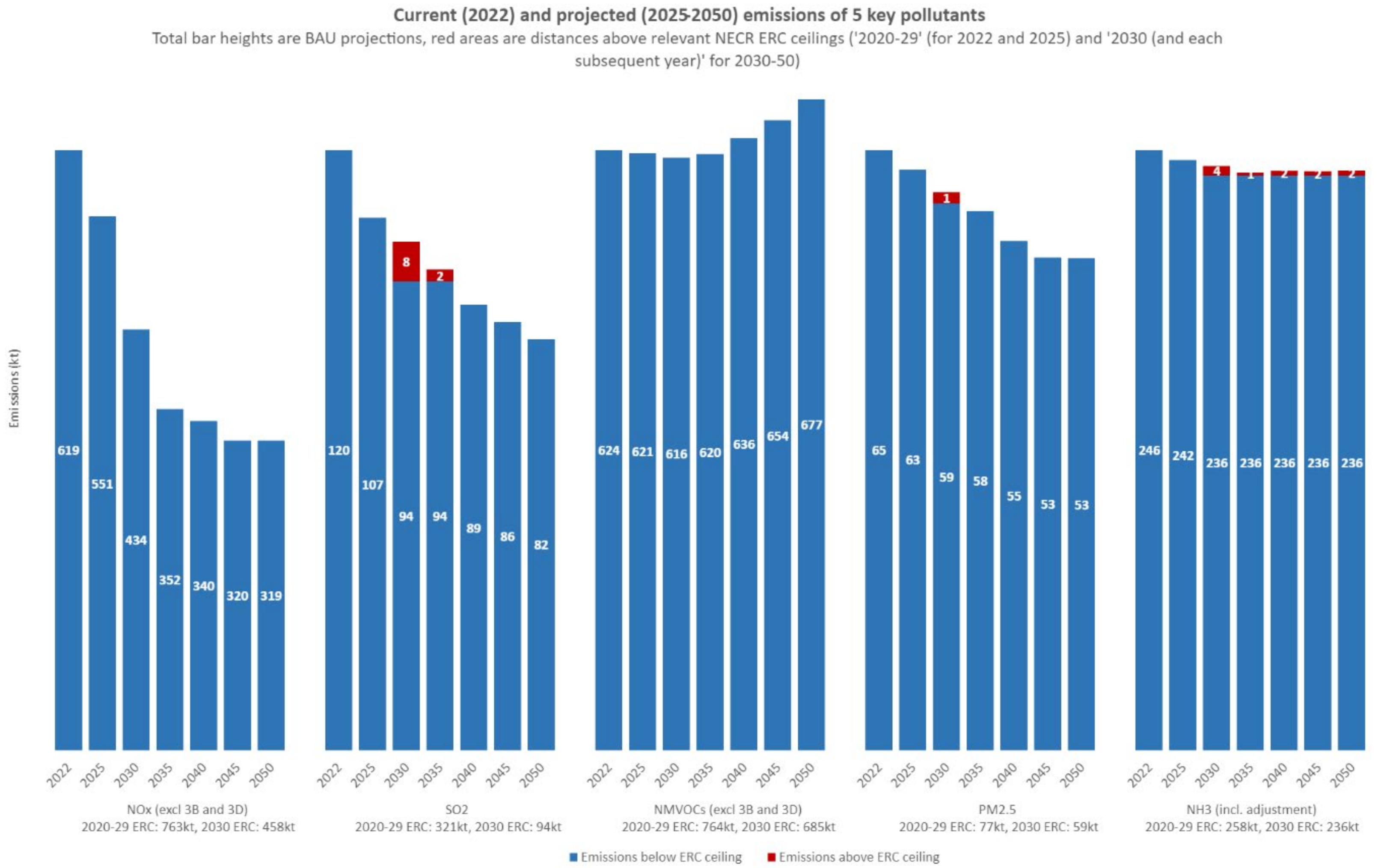
[a] Figures presented in this table for NH_3 take account of the approved adjustment regarding NFR sector 3Da2c.

[b] The NMVOCs and NO_X figures quoted in this column exclude emissions from 3B and 3D. Under the NECR, NMVOCs and NO_X emissions from 3B and 3D are not accounted in the National Total for the purpose of complying with the 2020-29 (or 2030) emission reduction commitments.

[c] The 2020-29 and 2030 emission reduction commitments have been calculated using the 2005 emissions of the current inventory submission as the base year.

[107] Emissions are rounded.

Figure 9-6 Comparison of UK 2022 national emissions, projected emission estimates for years 2025-2050 against NECR ERCs (NH_3 figures take account of the adjustment)



Notes:

- **Total bar heights are current 'with existing measures' projections, red areas are distances above relevant NECR ERC ceilings ('2020-29' (for 2022 and 2025) and '2030 (and each subsequent year)' for 2030 onward)**
- NH_3 **figures include the approved adjustment for NFR sector 3Da2c.**
- **The NMVOCs and** NO_X **figures quoted in this column exclude emissions from 3B and 3D. Under the NECR, NMVOCs and** NO_X **emissions from 3B and 3D are not accounted in the National Total for the purpose of complying with the 2020-29 (or 2030) emission reduction commitments.**

Based on these latest 'with existing measures' projections, the UK will likely need to take further action to meet its 2030 ERCs under NECR for NH_3, SO_X and $PM_{2.5}$. Emission projections described in this report take account of measures in place as far as is possible given the data available, but do not reflect measures which are still in development, thus, in this respect some parts of the projections could be conservative, i.e. too high. However, there are other areas of uncertainty that could mean the uncertainty is too low, e.g. uncertainties in projections of activities. Table 9-2, earlier in the chapter, shows how the projections are a mixture of WM (with measures) and WoM (without measures) dependent on data availability.

In general, projections for stationary sources are conservative with the exception of projections for a small number of source categories which consist of small numbers of large, regulated sites, such as power stations, cement kilns, steelworks or crude oil refineries. Projections for industrial-scale combustion and most smaller industrial processes will assume no change in emission factors beyond 2022.

10. Adjustment

10.1. Adjustment Mechanisms Under the Gothenburg Protocol and NECR

The 2012 amendment to the 1999 Gothenburg Protocol to the CLRTAP[108] and the National Emissions Ceilings Regulations, 2018[109] set emission reduction commitments (ERCs) for the UK from 2020 onwards for SO_X, NO_X, NMVOCs, $PM_{2.5}$ and NH_3. These ERCs were set based on the scientific understanding of emission sources in the late 2000s, as described in the EMEP/EEA 2009 Guidebook.

The scientific community and users of emission inventories have a need for emission estimates to be based on "best science", however, it is also recognised that it is unreasonable for Parties to become non-compliant with their international commitments as a result of unforeseeable improvements in the scientific understanding of the emission estimates (ECE/EB.Air/130)[110]. Therefore, under the 2012 amendment to the Gothenburg Protocol (and subsequently transposed under the NECR) a flexibility mechanism has been established that allows countries to apply for an "adjustment" to their national emission inventories incorporating the current best science emission estimates for the purpose of determining an emissions total which can be used for compliance checking against the set commitments, such as the ERCs.

As defined in the EMEP Executive Body Decisions 2012/3, 2012/12 and 2014/1, there are three specific circumstances under which such an adjustment can be applied:

1. Emission source categories are identified that were not accounted for at the time when emission reduction commitments were set.
2. Emission factors used to determine emissions levels for particular source categories for the year in which emissions reduction commitments are to be attained are significantly different than the emission factors applied to these categories when emission reduction commitments were set.
3. The methodologies used for determining emissions from specific source categories have undergone substantial changes between the time when emission reduction commitments were set and the year they are to be attained.

All new adjustment applications are submitted to the UNECE for scrutiny by technical experts who then decide whether the application should be accepted.

In this, the 2024 submission, the UK has applied an adjustment to its NH_3 emissions for 3Da2c (Other organic fertilisers applied to soils (including compost)) based on circumstance 1, as defined above. The adjustment was first applied for in 2021, and was reviewed and accepted by UNECE.

The UK's adjustment is based on a sub section of 3Da2c, specifically emissions from the spreading of non-manure digestate (arising from the anaerobic digestion of food waste, energy crops or other organic residues), a new source that has been included in the national inventory since the ERCs were agreed.

Table 10-1 shows the UK exceedance against its current NH_3 national emission reduction commitment as set in the 2012 amendment to the 1999 Gothenburg Protocol and the NECR, for the years 2020 to

[108] https://unece.org/sites/default/files/2021-10/ECE.EB_.AIR_.114_ENG.pdf
[109] The National Emission Ceilings Regulations (legislation.gov.uk) (NECR), which came into force in July 2018, transposes into UK law the original EU NECD (2001/81/EC) and subsequent revisions (including EU 2016/2284).
[110] https://unece.org/DAM/env/documents/2014/AIR/EB/ECE_EB_AIR_130_ENG.pdf

present. It also shows to what extent the adjustment to the emission inventory for non-manure digestate spreading eliminates the exceedance and brings the UK into compliance.

Table 10-1 Summary of the UK NH_3 emissions inventory for years 2005, 2020-latest and the adjusted national emissions total for compliance with Emission Reduction Commitment (ERC)

NH_3	2020	2021	2022
2005 National Total Unadjusted, kt	280.9	280.9	280.9
2005 Adjustment, kt	-0.5	-0.5	-0.5
2005 National Total Adjustment, kt	280.5	280.5	280.5
Emission reduction commitment	8%	8%	8%
ERC Adjustment, kt	258.0	258.0	258.0
National Total Unadjusted, kt	260.7	266.5	259.3
Adjustment, kt	-12.5	-12.9	-13.1
National Total Adjusted, kt	248.2	253.6	246.1
Progress to date towards ERC (including adjustment)	144%	120%	153%
Exceedance versus ERC, kt (including adjustment)	9.9 kt compliance	4.5 kt compliance	11.9 kt compliance

The remaining sections of this chapter provide the rationales and supporting information for this adjustment made for specific sources within the agriculture sector.

10.2. Adjustment for NH_3 from NFR 3Da2c

10.2.1. Justification

In accordance with Decision 2012/12, Annex[111], paragraph 2(i)a and 2(i)b, a Party's supporting documentation for an adjustment to its emission inventory shall include:

- Evidence that the new emission source category is acknowledged in scientific literature and/or the latest EMEP/EEA air pollutant emission inventory guidebook.
- Evidence that this source category was not included in the relevant historic national emission inventory at the time when the emission reduction commitment was set.

A methodology for estimating NH_3 *emissions from non-manure digestate spreading is presented in the EMEP/EEA 2019 Guidebook, chapter 3D, Table 3.1. There was no methodology presented for non-manure digestate spreading in the EMEP/EEA 2009 Guidebook - the guidance used to produce the national inventory for the 2009 submission, from which ERCs were determined and agreed.*

10.2.2. Description of the Evidence

In accordance with Decision 2012/12, Annex, paragraph 2(i)c, a Party's supporting documentation for an adjustment to its emission inventory shall include:

- Evidence that emissions from a new source category contribute to a Party being unable to meet its reduction commitments, supported by a detailed description of the methodology, data and emission factors used to arrive at this conclusion.

[111] https://unece.org/DAM/env/documents/2012/EB/Decision_2012_12.pdf

Specific evidence regarding that the identified sources relating to non-manure spreading contribute to the UK being unable to meet its reduction commitment for the 2020-29 NH_3 ERC is detailed in section 10.2.3 below.

10.2.3. Quantifying the Adjustment

In accordance with the Technical Guidance for Parties Making Adjustment, for the adjustment applications relating to the 2020 ERCs[112], an emission reduction following the application of an adjustment is calculated as in **Equation 10-1**.

Equation 10-1 - Calculation of emission reduction following application of an adjustment.

$$AER_Y (\%) = 100 \times (AE_{2005} - AE_Y)/AE_{2005}$$

Where:

AER_Y is the adjusted emission reduction in the year Y compared to the emissions in 2005, expressed as a percentage

AE_{2005} is the adjusted national emission total in the year 2005 (in some cases $AE_{2005} = E_{2005}$)

AE_Y is the adjusted national emission total in the year Y (in some cases $AE_Y = E_Y$ i.e. the emission in year Y is not adjusted)

Additionally:

AE_{2005} is defined as $E_{2005} + A_{2005}$

AE_Y is defined as $E_Y + A_Y$

It has been determined through investigation of previous CLRTAP submissions that the spreading of non-manure digestates on land was not captured in the inventory from which the 2020-2029 ERCs were determined, and as such can be considered a new source. Table 10-2 summarises the new sources that are being considered for an adjustment application and display the NH_3 emissions associated with each in the base year of 2005 and the year in which an adjustment is to be calculated (2020-2022).

Table 10-2 Determination of adjustment parameters for Equation 1.

Pollutant	NFR	Source	2005 Emissions, kt	2022 Emissions, kt
NH_3	3Da2c	Crop Digestates - TAN	0.0	4.7
NH_3	3Da2c	Food Digestates - TAN	0.3	7.7
NH_3	3Da2c	Other organic residue Digestates - TAN	0.1	0.8
NH_3	3Da2c	Total	0.5	13.1

Values determined in Table 10-2 can be input into Equation 10-1 along with the unadjusted national totals for NH_3 in 2005 and 2022 as presented in Table 10-1. The calculations to determine the emission reduction required to meet the ERC, taking account of the 3Da2c adjustment to NH_3 are displayed in Box 4.

[112] https://www.ceip.at/fileadmin/inhalte/ceip/00_pdf_other/2022/technical_guidance_for_erc_adjustments_issue1.1.pdf Section 3.3

Box 4 - Calculation of the emission reduction for NH_3 ***between 2005 and 2022, taking into account adjustments made to sector 3Da2c.***

$$AER_Y (\%) = 100 \times (AE_{2005} - AE_Y)/AE_{2005}$$

$$AER_Y (\%) = 100 \times ((E_{2005} + A_{2005}) - (E_Y + A_Y))/ (E_{2005} + A_{2005})$$

$$AER_Y (\%) = 100 \times ((280.9 + (-0.5)) - (259.3 + (-13.1)))/ (280.9 + (-0.5))$$

$$AER_Y (\%) = 100 \times (280.5-246.1) / 280.5$$

$$AER_Y (\%) = 100 \times 34.3 / 280.5$$

$$AER_Y (\%) = 12.2$$

From Box 4, it can be seen that the emission reduction between 2005 and 2022 for NH_3 following the adjustment to 3Da2c is 12.2% (AER_Y). This emission reduction is greater than the NH_3 ERC agreed for the UK between 2020-2029 of 8%. As a result, this ensures that the UK is compliant with respect to its 2020-2029 ERC for NH_3 for 2020-present.

10.3. Non-Compliant Pollutants

In this, the 2024 submission under CLRTAP and NECR, the UK is compliant for the 2020 ERC for all pollutants between the years 2020 to 2022 inclusive.

11. Reporting of Gridded Emissions and Large Point Sources

The latest submission of large point sources and gridded data under the UNECE CLRTAP was made in 2021 and reported the 2019 inventory. Although the next submission is not anticipated until 2025, gridded data are made publicly available for the latest inventory year on the NAEI website[113].

11.1. Introduction

This chapter describes the methodology used to compile the spatially disaggregated emissions maps at a 0.1° x 0.1° Long/Lat grid resolution which were submitted in 2021 under the UK NAEI 2019 system.

More recent gridded emissions for the UK NAEI 2020 and supporting datasets are made freely available in ASCII file format on the NAEI website at naei.beis.gov.uk/data/map-uk-das. The maps are also available through an online interactive GIS tool at naei.beis.gov.uk/emissionsapp/. The latest methodology report for the more recent gridded data can be found here[114]. Gridded data for the UK NAEI 2021 will become publicly available in the summer of 2023.

Gridded data and LPS 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 area are used in modelling studies as part of Environmental Impact Assessments.

The emission maps provide an important evidence base that is used to support a variety of policies at UK and Devolved Administration (DA) Government 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 UK air quality data[115]. These models are incorporated into the UK's national air quality compliance assessments that are reported under the Air Quality Standards Regulations 2010.

They are also used to compile and report on emissions as part of the UK's commitment to the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP). Under this reporting convention UK emissions are aggregated to the prescribed nomenclature for reporting sectors (NFR and GNFR sectors) and mapped to a 0.1° x 0.1° Long/Lat EMEP Grid spatial resolution in a geographic coordinate system (WGS84). The last submission was in May 2021 and these datasets are available through the WebDab emission database[116] or through the 2021 Submissions Template Annex V (Excel)[117].

11.2. Overview of Data Reported Under the CLRTAP and NECR

11.2.1. Years Covered

The UK emissions inventory programme compiles gridded data on an annual basis for the most recent version of the emissions inventory. Gridded data are not compiled for earlier years of the emissions

[113] https://naei.beis.gov.uk/data/mapping
[114] https://naei.beis.gov.uk/reports/reports?report_id=1082
[115] https://uk-air.defra.gov.uk/data/modelling-data
[116] https://www.ceip.at/webdab-emission-database/
[117] https://naei.beis.gov.uk/data/

time series, and neither are gridded emissions recalculated if/when historical emissions are recalculated.

Consequently, whilst there is always gridded data available that corresponds to the most recent year in the emission time series, there is no consistent time series of gridded emissions data, and no projected gridded emissions.

The UK submitted LPS and gridded data for the year 2019 in the 2021 submission.

11.2.2. Consistency with the National Inventory

The LPS and gridded data reported for the year 2019 are consistent with the national inventory (NFR tables) as reported in 2021. Differences occur in the shipping and fishing sectors, as the gridded data are based on fuel used and constrained to the location of vessel activity. Differences between shipping emissions between the gridded data and national inventory are provided in more detail in the section 11.9 below.

11.2.3. GNFR Sectors with a Brief Explanation of Gridded Methodology

Table 11-1 Explanation of GNFR sectors

GNFR Sector	Proxy used for distribution (Tiered numbering)
A_PublicPower	UK National Regulators Inventories (Tier 3); UK Inventory Agency own estimates of site specific emissions using proxies such as EU ETS[118] fuel data or site capacity (Tier 3); For the sites where such information is not available, we have used Employment Statistics as a proxy for the remaining activity (1A1a) (Tier 2).
B_Industry	UK National Regulators Inventories (Tier 3); UK Inventory Agency own estimates of site specific emissions using proxies such as EU ETS fuel data or site capacity (Tier 3); For the sites where such information is not available we have used Employment Statistics from each specific industry type (e.g. Chemicals, Food, Paper) as a proxy for the remaining activity in combination with the local natural gas availability (Tier 2); For the construction sector population distribution has been used (Tier 1).
C_OtherStatComb	Residential Natural Gas consumption has been aggregated from gas meter data (Tier 3); Residential other fuels have been estimated using a combination of Census data, Addresses and other regional statistics (Tier 3); Commercial and public sector estimates are based on UK Inventory Agency own estimates of site specific emissions using proxies such as EU ETS fuel data (Tier 3); For the sites where such information is not available we have used Employment Statistics from each specific work type (hospital, schools etc) as a proxy for the remaining activity in combination with the local natural gas availability (Tier 2).
D_Fugitives	UK National Regulators Inventories (Tier 3); UK Inventory Agency own estimates of site specific emissions using proxies such as site capacity (Tier 3); For the sites where such information is not available we have used Employment Statistics as a proxy for the remaining activity (Tier 2).
E_Solvents	Population distribution is used for sources such as other solvent use, aerosol and non-aerosol products, decorative paint, fireworks etc (Tier 1); For site specific data UK National Regulators Inventories and PRTR have been used (2D3d) (Tier 3); Also, UK Inventory Agency own estimates of site specific emissions using proxies such as site capacity (Tier 3); For the sites where such information is not available we have used Employment Statistics as a proxy for the remaining activity (Tier 2); For Agriculture - agrochemicals, land use data have been used (Tier 1).
F_RoadTransport	Exhaust emissions from road vehicles and the related fuel consumption estimates are calculated by the UK Inventory Agency using emission factors and traffic data for each vehicle type at road by road link basis (Tier 3).

[118] The 2019 inventory still used EU ETS. This has been replaced by UK ETS in inventory updates since the last gridded submission.

GNFR Sector	Proxy used for distribution (Tiered numbering)
G_Shipping	Inland waterways estimates have been made using data on actual vessel activity including gap filling with other statistics from Inland Navigation Authorities (Tier 3); We expect inconsistency between national reporting of domestic shipping and fishing due to the geographic restriction to report emissions within the EMEP grid shapefile (Tier 3).
H_Aviation	Emissions from aircraft operating on the ground and in the air over the UK, up to an altitude of 3000 feet (equating to the take-off and landing cycle); Emissions estimates are calculated from the number of movements of aircraft by type at UK airports (data provided by the Civil Aviation Authority) and from estimates of fuel consumption for component phases of the take-off and landing cycle (Tier 3).
I_OffRoad	Employment Statistics (Tier 2); Agriculture statistics (Tier 3); Rail statistics (Tier 3); For residential household and gardening land use data were used (Tier 1); Shipping information limited close to coastline (discrepancy as described in G_Shipping above) (Tier 3).
J_Waste	UK National Regulators Inventories (Tier 3); UK Inventory Agency own estimates of site specific emissions using proxies such as site capacity (Tier 3); For the sites where such information is not available we have used Employment Statistics as a proxy for the remaining activity (Tier 2) For waste burning land use data were used (Tier 1).
K_AgriLivestock	Agriculture Census data in combination with land use (Tier 2).
L_AgriOther	Land Use (Tier 1).

11.2.4. Pollutant Coverage

Emission maps are routinely produced for the 27 air pollutants listed in Table 11-2 below (including PM fractionation). Pollutants marked with an asterisk (*) were included for first time in the 2019 emissions grids.

Table 11-2 Pollutants mapped in the NAEI

Pollutants mapped in the NAEI	
1,3-butadiene	Hydrogen chloride
Ammonia	Indeno[123-cd]pyrene*
Arsenic	Lead
Benzene	Mercury
Benzo[a]pyrene	Nickel
Benzo[b]fluoranthene*	Nitrogen Oxides (NO_X)
Benzo[k]fluoranthene*	Non-Methane Volatile Organic Compounds
Black Carbon*	Particulate Matter (PM_{10} $PM_{2.5}$ PM_1 & $PM_{0.1}$)
Cadmium	Polychlorinated biphenyls*
Carbon monoxide	Selenium
Chromium	Sulphur dioxide (SO_X)
Copper	Vanadium
Dioxins	Zinc
Hexachlorobenzene*	

11.2.5. Source Sector Coverage

The maps provide modelled estimates of the distribution of emissions at a 1x1 km resolution and are aggregated to UNECE sectors using the Selected Nomenclature for reporting of Air Pollutants (SNAP).

The use of the SNAP nomenclature is partly historic, but also because the SNAP source structure includes technology in the hierarchical structure. It is therefore popular amongst emissions inventory compilers. The NFR structure is used for reporting under CLRTAP and NECR as required, and this is used as a reporting structure, rather than a compilation structure.

As this report is submitted for reporting commitments under the CLRTAP and the NECR, sources are presented according to the NFR source structure. However, in some cases the sub-sectors are labelled at a rather high level, and the detail within the sectors are derived from working within the SNAP structure. Data for large point sources are included within the relevant source sectors.

All sources within the UK emissions inventory are included in the gridded emissions data, ensuring completeness in terms of the gridded data coverage.

Table 11-3 presents the types of mapping distributions used for each of the UNECE level 1 SNAP sectors. The mapping methods used to develop these distributions are explained in sections 11.3 to 11.16.

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

Source sector and method	Report Section	UNECE Emission Sectors[119]										
		1	2	3	4	5	6	7	8	9	10	11
Accidental fires	Section 11.16									✓		✓
Agriculture	Section 11.14								✓		✓	
Airports	Section 11.5								✓			
Domestic	Section 11.11		✓			✓						
IDBR[120] agriculture	Section 11.4		✓									
IDBR[74] commercial & public	Section 11.4		✓									
IDBR[74] employment	Section 11.4	✓	✓	✓	✓		✓		✓	✓		
IDBR[74] industry	Section 11.4			✓								
Landfill	Section 11.15									✓		
Offshore	Section 11.13	✓				✓				✓		
Other	Sections 11.10, 11.12				✓	✓			✓			✓
Point Sources	Section 11.3	✓	✓	✓	✓	✓	✓			✓		
Rail	Section 11.7								✓			
Road transport	Section 11.6				✓			✓				
Shipping	Section 11.9				✓				✓			

11.3. NFR 1A1, 1A2, 1B, 2: Industrial and Commercial Sources

The NAEI receives detailed data on individual point sources in the industrial and commercial sectors. Point sources across the UK may be either collectively responsible for the total emission for that sector (such as coal-fired power stations) or in part (such as combustion in industry, for which only the larger combustion plant 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.

Point source emissions are compiled using a variety of different data sources and techniques, as summarised below.

[119] SNAP https://www.ceip.at/fileadmin/inhalte/emep/xls/ConversionTableReportingCodes_October2015.xlsx
[120] IDBR Inter-Departmental Business Register

1. Most of the point source data for onshore facilities are obtained from UK regulators. These are regulated by the Environment Agency, Scottish Environment Protection Agency, Natural Resources Wales and the Northern Ireland Environment Agency, under the Industrial Emissions Directive (IED). Data for these point sources are made available to the NAEI in the form of the Environment Agency's Pollution Inventory (PI), the Scottish Environment Protection Agency's Scottish Pollutant Release Inventory (SPRI), Natural Resources Wales' Welsh Emissions Inventory (WEI) and the Northern Ireland Pollution Inventory (NIPI).
2. Emissions data for offshore facilities producing crude oil and natural gas in the North Sea and elsewhere are available in the form of the EEMS dataset, provided by the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED).
3. The five datasets mentioned above (PI, SPRI, WEI, NIPI, EEMS) feed into the E-PRTR[121] and so most of the E-PRTR data just duplicates data that we already have from the other datasets. As a result, E-PRTR is mostly not used in the generation of the UK LPS dataset. The only very limited exception to this is for some Part A2 processes such as chipboard plant and certain large industrial coating processes. These particular facilities do not appear in the UK regulators' datasets and so E-PRTR data is used in both the derivation of UK emission estimates and LPS data.
4. Some facilities are included in more than one dataset, and we are also aware of occasions where the scope of emissions data in the datasets may not cover everything that we wish to include. There are also very occasional instances where reported emissions appear to be inaccurate. Therefore, we do deviate from the various datasets where we think this is necessary to ensure emission estimates that are accurate and complete, as far as this is possible.
5. Some additional information for some regulated processes is made available directly from process operators or trade associations.
6. Fuel consumption and CO_2 emissions are available for facilities registered with and trading emission credits under the EU-Emissions Trading System (EU ETS). The fuel consumption data can be used to generate emission estimates for those sites where we have no other data.
7. Many point sources are regulated under Local Authority Pollution Control/Air Pollution Control (LAPC/APC) in England and Wales/Scotland respectively. There is no centrally held database of emissions data for these sites but emissions for many sites are estimated by Ricardo based on site-specific data collected from regulators on an ad-hoc basis in the past.
8. Some additional point source' emissions are modelled by distributing national emission estimates over the known sources based on capacity or some other 'surrogate' statistic.

For emissions included in group 1 above, the most important sources of information are the various regulators' inventories. The largest of these data sets is the PI, which includes emissions data for most pollutants covered by the NAEI. The PI covers processes regulated by the Environment Agency in England including those regulated under the IED. It does not include any data on processes regulated by local authorities. Reporting of emissions started in 1991 and is conducted annually. The completeness of reporting for the largest point sources is very high from the late 1990s onwards. From 1998 onwards, emission reporting is only required where emissions exceed a 'reporting threshold', e.g. for carbon monoxide the reporting threshold in 2003 was 100 tonnes and this means that some point sources do not have to report emissions. The reporting thresholds mean that data can be much more

[121] The 2019 inventory still used the EU dataset

limited for sectors that consist mainly of medium rather than large industrial operations (for example industrial combustion) where it is far more likely that emissions will be below the reporting threshold.

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

The WEI covers sites regulated under IED in Wales. These sites were once included in the PI, but responsibility for compiling the Welsh data now rests with Natural Resources Wales. Data for Welsh sites extends back to 1991 (in the WEI and in historical versions of the PI) and the same reporting thresholds apply as in the PI.

The NIPI contains annual data from 1999 onwards and the same reporting thresholds apply as in the PI.

The E-PRTR contains much data which replicates what is in the regulators' inventories and so E-PRTR is not used as a source of additional information on processes regulated by the national regulators. It is, however, used as a source of information for a small number of processes regulated by local authorities (see below for further information).

The regulators' inventories do not contain emissions data for every potential release from permitted processes. Operators do not need to report emissions if these do not exceed reporting thresholds. 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 (by extrapolation from data for other years and/or other processes). This gap-filling is done for the NAEI, but 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 be relatively small.

The regulators' inventories provide much of the point source data used in the NAEI maps for NO_X, SO_X, CO, HCl, benzene, 1,3-butadiene, NMVOCs, PM_{10}, 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 plant.

Of the process operators and trade associations providing emissions data directly to Ricardo, notable examples are:

- Tata Steel Ltd and British Steel Ltd who have provided 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 have also previously supplied data for their electric arc steelmaking facility, however this is now operated by Liberty who have not provided data. These data cover most of the pollutants mapped in the NAEI for steelworks;
- Fuels Industry UK supply NO_X, SO_X, CO, PM_{10} and NMVOC emissions data for fuel combustion and for non-combustion processes at crude oil refineries;
- Oil & Gas UK provide emissions data for offshore oil and gas exploration and production installations as well as various onshore installations linked to the production of oil and gas. These data are taken from the EEMS database which is compiled for Oil & Gas UK and DESNZ. The data cover NO_X, SO_X, CO and NMVOCs.

The use of carbon dioxide emissions data from the EU ETS requires careful cross-checking with the carbon dioxide emissions reported in the PI/SPRI/WEI/NIPI, and with data from trade associations and process operators. This need arises because there is considerable duplication of emissions in these various sources and it is vital that where emissions data are included from the EU ETS dataset, that data for the same installations are not also included from other sources.

The cross-checking requires a thorough understanding of how the various processes permitted under IED and reported in the PI/SPRI/WEI/NIPI relate to processes that are permitted under EU 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 the two datasets. In the past, this has led to some revision of data from one version of the maps to the next, but the NAEI team's understanding of these relationships has improved to the point that further revisions are relatively unlikely.

A further complication is that even where a given installation is present in both the EU ETS and other data sets, the exact scope of the emissions data may not be the same. For example, emissions data in the PI and other regulators' inventories will include carbon dioxide from biofuels, whereas the EU ETS data will not. The PI will also include emissions from dryers, furnaces and other plant where fuels are burnt to provide heat which is used within the combustion device. In many cases, the EU ETS data set will exclude the emissions from these types of plant prior to 2012 (EU ETS phase III). As a result, there is a need to understand how the scope of each IED permit compares with the scope of each EU ETS permit. This is a major task which would require considerable resources to do fully. As an interim proportionate measure, resources have been focussed on understanding the relative scope of permits for those installations which report very different carbon emissions in the different data sets. Good progress has been made in understanding key differences; even so, work to fully understand these is ongoing.

One sector that is particularly complex is that of the terminals receiving crude oil and gas from North Sea production installations. For these facilities, we have emissions data from the EU ETS, the PI and SPRI, and also from the EEMS database, compiled for UK Oil and Gas and BEIS. 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. Carbon dioxide 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.

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

Point source data for some processes regulated under LAPC/APC are based on information obtained from regulators. This was an important information stream for processes using solvents during the late 1990s and early 2000s, but 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 for the regulators asked to provide such information. Data for a small number of solvent-using processes continues to be available via the E-PRTR, but for most sites, the points data are now based on historic reported data and are therefore subject to considerable uncertainty.

Even given the comprehensive information compiled in the above registers and datasets, point source data are not available for all installations. For those sites with emissions below the reporting thresholds described above, or for most sites regulated by local authorities, the NAEI will not be able to collect any emissions data from the regulator. Furthermore, some industrial emission sources are not regulated. For most pollutants, the available data are likely to cover those sites and sectors that emit large quantities: that is why the sites are regulated and emissions reported in the various data sets. In the case of NMVOCs and, to a lesser extent, particulate matter, there are considerable emissions from the LAPC/APC sites where emissions data are not generally available. For NMVOCs, there are also large 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 Ricardo has estimated the capacity of each of about 70 large, mechanised bakeries;
- Emission estimates for one pollutant can be used to disaggregate the national emission estimate of another pollutant. For example, emissions of PM_{10} from certain coating processes have been estimated by allocating the national total to sites based on their share of the national NMVOC emission;
- Assuming that plant which do not report emissions have similar rates of emission as plant within the same sector which do report emissions. In these cases, emissions are calculated by assuming that these sites will emit at the same rate 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 plant in a given sector have equal emissions. In a few cases where there are relatively few plant in a sector, but no activity data can be derived, emissions are assumed to be equal at all of the sites.

With the possible exception of using plant capacity 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 EU ETS etc. 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 less well correlated to emissions.

The Local and Regional CO_2 technical report (Turtle *et al*., 2020)[122] and the section '4 Large Industrial Installations' provides more details the methodology used to calculate the emissions for LPS.

11.4. NFR 1A4ai (1A2, 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[123], 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

[122] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/894790/local-authority-co2-emissions-technical-report-2018.pdf

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

statistics. Each distribution map provides the percentage of the UK's residual sector fuel consumption estimate to be allocated to each 1x1 km.

The method used is described in a separate document - Employment based energy consumption mapping in the UK[124]. The following data sets were used:

- Office for National Statistics Inter-Departmental Business Register (IDBR), which provides data on employment at business unit level by Standard Industrial Classification (SIC) code[125];
- Energy Consumption in the UK (ECUK) data on industrial and service sector fuel usage[126];
- Site-specific fuel consumption. These are compiled from data for regulated processes reported in the EA Pollution Inventory, Scottish SPRI, DoE Northern Ireland Inventory of Statutory Releases, by the EU-ETS and from other data obtained by the inventory;
- Xoserve's Off-Gas Postcode dataset[127];
- Business Register and Employment Survey (BRES) annual employment estimates for the UK split by Region and Broad Industry Group (SIC2007)[128].

The first step was to allocate NAEI point sources to SIC sector 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 that is already accounted for by point sources, and therefore estimate the total residual energy that needs to be distributed using the employment data. This retained the level of detail across emissions subsectors required for the mapping, as the use of total energy by SIC codes would have resulted in a reduction in the quality of the final distribution.

The employment data by SIC codes in the IDBR database were matched with the BEIS 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; where this 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 local unit level were aggregated to 2-digit SIC codes at Local Authority 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 across the sector. This is a simplification of reality but necessary because of a lack of more detailed estimates of fuel use.

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

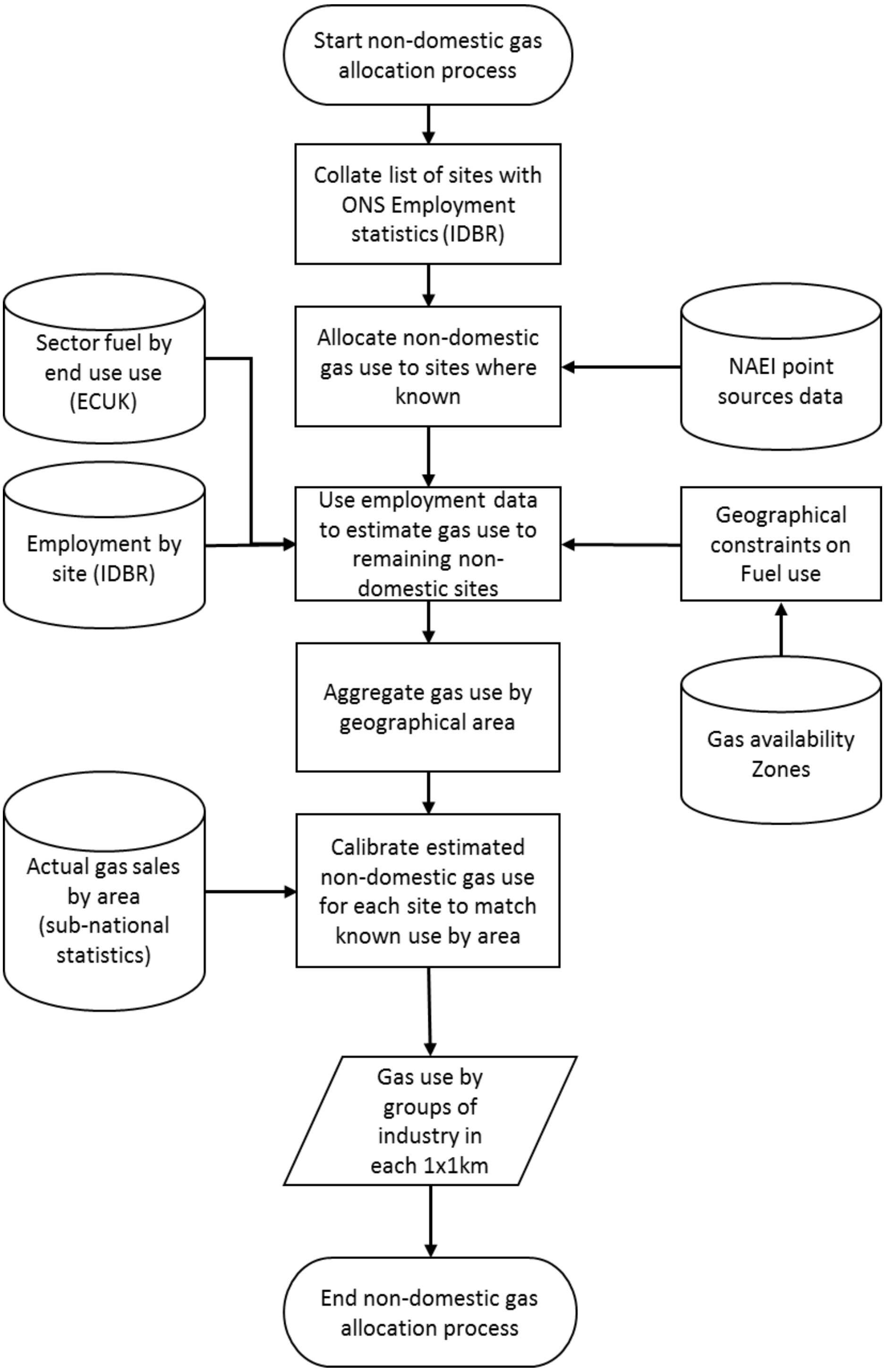
- Sites of employment corresponding to the locations of the highest emissions (as defined by the NAEI point source database) have been removed from the distributions. This is to prevent double counting of emissions at these locations (emissions are mapped as point sources).

[124] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/996060/employment-based-energy-consumption-local-authority-mapping-2019.pdf
[125] https://www.ons.gov.uk/aboutus/whatwedo/paidservices/interdepartmentalbusinessregisteridbr
[126] https://www.gov.uk/government/statistics/energy-consumption-in-the-uk (Industrial and Services tables)
[127] https://www.xoserve.com/media/2687/off-gas-postcodes-v2.xlsx
[128] http://www.ons.gov.uk/ons/rel/bus-register/business-register-employment-survey/index.html

- High-resolution gas consumption data at Middle Layer Super Output Area (MSOA) 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, Xoserve's Off-Gas Postcode dataset has been used to identify sites that are in or out of the natural gas grid.
- Based on expert knowledge of fuel use by industry and businesses the distributions of fuel oil and gas oil have been modified so that consumption is lower per employee in grid squares with Natural Gas availability using a weighting factor.
- The distribution of coal has been further limited to outside the locations of large urban areas.

Figure 11-1 shows the process to convert industrial and commercial fuel usage from individual employment sites into emissions.

Figure 11-1 Non-domestic gas use allocation process



11.5. NFR 1A3a: 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 3000 feet (equating to the take-off and landing cycle). Emissions estimates are calculated from the number of movements of aircraft by type at UK airports (data provided by the Civil Aviation Authority) and from estimates of fuel consumption for component phases of the take-off and landing cycle. Emissions from aircraft at cruise are also included in the NAEI, although these emissions are not mapped.

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 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 3000 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 3000 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, 2017)[129].

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.

11.6. NFR 1A3b: 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 Devolved Administrations are derived using Regional Vehicle Licensing Statistics (from the DVLA) and the DfT's 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 Devolved Administrations.

11.6.1. 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 sub-divided 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 pre-Euro 1 and Euro 1-4 vehicles in the national car fleet can be associated with the age of the car fleet (year of first registration).

Fuel consumption and emission factors are expressed in grams of fuel or emissions 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 Automatic Number Plate Recognition (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

[129] http://www.heathrowairwatch.org.uk/documents/Heathrow_Airport_2016_Emission_Inventory_Issue_1.pdf

different road conditions. There are many parameters that affect the amount of fuel a vehicle uses and average vehicle. Speed is one of them, so the NAEI uses functions that relate fuel consumption to average speed.

Factors for all vehicle types are derived from the fuel consumption-speed relationships given in COPERT 5. 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 EU Member States to calculate emissions from road transport. It is a source of emission factors recommended for national inventory compilation according to the 2016 EMEP/EEA Guidebook[130]. It 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 2005-2016. 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[131]. The real-world uplift uses empirically derived equations in the Guidebook that take account of average engine capacity and vehicle mass. Previously, the inventory calibrated speed-fuel consumption curves for HGVs and buses with independent data from DfT on the fuel efficiencies of these vehicles obtained from surveys of haulage companies and bus operators' fuel returns. However, DfT have recently found the data to be less complete than was previously considered and therefore less suitable for use in the inventory.

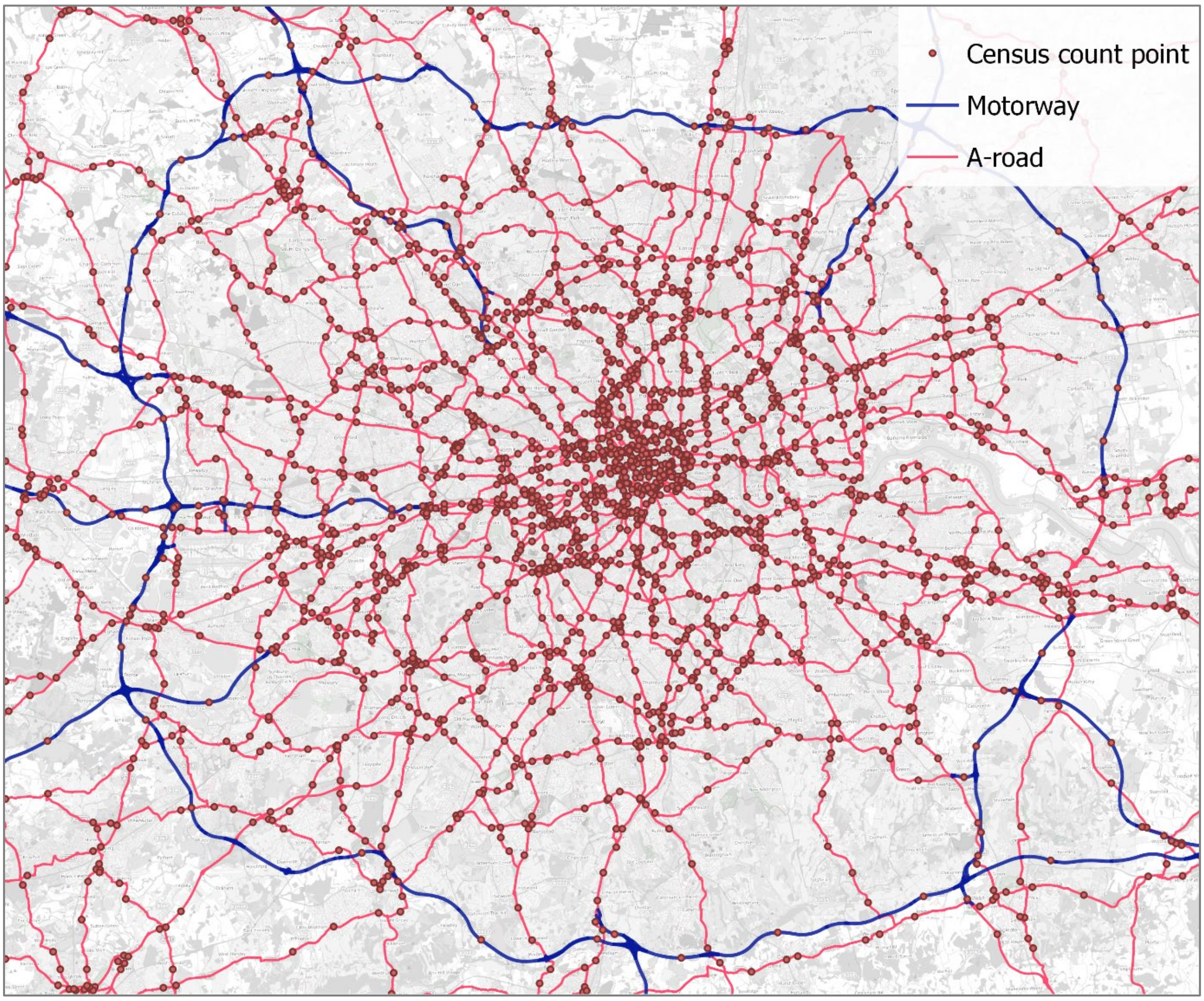
The emission maps are calculated from the speed-related emission factors multiplied by vehicle flows. The method for calculating these maps is described in the next section.

11.6.2. 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 11-2) provides locations of all roads (motorways, A-roads, B-roads and unclassified roads) in Great Britain (GB). Prior to 2017 the Ordnance Survey's Meridian 2 (OSM2) road network was used, but this has been superseded by OSOR and the NAEI has adopted this new OS product as part of the continual improvement of the mapping process. OSOR is more detailed and accurate than OSM2 and links to the definitive OS MasterMap Highways Network products. For Northern Ireland (NI) a dataset of roads was obtained from Ordnance Survey of Northern Ireland, part of Land and Property Services Northern Ireland.

[130] https://www.eea.europa.eu/publications/emep-eea-guidebook-2016
[131] http://www.smmt.co.uk/

Figure 11-2 Illustration of the major road network and DfT count point data for the Greater London area



Traffic flow data for major roads (A-roads and motorways) are available on a census count point basis for both GB[132] and NI[133]. 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. Differences between GB and Northern Ireland datasets should be noted. The census count point coverage of roads in GB is considerably denser than that for NI. Additionally, in NI, some count points record total vehicles, rather than a split of different vehicle types. An average vehicle split has been applied to these records.

Since 2018, the Northern Ireland traffic data provided by Northern Ireland's Department for Infrastructure (DfI) has had a different vehicular classification from previous and from GB. Specifically, the LGV class was omitted and the LGV count was merged with Car class. As a result, and in order to be consistent with the previous vehicular classification (as well as GB), historic traffic pattern data by road type and urban status, was utilised to generate an LGV-to-Car ratio.

In addition, the DfI in Northern Ireland has provided a lower number of traffic count points than they did in previous years. From a total of 367 count points only 89 were updated with 2018 data. This has

132 https://roadtraffic.dft.gov.uk/#6/55.254/-6.053/basemap-regions-countpoints
133 https://www.infrastructure-ni.gov.uk/publications/traffic-and-travel-information-incorporating-annual-traffic-census-and-variations

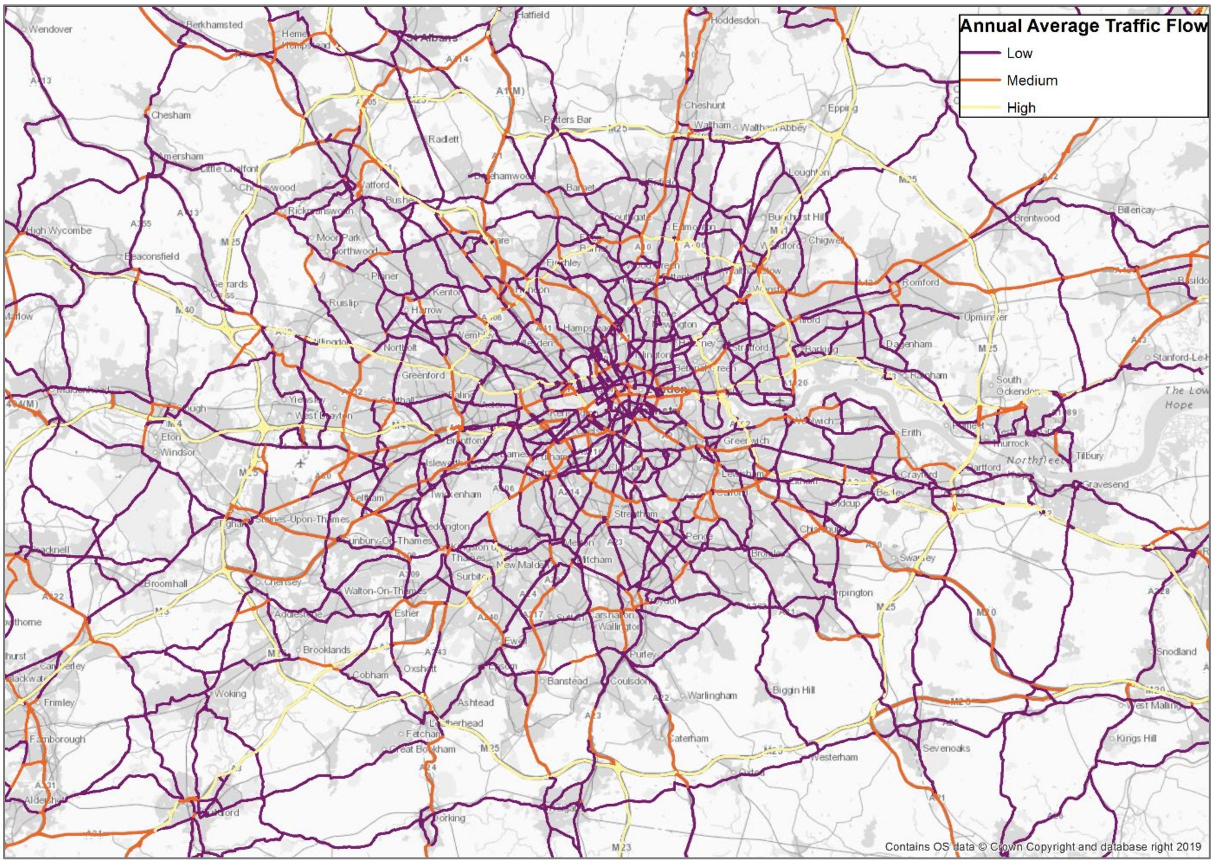
led to adopting a scaling factor using historic traffic counts for Northern Ireland. This enabled the scaling of 278 traffic points to fill in the gaps.

For NI, 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 GB, the OSOR network is more complex than the Northern Ireland road network, and 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 11-3). This was done by using a highly simplified, straight line, Department for Transport (DfT) representation of the start and end of each count points' coverage ('count point lines'). A series of computer-based processes were used to automatically perform this allocation. Where count point lines overlapped Local Authority boundaries, OSOR roads were split at that boundary and each split assigned to the relevant LA. Automated allocation was followed up with manual checking and verification.

Figure 11-3 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)

Figure 11-4 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 most minor roads. But where these data are available, they have been used to enhance the accuracy of the mapping. Minor road count points were allocated to minor roads from the OSOR dataset by using the 2016 OSM2-based allocation. These allocations were transferred by matching the spatial extent of OSM2 road sections to comparable OSOR road sections.

Traffic flows in most minor roads 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 - B and C roads or unclassified roads.

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*[134] which provides information on vehicle kilometres travelled for vehicle types and by road types.

County-level vehicle kilometre 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 vehicle kilometres in the NAEI mapping.

The next step after mapping vehicle movements was to apply the emissions and fuel consumption factors discussed earlier. These factors are assigned to individual roads based on a number of criteria, including urban/rural status, road type (e.g. principal, motorway) and average speed travelled.

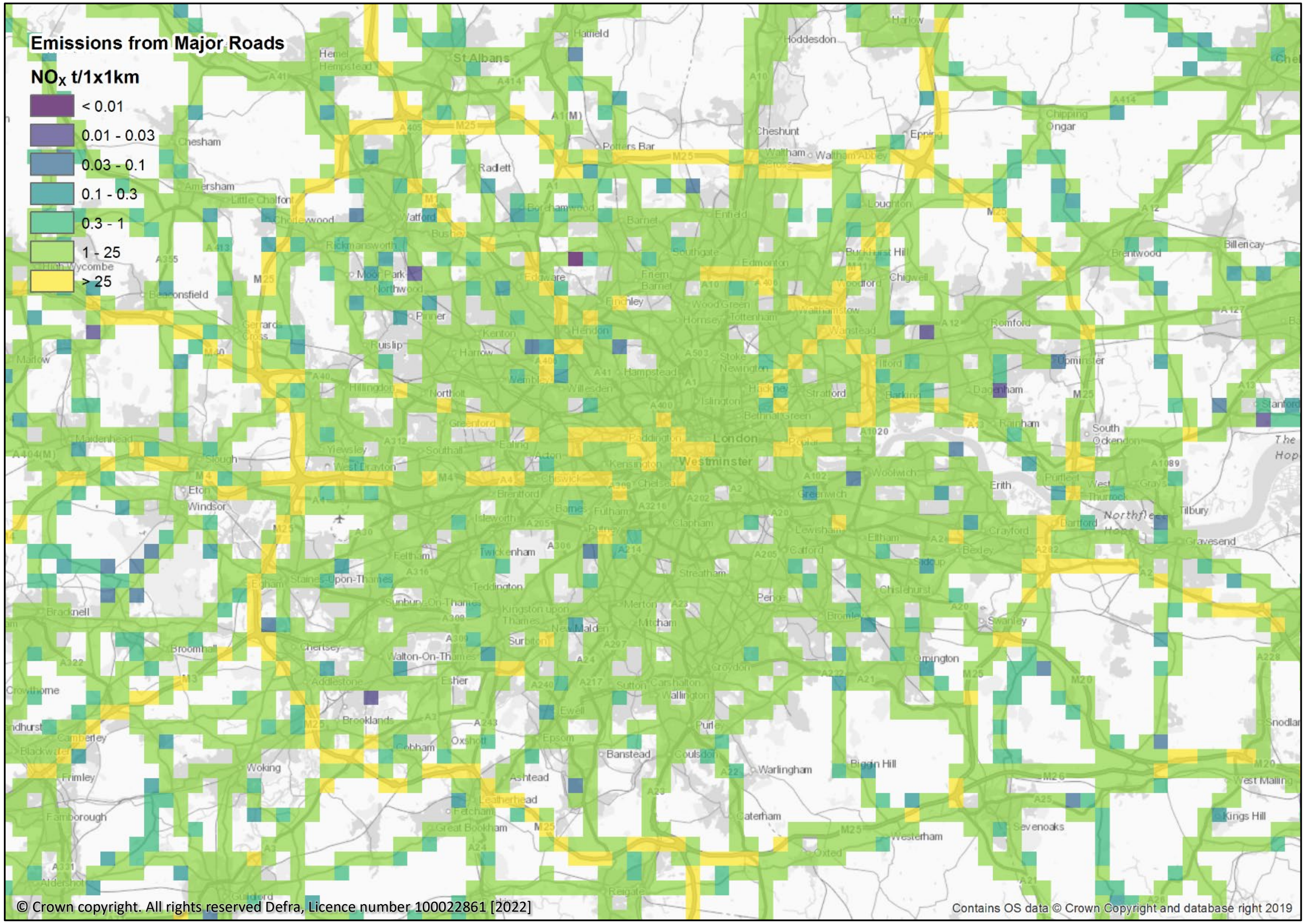
Vehicle kilometres (VKM) estimates by vehicle type for each road link were multiplied by fuel consumption or emission factors taking into account the average speed on the road of concern. These calculations were performed for each major road link in the road network, resulting in maps of fuel

[134] https://www.infrastructure-ni.gov.uk/publications/annual-road-traffic-estimates-vehicle-kilometres-travelled-northern-ireland-2014

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 11-5).

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.

Figure 11-5 2019 NO_X **road transport emissions on major roads aggregated to 1x1 km resolution**



11.6.3. Other Road Transport emissions

Cold start emissions are produced by vehicles before the engine has reached normal operating temperature. Estimates of the distance travelled by vehicles whilst operating under cold start conditions are available in the NAEI for cars by average trip length and trip type. Cold start conditions in Northern Ireland are assumed to have similar characteristics to those in Great Britain. These data enable estimates of the associated emissions to be determined at the UK level.

The trip types used in the mapping of cold start emissions are classified as 'home to work', 'home to other locations' and 'work based' trips. 'Home to work' related emissions were distributed across the UK using detailed population data from the 2011 census on whether people use their car as their method of transport to work. Emissions for trips from home to other locations were mapped using data on car ownership, once again collected from the 2011 census. Work based cold start emissions were mapped on a distribution of all employment across the UK. These were reconciled with the outputs from DfT's TEMPRO[135] model (DfT, 2013). Predicted population movements by mode of transport in the TEMPRO model were produced through reconciling the National Trip End Model (NTEM) version 6.2 (April 2011) datasets[136], which contains a long-term travel response to demographic and economic trends within Wales, Scotland and the 9 regions of England. A comparable NTEM dataset representative of current socioeconomic conditions in Northern Ireland was recently commissioned by the Department for Regional Development and is expected to be included in future releases. The ratio of Northern Ireland to UK cold-start emissions, for each pollutant, was calculated from the NAEI road transport model. These emissions estimates are based on the COPERT III model for cold-starts (Ntziachristos & Samaras, 2000).

Evaporative emissions of benzene and NMVOCs from petrol vehicles were distributed using a map of petrol fuel use on all roads derived using the method described in section 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 vehicle kilometres on major and minor roads.

There are two other small sources of emissions from road traffic included in the inventory - combustion of waste lubricants and emissions from Liquid Petroleum Gas (LPG) vehicles. Both sources were distributed using estimates of total vehicle kilometres calculated from the NAEI maps of traffic flows.

11.7. NFR 1A3c: 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 2011 emission maps. The emissions were spatially disaggregated using data from the Department for Transport's Rail Emissions Model (REM). This provided emission estimates for each strategic route in Great Britain for passenger and freight trains. The emissions along each rail link 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. The most recent year in REM is 2009/10 and therefore the emissions for each strategic route have had to be scaled appropriately, as described in the UK Informative Inventory Report (Churchill, *et al.*, 2021), using trends from Accredited Official Statistics on fuel consumption by rail operators. These were then distributed across Great Britain with the use of GIS data provided by Network Rail, containing the Strategic Routes Sections (SRS) as those have been defined in 2012.

[135] Trip End Model Presentation Program
[136] https://www.gov.uk/government/publications/tempro-downloads/tempro

Rail emissions are distributed across Northern Ireland using 2012 data from Translink[137] on amounts of fuel used on different sections of track aggregated to LA. These data are for passenger trains only as there is no freight activity in Northern Ireland.

Coal based rail emissions have been accounted for by extracting station, line and operating information from the latest version of the 'UK Heritage Railways' website[138]. This information was then verified against additional independent UK heritage railway guides[139], and dedicated webpages for specific lines. National coal-based rail emissions have been proportionally allocated based on the number of days a line operated per year (consistent across all sections of a lines track). In total, 86 operational heritage lines were identified, and their main station coordinates plotted. Those stations with track lengths >5 miles were mapped with the assistance of route schematics alongside the aerial imagery and OS Open Background map services provided by Esri. For the remaining 48 stations activity was assigned to a single 1x1 km grid.

11.8. NFR 1A3di: 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 all fuel consumed by all sources in the UK was captured by the inventory, emissions from inland waterways were effectively captured, but were previously 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:

- Sailing Boats with auxiliary engines;
- Motorboats/Workboats (e.g. dredgers, canal, service, tourist, river boats);
  - recreational craft operating on inland waterways;
  - recreational craft operating on coastal waterways;
  - workboats;
- Personal watercraft i.e. jet ski; and
- 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.

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[140]. The

[137] http://www.translink.co.uk/Services/NI-Railways/
[138] http://www.heritage-railways.com/index.php
[139] http://www.heritagerailwaysmap.co.uk/
[140] http://www.aina.org.uk/members.aspx

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.

11.9. NFR 1A3dii, 1A4ciii: Shipping (Including Fishing)

A revised, more sophisticated, method has been used to map UK shipping emissions starting from NAEI 2016. Previously, shipping emissions were estimated by modelling fuel consumption from a database of shipping activities around UK waters for different vessel, fuel and journey types (Entec, 2010). This approach provided the best available solution at that time but had some recognised issues such as the age of the dataset (dating from 2007), estimated location of vessels rather than actual locations, low spatial resolution compared with other NAEI outputs[141] and insufficient representation of shipping types other than internationally trading vessels. Improvements made to the shipping emissions modelling for the National Inventory, which were first reported in Scarbrough *et al*. (2017), give a higher 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 compared with the previous approach.

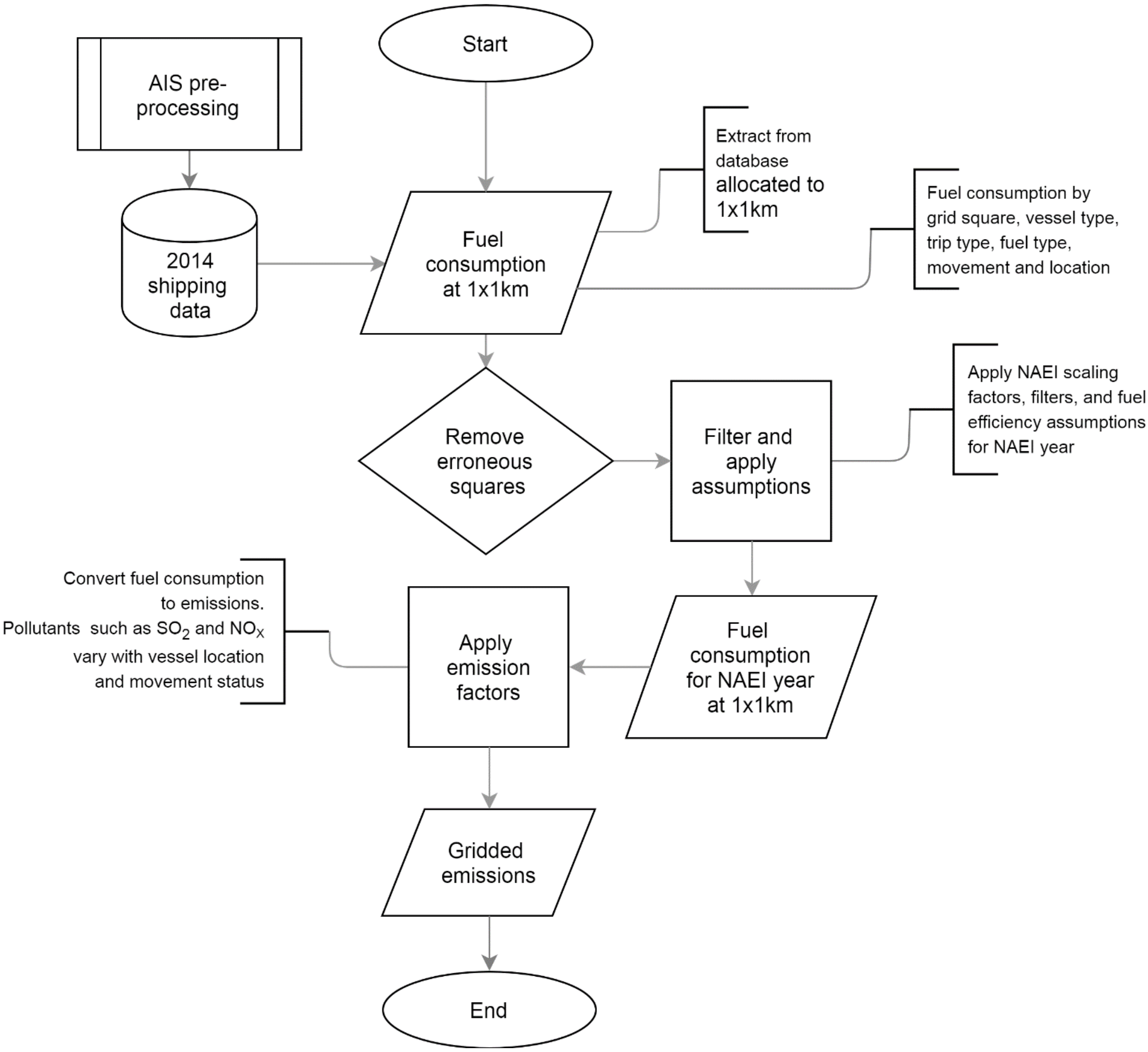
The revised method has been developed using Automatic Identification System (AIS) data supplied by the Maritime and Coastguard Agency. AIS is an on-board ship system that transmits a message containing a vessel's position - and other information such as speed - every few seconds, to be received by other vessels, onshore or by satellites[142]. 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 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 the figure below. 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 (Scarbrough *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.

[141] NAEI maps are drawn on 1x1 km resolution grid, but pre-2016 shipping emissions were based on 5x5 km gridded emissions and the NAEI inherited this lower resolution limit.
[142] http://www.imo.org/en/OurWork/Safety/Navigation/Pages/AIS.aspx

Figure 11-6 Shipping emissions mapping process

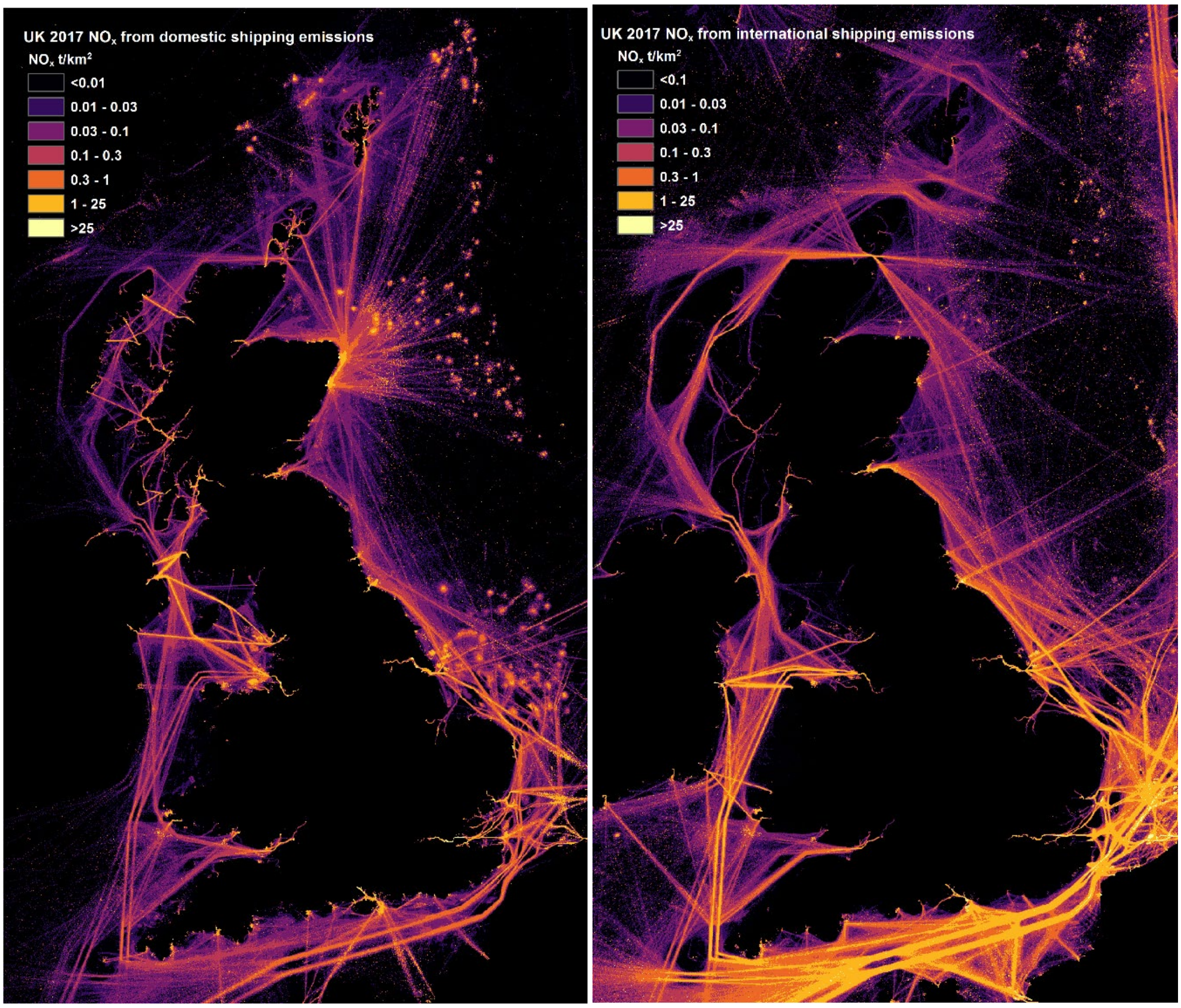


Other differences between mapping and inventory production processes are listed in Table 11-4, along with the reason why the two datasets differ and a description of how this may influence interpretation. The effect of one of these differences is illustrated in Figure 11-7, which shows NO_X emissions 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 traveling from Crown dependences and any passing through activity (e.g. navigating through the English Channel).

Table 11-4 Differences between shipping emissions represented by UK NAEI mapping and the NAEI National Inventory

Difference	Description		Motivation for difference	Consequence(s) of difference
	NAEI (National Inventory)	NAEI maps		
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 maps 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 (National Inventory).	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 1 km grid cell, which would misrepresent the location of emissions. There was no need to exclude this from the NAEI National Inventory as that inventory is not spatially disaggregated.	Lower emissions included in the NAEI maps than in the National inventory total. However, the emissions not included in mapping 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 mapping outputs.	As above.

Figure 11-7 NO_X **shipping emissions by trip type for 2017**



Although differences exist between NAEI maps and the National Inventory, mapping outputs also illustrate how key features of the inventory compilation process affect the geography of emissions. One such example is the impact emissions control areas have on the pattern of SO_X emissions. From 2015 onwards, vessels within emission control areas are assumed to switch from fuel oil to gas oil[143]. The boundary of the Sulphur Emission Control Area (SECA) around the UK is clearly visible in maps of SO_X from shipping emissions. Part of the SECA boundary is present off the coast of south-west Britain, and this is shown in Figure 11-8. 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 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_X.

[143] 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 11-8 SO_X **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**

11.10. NFR 1A2gvii, 1A4cii: Industrial Off-Road

Industrial off-road emissions derive from a range of machinery used in agriculture such as tractors and combine harvesters; industry such as portable generators, forklift trucks and air compressors; construction such as cranes, bulldozers and excavators; domestic lawn mowers; and aircraft support equipment. These emissions have historically been mapped based on employment in heavy industry. In earlier studies, modelling artefacts have resulted in emission estimates being disproportionately allocated to city centres because of the location of the headquarters of many companies associated with heavy industry and therefore employees in such areas. The NAEI team have reviewed the employment dataset for the maps to identify and remove those instances where high industrial employment in urban areas did not correlate well with expected heavy industry activity.

11.11. NFR 1A4bi: Stationary Domestic Combustion

11.11.1. 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 point level to 1x1 km resolution. For Northern Ireland, gas connections information for domestic properties was provided by SSE Airtricity[144] and Firmus Energy[145]. In recent years, Northern Ireland has been moving away from solid fuels and oil in favour of gas by expanding its gas grid network. Until 2018, the Northern Ireland gas distribution grid was based on statistics from the 2011 Census and therefore did not take into account recent expansions of the gas network. As such, estimates were reviewed, and the distribution grid was updated to reflect the new pipelines that have been created to reach over a dozen new towns.

Residential use of LPG is allocated in off gas grid output areas, where census returns indicate gas central heating.

11.11.2. 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 the 2011 census with data from the BEIS National Household Model (NHM), which provides average household energy consumption estimates across the 13 regions of England, Wales and Scotland. Regions within England and Wales follow the regional classification scheme[146], 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[147]. 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) OS AddressBase Premium

- The AddressBase data links any property address to its location on the map. It was created through matching the Royal Mail's postal address file (PAF) to building locations contained in the OS Topography Layer, to provide precise coordinates for each of the 24.7 million residential properties in Great Britain.

b) Ordnance Survey of Northern Ireland (OSNI) Pointer

- The Pointer address product is the most comprehensive and authoritative address database for Northern Ireland, containing location data for just under 740,000 residential address records. Each record adheres to the OS common address standard.

2. 2011 Census returns on dwelling type and central heating fuel types

a) Office for National Statistics (ONS) - cross-tabulated records[148]

- Census table 'CT0213' provided 2011 estimates classifying all occupied households by type of central heating by dwelling type at the Lower Super Output Area (LSOA) level in England and Wales on census day (27th March 2011). 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).

[144] http://www.airtricitygasni.com/at-home/
[145] http://www.firmusenergy.co.uk/
[146] http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/maps/index.html
[147] http://www.metoffice.gov.uk/climate/uk/regional-climates
[148] www.ons.gov.uk/ons/guide-method/census/2011/census-data/2011-census-data-catalogue/commissioned-tables/index.html

- Output Area (OA) information of dwelling type (only) contained in census tables 'KS401EW' for the 10 regions of England and Wales allowed for a more spatially detailed analysis.[149]

b) National Records of Scotland (NRS)[150] - cross-tabulated records

- Census table 'CT_0043_2011' provided 2011 estimates classifying all occupied households by type of central heating by dwelling type at the Output Area (OA) level in Scotland on census day (27th March 2011). These data were provided to Ricardo by NRS in June 2015.

c) Northern Ireland Statistics and Research Agency (NISRA) - cross-tabulated records

- Census table 'CT0084NI' provided 2011 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 (27th March 2011).[151]

3. BEIS National Household Model (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 BEIS 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.

4. BEIS Residential Wood Survey

- BEIS undertook a survey of residential wood use during 2015 and this provides estimate of wood users for 2014 at regional level as well as data on technology splits of these users, among other statistics. The Number of Wood Fuel users by Region from the summary results[152] allowed additional assessment of the wood use mapping.

A summary of how these datasets were utilised in the process is given in Table 11-5 below.

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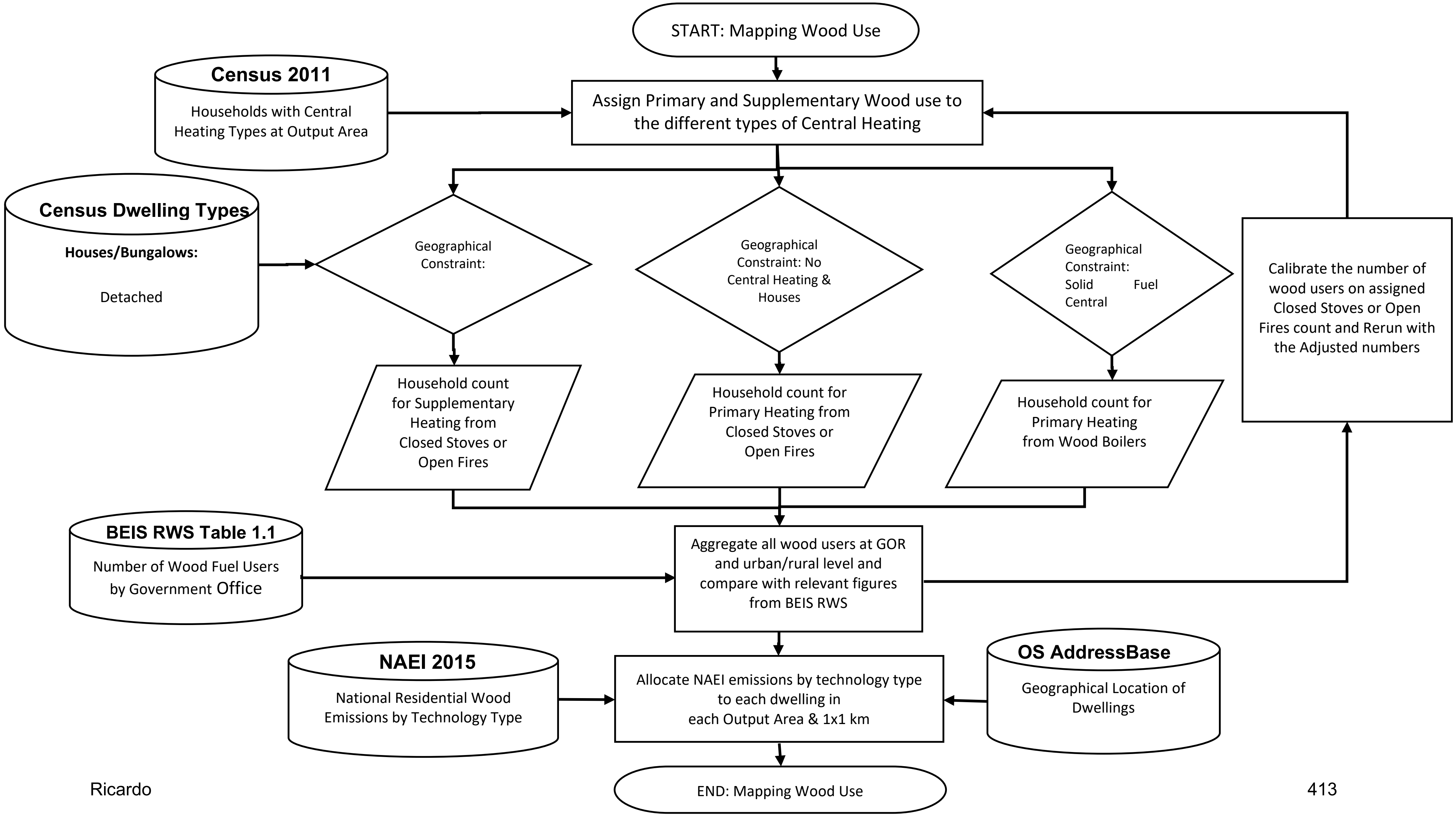
149 http://www.ons.gov.uk/ons/datasets-and-tables/index.html
150 http://www.nrscotland.gov.uk/
151 http://www.ninis2.nisra.gov.uk/public/Theme.aspx
152 https://www.gov.uk/government/publications/summary-results-of-the-domestic-wood-use-survey (Table 1.1)

Table 11-5 Description of methods using the above data series

Task & data series used	Application
1	OS AddressBase Premium geographies were used to generate a spatially resolved database of ONS/NRS 2011 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). For Northern Ireland, a fully standardised geo-referenced address layer was retrieved from the OSNI Pointer dataset and combined with NISRA 2011 census household type returns at the Small Area (SA) level. SAs on average contain 155 households a figure comparable to OA's within England / Wales which on average contain 125 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)[153]. 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	BEIS 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 BEIS 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. 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 BEIS NHM assumptions on wood use. The number of supplementary heating users for wood was calibrated at Regional level by comparing the total wood user count (as derived from all the above assumptions) against the regional count from the BEIS Residential wood survey. Figure 11-9 presents a summary of how wood use was mapped. Emissions were mapped from the NAEI estimates for residential boiler and non-boiler technologies.

[153] https://data.gov.uk/dataset/c481f2d3-91fc-4767-ae10-2efdf6d58996/lower-layer-super-output-areas-lsoas

Figure 11-9 Domestic wood use allocation process



11.12. NFR 1B1, 2A5a: Quarrying and Mining

Emissions of PM_{10} from mines and quarries were distributed using data from the British Geological Survey on the locations of mines and quarries in the UK. This data set includes the location of the site and a brief description of products and commodities. There are no data on actual production amounts for each mine or quarry. Regional production statistics for the various commodities 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 1 km^2 grid and PM_{10} emissions distributed on this basis.

11.13. NFR 1B2: Offshore Oil and Gas

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

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

These estimates are aggregated for the UK totals. For the UK emission maps, the reported emissions by installation 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 will be in that vicinity and, in the absence of better information, this is the best compromise that can currently be achieved. In some cases, this will inevitably lead to platforms being mapped some distance away from their actual position. This is more evident in large fields with multiple platforms that clearly cannot all be located at the same place. For example, the Brent & Forties fields have multiple platforms that are located some kilometres apart but are mapped at the same location. However the approach is considered to be sufficiently accurate for the purposes of modelling long range air pollution from these sources. 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.

11.14. NFR 3: Agriculture

Emissions of PM_{10} and $PM_{2.5}$ from agricultural livestock and poultry sources were distributed using agricultural census data 2014. Detailed, farm/holding level data within England was obtained from Defra for this purpose and was used to generate 1x1 km resolution datasets for different livestock types. For Scotland, Wales and Northern Ireland agricultural census data 2014 were only available for larger spatial units - Parishes in Scotland, Districts in Northern Ireland and Small Areas in Wales.

Therefore, land use data were used to generate a distribution of emissions within these spatial units. The distribution of grass land was used to distribute livestock. The resulting distributions for England, Scotland, Wales and Northern Ireland were combined and weighted according to the relevant regional statistics on the number of livestock or poultry in these regions.

The distributions of ammonia, methane and N_2O emissions from agricultural sources were mapped at by the United Kingdom Centre for Ecology and Hydrology (UKCEH). Data from the Agricultural Census for England, Scotland, Wales and Northern Ireland were combined with emission factors for livestock, fertiliser use and UKCEH Land Cover Map 2007 data within the UKCEH model to calculate emissions maps.

A small proportion of emissions from the incineration of animal carcases were mapped as a point source. For the majority of national total emissions, however, little is known about the location of this activity. As a result, the residual was mapped as an area source across all UK arable land.

Land Cover Map 2007 data from UKCEH was used to map a variety of other agricultural emissions. These were distributed evenly across the arable land cover map for the UK:

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

Agriculture stationary combustion was also mapped using the IDBR employment data and the UK agriculture energy consumption by fuel (ECUK Table 5.1c)[154]. The distribution of solid and liquid fuels was made based on the location of smoke control areas[155] and the geographical distribution of gas availability. The method used is explained in detailed in *Employment based energy consumption mapping in the UK*[156].

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 the Inventory Agency to improve the NAEI in this sector.

11.15. NFR 5A: Landfill Sites

Emissions from landfill sites feature in the NAEI in two different source sectors. The first is landfill gas combustion 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 it 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:

[154] https://www.gov.uk/government/collections/energy-consumption-in-the-uk
[155] These did not incorporate the updated SCA locations
[156] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/996060/employment-based-energy-consumption-local-authority-mapping-2019.pdf

- Regional MSW waste arising by Devolved Administration;
- Actual infill rates for landfills in Scotland for 2008; and
- 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).

11.16. NFR 6A, 5C2: Accidental Fires and Small-Scale Waste Burning

The distribution of accidental fires across the UK is particularly uncertain. Distribution maps were made using the Land Cover Map 2007 supplied by UKCEH[157]. The land cover type was matched to the type of accidental fire as shown in Table 11-6. Classes were added together on an equal basis to make aggregated land cover maps for each NAEI sector.

The ‘Accidental fires - dwellings’ and ‘Accidental fires - other buildings’ sectors have been mapped using the ONS population estimates (ONS, 2022f).

Table 11-6 Land cover data used to distribute emissions from fires

NAEI Source sector	Land Cover classes
Accidental fires - forests	Broad leaved/mixed woodland Coniferous woodland
Accidental fires - straw	Arable cereals Arable horticulture Arable non-rotational
Accidental fires - vegetation	Set-aside grass Natural grass Calcareous grass Acid grass Bracken Bogs (deep peat) Dense dwarf shrub heath Open dwarf shrub heath
Accidental fires - vehicles	Suburban
Small scale waste burning	Suburban
Bonfires	Suburban

11.17. Uncertainties and Verification

Uncertainty and verification studies have been conducted with the gridded emissions data. Findings and conclusions can be found in UK Spatial Emissions Methodology 2019 Emissions (Tsagatakis, 2020)[158] and more specifically in the section ‘5 Uncertainties and verification’.

11.18. Recent and Planned Improvements

A rolling improvement programme for the UK’s spatial inventory is in place. A prioritised list is produced each year, considering the uncertainties in the current methods, and new data that are identified.

[157] http://www.ceh.ac.uk/landcovermap2007.html
[158] https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2107291052_UK_Spatial_Emissions_Methodology_for_NAEI_2019_v1.pdf

Since the last submission (based on the UK NAEI 2019), the following improvements have been made:

- An update to domestic combustion grids based on more recent household solid fuel use survey data.
- Utilisation of postcode level gas data in the employment-based distribution of other industrial, commercial and public sector consumers (currently Middle Layer Super Output Area). Also postcode level gas data are not weather corrected and are more complete compared to the data previously submitted.
- An update to rail emission distributions based on activity from 2019 (previously based on 2009/2010 activity).
- An update to the road transport cold start distribution grids utilising the latest census data (2021).
- An update to the 2007 landcover maps used to distribute various emission sources, such as accidental fires, household garden machinery and other natural sources.
- Generation of a time series of gridded emissions data from 2005 to the latest inventory year

Upcoming planned improvements include:

- Expansion of road transport cold start distribution grids to cover HGVs and buses.
- Use of more recent data to split London taxis from the combined passenger car and taxi road traffic counts.
- Use of Energy Performance Certificates data to inform the fuel type burnt in non-domestic combustion at site level.
- A review of airfields using aviation spirit to better disaggregate Lead emissions.

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Not Applicable

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